CAPABILITIES OF THE IMPACT TESTING FACILITY AT MARSHALL SPACE FLIGHT CENTER

ANDY FINCHUM*, MARY NEHLS*, WHITNEY YOUNG*,
PERRY GRAY**, BART SUGGS***, NIKKI M. LOWREY****

*Materials and Processes Laboratory - Environmental Effects Branch,
NASA Marshall Space Flight Center, Huntsville, Alabama 35812;
**ERC, Inc., 4901 Corporate Drive NW Suite E, Huntsville, AL 35805
***InfoPro Corporation, 6705 Odyssey Drive, Huntsville, AL 35806
****Jacobs Technology, Inc., 1500 Perimeter Parkway, Suite 400, Huntsville, Alabama 35806

Summary - The test and analysis capabilities of the Impact Testing Facility at NASA's Marshall Space Flight Center are described. Nine different gun systems accommodate a wide range of projectile and target sizes and shapes at velocities from subsonic through hypersonic, to accomplish a broad range of ballistic and hypervelocity impact tests. These gun systems include ballistic and microballistic gas and powder guns, a two-stage light gas gun, and specialty guns for weather encounter studies. The ITF "rain gun" is the only hydrometeor impact gun known to be in existence in the United States that can provide single impact performance data with known raindrop sizes. Simulation of high velocity impact is available using the Smooth Particle Hydrodynamic Code. The Impact Testing Facility provides testing, custom test configuration design and fabrication, and analytical services for NASA, the Department of Defense, academic institutions, international space agencies, and private industry in a secure facility located at Marshall Space Flight Center, on the US Army's Redstone Arsenal in Huntsville, Alabama. This facility performs tests that are subject to International Traffic in Arms Regulations (ITAR) and DoD secret classified restrictions as well as proprietary and unrestricted tests for civil space agencies, academic institutions, and commercial aerospace and defense companies and their suppliers.

INTRODUCTION

The Impact Testing Facility (ITF) is one of NASA's premiere impact test facilities for materials science, with gas, powder, and two-stage light gas guns that can accommodate a wide range of projectile and target options. These systems allow scientists and engineers to simulate impacts ranging from rain, hail, and sand to micrometeoroids and orbital debris in order to evaluate materials and components for flight and ground based systems.

This facility is part of the Marshall Space Flight Center (MSFC) Materials and Processes Laboratory's Environmental Effects Branch, where it augments Space Environmental Effects (SEE) efforts to simulate harsh environments such as charged particle radiation, ultraviolet radiation, atomic oxygen, and plasma in order to fully examine how the space environment affects materials and systems. The ITF is an integral part of a one-stop shop for materials analysis that also offers capabilities such as accelerated aging, nondestructive evaluation (NDE), failure analysis, mechanical testing, and design and fabrication of custom test fixtures.

The Department of Defense (DoD) has identified this facility as a valuable resource for testing and development of materials to be used in missile systems. Located at Marshall Space

Flight Center, on the U.S. Army's Redstone Arsenal, the Impact Testing Facility performs tests that are subject to International Traffic in Arms Regulations (ITAR) and DoD secret classified restrictions as well as proprietary and unrestricted tests for civil space agencies, academic institutions, and commercial aerospace and defense companies. The ITF has performed testing on behalf of the European and Russian space agencies.

The Impact Testing Facility provides low-cost methods for testing and validation of materials and hardware components, which help define follow-on system level testing normally accomplished by large-scale facilities such as rocket sled ranges and by flight tests. Data acquired during ITF impact tests are also used to validate math models used for design and verification of full scale hardware for survivability to natural and induced ground, atmospheric flight, and space environments. The ITF makes advances in materials science possible that not only enable safer space flight for astronauts but also help develop systems to protect soldiers and civilians on Earth through advances in ballistic shielding, body armor, aircraft survivability, and other applications.

HISTORY OF THE IMPACT TESTING FACILITY

The Marshall Space Flight Center's Impact Testing Facility was established and began its research in spacecraft debris shielding in the early 1960s. In the 1980's and 1990's, the ITF played a major role in the development of the orbital debris shields for the International Space Station. As NASA became more involved in the characterization of launch debris and in-flight impact risks, the ITF grew to encompass research in a variety of impact genres.

Collaborative partnerships with the Department of Defense led to a wider range of impact test capabilities being relocated to MSFC as a result of the closure of the Particle Impact Facility in Santa Barbara, California. The Particle Impact Facility had a 30 year history in providing evaluations of aerospace materials and components during flights through rain, ice, and solid particle environments at subsonic through hypersonic velocities. The facility's unique capabilities were deemed a "National Asset" by the DoD. To retain these test capabilities for the DoD, in 2005 NASA's MSFC Impact Testing Facility stepped in to assume ownership and operation of this unique test equipment.

In addition to direct support for NASA test programs, over the years the ITF has performed work under partnering or contracting relationships with the Department of Defense and DoD contractors, universities, private industry, and foreign government agencies for state-of-the-art materials and systems research and development. The ITF continues to provide test services to non-NASA entities through reimbursable and partnering agreements authorized by the National Aeronautics and Space Act of 1958, as amended (42 U.S.C. º 2451 et seq.), commonly referred to as Space Act Agreements.

The ITF now has capabilities including climactic, ballistic, and hypervelocity impact testing utilizing an array of gas, powder, and two-stage light gas guns to accommodate a variety of projectile and target types and sizes. Numerous upgrades including new instrumentation, triggering circuitry, high speed photography and digital video, and optimized sabot designs have been implemented. In early 2011, a high temperature target furnace was added to the ballistic range to further expand the test capabilities of the ITF. This new system provides the capability to heat flat target specimens up to 1200^{o}C during ballistic testing in order to simulate impacts on high temperature hypersonic materials and structures.

The expected completion of the Marshall Micrometeorite Gun in 2011 will further expand the capabilities of the Impact Testing Facility beyond the current high-hypersonic velocity limits to achieve velocities encountered during planetary re-entry. The current and soon-to-be-completed ITF capabilities allow for test simulation of impactors from rain to micrometeoroids allowing the widest test parameter range possible for materials investigations in support of advanced space, aeronautics, and ground systems.

OPERATIONAL FACILITIES

The Hydrometeor Impact Gun

The Hydrometeor Impact Gun (HIG), also known as the “rain gun”, shown in Fig. 1, has been utilized for Department of Defense weather encounter test and evaluation since the 1970’s. The HIG has been deemed a national asset by the U.S. Army, Navy, and Air Force. For nearly 25 years, every DoD infrared window, infrared dome, and radome material has been tested using this system.

Fig. 1. The Hydrometeor Impact Gun.

Originally built and operated at the Particle Impact Facility in Santa Barbara, California by Dr. William F. Adler, it was transferred to NASA from AT&T Government Solutions after the company decided to discontinue its operation. The MSFC Environmental Effects branch, collaborating with the U.S. Army Aviation and Missile Research Development and Engineering Center (AMRDEC) and the Space and Missile Defense Command, both located at Redstone Arsenal; the Naval Surface Warfare Center at the Washington Naval Yard in Washington, D.C.; and the Naval Air Warfare Center in China Lake, California, transferred, installed and upgraded the Hydrometeor Impact Gun within the MSFC Impact Testing Facility in 2005 [1].

The HIG is the only hydrometeor impact gun of its type known in existence in the United States. It provides the ability to test materials against a single water droplet of known size up to 5 mm. Unlike other ballistic impact guns that launch a projectile toward a stationary test article, the Hydrometeor Impact Gun launches the test material into the water drop and then decelerates the test item as gradually as possible to preserve the specimen for analysis. The test specimen is mounted on a 30 mm sabot and launched toward a falling water droplet that is precisely timed for impact. The HIG can also produce distorted drops, as shown in Fig. 2, to simulate demised droplet impacts.

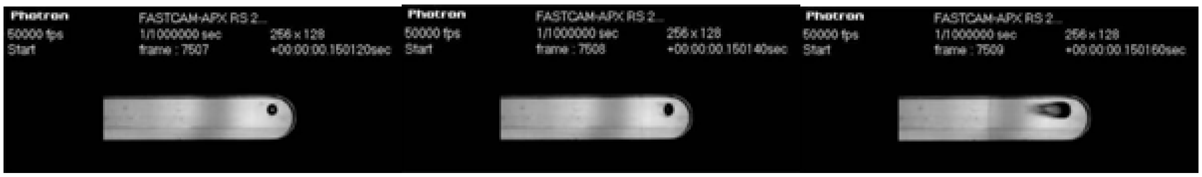


Fig. 2. Three images showing high speed photographic capture of demised droplet shots in the Hydrometeor Impact Gun.

The typical test specimen shape is a disk approximately 19 mm (0.75 inch) in diameter and can vary in thickness. For angled shots, the shape of the specimen may vary provided the projected diameter does not exceed 19 mm (.75 inch). The specimen experiences high g-loads during launch and recovery, which may affect the suitability of a material for rain impact testing using this gun. Material samples are accelerated anywhere from 0.09 to 1.40 km/s (300 to 4,600 ft/s or Mach 4.12), with impact angles ranging from 30 to 90 degrees. A brake tube, 40 ft or longer, is used to allow safe braking and recovery of the sample vehicle without doing damage to the sample following the impact event. A summary of the testing capabilities of the Hydrometeor Impact Gun is shown in Table 1.

The Hydrometeor Impact Gun has completed test series on infrared transmitting windows with spherical and distorted drops, radome materials, and external Thermal Protection System insulation for launch vehicles.

Table 1. Hydrometeor Impact Gun capabilities

Parameter	***Capability***
Velocity Range	300 to 4,600 ft/s (Mach 4.12)
Velocity Tolerance	+/- 5%
Raindrop Diameter	1.5 to 5 mm (0.06 to 0.2 in)
Projectile Shape	Disk or coupon up to 19 mm (0.75 inch) projected diameter
Projectile Material	Test material specimen
Velocity Measurement	High-speed digital video and lasers
Specimen Size	Up to 19 mm (0.75 in) diameter

The Large Ballistic Gun

The Large Ballistic Gun, shown in Fig. 3, is used to shoot projectiles of large mass and size at subsonic and transonic velocities. Velocity and impact data collection are performed using high-speed cameras and customer-defined data acquisition systems (e.g., load, strain, acceleration, etc.).

Fig. 3.   The Large Ballistic Gun.

Recently, the Large Ballistic Gun was used to provide data for computer model validation supporting a Space Shuttle launch debris investigation including liberated launch pad firebrick and thermal protection system debris impact on Space Shuttle Main Engine nozzles.

Projectile diameters up to 63 mm (2.75 in) can be accommodated in the current 76.2 mm (3 in) barrel. Barrels may be customized up to 152 mm (6 in) to accommodate larger projectiles. Projectiles accelerated within custom fabricated sabots can be of varying shapes and materials.

Projectiles velocities up to 2,000 ft/s (Mach 1.8) are achievable depending on the mass of the projectile. Velocity is measured by high-speed digital video. Targets are positioned on an outdoor test range, facilitating the testing of small or large test items up to and including full scale systems and flight hardware. A summary of the testing capabilities of the Large Ballistic Gun is shown in Table 2.

Table 2. Large Ballistic Gun capabilities

Parameter	*Capability*
Velocity Range	Up to 2,000 ft/s (Mach 1.8)
Barrel Diameters	76.2 mm (3 in), customizable up to 152 mm (6 in)
Projectile Diameter	Up to 63 mm (2.75 in)
Projectile Shape	Various
Projectile Material	Various
Velocity Measurement	High-speed digital video
Target Size	Up to and including full-scale flight hardware

The Small Ballistic Gun

The Small Ballistic Gun, shown in Fig. 4, is used to perform small subsonic and transonic impacts at velocities from 50 to 1,500 ft/s (Mach 0.05 to 1.4), with maximum velocity dependent on the projectile mass. A combination indoor/outdoor range is used to accommodate a wide variety of targets and target sizes up to and including full-scale flight hardware.

Fig. 4. The Small Ballistic Gun.

With the use of custom fabricated sabots, various projectile materials and shapes can be accommodated to simulate impacts such as plume debris impingement and hail. Three barrel diameters are used to accommodate projectile sizes up to 0.025 m (1 in). The available barrel diameters are 0.013 m (0.5 in), 0.025 m (1 in), and 0.031 m (1.2 in) for simulation of hail [2] per MIL-STD-810. The system may be customized with larger barrels to accommodate larger projectiles. Velocity is measured using high-speed digital video. A summary of the testing capabilities of the Small Ballistic Gun is shown in Table 3.

The Small Ballistic Gun has been used to conduct several test series supporting launch debris computer model validation efforts for the Space Shuttle. The SBG was also recently used for Space Shuttle external tank testing during the investigation of a hydrogen flow control valve failure for STS-126.

Table 3. Small Ballistic Gun capabilities

Parameter	*Capability*
Velocity Range	50 to 1,500 ft/s (Mach 0.05 to 1.4)
Barrel Diameters	0.013 m (0.5 in), 0.025 m (1 in), 0.031 m (1.2 in)
Projectile Diameter	Up to 0.025 m (1 in)
Projectile Shape	Various
Projectile Material	Various
Velocity Measurement	High-speed digital video
Target Size	Up to and including full-scale flight hardware

The Microballistic Powder Gun

The Microballistic Powder Gun (MBPG), shown in Fig. 5, was designed to shoot polymeric beads to simulate raindrop impacts. Using customized beads, bead sizes from 2 to 4 mm (0.08 to 0.157 in) in diameter may be used to simulate the more extreme raindrop sizes specified in MIL-STD-810G [3]. This gun has very good impact accuracy at consistent velocities. An adjustable sample stage is used to vary the angle of attack and to allow multiple shots on one target.

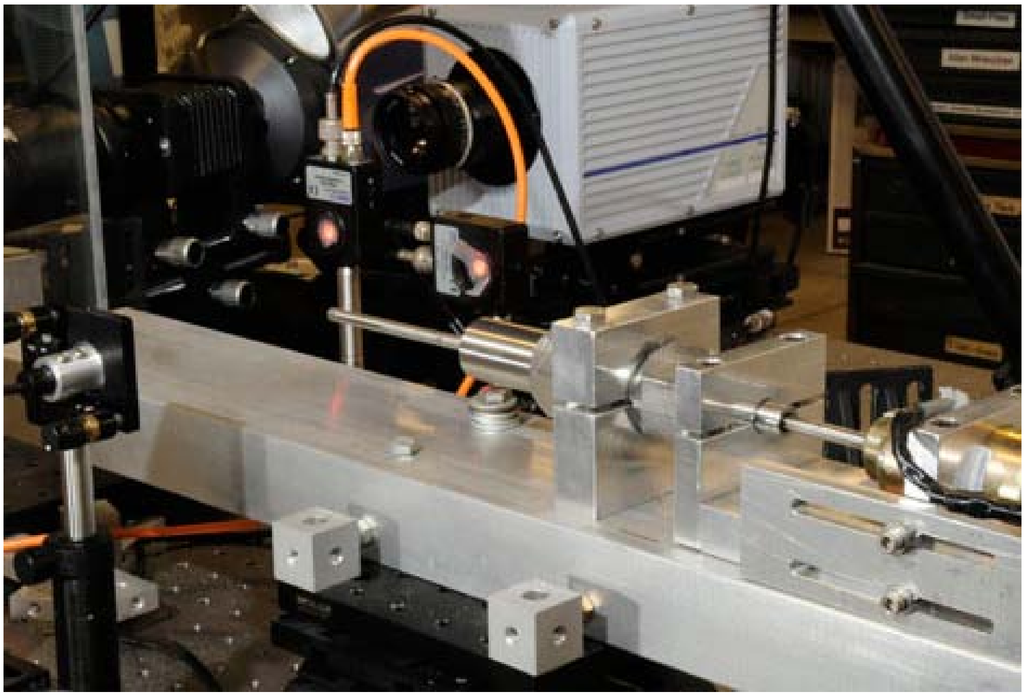


Fig. 5. The Microballistic Powder Gun.

Using the Microballistic Powder Gun, hypersonic weather encounters can be simulated at velocities up to 6,000 ft/sec (Mach 5.5). Like the Small Ballistic Gun, velocity is measured using high-speed digital video. Targets can range from 51x51 mm (2x2 in) up to full scale flight hardware. A summary of the testing capabilities of the Microballistic Powder Gun is shown in Table 4.

Table 4. Microballistic Powder Gun capabilities

Parameter	*Capability*
Velocity Range	Up to 6,000 ft/s (Mach 5.5)
Barrel Diameter	2 – 4 mm (0.08 – 0.157 in), or customizable barrels
Projectile Diameter	2 – 4 mm (0.08 – 0.157 in)
Projectile Shape	Spheres, slugs, or customized shapes
Projectile Material	Polymeric beads
Velocity Measurement	High-speed digital video
Target Size	51x51 mm (2x2 in) up to full scale flight hardware
Target Heating	Up to 2000^{o}C

The Microballistic Gas Gun

Complementing the capability of the Microballistic Powder Gun, the Microballistic Gas Gun shown in Fig. 6, was designed to shoot polymeric beads to simulate raindrop impacts at velocities below 2,500 ft/s (2.24 Mach) using helium as the propellant. Using customized barrels, bead sizes from 2 to 4 mm (0.08 to 0.157 in) in diameter may be shot into material samples or full-size hardware. Like the Microballistic Powder Gun, the Microballistic Gas Gun has an adjustable sample stage, used to vary the angle of attack and to allow multiple shots on one target. A summary of the testing capabilities of the Microballistic Gas Gun is shown in Table 5.

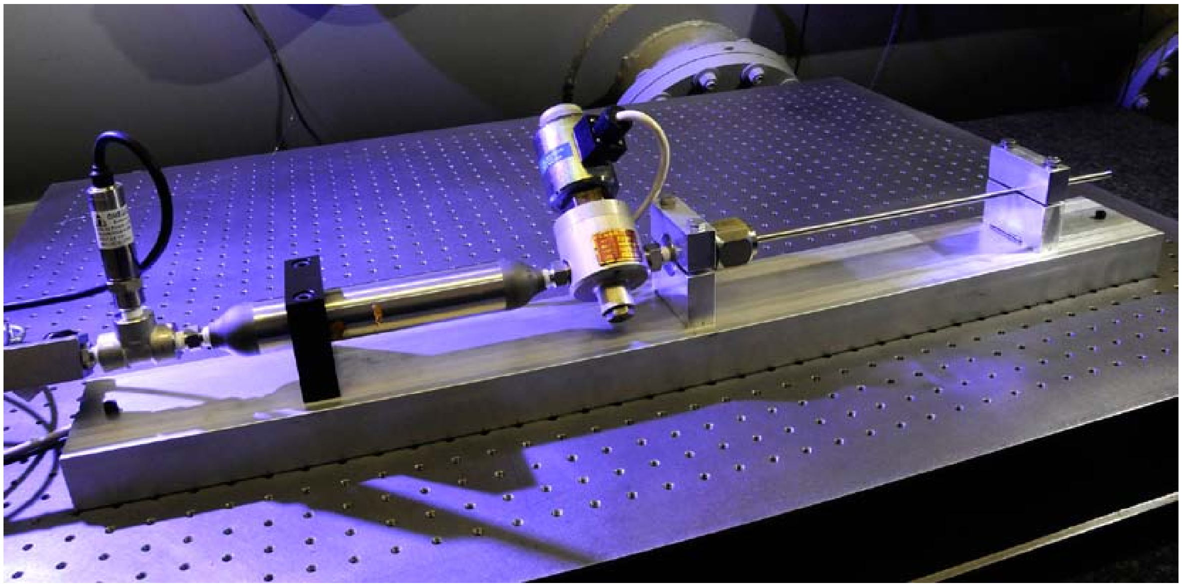


Fig. 6. The Microballistic Gas Gun.

Table 5. Microballistic Gas Gun capabilities

Parameter	*Capability*
Velocity Range	Up to 3,000 ft/s (Mach 2.76)
Barrel Diameter	2 – 4 mm (0.08 – 0.157 in), or customizable barrels
Projectile Diameter	2 – 4 mm (0.08 – 0.157 in), customizable for < 2 mm projectiles
Projectile Shape	Spheres, slugs, or customized shapes
Projectile Material	Polymeric beads
Velocity Measurement	High-speed digital video
Target Size	51x51 mm (2x2 in) up to full scale flight hardware
Target Heating	Up to 2000^{o}C

The Single-Particle/Multiparticle Impact Gun

The Single-Particle/Multiparticle Impact Gun, shown in Fig. 7, is designed to simulate impacts and weather erosion from a variety of debris environments. It has been used primarily for weather encounter studies on missile radome materials. Projectile sizes up to 5 mm (0.2 in) may be accommodated. Multiple smaller particles, not limited by material or shape, may be accelerated toward a target in a single shot to simulate dust and sand environments in support of weather erosion studies for hardware to be used in desert applications or extraterrestrial surface environments.

Fig. 7. The Single-Particle/Multiparticle Impact Gun.

The target chamber dimensions for the Single-Particle/Multiparticle Impact Gun are 0.3 m high by 0.6 m wide by 0.9 m deep, with clear walls for viewing of the test specimen in situ. An example of a typical test specimen installed in the target chamber, a radome undergoing sand erosion testing, is shown in Fig. 8. A summary of the testing capabilities of the Single-Particle/Multiparticle Impact Gun is shown in Table 6.

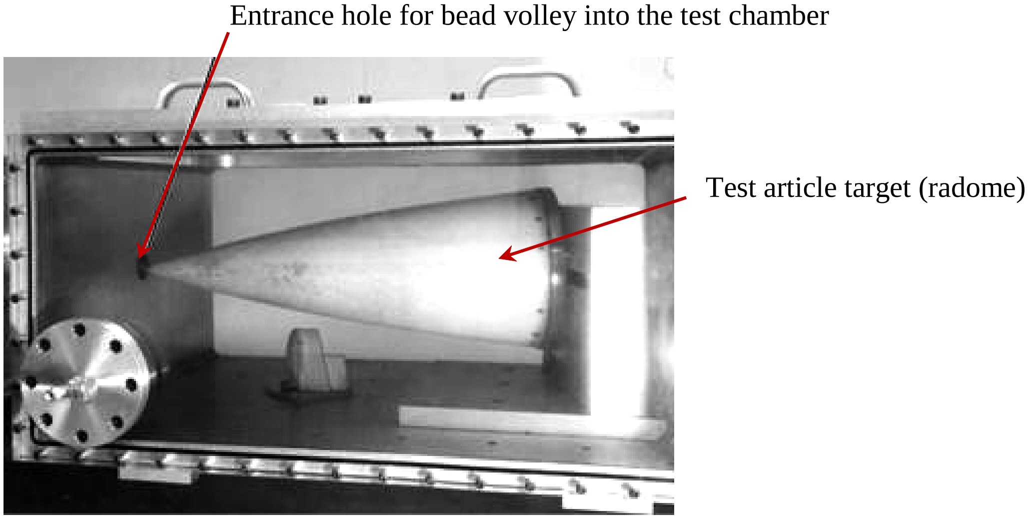


Fig. 8. A test article installed in the Single-Particle/Multiparticle Impact Gun test chamber.

Table 6. Single-Particle/Multiparticle Impact Gun capabilities

Parameter	*Capability*
Velocity Range	Up to 6,000 ft/s (Mach 5.5)
Barrel Diameter	50 mm (1.97 in)
Projectile Size	0.01 – 5 mm (0.004 – 0.2 in), multiple particles
Projectile Material	Various
Velocity Measurement	High-speed digital video
Target Chamber	0.3 m (1 ft) high x 0.6 m (2 ft) wide x 0.9 m (3 feet) deep

The Exploding Wire Gun

The Exploding Wire Gun is a device that propels projectiles at velocities ranging from 100 m/s up to 7 km/s by means of a plasma-driven explosion at the base of a short barrel. The plasma is created by the vaporization of a thin wire connected to a capacitor bank charged to voltages as high as 22 kV. These capacitors will drive a high current through the plasma for several microseconds. The energy expended can be quite high, far exceeding the available energy per unit volume of conventional explosives. The plasma temperature is driven much higher than those attainable through chemical means, and the corresponding expansion velocity is much higher allowing these high projectile velocities to be obtained. During operation, the capacitor voltage is switched to the wire through a rail gap switch. This switch is designed to carry currents as high as 1.2 million amps.

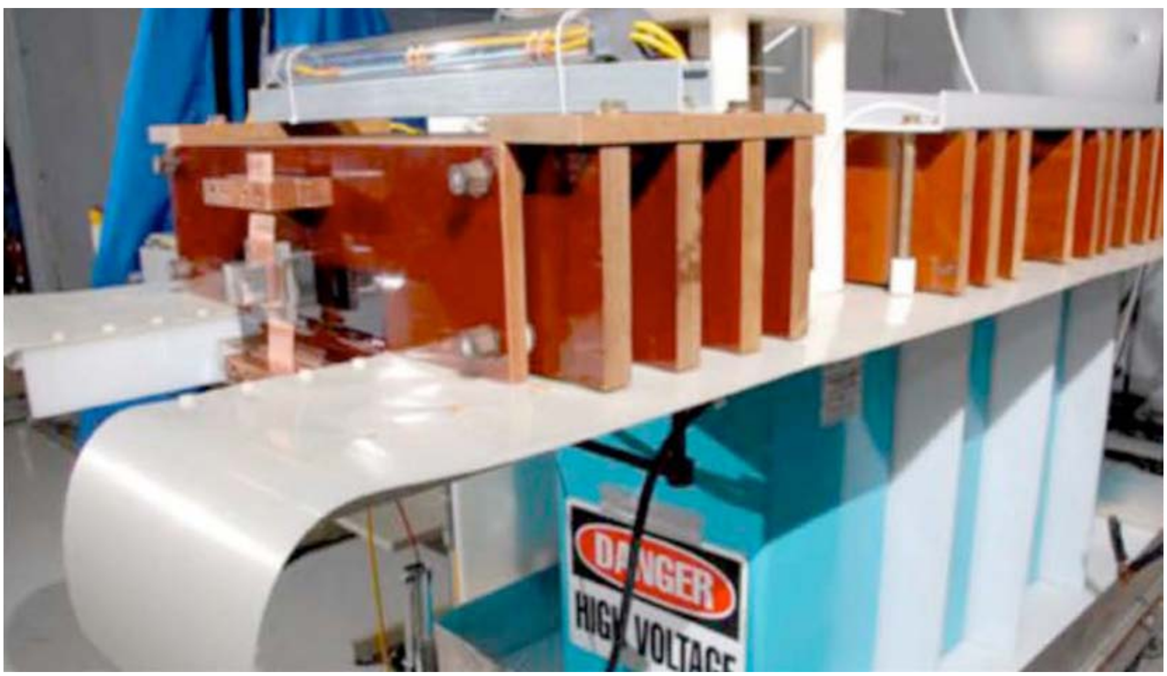


Fig. 9. The Exploding Wire Gun.

The Exploding Wire Gun, shown in Fig. 9, was initially developed to provide a laboratory simulation for hypervelocity raindrop impacts using solid beads composed of various materials, e.g., glass, nylon, and ceramics. However, the customizable barrel also allows this gun to be used with a variety of projectiles to characterize many different impact scenarios over a wide range of velocities. Targets can be up to 3 meters (188 in) in diameter, allowing the Exploding Wire Gun to be used to test large components, armor panels, and full scale end items.

With the Exploding Wire Gun, single or multiple projectiles may be fired per test at velocities up to 7 km/s (Mach 21). Projectile materials have included glass, nylon, and aluminum. For velocities up to 5 km/s (Mach 15), projectile impact velocity and material response to impact are documented using high-speed digital photography. A summary of the testing capabilities of the Exploding Wire Gun is shown in Table 7.

Table 7. Exploding Wire Gun capabilities

Parameter	*Capability*
Velocity Range	100 m/s to 7 km/s (328 ft/s to Mach 21)
Barrel Diameter	Customizable
Projectile Diameter	Up to 0.25 in (6.4 mm)
Projectile Shape	Single and multiple beads
Projectile Material	Glass, nylon, aluminum, and ceramic
Velocity Measurement	High-speed digital video
Target Size	Up to 3 m (118 in) diameter

The Micro Light Gas Gun

The ITF Micro Light Gas Gun (MLGG), shown in Fig. 10, became fully operational in 2002. Since that time, the gun has performed over 1,500 shots. By reconfiguring the gun barrels and switching between gaseous hydrogen and helium, this gun is capable of performing shots at both ballistic and hypervelocity ranges. The MLGG has supported numerous studies for a wide variety of projects including thermal protection system materials, piston materials, radiation/micrometeriod orbital debris shielding, waterless concrete for lunar bases [4], luminescent surface coatings, and self-healing plastics.

Fig. 10. The Micro Light Gas Gun.

The Micro Light Gas Gun was used to impact thin film solar sail materials following exposure to charged particle radiation as part of a study of the effect of the space environment on solar sails [5]. Radiation embrittles the fragile solar sail materials, making them more susceptible to damage [6]. The collocation of all required test facilities at MSFC enabled transport of the materials between test facilities without harm. Customers of this facility have included several

MSFC engineering directorate groups, the Space Shuttle Columbia Return to Flight effort, other NASA centers and the Department of Defense.

The Micro Light Gas Gun accommodates spherical and cylindrical projectiles with diameters of 0.2 to 4 millimeters (0.008 to 0.157 inches) within barrel diameters ranging from 1.73 to 4 mm (0.068 to 0.157 in). Projectile velocities range from 0.3 to 7.5 kilometers/ second (Mach 1-23). Projectile materials include aluminum, glass, polymers, ceramics, and similar materials.

Velocity is measured in the MLGG by high speed digital video cameras, lasers, or photodiodes as required by the customer. The target chamber is approximately 1.2 meters (4 feet) in diameter by 1.52 meters (5 feet) long. A summary of the testing capabilities of the Micro Light Gas Gun is shown in Table 8.

Table 8. Micro Light Gas Gun capabilities

Parameter	*Capability*
Velocity Range	0.3 – 7.5 km/s (Mach 1-23)
Barrel Diameter	1.73 – 4 mm (0.068 – 0.157 in)
Projectile Diameter	0.2 – 4 mm (0.008 – 0.157 in)
Projectile Shape	Spheres and cylinders
Projectile Material	Aluminum, glass, polymers, ceramics, and similar materials
Velocity Measurement	High-speed digital video, lasers, photodiodes
Target Chamber	1.2 m (4 ft) diameter by 1.52 m (5 ft) long

FACILITIES IN DEVELOPMENT

The Marshall Micrometeorite Gun (MMG) Plasma Accelerator

The Marshall Micrometeorite Gun, shown in Fig. 11, is currently in development. The design goal of this gun is to accelerate 10 to 200 micrometer (0.0004 – 0.008 in) diameter particles at velocities up to 20 km/s (Mach 60) in a vacuum to test the effects of micrometeoroid impacts on hardware to be used in the interplanetary space environment. Survivability to such impacts is critical to the success of future manned missions to the Moon and Mars.

Not constrained by a projectile barrel, the Marshall Micrometeorite Gun operates by colliding electromagnetically accelerated high-speed plasma with particles that are injected into the plasma path. This system is designed to achieve free plasma velocities of 150 to 200 km/s. Velocity will be measured by scintillation, using a high-speed streak camera. Target size will be a nominal 152 mm (6 in) square, housed within a 1.2 m diameter (4 ft) by 2.4 m (8 ft) long target chamber. The anticipated capabilities of the Marshall Micrometeorite gun, based on theoretical calculation, are shown in Table 9.

When operational, the Marshall Micrometeorite Gun is expected to be the fastest particle gun in the world. The Marshall Micrometeorite Gun is scheduled to be operational in late 2011.

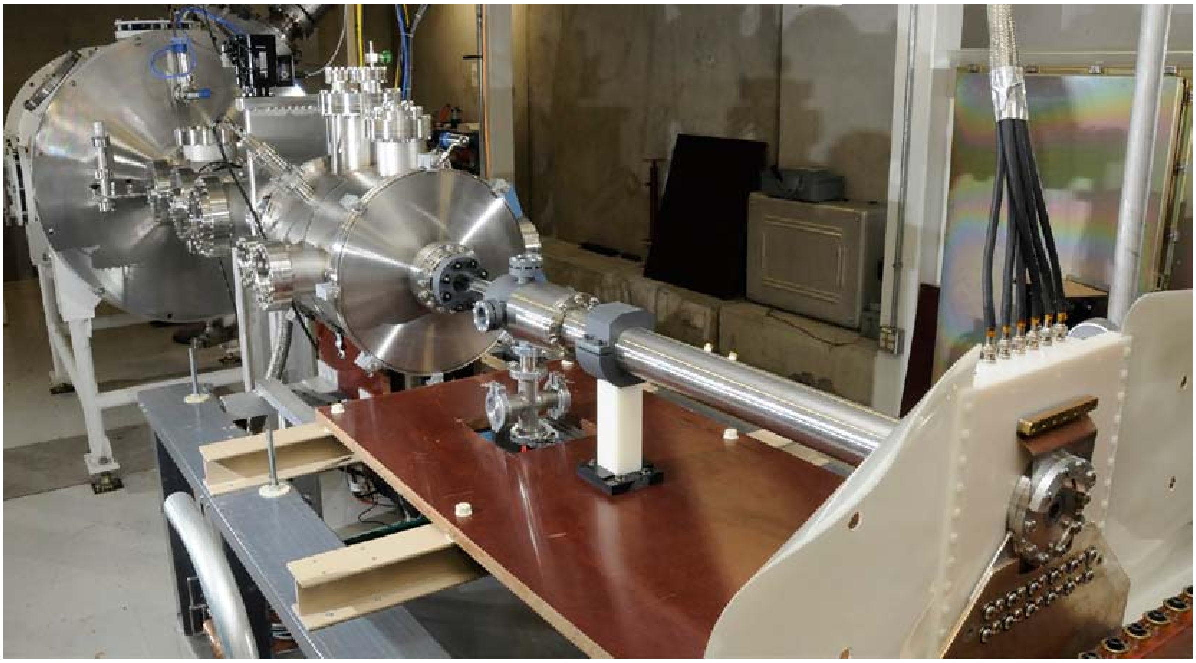


Fig. 11. The Marshall Micrometeorite Gun now in development.

Table 9. Marshall Micrometeorite Gun capabilities (theoretical)

Parameter	*Capability*
Velocity Range	Up to 20 km/s (Mach 60)
Barrel Diameter	Customizable
Projectile Diameter	10 – 200 µm (0.0004 – 0.008 in)
Projectile Shape	Sphere
Velocity Measurement	Scintillation, using a high-speed streak camera
Target Size	152 mm (6 in) square, nominal
Target Chamber	1.2 m diameter (4 ft) by 2.4 m (8 ft)

TEST SCENARIO CAPABILITIES

The wide variety of guns available in the Impact Testing Facility provides the capability to support most impact test scenarios. The ITF has the capability to challenge the broadest range of advanced materials including multilayer armor, advanced ceramics, thermal protection system foams and heat shield materials, ablators, self-healing materials, nanocomposites, and ceramic matrix composites. The potential applicability of the array of guns in the ITF to various impact test scenarios is shown in Table 10.

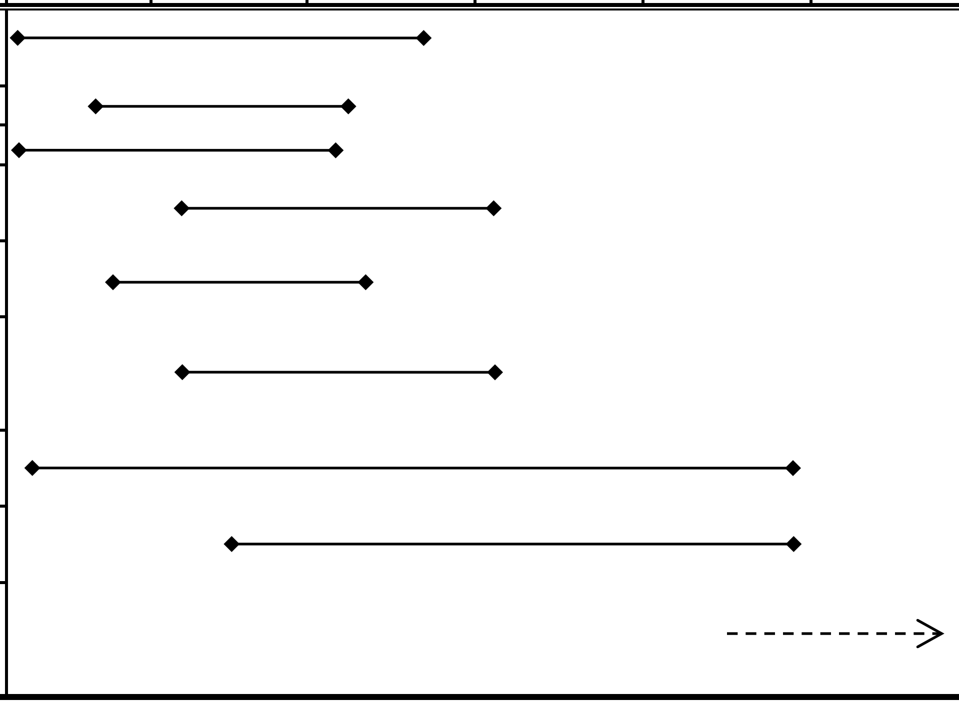
The range in velocity that may be achieved with each gun in the ITF arsenal is shown in Table 11. In most cases, the velocity that can be achieved in each gun is inversely proportional to the mass of the projectile. As shown in Table 11, the array of guns available in the ITF can achieve virtually any desired test velocity from sub-sonic through high-hypersonic, depending on the mass of projectile desired. When the Marshall Meteorite Gun is operational, the velocity range of the ITF will be extended well beyond the high-hypersonic range and into the realm of re-entry speeds.

Table 10. Applicability of the ITF guns to various test scenarios

Gun	*Test Scenario*		
	Ballistic Impact	*Weather Encounter*	*Hypersonic Impact*
Hydrometeor Impact Gun		✓	
Large Ballistic Gun	✓		
Small Ballistic Gun	✓	✓	
Microballistic Powder Gun	✓	✓	
Microballistic Gas Gun	✓	✓	
Single-Particle/Multiparticle Impact Gun	✓	✓	
Exploding Wire Gun	✓	✓	✓
Micro Light Gas Gun	✓	✓	✓
Marshall Micrometeorite Gun			✓

Table 11. Velocity range of the ITF guns (in mach)*

Gun	*Regime*					
	Subsonic <0.8	*Transonic* 0.8-1.2	*Supersonic* 1.2-5.0	*Hypersonic* 5.0-10.0	*High-hypersonic* 10.0-25.0	*Re-entry* >25.0
Hydrometeor Impact Gun						
Large Ballistic Gun						
Small Ballistic Gun						
Microballistic Powder Gun						
Microballistic Gas Gun						
Single-Particle/Multiparticle Impact Gun						
Exploding Wire Gun						
Micro Light Gas Gun						
Marshall Micrometeorite Gun						



*Dependent on the mass of the projectile(s).

In addition to the range of velocities achievable by the ITF guns, a high temperature target furnace provides the capability to heat flat target specimens up to 1200°C during ballistic testing with the microballistic powder or microballistic gas guns. This capability was added in 2011 to respond to customer demand to simulate rain impacts on high temperature materials and structures in hypersonic flight. Additional work is in progress to add high temperature rapid target heating capability to better simulate the dynamic environmental conditions of hypersonic flight.

SIMULATION AND MODELING CAPABILITIES

Smooth Particle Hydrodynamic Code

The SPHC™ Smooth Particle Hydrodynamic Code (Stellingwerf, 2006 [7]) is a software tool used by the MSFC Impact Testing Facility that can handle one-, two-, or three-dimensional versions of a problem to support high-velocity impact simulation and modeling. It accommodates any material for which a specified set of properties is known, using any of ten equations of state and seven material strength models. The SPHC has flexible geometric modeling capabilities, allowing a variety of articles to be simulated including complex shapes such as bullets, porous items, and multilayered/multi-material objects.

With the SPHC, impacts can be modeled at any speed below approximately 50 km/s (Mach 150) using initial temperatures, densities, porosities, and internal pressures specified by the user. Complex objects can be built up from simple geometric constructs, then duplicated and moved as desired in the simulation space. The SPHC has been used at MSFC to simulate a wide variety of impact scenarios from orbital debris impact on Space Shuttle thermal tiles [8] to space tether debris [9].

Fig. 12 shows a display from a SPHC simulation. This example shows a frame from a two-dimensional simulation of a 5.5 km/s (18045 ft/s or Mach 16) impact of a 0.8 mm (0.03 in) glass projectile on a candidate insulation design. The insulation in this simulation is composed of a 0.08 m (3 in) layer of urethane foam faced with a 0.25 mm (0.01 in) layer of Kapton® polyamide film and shielded by a 0.76 mm (0.03 in) layer of aluminum. As seen here, the shielding was inadequate to prevent penetration of the back wall.

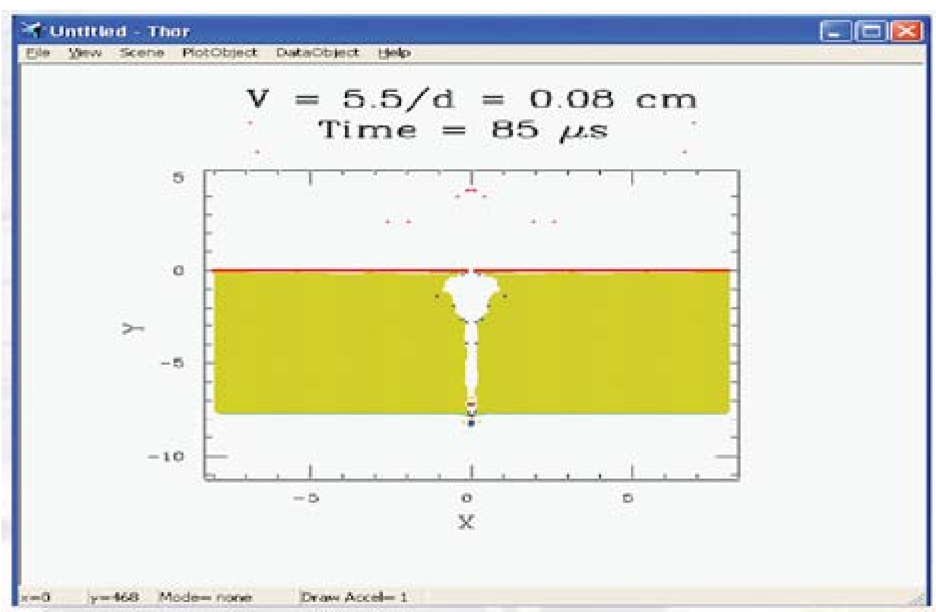


Fig. 12. Example of a Smooth Particle Hydrodynamic Code simulation showing impact penetration.

Fig. 13 shows a Smooth Particle Hydrodynamic Code simulation of a 7.62 mm (0.3 in) ball round impacting an aluminum-Spectra™ laminate at 747 m/s (2,450 ft/s).

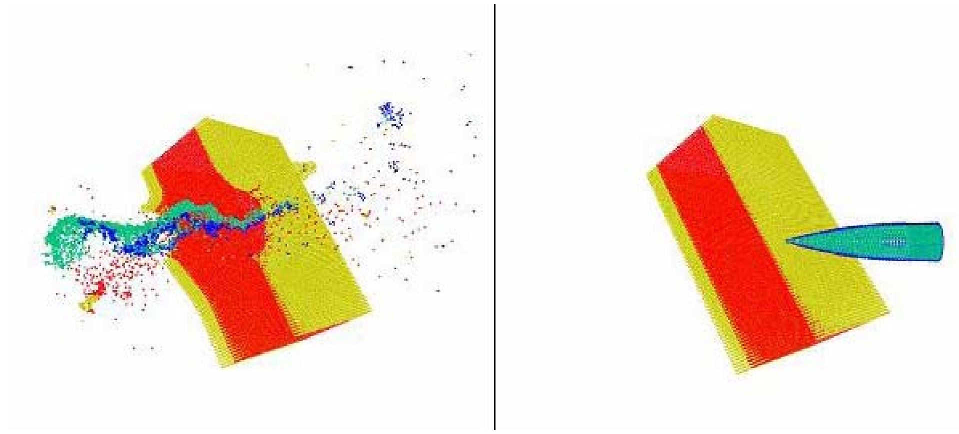


Fig. 13. A Smooth Particle Hydrodynamic Code simulation of a ball round impact.

CONCLUSION

The Impact Testing Facility at NASA - Marshall Space Flight Center offers a wide range of capabilities for impact simulation and testing of advanced materials and full scale hardware. The eight operational gun systems are capable of simulating a variety of impact scenarios including rain, hail, sand, and dust encounter during atmospheric flight; ballistic impact from weapon systems; and hypervelocity impact from meteoroids and orbital debris. With the addition of the Marshall Micrometeorite Gun, the MSFC Impact Testing Facility will be capable of performing impact tests through the complete velocity range from subsonic through the highest hypersonic velocities of any known test facility.

The location of the Impact Testing Facility at Marshall Space Flight Center on the U.S Army's Redstone Arsenal provides a secure facility for test programs that may be subject to International Traffic in Arms Regulations (ITAR) or restrictions on DoD secret classified information, as well as projects that are client proprietary.

The Impact Testing Facility supports ongoing test projects for NASA and NASA contractors; the U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC); and Department of Defense contractors. Over the years, the ITF has also performed work under partnering or contracting relationships with universities, private industry, and foreign government agencies for state-of-the-art materials and systems research and development.

REFERENCES

1. J. Robertson, New Marshall facility increases impact testing capabilities, *Marshall Star*, May 26 (2005).
2. Mil-Std-810G, Department of Defense Test Method Standard Environmental Engineering Considerations and Laboratory Tests, Part Three, Section 5.11, Hail.
3. Ibid., Part Three, Section 5.2, Rain.
4. H. Toutjani, S. Evans, R. N. Grugel, Performance of Waterless Concrete, *Proc. 13th Int. Cong. on Polymers in Concrete*, June 15, Funhal, Madeira Islands, Portugal (2010).
5. D. Edwards, M. Hovater, W. Hubbs, G. Wertz, W. Hollerman, P. Gray, Characterization of Candidate Solar Sail Material Exposed to Space Environmental Effects , AIAA-2004-1085, *Proc. 42nd AIAA Aerospace Sciences Meeting*, Jan. 5-8, (2004).

6. D. Edwards, C. Semmel, M. Hovater, M. Nehls, P. Gray, W. Hubbs, G. Wertz, G., Status of Solar Sail Material Characterization at NASA's Marshall Space Flight Center, *Proc. 7th Int. Space Conf., Protection of Materials and Structures from the Space Environment*, ICPMSE-7, May 10-13 (2004).
7. R. Stellingwerf, *SPHC.* Smooth Particle Hydrodynamics Code in C, Ver. 8.0, Stellingwerf Consulting, Huntsville, AL, (2006)
8. S. Evans, J. Williamsen, Orbital Debris Shape and Orientation Effects on Impact Damage to Shuttle Tiles, AIAA-2006-2221, *Proc. 47th Structures, Structural Dynamics, and Materials Conference*, May 1-4 (2006).
9. S. Evans, Tethers as Debris: Hydrocode Simulation of Impacts of Tether Fragments on Planar Aerospace Matierls, *Proc. 34th COPSAR Scientific Assembly, The Second World Space Congress*, October 10-19 (2002).