T H E G U N S O F N A S A

by William L. Ross, Sr., and Donald Henderson
Claire G. Meador, Technical Editor
NASA Johnson Space Center White Sands Test Facility

Aerial view of White Sands Test Facility northeast of Las Cruces, New Mexico

In the desert foothills where the six-guns and rifles of Pat Garrett, Billy the Kid, and Geronimo once barked, the big guns of NASA now thunder. They would have been awed at the size, power, and purpose of NASA's light-gas guns that send projectiles downrange at the speed of shooting stars in the night skies over New Mexico. At a remote location northeast of Las Cruces, the rich legacy of the Wild West commingles with the modern Space Age at NASA Johnson Space Center (JSC) White Sands Test Facility (WSTF). A select group of engineers and scientists at WSTF support Space Shuttle and International Space Station (ISS) missions by testing all materials used in the Space Program. Their primary responsibility is to promote and ensure Mission safety, of which the guns of NASA play a critical role.

Sidebar story on space debris: [GunsofNASA_debris.doc]

For millions of years, Earth has been bombarded from outer space by meteoroids. An orbiting layer of man-made debris, composed of spent rocket fragments, exploded satellites, and other space mission bits and pieces, now join the naturally occurring meteoroids. These objects travel at hypervelocity speeds, by definition in excess of 2 km/sec (6,600 f.p.s.), and are a significant threat to spacecraft during launch, orbit, and re-entry operations.

Space debris impacts are a real danger to astronauts doing extra-vehicular maneuvers and to high-pressure vessels and toxic aerospace materials carried aboard spacecraft. Traditionally, astronauts have faced these life and mission threatening dangers every time they went into space. Their defenses are much better now, with improved shielding and ballistic quality windows that protect them from impacts caused by the smaller pieces of space debris.

EMU-equipped astronaut working alone in space
[NASA JSC Archives Photo]

Remotely located light-gas gun facility at WSTF. The target tanks extend outside of the building (at right).

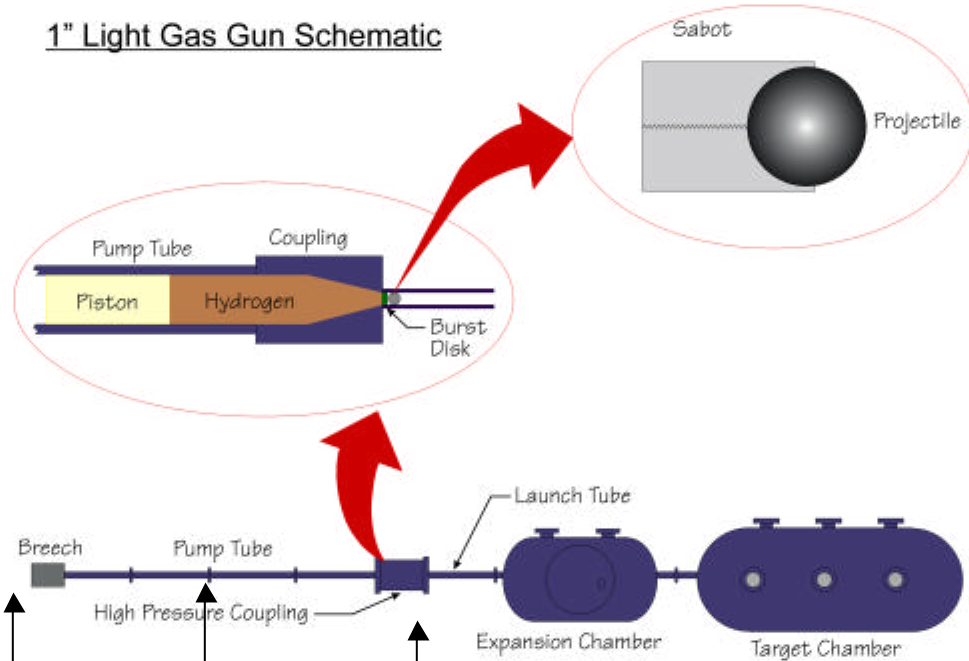
The Hypervelocity Group at WSTF works in close partnership with the JSC Hypervelocity Impact Technology Facility (HITF) in Houston. HITF determines the risk posed by space debris, and designs spacecraft shields based on probability of impact and spacecraft geometry. HITF builds and sends target shields to WSTF for ballistic-limit verification testing and then analyzes the results. Other spacecraft materials and components are also targeted, as well as toxic and explosive cargo, including fuel (up to 5-lb TNT equivalent).

The WSTF Hypervelocity Impact (HVI) Testing Program assesses candidate shield materials using two-stage light-gas guns (LGGs). These guns shoot projectiles at hypervelocities up to 24,000 f.p.s., roughly six times faster than the fastest rifle bullet, and mimic the impact of real space debris traveling at even higher speeds.

The main LGG facility at WSTF houses 1-in, .50, and .17 cal. guns. Because of the hazardous nature of the testing, the facility was built in a remote location, and the LGGs are remotely operated from underground control bunkers. TV cameras constantly monitor the entire area. Access warning lights, signs, and a remotely operated road gate control all possible area entry. Safety or warning announcements are broadcast before and after each shot. For non-hazardous testing, smaller .07 and .17 cal. guns are operated within another controlled-access laboratory. Even with an intense testing schedule of 647 official test shots (plus another 60 to 80 calibration shots) over the last two years, the continued emphasis on safety has paid off. The HVI program now has over 1600 continuous accident-free workdays.

The two-stage LGG uses conventional smokeless gunpowder as its first stage. The second-stage propellant is a highly compressible light gas such as hydrogen. Since light gases have very low molecular weights, they are easily compressed to the high-pressure levels needed to efficiently launch projectiles at hypervelocity speeds—usually from 8,000 to 24,000 f.p.s.

1" Light Gas Gun Schematic



The gun's breech (powder chamber) contains the first-stage charge, set off by an electronic igniter, and upon exploding provides the rapidly expanding gas that drives the piston forward.

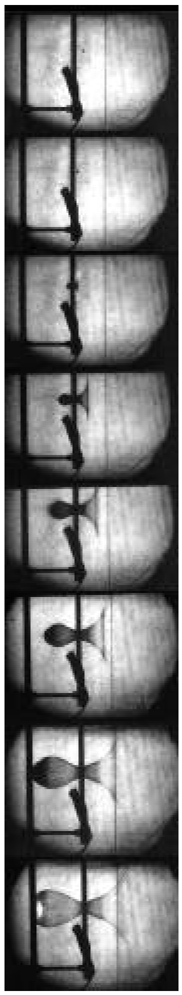
The taper-bored, high-strength monolithic-forging steel high-pressure (HP) section, also referred to as the high-pressure coupling, halts the propelled piston at the end of its travel down the pump tube. In the HP section, rapid internal pressurization is followed by an extremely high level of impact caused by the halted piston. Upon petal-valve rupture, the sabot is launched—propelled by the rapidly expanding light gas—down the barrel into the expansion tank.

The ASME-rated target tank is designed to contain resultant second-stage light gas and the eruption of shrapnel and debris from the impacted target. It is equipped with optical ports to permit high-speed flight, and impact photography and flash radiography.

The high strength, heavy-wall pump tube contains the precision-machined plastic piston assembly that rapidly compresses the light gas column and provides the second-stage firing power.

The expansion tank downstream of the barrel allows collection and dissipation of second-stage high pressure light gas and permits the controlled separation of the sabot/projectile assembly. It is equipped with optical ports for in-flight photography of projectiles.

Depending on the gun and velocity required, smokeless powder charges range from 21 to 27,800 grains (~4 pounds). The charge propels a cylindrical polyethylene (plastic) piston at 2500 f.p.s. down the pump tube, compressing the hydrogen gas. The piston enters the internally tapered high-pressure (HP) section and deforms in a rapid energy-absorbing stop. A stainless steel petal-valve diaphragm retains the gas until it bursts, and the highly compressed (about 100,000 psi) hydrogen rapidly expands, accelerating the launch package down the barrel with little loss of energy. The hydrogen dissipates through the muzzle into an expansion tank. A stripper plate separates the launch package (sabot and projectile) while in free flight. The projectile then enters the evacuated target tank where it impacts the target.



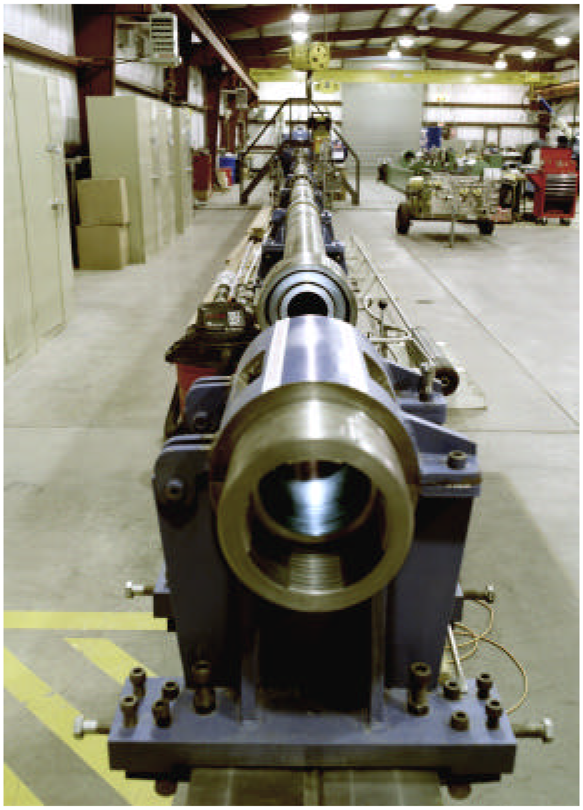
A laser-illuminated shadowgraph sequence of a 6-mm projectile traveling at 23,000 f.p.s. and its progressive impact, resulting in debris and ejecta cloud images. The first target plate is a bumper plate, 1/8" thick 6061-T6 aluminum. State-of-the-art cameras shoot up to 48 exposures at framing rates up to 100 million frames per

The projectile is photographed with high-speed cameras and flash x-rays just before impact. At times, the impacts are photographed to characterize the debris cloud. Three types of high-speed cameras are used. Cinema cameras run at 10,000 frames per second; 35-mm infrared cameras are capable of 2 million, and the digital cameras are capable of 100 million frames per second.

Laser intervalometers measure projectile velocity. The time difference between interruption of laser beams by the projectile yield an extremely accurate calculation of its velocity—in the case of the 1-in. LGG, 23,000 f.p.s. in just 22 ft of barrel. In addition, high-speed data acquisition systems—using light detectors, strain gauges, pressure transducers, accelerometers, and thermocouples—provide reliable diagnostics.

The barrel, a long high-strength section of steel with a precision-honed smooth bore, allows for controlled acceleration of the propelled sabot/projectile assembly into the downstream expansion tank. A horizontal honing machine uses computer-controlled depth of cut, auto-fluid feed, and a single-spindle 14-stroke reciprocating/rotating stone honing tool with various grit sizes. Before honing a new barrel, a plastic slug is fired to knock off the bore's rough edges. Initial honing establishes the original LGG bore size. Subsequent honing cleans the bore and establishes the new bore size for the next sabot.

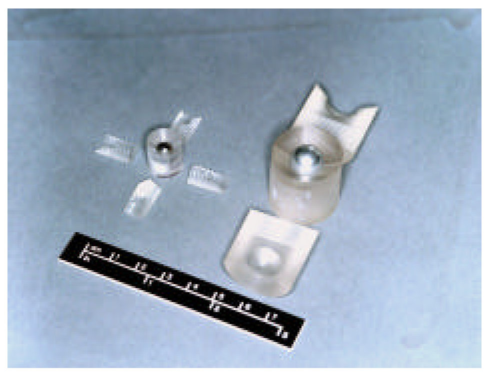
LGG alignment is checked before every shot. A pedestal-mounted surveyor transit sights down the bore's centerline from the open end of the LGG's powder chamber (breech). The gun is bore-sighted, focusing the transit on various alignment plugs located at both ends of the pump tube and the barrel, and the HP section. LGG alignment is further verified by sighting on the stripper plate orifice in the expansion tank and finally on the pre-marked target itself. Shots for any of the WSTF LGGs are normally within one-projectile diameter of the marked point-of-impact on the target.



Looking down the 1-in LGG from the open end of the breech toward the target tank just outside the building, 175 ft away. Projectile achieves 23,000 f.p.s. in just 22 ft of barrel.

(Alternate pictures are available to choose from in lieu of this one)

The projectile/sabot launch package is carefully loaded into the entry end of the barrel. The petal valve and ring seal are inserted, and the gun barrel assembly and HP section are clamped together with hydraulic collars. At the entrance end of the pump tube, a freezer-stored ultrahigh-density 12-lb polyethylene piston is inserted. The front face of the piston is a hollow cone that forms a gas seal as it compresses the H_2 at a speed of ~2500 f.p.s. The back end of the piston uses an O-ring to seal the expanding gases from the powder charge.



Shown above are .50-cal and 1-in. sabots in both assembled and separated modes. These highly engineered, precision-machined plastic parts are designed to protect the projectile from barrel friction/abrasion, and provide an effective gas seal up to the exit point into the expansion tank.

HVI team members display two high-density polyethylene pistons, one before and one after firing. Behind them is the 1-in . LGG.

(At right:) Two petal valves, 1-in. and .50 cal., shown before and after shooting. They are highly engineered, precision-machined 304L stainless steel disks that control the release of the second-stage light

Once the LGG is reassembled, a powder charge is inserted in the breech. A typical powder charge is about 18,500 grains (2.6 lb) of IMR 4831 for the 1-in. LGG. Maximum charges use 4.1 lb. An electrically activated igniter (Standard Mark 27 torpedo igniter) is contained in the center of the powder charge. The downstream barrel section, expansion tank, and target tank are maintained at near vacuum in readiness for firing.

Typical Charges and Igniters		
LGG	Type of Powder	Primer
1 inch	IMR 4831	Standard Mark 27 torpedo igniter
.50 cal.	IMR 4198	Standard Mark 27 torpedo igniter
.17 cal.	Alliant UNIQUE	CCI 209/solenoid firing pin
.07 cal.	Alliant UNIQUE	CCI 209/solenoid firing pin

Firing is performed from one of the underground control bunkers. Area TV surveillance monitors are checked to ensure that the area is secure; warning announcements are made; and the bunker blast doors are secured to provide overpressure protection. The area warning lights are switched to red. The pump tube is remotely backfilled with hydrogen to 50 psig. The firing circuit is turned on, and the x-ray system and high-speed cameras are activated. After a countdown, the FIRE button is pressed.


Inside the HVI facility, looking from the muzzle ends of the .50 cal. (left) and 1-in. cal. (right) guns. The precision barrel honer is in the middle.

The LGG, like any other powder-charged gun, recoils upon firing. To accommodate this, the entire gun assembly is held within either anchored sleeves or sliding anchor assemblies, which allows the gun to move both forward and back. When the powder charge ignites, the normal recoil is counteracted when the piston slams into the HP section. The muzzle end of the barrel is sleeved into the expansion tank at the entry flange orifice via O-ring seals that accommodate movement in either direction. This linear recoil arrangement essentially isolates the anchored expansion and target tanks from any effects of recoil that could affect accuracy.

LGG Critical Dimensions and Firing Pressure Ratings			
Bore size	1 inch	.50 cal.	.17 cal.
Pump tube length (ft)	80	40	4
Barrel length (ft)	22	12	2-3
Target tank (ft^3)	~800	100	20
Overall length	175	85	29
Breech pressure (psi)	3,800	3,000	7,300
Piston velocity (f.p.s.)	2,500	2,200	3,000
Petal valve burst pressure (psi)	5,000	10,000	2,500
Barrel pressure (psi)	105,000	90,000	120,000 (est.)

Actual projectiles encountered in space vary in size, shape, and mass. The shape, size, and material of LGG projectiles are standardized to obtain specific levels of impact energy.

Compare impact damage from conventional .22 cal. ammo fired point-blank vs. a .125-in. aluminum projectile fired from an LGG.

TYPICAL WSTF LGG BALLISTICS						
	Projectile			Powder	Velocity	Energy
Cal.*	Shape	Matl.	Wt. (grains)	(grains)	(f.p.s.)	(ft-lb)
			.17 cal. LGG			
1 mm	Sphere	Al**	0.02	71	22,900	23
2 mm	Sphere	Al	0.18	71	22,500	202
3 mm	Sphere	Al	0.55	77	22,600	624
.17	Slug***	Nylon	0.92	80	24,900	1,270
			.50 cal. LGG			
.17	Sphere	Al	1.9	2,890	23,000	2,200
.31	Sphere	Al	11.3	2,920	22,900	13,200
.41	Sphere	Al	24.8	3,470	22,300	27,400
.50	Slug	Plastic	30.5	2,700	22,300	33,700
			1-in. LGG			
.25	Sphere	Al	5.8	19,140	23,100	6,900
.50	Sphere	Al	46.2	19,910	23,400	56,200
.69	Sphere	Al	120.0	22,380	21,700	125,000
1.00	Slug	Plastic	236.9	23,150	22,600	269,000

* Actual or rounded to nearest caliber
** Projectiles are typically aluminum alloy 2017-T4
*** Flat-faced cylinder with a length to diameter ratio of ~ 1.0

The basic designs of WSTF LGGs originate from the 1940s and 1950s, with improvements and updates through the years. Most of the gun parts are made from high-strength low-alloy steels such as AISI 4340, with a minimum design yield strength of 140,000 psi. Recently, the need for higher-strength materials was established to provide added safety, extended life, and increased gun performance.

In 2001 the Hypervelocity Group purchased some highly engineered Grade C250 maraging steel for a new .50 cal. HP section. It was supplied as a fully annealed, rough-turned custom forging. The critical internally tapered HP Section bore was precision-machined using electron-discharge machining. After machining, the part was then heat treated to achieve its final properties. Test results indicate a yield strength of 285,000 psi, twice the minimum design yield strength required for conventional gun steels used at WSTF.

All gun components are thoroughly inspected and verified using ultrasonic testing, magnetic particle testing, x-ray, chemical analysis, Charpy V-notch, and tensile and hardness testing. A rigorous final dimensional inspection is also performed to ensure the components match the original NASA design drawings.

HVI testing at WSTF has contributed significantly to the design and evaluation of materials and shield configurations for the ISS, Space Shuttle, Extravehicular Mobility Unit (EMU), Long Duration Exposure Facility, Russian Space Station Mir, the X-38, and the ISS proposed Crew Return Vehicle. Because of the program's success, the future of Hypervelocity Impact Testing will continue to include evaluation of new materials and concepts for the space program.

NASA is currently evaluating the feasibility of manned missions to Mars. Although debris generated by man is not a problem once we are away from Earth, the threat of meteoroids with unknown velocities presents us with new challenges. Some estimates of velocities in our solar system are up to 230,000 f.p.s (70 km/sec). Deep-space debris may travel even faster, up to ~787,000 f.p.s (240 km/sec). Hopefully, new technology will emerge to enable scientists to more accurately predict the terminal ballistics of such superhigh-velocity debris.

For further information about WSTF and the HITF, visit:
http://wstf.nasa.gov and *http://hitf.jsc.nasa.gov*