Using Lasers to Capture the Speed of a Hypervelocity Projectile

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Millions of human-made debris particles and naturally occurring meteoroids are found in the near-Earth space environment. These objects travel through space at any velocity with a magnitude over 3 km/s, or hypervelocity. This near-Earth region of space is where our satellites, space shuttle, and the International Space Station travel. The design and testing of vehicle shielding is thus very critical, since collisions with these orbiting particles could catastrophically damage vehicles and hardware. Scientists have developed several computational models to aid in the design of these shields. The actual laboratory testing of shield designs can validate and improve models, or test final designs for flight worthiness. The NASA White Sands Test Facility (WSTF) Remote Hypervelocity Test Laboratory (RHTL) works in close partnership with the Johnson Space Center Hypervelocity Impact Technology Facility (HITF) to determine the risk posed by space debris, and to design spacecraft shields based on probability of impact and spacecraft geometry. HITF builds and sends target shields to WSTF for ballistic-limit verification testing, and the RHTL analyzes the results to improve the HITF models.

The RHTL uses a two-stage light-gas gun (figure 1) to propel projectiles to hypervelocity and simulate the impacts in a controlled environment. The first stage of the light-gas gun compresses hydrogen gas to extremely high pressure. This high-pressure hydrogen is released into the second stage – the gun barrel. The gun barrel is separated from the first stage by a high-pressure rupture disk. When the disk ruptures, hydrogen gas is released into the barrel and the sabot is accelerated down the barrel to hypervelocity. The sabot holds the projectile and protects the projectile from erosion as the sabot travels down the barrel. When the sabot exits the barrel, it separates from the projectile and impacts a "stripper" plate, thus allowing just the projectile to continue downrange and impact the test article. The test article, stripper plate, and barrel are contained in a chamber (flight range) so the test can be conducted in a vacuum, allowing for hypervelocity projectile flight.

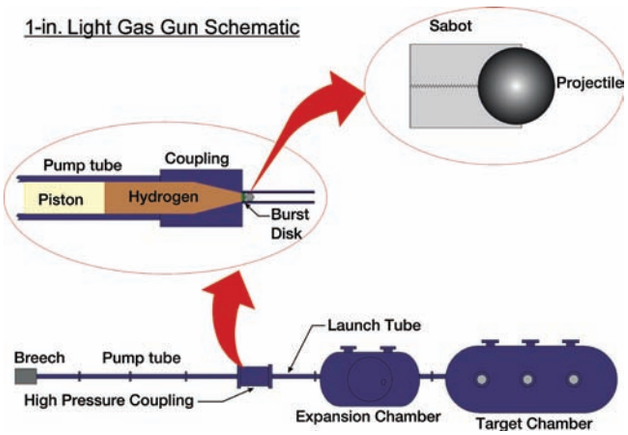

Fig. 1. *Two-stage light-gas gun.*

The WSTF RHTL is provided with a projectile, a test article, and the requested projectile velocity. This requires acquiring the projectile velocity during the test to ensure the test article was impacted with the prescribed velocity. The velocity of the projectile is captured by two laser stations set a specified distance apart from one another. These laser stations are comprised of a 690-nm visible wavelength, red laser source projected through the flight path of the projectile and terminating at a high-sensitivity, fast-acting photodiode. When the projectile or sabot intersect and break the beam, an event is triggered and recorded. Photodiodes used for this application have a response of 50 ns. While a photodiode receives uninterrupted light from the laser source, its resistance remains high and voltage across the detection circuit also remains high. When the beam is interrupted by the projectile or sabot, the resistance is lowered briefly, allowing current flow to lower the voltage across the detection circuit. The data acquisition system records voltage difference relative to time in microsecond resolution. The difference in time between the two recorded events and the known distance between the two laser stations allow projectile velocity to be calculated. Figure 2 shows a typical response from the photodiode captured by the data acquisition system. The laser velocity stations directly measure the sabot or projectile velocity.

Prior to the advent of the RHTL, primary laser stations were mounted external to the flight range and perpendicular to the flight path. The laser was projected through a view port in the flight range, across the path of the projectile, and terminated in a photodiode mounted externally in an opposing viewport. On smaller-caliber, two-stage light-gas guns, the projectile is often too small to register a detectable event or has drifted slightly out of plane. It is

impossible to predict the plane of separation of the sabot, and it is unlikely that it will coincide with that of a single-beam laser station. This results in a higher incident of tests where velocity cannot be provided by the single-beam laser station due to insufficient projectile size. The RHTL, by contrast, routinely shoots projectiles with an average size of 1.3 mm ranging down to single 0.05-mm projectiles.

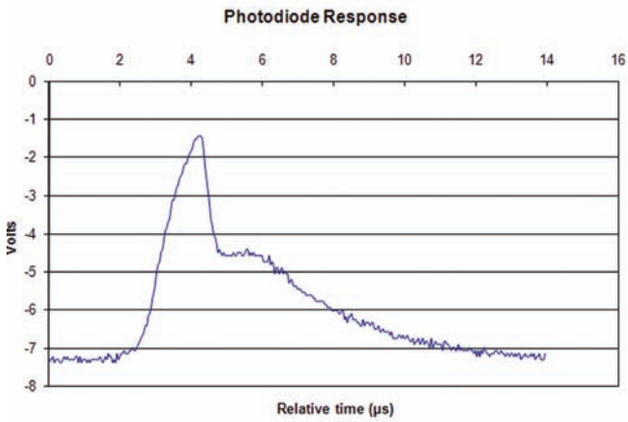

Fig. 2. *Response of photodiode from 2.5 km/s test.*

Increasing the density of laser beams traversing the projectile flight path increases the likelihood of the sabot or projectile being sensed by the laser station. Improvements made to the laser station do this by reflecting a single laser beam up to 10 times between two mirrors. Figure 3 illustrates a typical laser station and its parts. Items 7 and 4 are the laser source and photodiode, respectively. The gold-plated mirrors (items 5 and 6) reflect the beam to form multiple beam trajectories from one laser source, any of which, if interrupted, would be detected by the photodiode.

The gold-plated mirrors can be adjusted to increase or decrease the number of beam trajectories in line of the projectile flight path. The number of beam trajectories that can be created while maintaining a high resistance at the photodiode is restricted due to losses of incomplete reflection incurred at the mirror and limitations of the laser source power. Increasing the number of reflected beam trajectories can improve detection ability, but it would require a more powerful laser source – which would, in turn, produce a safety risk for personnel aligning and tuning the laser station assembly – to provide the optimal signal at the photodiode. Regular cleaning of the mirrors also reduces signal losses. In addition, the laser stations were moved inside the flight range as an assembly to avoid the losses and refraction caused by projecting through a glass viewport. The improved laser station design significantly increased successful detection of sabot velocity. On the 0.17-caliber light-gas gun range, where the laser stations capture the sabot, velocity has been successfully captured for every shot since installation of the improved laser stations.

Certain projectile sizes (e.g., smaller than 2 mm) require the sabot to be detected by the laser stations. The ability to acquire the velocity of small projectiles would be an added capability, useful in the analysis of impacts as it would be a direct measurement of projectile velocity. The WSTF RHTL team was recently approached to develop a new capability to launch single particles smaller than 0.05 mm. However, as this added capability presents an even greater challenge in acquiring direct projectile velocity without relying on the sabot, this may require an entirely new design of laser station or detection methods.

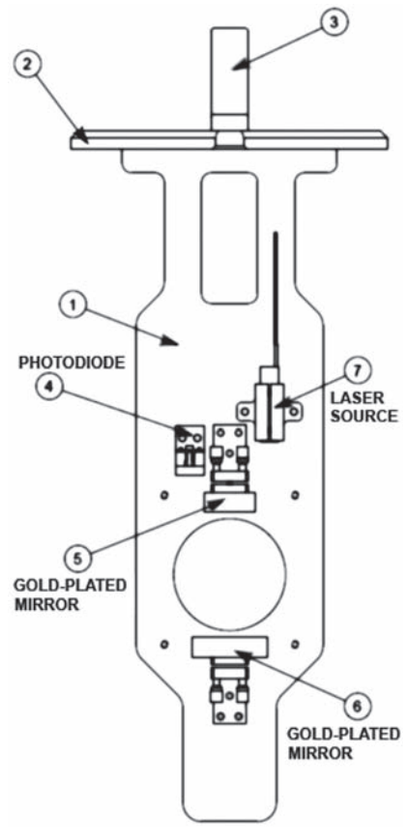

Fig. 3. *Improved laser station, sketch no. 33142.*

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