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The SHARP Scramjet Launcher

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Abstract:-The worlds largest light gas gun at SHARP (Super High Altitude Research Project) is completed and in the past year has launched 9 scramjets. Typical masses and velocities are 5.9 kg at 2.8 km/sec and 4.4 kg at 3.1 km/sec. In so doing SHARP launched the first fully functioning, hydrogen burning scramjet at mach 8.
The SHARP launcher is unique in having a 4 inch diameter and 155 foot long barrel. This enables lower acceleration launches than any other system. In addition the facility can deliver high energy projectiles to targets in the open air without having to contain the impact fragments. This allows one to track lethality test debris for several thousand feet.

1. Introduction

SHARP is a classic two stage light gas gun with a couple of twists:

1. The piston is propelled by combusting fuel-air. This was motivated by a desire to have environmentally benign propellent products. In addition fuel-air is logistically easier to work with than gunpowder in these quantities.

2. There is a right angle between the launch tube and the pump tube. This enables one to perform launches into space by elevating the launch tube and leaving the pump tube on the ground.

SHARP was originally designed to deliver 5 kg at 4 km per second with a near vertical trajectory. This suffices to deliver a vehicle to a suborbital 450 km apogee. If and when this experiment is performed it will demonstrate the utility of launching larger vehicles into low earth orbit. A larger light gas gun can then be built reducing the cost of delivering satellites, consumable and building material into low earth orbit. The future, larger systems will use hydrogen as propellent but shall utilize side injectors to give the vehicles multiple gentle pushes versus one large push.

2. Launcher Description

In the current location at Site 300 (a 10 square mile test area) in Tracy California SHARP enjoys a large test area with a 4000 foot radius if necessary for target debris. For scramjet testing the keepout radius is only 2000 feet since the scramjets impact sandbags rather than hardened targets. Figure 1 shows SHARP schematically. Figure 2 is a photograph of SHARP firing a scramjet.

The fuel-air propellent is a fuel rich mixture of methane and synthetic air. The synthetic air has 17.8% Oxygen and 82.2% nitrogen due to our desire to bring the combustion burn rate down. Typical fuel-air pressures are 800 psi, while hydrogen pressures are about 100 psi. Strain gauges located along the combustion section, pump tube, high pressure section and launch tube indicate and record internal pressures during a shot.

SHARP doesn't recoil. This is desirable since a recoiling pump tube would couple into the launch tube and send transverse waves up it thereby causing problems. Momentum is instead transferred to two 100 ton steel sleds at both ends of the pump tube. This absorbs the piston momentum both during its acceleration by the propellent and its subsequent deceleration by the hydrogen. Similarly a 10 ton sled is located at the projectile release location and counters the projectiles momentum.

The SHARP launcher is operated remotely from a control room 800 feet away. Labview running on a Macintosh FX is used both to operate the vacuum systems and gas manifold as well as acquire data. During a shot, data is stored in real time on DSP memory modules which are located in a small building near the launcher. After the shot the data is downloaded to the Macintosh for display, processing and printing.

3. Applications

The applications to date are aerophysics, lethality and meteor impact simulation. We'll address these by turns.

Aerophysics: SHARP can perform realistic aerophysics experiments by virtue of the large vehicle size (4" diameter by 20" long), as well as the sea level density air which the vehicle flys through at high velocity. Typical Reynolds numbers as a result are 100 million which coincidently is the the NASP requirement and is higher than required for HySTP. It is relatively easy to lower the Reynolds number on the tests by enclosing the scramjet trajectory in a one foot diameter acrylic pipe, which is then evacuated to the required pressure. The acrylic pipe can be replaced every shot. As an interesting note, the wind tunnels and shock tubes used for NASP ground testing obtain Reynolds numbers of about 20 million. The reason they have low Reynolds number is simply due to the fact that in order to achieve high mach number, the gas in a blow down facility loses density fast and hence Reynolds numbers drop.

To date metal scramjets have been launched at up to Mach 9. We are designing a lighter weight composite vehicle which should allow launches at Mach 15.

Another advantage SHARP has over conventional ground tests is that it is not a ground test. In fact the vehicle is in free flight through undissociated, non turbulent air. These last two are hard to come by in ground test facilities.

Lethality: On Sept 13, 1993 SHARP delivered a 5 kg, 2.9 km/sec projectile into a full scale target. This was a world record for kinetic energy on a target at that velocity. The results are on videotape. Future tests can be accommodated with a full diagnostic suite of Hycams and flash x-ray and other user specified diagnostics. The two absolutely unique features beside high kinetic energy are the low g loads on the projectile (about 2/3 of the next best facility) and the open air impact area.

Meteor impact simulation: On two scramjet tests a team of geologists and scientists from LLNL fielded a variety of experiments designed to study the physics and chemistry of meteorite impact processes 3 orders of magnitude in scale larger than conventional light-gas gun experiments. A target consisting of a 20° slope of unconsolidated quartz sand was constructed for both tests. High-speed ejecta was captured in steel tubes filled with low-density commercial foam insulation positioned up-range and down-range from the point of impact. Particle speeds were derived from the mass of the individual grains and the depth of penetration. After the impacts a controlled excavation was made of the entire target area and the distribution of projectile fragments, shock-comminuted sand and shock-lithified sand were mapped. No melted sand was found in the higher velocity experiment (3.0 kps). These results were compared to smaller cratering experiments in sand using the AVGR at NASA Ames as well as terrestrial and lunar impact craters.

In one experiment an array of thermocouples were distributed throughout the target sand and along the surface of the sand as a function of distance from the point of impact. Temperature was recorded at regular intervals for up to two hours after the impact. Thermocouples buried beneath the crater recorder little or no thermal effect from the impact. In contrast, the thermocouples at the surface were buried by hot ejecta (temperatures exceeded 150°C above ambient). Ejecta deposited far from the impact point was measurably hotter than the proximal ejecta, confirming that material ejected farthest from an impact crater experiences both high pressure and higher temperature. This may shed light on the production and distribution of tektites from terrestrial impact craters.

X-ray diffraction analyses of the ejecta showed that, despite the high temperature, no measurable oxidation of the vaporized projectile took place. This suggests that the most of the heat in the ejecta is created by friction during crater excavation, not by entrainment in a hot burning cloud. This also suggests that impact plumes in general may be very reducing chemical environments.

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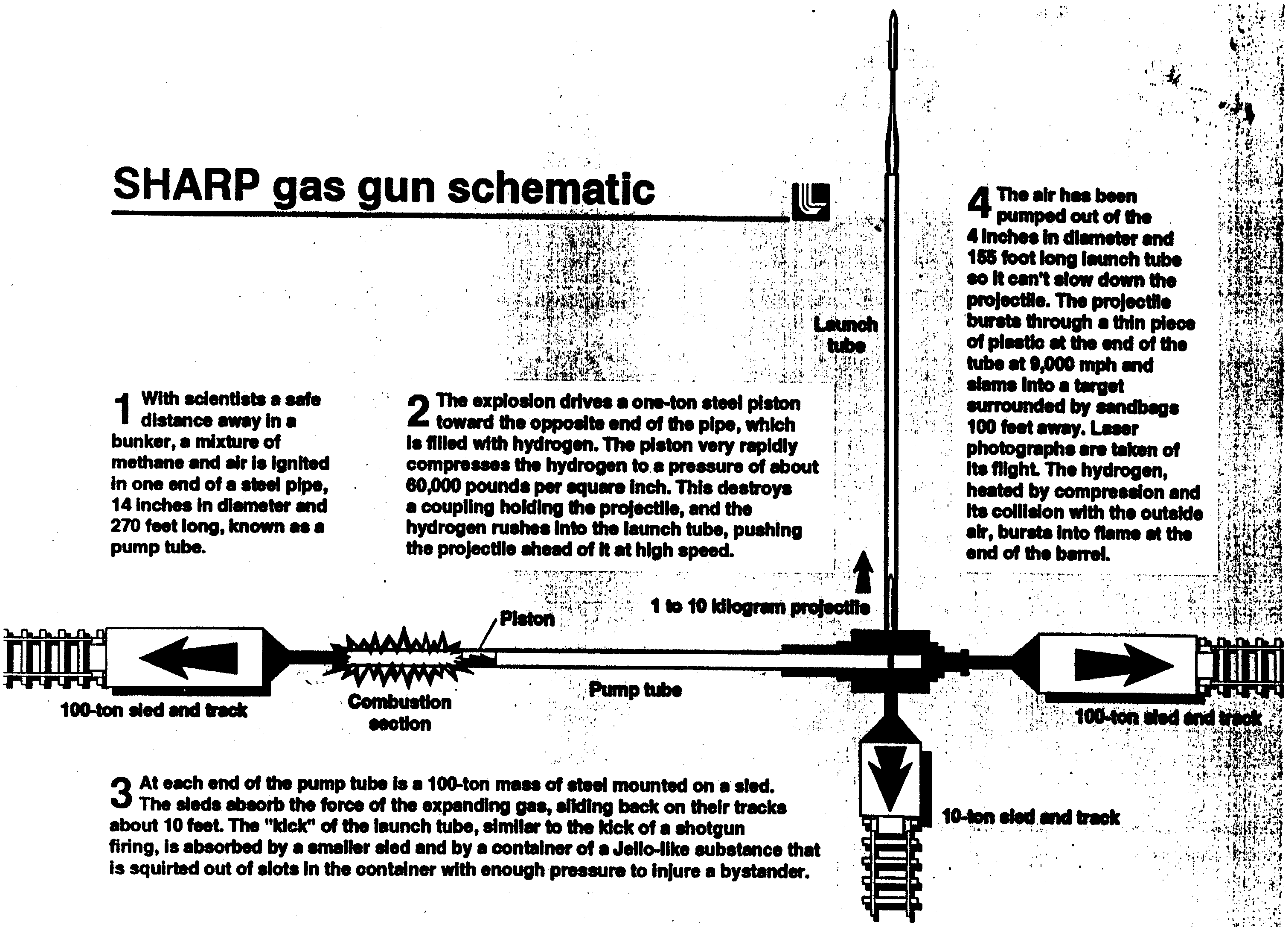
SHARP gas gun schematic



1 With scientists a safe distance away in a bunker, a mixture of methane and air is ignited in one end of a steel pipe, 14 inches in diameter and 270 feet long, known as a pump tube.

2 The explosion drives a one-ton steel piston toward the opposite end of the pipe, which is filled with hydrogen. The piston very rapidly compresses the hydrogen to a pressure of about 60,000 pounds per square inch. This destroys a coupling holding the projectile, and the hydrogen rushes into the launch tube, pushing the projectile ahead of it at high speed.

3 At each end of the pump tube is a 100-ton mass of steel mounted on a sled. The sleds absorb the force of the expanding gas, sliding back on their tracks about 10 feet. The "kick" of the launch tube, similar to the kick of a shotgun firing, is absorbed by a smaller sled and by a container of a Jello-like substance that is squirted out of slots in the container with enough pressure to injure a bystander.

4 The air has been pumped out of the 4 inches in diameter and 155 foot long launch tube so it can't slow down the projectile. The projectile bursts through a thin piece of plastic at the end of the tube at 9,000 mph and slams into a target surrounded by sandbags 100 feet away. Laser photographs are taken of its flight. The hydrogen, heated by compression and its collision with the outside air, bursts into flame at the end of the barrel.