

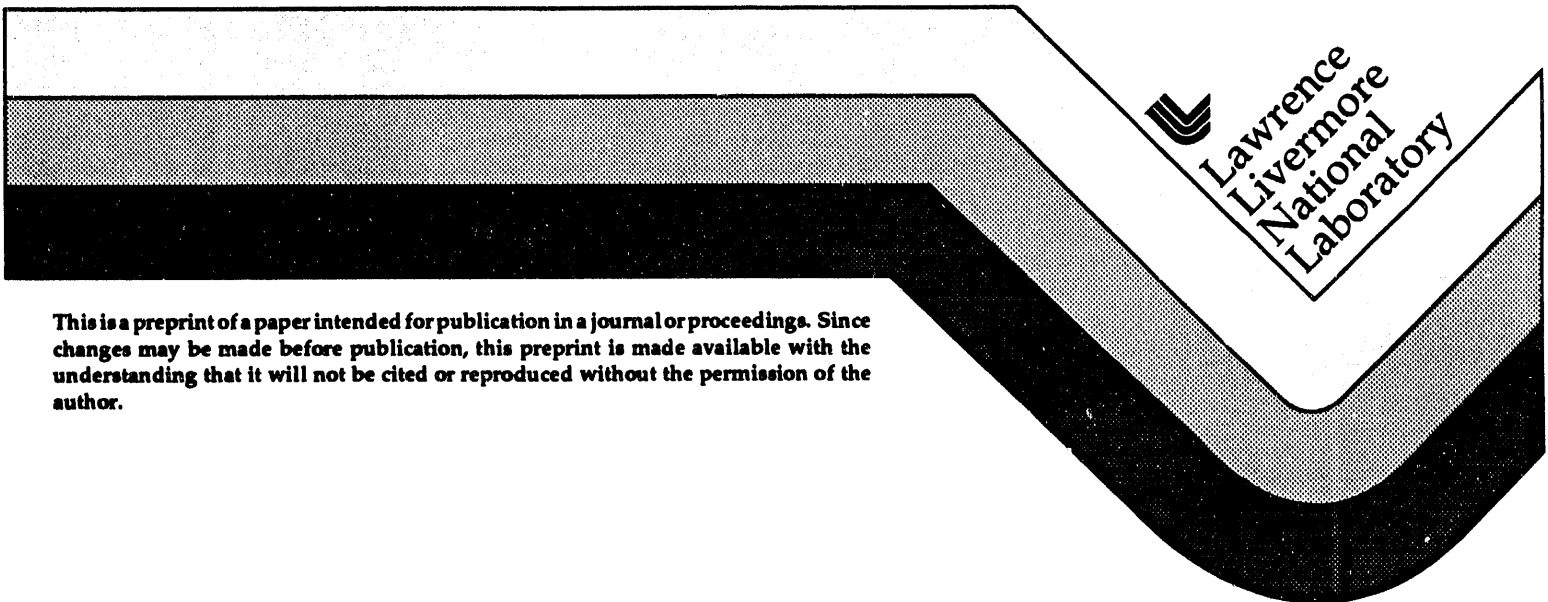
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**SHARP, A First Step Towards A Full  
Sized Jules Verne Launcher**

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# SHARP, A FIRST STEP TOWARDS A FULL SIZED JULES VERNE LAUNCHER

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## Abstract

A vital element for space exploration and utilization is the ability to affordably place large quantities of consumables and building material into low earth orbit. Calculations and supportive data indicate this can be done with a large hydrogen gas gun referred to as the Jules Verne Launcher (JVL). We present a design for the JVL based upon the concept of side injecting preheated hydrogen along a long barrel. This dramatically reduces the peak pressures in the launcher as well as the pressures and g-loads at the vehicle. The JVL has the promise of reducing payload delivery costs to Low Earth Orbit (LEO) to below \$500/kg.

The Super High Altitude Research Project (SHARP) is a conventional two-stage hydrogen gas gun which is configured to launch 5 kg packages on suborbital trajectories. It is the first step towards the much larger Jules Verne system and will demonstrate several important features of the larger system. SHARP is currently in the middle of a series of tests aimed at its first milestone. This is to launch 5 kg at 4 km/sec horizontally. In its inclined configuration SHARP should launch vehicles to apogees in excess of 400 km and ranges in excess of 700 km.

## 1. Light Gas Gun Background

Light gas guns have been around for over 30 years and are considered the gold standard for impact studies, equation of state work and reentry physics at velocities above 3 km/s. They have held the record for velocity (11.3 km/sec) and kinetic energy at all velocities above 3 km/sec for the last 30 years. Their success is simply due to the high sound speed of hydrogen.

The maximum velocity theoretically obtainable with a light gas gun is 5 times the maximum sound speed in the gas reservoir. This dependence holds for all types of launchers using expanding fluid to push the vehicle. (The coefficient may differ from 5 being a simple function of the specific heat ratio.) In practice with finite mass projectiles, heat loss to the walls and drag on the walls the maximum projectile velocity is 2 to 3 times the reservoir sound speed.

Sound speed is proportional to the square root of temperature divided by molecular weight. Since hydrogen has the lowest molecular weight the next question is how to heat it up. Rapid heating is a necessity due to the large heat losses obtained in high pressure vessels. The conventional technique for heating hydrogen is to compress it rapidly with a piston. Once the pressure in the hydrogen reaches 5 to 10 kpsi a

diaphragm opens and the hot, high pressure hydrogen pushes the vehicle down the barrel. The highest performance light gas guns have been of this type and are designated two stage light gas guns. The first stage refers to using a propellant to fire a piston down a large diameter tube (the pump tube) thereby compressing and heating the hydrogen. The second stage refers to the hot hydrogen pushing a vehicle down a second, smaller diameter tube (the launch tube).

Recent developments (namely particle bed heaters and side injection) enable one to construct a light gas gun which has a longer length to diameter ratio and runs at lower pressures than two-stage guns do. This will be described in the section on the Jules Verne Launcher.

## 2. SHARP Description

SHARP is the largest hydrogen gas gun that we know of. It is designed to launch a variety of masses at different velocities. Milestone 1 is to horizontally launch 5 kg at 4 km/sec. SHARP should also deliver 1.5 kg at 6 km/sec as well as other masses at lower velocities. It is shown schematically in Figure 1 and literally in Figure 2.

SHARP is a two stage light gas gun with several novel features. These include:

1. Using fuel-air to propel the piston as opposed to gunpowder. It can also use compressed air or helium.
2. A right angle between the pump and launch tubes. This enables launches at different inclinations into space without elevating the massive pump tube. See Figure 3
3. The absence of recoil. Due to the L shape of SHARP it is necessary to decouple the momentum associated with pushing the piston from the gun itself.

This is accomplished by coupling 100 ton masses at both ends of the pump tube. These masses get kicked to the left and right respectively when the gun fires.

A typical operation involves filling the pump tube with 10 bars of hydrogen. The combustion section is then filled with 80 bars of slightly lean methane and air. Exploding bridgewire ignitors are spaced inside the combustion section to deliver simultaneous ignition. This technique reduces the chance of a detonation wave.

The vehicle is located in the high pressure section at the cross hole where the launch tube and pump tube join. The launch tube ahead of the vehicle is evacuated to several Torr. This reduces the amount of extra mass the vehicle would otherwise have to push down the launch tube. At the end of the muzzle a Mylar diaphragm is installed to hold off the atmosphere.

Fifteen feet from the muzzle is located a sabot stripper. This is an 8 inch diameter tube surrounded by sand bags and concrete blocks. Its purpose is to allow the sabot which in many cases encapsulates the vehicle during its acceleration in the barrel to separate from the vehicle and be destroyed without entering the target area. The sabot stripper also prevents the hydrogen following the vehicle from entering the target area. The target area is 70 feet from the muzzle. This is where the fast cameras which show the vehicle in flight are located. (Hycam, shadowgraph etc.)

The shot process is as follows: The exploding bridgewires in the combustion section are electrically fired providing multiple ignition points for the fuel-air. When the fuel-air burns the pressure rises to 9 times the initial pressure. This occurs in about 400 milliseconds. When the pressure has risen to 6 times the initial pressure, aluminum pins restraining the piston, shear, thereby releasing the piston. The piston accelerates to 400 meters per

second down the pump tube. When it gets near the high pressure section. The hydrogen pressure ahead of the piston has been adiabatically compressed to 7 kpsi. At this pressure a tensile restraint on the vehicle base fails and the vehicle is pushed down the barrel. Meanwhile the pressure continues to increase while the piston is slowing down. The hydrogen pressure peaks at 60 kpsi while the vehicle is one third of the way down the launch tube. The pressure then steadily drops until the piston impacts the reaction mass inside the high pressure section. The local pressure in the polyethylene nose then rises to 30 kpsi briefly as the last of the piston kinetic energy goes into deforming the nose. At this time the vehicle has left the muzzle. The gun is stationary but the two 100 ton reaction masses are moving at a few meters/second and the 10 ton mass which opposes the vehicle is also moving slowly.

After the vehicle leaves the muzzle, the sabot petals separate due to aerodynamic forces. They move radially about 10 inches from the nominal trajectory and vaporize upon hitting the sandbags on the sabot stripper. Meanwhile the hydrogen following the vehicle burns with the air at the muzzle forming water vapor, nitrogen and lots of noise. This lasts about a second. The products of the fuel-air combustion, namely water vapor, carbon dioxide and nitrogen are also released from the combustion section. This occurs after the 100 ton combustion section reaction mass has moved several feet allowing vents to open.

The vehicle flies 70 feet into the target area where it is photographed before it vaporizes on impact with a container full of water.

### 3. SHARP Predicted Performance

There are many computer codes available which model two-stage light gas gun performance well. We use one called

REHEAT (See Reference 1) which has been checked against data on several launchers and typically predicts velocity within 5%. The computed acceleration experienced by the vehicle as it moves down the launch tube is under 40,000 gs. This corresponds to a peak pressure at the vehicle base of 36 kpsi.

Figure 3 depicts SHARP configured for Milestone 2. That is a successful launch into space obtaining an apogee in excess of 400 km. There are several US launch sites appropriate for Milestone 2.

The range and apogee is calculated assuming a vehicle mass of 4 kg (1 kg is assumed for a modest sabot mass) leaving the muzzle from sea level on an inclined trajectory. An average drag coefficient of .05 is used based upon analysis performed for us by General Research Corporation. A conical shape is assumed with a base diameter of 3.5 inches, and a nose radius of 0.2 inches. Based on these values one obtains an apogee of 450 km for a launch angle near 90 degree. A range of 700 km is obtained for launches near 45 degrees.

Ab' :tion analysis has not been done for the SHARP vehicle specifically, however analysis has been done by SDIO for a similar vehicle. The amount of mass ablated near the front of the vehicle was less than 5% of the total vehicle mass. One of the important data points SHARP will obtain is whether a vehicle can survive atmospheric egress when it is launched at velocities above 4 km/sec. At that velocity and initial air density the stagnation pressure and heating rates at the nose are very high although lasting for a short time. This is a compelling reason for the SHARP suborbital launches.

### 4. SHARP Performance to Date

Since a scaled version of SHARP has not been built and tested, we approached the shot sequence cautiously.

As Alex Charters, one of our consultants described it, we embarked on a "voyage of discovery". The three phases of the SHARP shots are as follows:

**Phase 1:** Shots 1 to 3. (The first shot was on December 29, 1993.) These were single stage compressed air shots where the piston did not move. In these cases the pump tube was filled with compressed air at between 80 and 180 psi. The tensile restraint on the vehicle was machined to release at a set pressure. We "discovered" the actual release pressure was 60 % higher than expected. This was shown to be a result of notch strengthening the tensile restraint rather than weakening it. The masses were 1.5 kg and 5 kg. Velocities were not measured. Many of the diagnostics were being broken in.

**Phase 2:** Shots 4 and 5. These were two stage shots using compressed air in the combustion section at 550 psi to drive the piston. The hydrogen in the pump tube was at about 10 psi. The 5 kg projectiles attained velocities of approximately 800 m/s. Scoring was observed in the combustion section and high pressure section during these shots. It was caused by the steel on steel interface between the tubes and the insert sleeves in those areas. Aluminum bushings were installed to prevent the scoring.

**Phase 3:** Shots 6 to 9. These were two stage shots using the combustion of methane and air to drive the piston. The initial fuel-air pressure was at 168, 168, 395 and 730 psi respectively. The 5 kg projectiles attained velocities of 0.9 km/s on shots 6 and 7. Shots 8 and 9 obtained velocities of 1.6 km/s and 1.8 km/s.

On shot 9 the combustion section was damaged when the first and second combustion tubes blew apart from one another. This caused premature combustion product venting and resulted in damage to the combustion tubes, the piston and the piston restraining rod. The tube separation has been determined to be

caused by the aluminum bushings installed during phase 2, and modifications are being made. Shots will resume by the end of May.

Additionally it was determined that the paraffin piston nose slowed the piston down due to the paraffin shearing off on the walls. The paraffin is being replaced by high density polyethylene. This should also allow easier cleanup after every shot.

## 5. The Jules Verne Launcher

The JVL is depicted in Figure 4. It is designed to launch 10 metric ton vehicles at 9 km/sec into Low Earth Orbit (LEO). The JVL is a 3 kilometer long launcher with a 2 meter diameter launch tube. It is housed in a tunnel with a 30 degree inclination from horizontal. A long muffler at the muzzle is used to capture the hydrogen after each shot for recycling. Aside from size the two features which distinguish the JVL from a classic two stage gun are:

1. The JVL uses hydrogen side injectors. This technique for periodically boosting the vehicle base pressure has recently been demonstrated at General Dynamics. (See Reference 2) The trick is to switch a source of moderate pressure but hot hydrogen into the launch tube close behind the vehicle. The important constraints are timing and small injection angle. Computer simulations have also been developed which compare well with the successful side injection performed at General Dynamics.

2. The JVL uses particle beds to heat the hydrogen. Brookhaven National Laboratories has recently developed particle beds with output power densities in excess of 10 gigawatts per cubic meter and energy densities exceeding a gigajoule per cubic meter. (See Reference 3) This technology is based upon small sized ceramic particles which have a high rate of heat transfer as well as high thermal storage capacity. In

operation the particles are enclosed in a frit (sieve) which allows high gas flow rates at minimal pressure impedance. The particles are heated by flowing hot combustion products through the assembly for a few minutes. When the bed is hot one merely counterflows room temperature hydrogen through the assembly. The hot hydrogen is switched into the side injector during the shot.

These two features eliminate the entire pump tube and combustion section of a two-stage launcher. Excess momentum (recoil) is reduced dramatically since there is no piston required to pump up the hydrogen. The peak system pressure is also reduced dramatically to less than 30,000 psi since the pressure is much more evenly distributed over the entire launch tube. (In fact the launch tube can be made arbitrarily long and hence the g loads arbitrarily low.) The JVL will produce a maximum of 2000 gs on the vehicle.

The vehicle is 1.8 meters in diameter and 10 meters long. It is composed of the following components:

1. A sabot to transmit the pressure and stabilize the vehicle while in the launch tube. This falls away immediately after the vehicle leaves the muzzle.
2. The structural portion of the vehicle. This is primarily a conical graphite composite. The nose shape is a five degree half angle. The total drag coefficient is approximately .05. The vehicle is passively stable during atmospheric transit due to its shape and mass distribution. Alternatively attitude control thrusters can be used for active stability during atmospheric transit.
3. The ablative heat shield. This is carbon-carbon and may include a sacrificial rod at the nose where the heating and stagnation pressure are extreme. After the vehicle reaches 100 km altitude the heat shield is discarded.

4. A small rocket to circularize the orbit once the vehicle is near 500 km altitude. The total delta V required at that point is approximately 200 meters/sec. Six small attitude control thrusters will also be needed.

5. Payload. This can range from water and fuel/oxygen to building materials and food. It is estimated that over 80% of the supplies required to support a major space presence can be easily g-hardened. Each launch will deliver 5 tons of payload into LEO at a 500 kilometer altitude. Each payload will automatically dock with a depot. The depot will be periodically unloaded and supplies ferried to a space station or wherever they are needed.

The total JVL cost including the construction and 10 years of operation is 5 billion dollars. This includes R&D and the construction of smaller but still useful versions. Our cost analysis is similar to that in Reference 4. Figure 5 predicts that the JVL can bring the cost per kilogram into LEO down below \$500/kg at launch rates in excess of 1000 metric tons per year. The natural launch rate for the JVL is several launches every working day. This translates into several thousand metric tons of payload delivered into space per year.

The JVL can be built and working by the year 2001.

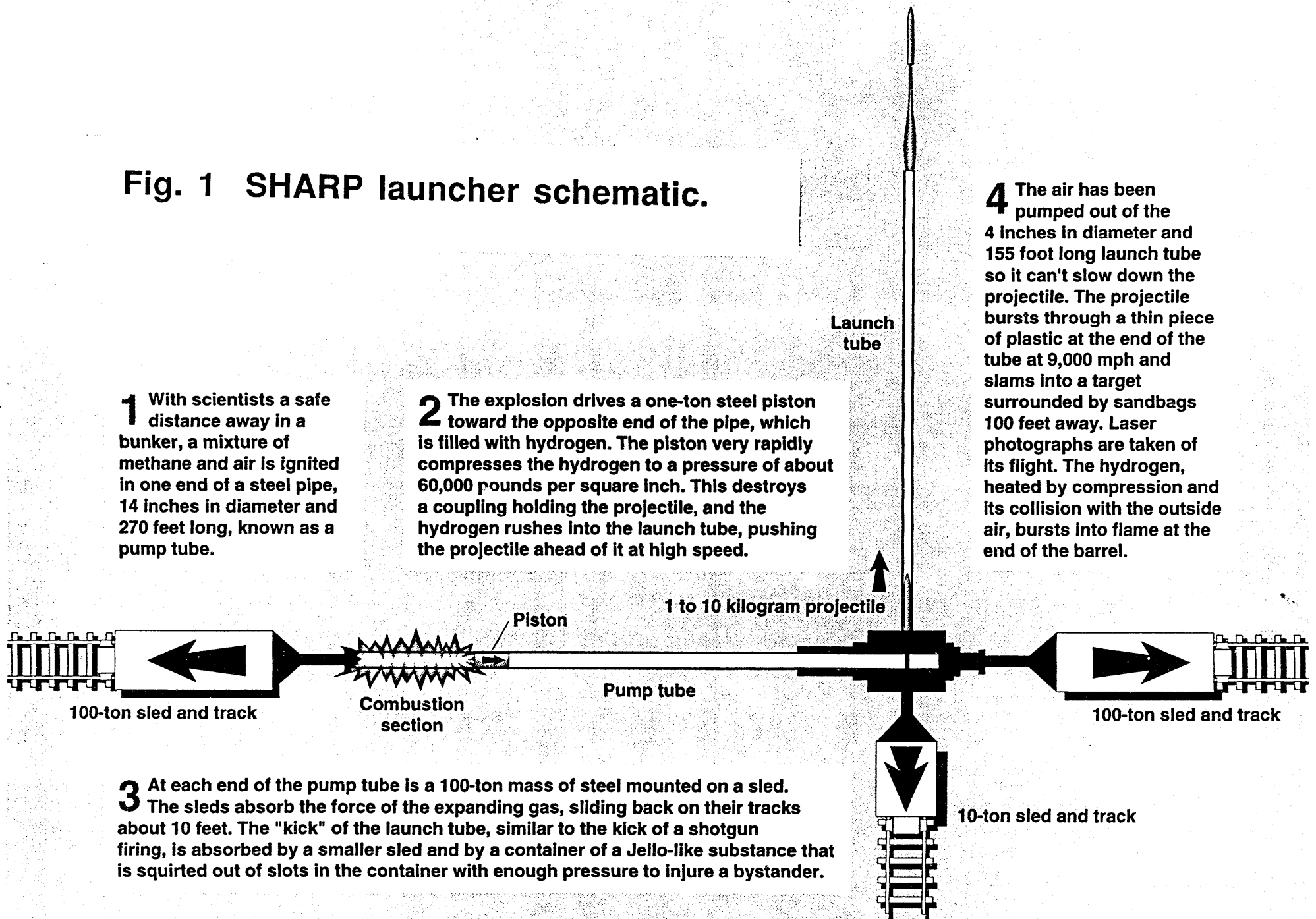
## 6. Acknowledgements

We wish to thank Fred Riencker for his guidance and superb intuition in the SHARP design. Without Fred's help and can do attitude SHARP would not have been built. George Sutton was a lot of help in sizing the vehicle. Major thanks to the people who assembled SHARP and make it work. They include Ken Haney, Drew Hargiss, Paul Heston, Warren Massey, Steve Gemberling, Chuck Jackson, Don Hughes and Frank Snell as well as the Site 300 support. Work performed for DOE by LLNL under contract W-7405-Eng-48.

## 7. References

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2. D. A. Tidman and D. W. Massey, "Electrothermal Light Gas Gun," IEEE Trans. Mag., Vol 29, pp 621-624, January, 1993.
3. J.R. Powell and F.L. Horn, "High Power Density Reactors Based on Direct Cooled Particle Beds," Space Nuclear Power Systems 1985, p 319, Edited by M. S. El-Genk and M. D. Hoover, Orbit Book Company, Malabar, Fl, 1986.
4. "Hypervelocity Gun Report: Hypervelocity Light Gas Gun", Prepared by the Advanced Applications Program, Lawrence Livermore National Laboratory, November, 1990.

**Fig. 1 SHARP launcher 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.

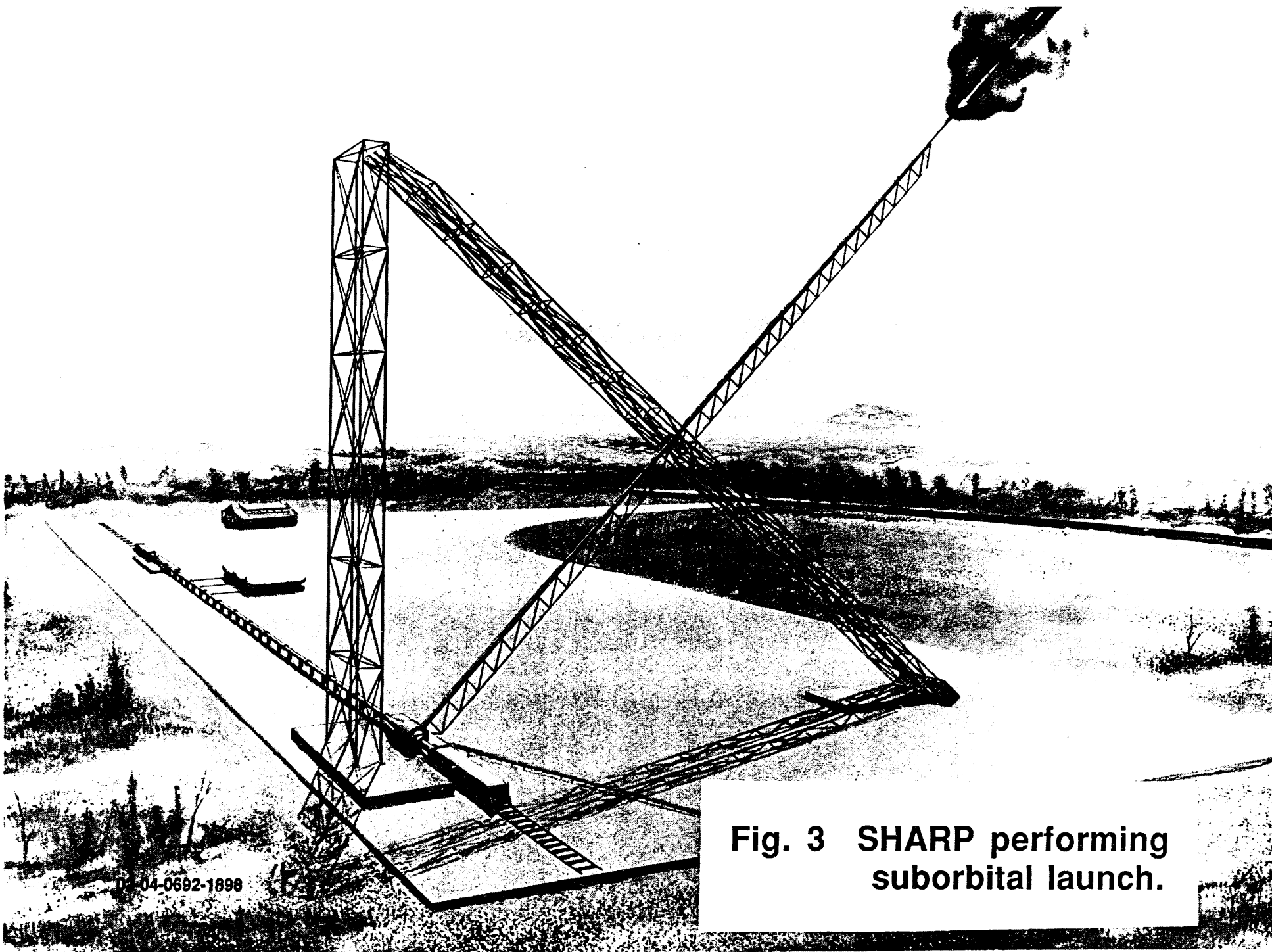
**2** The explosion drives a one-ton steel piston toward the opposite end of the pipe, which is filled with hydrogen. The piston very rapidly compresses the hydrogen to a pressure of about 60,000 pounds per square inch. This destroys a coupling holding the projectile, and the hydrogen rushes into the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

**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.

**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.

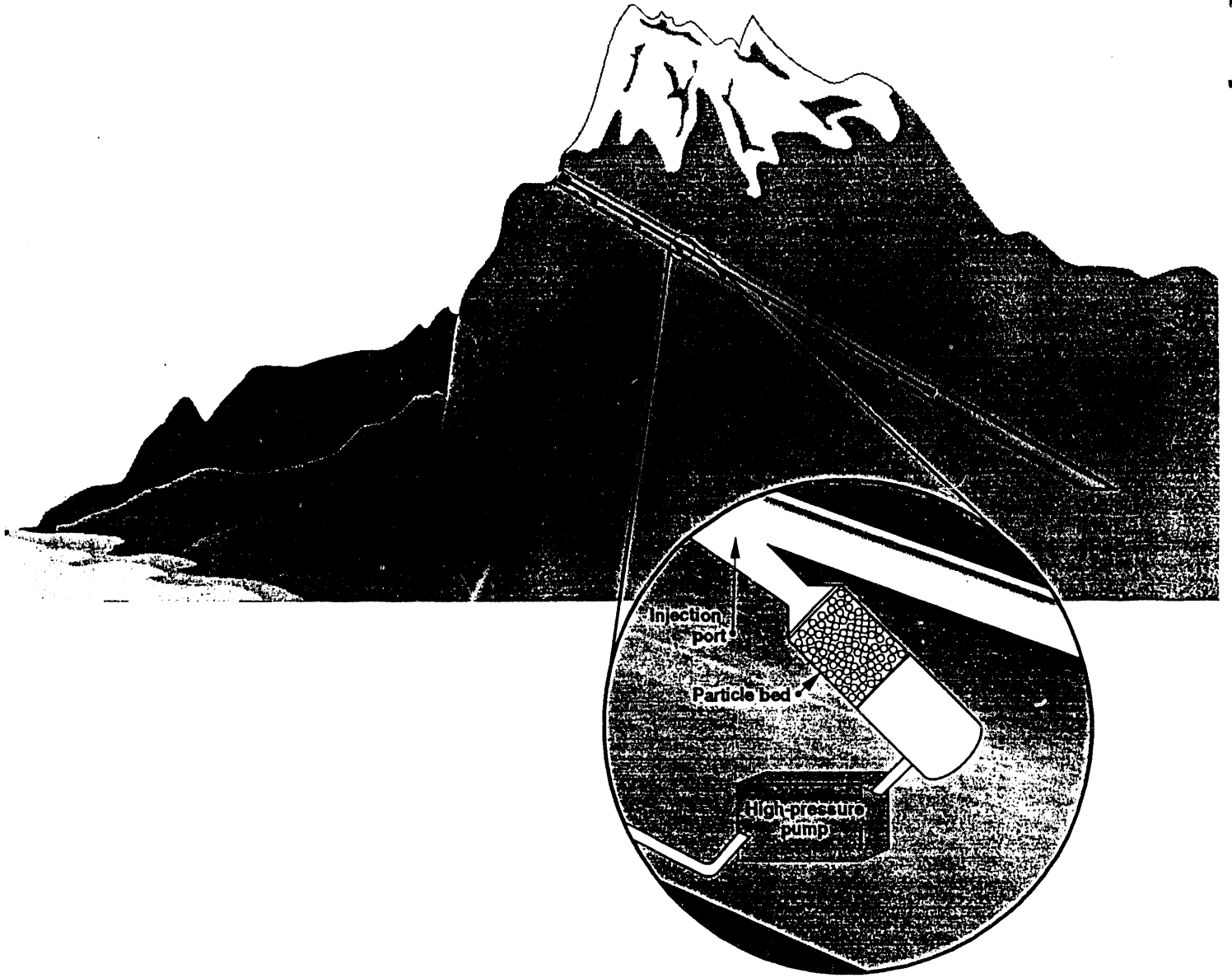


Fig. 2 SHARP.

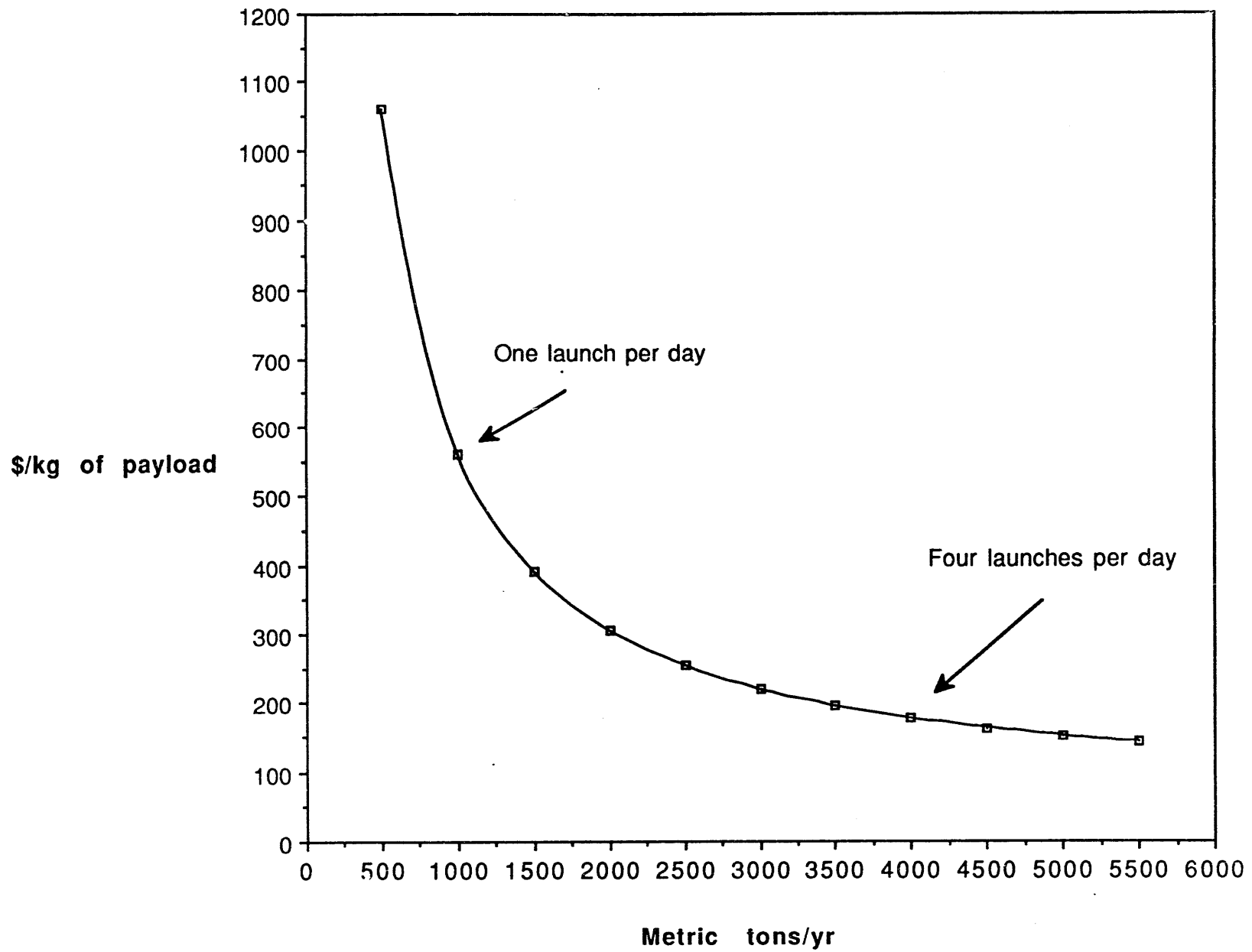


**Fig. 3 SHARP performing suborbital launch.**

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**Fig. 4 Jules Verne Launcher.**



**Fig. 5 Jules Verne Launcher delivery rates.**

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