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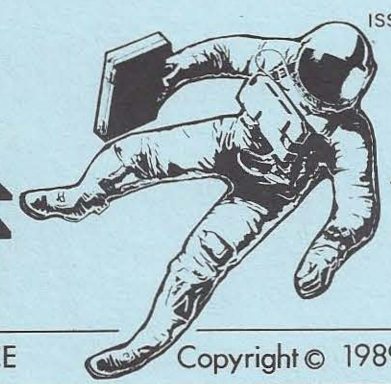

A MONTHLY NEWSLETTER ON FREE ENTERPRISE IN SPACE

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Private Company Proposes Electromagnetic Cannon For Low-Cost Space Transportation

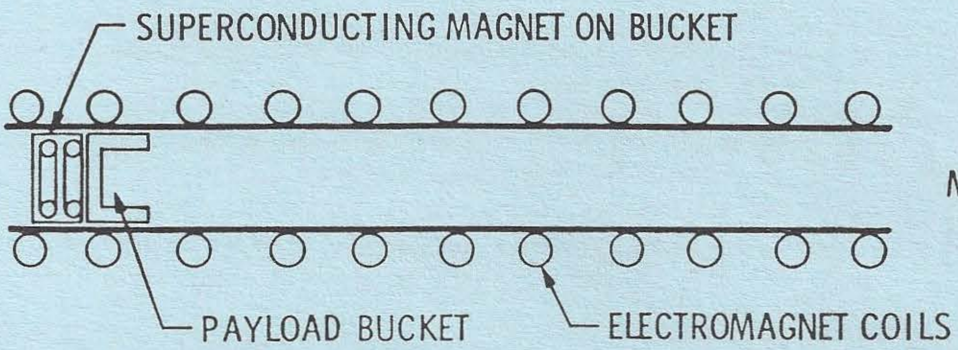
A company called Orbital Transport Services, Inc. (OTS) is working to develop a commercial space transportation system that would propel payloads into space using an electromagnetic launcher (EML), a three-mile-long evacuated tube along which a series of electromagnetic coils is mounted. This system would be capable of firing projectiles containing 1,000 lbs. of cargo into low earth orbit (LEO).

The estimated cost of launching a payload into LEO using the EML is about $20 per pound--one-half of one percent of the approximately $4,000 per pound it now costs using existing rocket-powered launch vehicles (it is interesting to note that the actual cost of the energy imparted to place a payload in orbit is only about 20 cents per pound according to Boeing Aerospace researcher Gordon Woodcock). The estimated cost of constructing the EML ranges from a few hundred million to a little under a billion dollars (the cost of the U.S. Space Shuttle program was over 15 billion dollars).

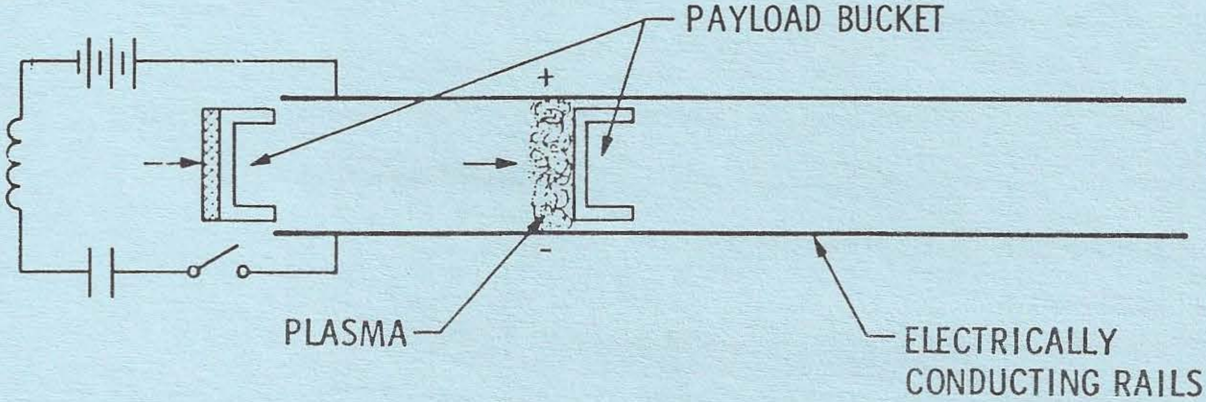
The idea of launching payloads into space by firing it from some form of gun has been around for many years. One of Isaac Newton's thought experiments showed that if a gun were powerful enough, and air resistance discounted, a projectile could theoretically be given sufficient velocity to orbit the Earth. Jules Verne, in his science fiction book *From The Earth To The Moon,* described a space vehicle for a trip to the Moon that was essentially a huge artillery shell. This shell was fired on its interplanetary trip from a 900-foot vertical cannon christened *Columbiad* (although Verne was careful to work out much of the mathematics involved, including the required velocity for a projectile to reach the Moon, there are a number of technical reasons why such an attempt would have failed--the chief one being an underestimation of the resistance of the Earth's atmosphere to the projectile's passage out of the gun). In Robert A. Heinlein's book *The Moon Is A Harsh Mistress,* mass drivers or "catapults" figure prominently in the story, where they are the primary means for launching cargoes from the Moon to the Earth.

In recent years, however, technology has advanced to the point where such launching methods are becoming feasible for certain payloads. The chemical explosions that powered Newton's and Verne's projectiles have been replaced by systems using electrical energy to impart huge velocities to a projectile. These electrical launchers are sometimes referred to generically as "mass drivers."

There are two basic kinds of mass driver: the railgun and the electromagnetic launcher or EML (the EML is also sometimes referred to as a "coaxial accelerator" or "coilgun"). Without getting into too much technical detail, an EML operates by sending electromagnetic pulses through a series of coils, propelling a payload magnetically to high velocities. A railgun uses two charged rails which propel a payload by creating a plasma behind the projectile (see illustration on page 2).



MASS DRIVER



RAIL GUN

OTS has selected EML, or coilgun, technology over railguns for its commercial application. The company cites four major reasons for this: First, coilguns scale upward more easily than railguns, which work best with small projectiles. This gives OTS the option of using larger projectiles in the future. Second, coilguns are more efficient in their use of energy than railguns. Third, a railgun applies force to the base of a projectile, while a coilgun can apply force along the entire length of a projectile. This allows the use of long, thin projectiles which--as will be mentioned later--is important for aerodynamic considerations. And fourth, coilguns operate well at "moderate" accelerations of about 1,000 gravities (Gs) compared to the 2,000 to 20,000 G accelerations typical of railguns.

The design of an EML to launch payloads into space from the surface of the Earth presents a number of difficulties. Many previous EML studies have concentrated on EMLs which would operate on the surface of the Moon or in space, where the low or non-existent gravity and lack of an atmosphere make the design and operation of an EML much easier. OTS has addressed four major areas where of design difficulty:

Energy Storage. The minimum energy required to accelerate a payload from the Earth's surface to low earth orbit is about 10 megawatt-hours per metric ton (about 2,200 lbs.) This quantity of energy must be delivered to the EML in about 1 second to keep the length of the system at a minimum. To use conventional technologies to accomplish this could raise the EML construction cost by a factor of ten, in part by requiring the construction of dedicated electrical power plants to deliver the needed energy.

OTS proposes using Superconducting Magnetic Energy Storage (SMES) technology to alleviate this problem. Such a system uses superconducting coils to store electromagnetic energy for long periods of time, with the only losses being those associated with keeping the superconducting materials refrigerated. Such systems are being researched by electrical utility companies, since they would permit storing energy produced in non-peak hours for release during peak hours, reducing the need for excess generating capacity. Prototype SMES units have been built and tested. Use of such a system would permit an EML facility to tap existing utility grids at a low level, storing the energy needed for a launch over a period of time. If recent advances in high-temperature superconductors pan out, the SMES solution becomes even more feasible and less expensive.

High-Speed Switching. Extremely fast and powerful switches are needed to direct the power supplied to the EML drive coils. Although existing, off-the-shelf switching technology is capable of handling the requirements of lunar and space-based EML designs, it is not sufficient to meet the more demanding requirements of an EML designed for operation from the surface of the Earth. Fortunately, advanced-technology switches are currently being developed in areas like fusion research. Such switches could probably be modified to meet the needs of the EML with a minimum of additional research and development work.

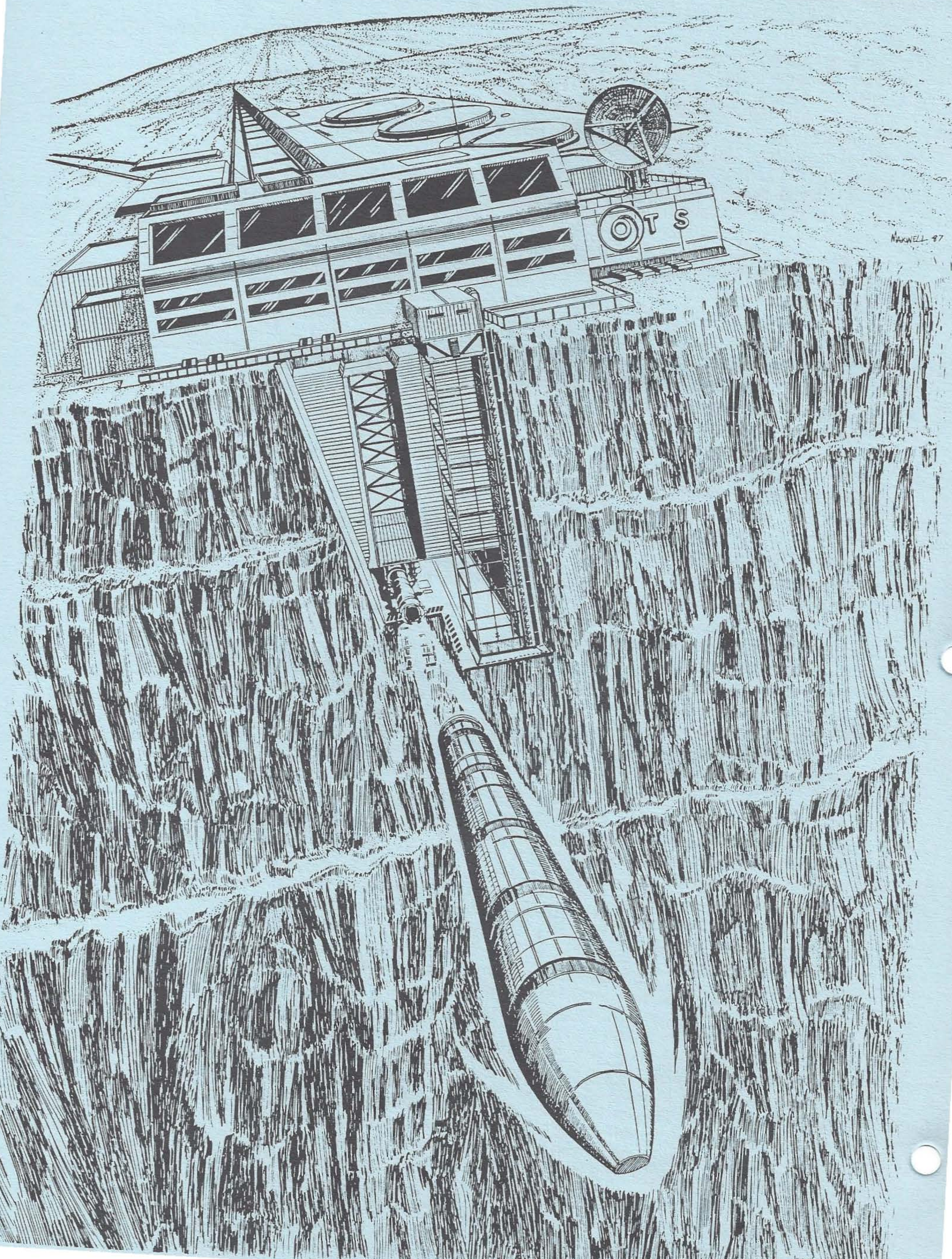
Atmospheric Heating. Originally it was assumed that an EML projectile would be incinerated by the Earth's atmosphere as soon as it left the barrel of the gun. However, actual research indicates that proper design and selection of materials should result in a successful passage out of the atmosphere with a minimum loss of materials. The shape of the projectile is important, and analysis indicates that the ideal shape is long and thin with a conical nose, something like a sharpened pencil (although the size of the actual EML projectile would be more comparable to a telephone pole). Such a projectile would pass through the atmosphere losing about 4 inches worth of ablative off its nose, and about 10% of its initial muzzle velocity.

Fiber-reinforced ice has been shown to be a possible candidate as an ablative material for a projectile. Under the conditions of launch, its thermal properties compare favorably with other materials, and its strength is remarkably high. More importantly, the use of ice as a material fits in well with the primary mission envisioned for an EML by OTS: delivering fuel into orbit (more on this later).

Orbit circularization. Unless an additional velocity is imparted to the projectile in orbit, it will return and crash into the Earth on its first pass. It is estimated that a delta-V of about 6,500 ft/sec would be sufficient to accomplish this. It is therefore necessary to provide the projectile with some form of on-board propulsion such as a solid-fueled rocket motor. This propulsion package, along with required electronics and other systems, raise the total weight of the projectile to about 2,200 lbs. for a 1,000 lb. payload.

OTS' baseline EML design consists of an evacuated tube 5 km (3.1 miles) in length. Electromagnetic coils are wrapped around this tube like rings on a finger. This tube would be buried at a suitable location, rising at an angle of about 12 degrees from the horizontal. Although this shallow angle means that the projectile must pass through more of the atmosphere, it also means that less excavation would be required to bury the tube (lowering construction costs). In addition, the shallow launch angle reduces the delta-V requirements for circularization. The muzzle of the tube would be fitted with a high-speed "valve," which would prevent air from entering the tube but would move aside in time to allow the passage of the projectile. Facilities for energy storage and handling would be located nearby.

The ideal location for the EML would be a mountain near the equator with a large uninhabited area to the east. The equatorial site means the launch system would be more efficient due to the added velocity of the Earth's rotation. Constructing the EML on a mountain at as high an altitude as possible enhances the EML's performance by reducing the amount of atmosphere the projectile must pass through. The site selected by OTS for its initial design concept is the island of Hawaii, specifically the Mauna Loa volcanic mountain. The site is located about 20 degrees north of the equator, and is at an altitude of about 4 km (about 13,000 ft.)


OTS
MAXWELL 87

The illustration on the opposite page (by Mark Maxwell for OTS) shows the EML as it would appear from over the caldera of Mauna Loa. The circular structures shown to the right of the launch tube are superconducting energy storage coils. They are located at the muzzle end of the tube because peak power demands occur there. Also at the muzzle end are tracking systems and control circuitry (the illustration also shows large plate glass windows on the building, which I believe is somewhat optimistic considering the sonic boom which would be generated by a projectile hitting the air at a velocity of over six miles per second).

A typical mission, taking a 1,000 lb. payload to a 270-nautical-mile orbit, would require accelerating the projectile to a muzzle velocity of about 10 km/sec (22,370 mph). By the time the projectile reached space, atmospheric drag would have reduced its velocity to about 7-8 km/sec. At the proper time, the circularization burn would take place and the payload would be in orbit. It would then be recovered by the fuel depot or space station where the payload is needed. Although the launch tube cannot be moved to "aim" the projectile at a specific orbit, changes in imparted velocity and circularization burn parameters allow some flexibility in the final orbit. By increasing the acceleration imparted to the projectile, and hence its muzzle velocity, missions to geosynchronous orbits or even to lunar orbit are possible.

OTS is targeting fuel transportation as its primary market. When the Space Shuttle carries a satellite into low earth orbit that is to be transferred into geosynchronous orbit, up to 80% of that satellite's mass in LEO is fuel required to make the transfer. Large quantities of fuel in LEO are also required for lunar and interplanetary missions. A low-cost method of transporting fuel to a depot in LEO would increase the effectiveness of existing launch systems like the Shuttle, which would no longer need to carry this fuel up from Earth.

The most convenient way to launch fuel from Earth into space is in the form of water, which can then be broken down into hydrogen and oxygen. In the case of an EML, the water can best be handled in the form of ice. As mentioned earlier, if the fuel ice is reinforced by carbon or ceramic fibers, it doubles as a structural and thermal protection material.

Once the ice is in orbit, it would be collected at a fuel processing and storage station. It would then be broken down by thermal or electrical means using power from solar collectors or nuclear reactors. The resulting gases would then be compressed, liquefied and stored for use by other spacecraft as needed.

There are other payload markets besides fuel. Any bulk cargo capable of withstanding the 1,000 G acceleration could be successfully launched, including structural elements for space platforms, food and other supplies, gases and liquids. Many modern electronic systems are capable of being hardened to withstand even higher accelerations than would be delivered by the EML (this is commonly done for military applications). This raises the possibility that inexpensive satellites or space probes could be built to take advantage of this low-cost launch method.

Launching human beings via EML is currently impractical. If one were to maintain a maximum acceleration of 3 Gs, attaining a velocity of 10 km/sec would require an EML over 350 miles in length. Even then, unless the EML muzzle is raised to such an extreme altitude so as to be in near-vacuum, the deceleration resulting when the projectile strikes the atmosphere at the muzzle of the EML would most certainly be fatal to any passengers.

In the near term, OTS proposes using EML technology to manufacture motors and pumps for earthbound applications, such as refrigeration compressors, linear motors, and other specialty motors. Income from these near-term applications would help bootstrap the company towards its eventual goal of constructing the space EML.

Another near term project would involve building a subscale EML to launch sounding rocket payloads. These payloads would weigh about 200 lbs., and could include instrument packages or certain materials processing experiments.

Besides OTS, there are other organizations which are also studying the potential of mass drivers for various applications.

One of the earliest and most productive efforts has been the research program undertaken by the Space Studies Institute in Princeton, New Jersey. Researchers in this program include Dr. Gerard O'Neill, Dr. Henry Kolm and Dr. Les Snively. This effort, begun in the mid 1970s, has resulted in the construction and successful testing of three operational sub-scale mass-drivers. The Institute is investigating the use of mass drivers for several applications. These include transportation into free space from the surface of the Moon, transportation into orbit from the surface of the Earth, and the use of a mass driver as a propulsion system for deep space vehicles. In the propulsion application, the mass driver would be mounted on a spacecraft and would fire waste material at high velocities out the back of the spacecraft. This would propel the spacecraft forward in the same manner as the expelled gases of a rocket exhaust. Power for the mass driver would be supplied by either solar energy or by a nuclear reactor.

Other studies of mass driver technology for use in space transportation have been done by General Dynamics Space Systems, Batelle Columbus Laboratories, and many others. The U. S. Strategic Defense Initiative is examining mass drivers, specifically railguns, for use as a kinetic weapon for shooting down enemy missiles from space.

For More Information

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- Space Studies Institute, P.O. Box 82, Princeton, NJ 08542 Tel.: (609) 921-0377 (Dr. Les Snively, principal mass driver investigator).

Until next time,

Tom Brosz
August 14, 1989

The Commercial Space Report (C.S.R.) is published monthly, and endeavors to report and analyze developments in the field of private initiatives in space transportation and exploitation.

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