Starbridge: an elevator to near earth orbit

by Charles B. Stevens

In a review of methods of putting payloads into orbit, "Earthbreak: A Review of Earth-to-Space Transportation" (UCRL-89252), Dr. Roderick A. Hyde of the Lawrence Livermore National Laboratory O Group reveals outlines of an advanced approach for achieving such transport at costs thousands of times less than now prevail—making space colonization economically feasible. Hyde, whose group has pioneered the development of x-ray lasers and high-power x-ray optics, presents a concept called Starbridge, developed by Dr. Hyde and O Group's leader Dr. Lowell Wood, which consists of an elevator built from the ground up.

Earth's gravitational field and atmosphere, combined with the existing limits on the strength of materials, constitute the essential limits on transporting materials into space. The minimum energy needed to propel material to a sufficient velocity to escape Earth's gravitational field is 62.5 million joules per kilogram. If this could be achieved with electrical energy, assuming a bulk rate of $0.02 per kilowatt hour, the cost would be $0.35 per kilogram. The present cost is about $10,000 per kilogram.

The problem of escape involves two stages. The first is to get to an "orbital ledge" above the Earth's atmosphere. This is because air resistance limits useful velocities that can be attained within the atmosphere—well below escape, or stable orbital, velocities. Because of this, stable orbits exist only above the atmosphere.

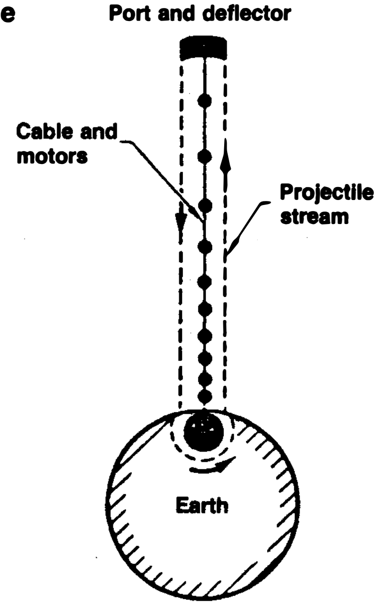
The second stage can be approached in a variety of alternative and efficient methods. Starbridge provides an efficient means of reaching stable Earth orbits at low costs approaching $0.35 per kilogram.

Skyhooks

The simplest solution to cheap transport into near-Earth orbit, as Dr. Hyde relates, is to place a rope from the surface of the Earth to space and climb it. This "Skyhook" approach was first described by Soviet scientists—a good English description can be found in *Acta Astronomica,* Vol. 2, p. 785 (1975). It consists of a long rope with one end anchored to the Earth's equator, and the other some 150,000 kilometers overhead. The rope rotates with the Earth and therefore is acted on by centrifugal force as well as gravity. The centrifugal force on the outer portions balances the gravitational force on the inner sections. To escape the Earth, a vehicle need only climb along the rope and release its payload at an altitude of 47,000 kilometers. Transport costs would approach the minimum.

The problem is that the centrifugal and gravitational forces are only globally balanced. Locally, the rope experiences varying and large tensile loads. The Skyhook could be operated at a constant stress level by tapering its cross-section. For example, making the rope of Kevlar—one of the strongest commercial materials—would lead to an impractical taper ratio of 22,000. Other considerations, like energy supply for the climbing vehicle, make the simple skyhook currently impractical. Another roadblock is that it would have to be constructed from the orbit down.

Starbridge



The Starbridge elevator connects a massive, orbiting space port and deflector with the surface of the earth. Counter streaming projectiles provide local support to the cable and motor structure.

Starbridge

To overcome these problems, Drs. Hyde and Wood, with other collaborators, developed the concept of Starbridge: a skyhook globally and locally supported by a stream of projectiles traveling simultaneously up and down the "rope." The structure can locally balance its weight by pushing down on a projectile stream. Several thousand discrete motors tied to the vertical cable are used. Each pushes down on a climbing projectile, briefly storing the energy removed from it. This energy is then used to push down on a falling projectile. If the motors were perfect, no net energy would be needed to maintain the Starbridge. Obviously there would be losses, but today motors can be designed at very high efficiencies with low mass.

As Hyde et al. detail: "The Starbridge motor stations would each consist of an inductive motor coil, a capacitor, switchgear and busbars, and a radiator to dispose of waste heat. The projectiles are inert, non-superconducting, metal loops, which are inductively kicked as they pass through motor stations. Between motor stations, there are Kevlar cables and a ferromagnetic track, which is used to guide the projectiles and to resist Coriolis accelerations. The projectile stream must be reflected at the top and bottom of the Starbridge. This is done with very little loss by a curved and static superconducting track. As projectiles climb the Starbridge, their speed drops, as does the distance between them. This places a limit on the speed at the top reflector; for current designs, the resulting reflection force cannot be resisted by Kevlar cables. Instead a counterweight will be used; this restricts the height of the skyhook to be less than geosynchronous, but allows it to support a large spaceport at its top. This port will be used to receive and process cargo, which can then be shipped the rest of the way out of the [Earth's gravitational] well with either a simple Kevlar skyhook or low thrust tugs.

"A specific Starbridge design calls for a 100 gm/cm cable-track mass, ending at a radial position of 40,000 km (95% of synchronous), and supported by 7,500 five-Mg [millions of grams thrust] motors. There are two complete projectile streams, with a total flux of 83 Mg/sec; the base speed is 13.9 km/s, slowing to 3.6 km/s at the tip. A projectile requires 3.6 hours to complete a transit, losing 0.3% of its energy in the process. Hence, the power required to support this skyhook is 20 Gigawatts; with another 20 Gigawatts we can send 10 trillion grams/year up the Starbridge.

"A critical feature of the Starbridge is that it works at any height. First, this means that small versions can be built and tested; the concept, engineering, and reliability can be proved out before a full-scale one is commissioned. Very crucially, it also permits us to build this type of skyhook from the ground up. The Starbridge is extruded: Cable, track, and motors are added at the ground, while only the counterweight must be added to in space—using the payload-lifting capability of the growing skyhook. The payload cars can either climb the cables, or react against the projectile stream as the motor stations do. We will use the mass stream to transmit power up the Starbridge. This power is utilized both to make up motor losses, and to supply energy to the climbing payload cars, thereby solving one of the problems with conventional skyhooks. . . ."

The laser railroad

Dr. Hyde points out that a laser railroad may provide the nearest-term solution to significant cost reductions of placing payloads in near-Earth orbits. The concept is based on a scheme developed by AVCO Company and Dr. A.R. Kantrowitz and his colleagues in the 1978. Because the laser railroad would use existing technologies, development costs would be minimal. Even so, the laser railroad could reduce costs by as much as a factor of 100.

One of the most significant built-in inefficiencies of rockets is that they must carry along both the fuel and propellant. Rocket engine fuel in particular represents excess baggage until it is actually burned. In most cases the rocket engine fuel and rocket propellant consist of the same material. That is, for example, hydrogen and oxygen can be reacted to form water. The heat of the reaction provides the energy to drive the resulting water through a rocket nozzle at high velocities. An alternative would be to use a ground-based laser beam to heat the rocket propellant. And this is the basis for the AVCO proposal discussed by Hyde.

In the AVCO design a billion watt carbon dioxide laser based on the ground is utilized. This powerful laser beam is directed onto the rear of a small rocket, which carries 5.4 tons of water, which will act as the rocket propellant when it is heated by the laser beam. The AVCO laser driven rocket would deliver 1 ton of payload contained within a .5 ton package into orbit.

The carbon dioxide laser is utilized in a pulse mode. One hundred sixty laser pulses per second would irradiate the water. Each pulse would first vaporize a thin layer of water and then ignite a detonation wave in the blown-off material. This ablative laser drive only converts 44% of the laser energy into rocket thrust, but it achieves a blow-off (exhaust) velocity of 8 kilometers per second without a nozzle or laser optics. Only a 70 centimeter expansion skirt on the rocket is needed.

The billion-watt average power carbon dioxide laser delivers sufficient energy to the rocket within 340 seconds to achieve earth orbit. At this point the rocket would be at a 1,000 kilometer slant range. The system could deliver upwards of 100,000 tons of payload into space per year—roughly equal to 700 shuttle flights.

The first thing to note about the laser railroad is that the carrier rocket is extremely simple. Tasks such as steering and propellant injection are done from the ground through tailoring laser pulses. The use of pulsed energy relaxes temperature constraints and allows attainment of high exhaust speeds while using very convenient propellants such as water.

With a 20% efficiency of conversion of electricity into carbon dioxide laser light, the system would necessitate 5 billion watts of electrical power to run. But it would lower the overall cost of placing payloads into earth orbit by a factor of 100 with existing technology. Recent developments with free electron lasers (FELs) indicate that major improvements could be made in a laser railroad system. The FEL could be twice as efficient as the carbon dioxide laser. Also, because of its short wavelength operating capability, the FEL would be capable of driving the rocket over a much greater range. This would permit larger payloads per launch.