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E11
First Draft

Space Elevator Now
Investigating the Feasibility of a Space Elevator

The space elevator would revolutionize space travel fundamentally and promises the single most important development in space travel since the rocket. A 100,000 km cable stretching from the Earth's surface to geostationary orbit would allow spacecraft to literally climb up a cable instead of being launched into space using conventional rockets. A space elevator would radically change the field of space travel resulting in cheap, more efficient, and gentler trips to space.

The basic design of the space elevator involves a tether between the Earth's surface and a counterweight that puts the center of mass at geostationary orbit. The result is similar to swinging a rock on the end of string in a circle. Centrifugal force pulls the rock away from the center of rotation from a rotating frame of reference. The space elevator uses the same principle, with the elevator itself as the rope, the counterweight as the rock, and the Earth as the center. This allows for the tower to be in tension, and is the only way to make this project at all feasible.

The primary benefits of the space elevator are a dramatic increase in efficiency and a gentler method to deploy spacecraft to orbit. Currently, high thrust rockets are required to launch payloads into space. These rockets are almost always use chemical propulsion, such as hydrogen or kerosene and oxygen. By contrast, payloads would climb up the space elevator using motors and wheels, most likely with power beamed up to the climber with a high power laser. Additionally, only the potential energy component of the orbital energy is required, as the remaining kinetic energy is put into the system from rotational energy of the Earth.

Because the instantaneous power is so lower, the systems are easier to design and build. This also would result in a dramatic reduction in the vibrations that so often drive the design of spacecraft. The gentle trip to orbit would allow for delicate spacecraft to easily be placed in orbit. In fact, even for the Mars Exploration Rover (MER) mission, the launch from the Earth's surface to space was more violent than the entire entry-descent-landing sequence to get safely to the Martian surface. Effective use of this ability would require a paradigm shift in spacecraft design to more economically make use of the gentler deployment.

Fig. 1.1: Scale drawing of the Earth with a space elevator.

Secondary and longer-term benefits of the space elevator include the possibilities of an orbiting space station at geostationary orbit, allowing for a large, permanent manned orbital presence, which could accommodate space tourism, industry, and construction of large spacecraft. By extending the cable beyond geostationary altitudes, spacecraft could fall down the rest of the cable using centrifugal force and get flung out of Earth's gravity on trajectories that could place them at Venus, the Moon, Mars, and Jupiter with almost no expenditure of fuel.

As with any large project, there are numerous challenges that must be overcome before its completion. This paper will primarily focus on the feasibility of the space elevator by identifying the remaining important challenges, evaluating the progress thus far in solving those challenges, and determining a reasonable timeline for the completion of the first space elevator. This will be accomplished by investigating the basic technological challenges and the status of key technologies required, the economic costs and risks along with potential funding sources and methods, and the political aspects of the project that could help or hinder progress.

Among the numerous technological challenges, the fabrication of a strong enough cable is single most pressing need of the space elevator program. The cable used for the space elevator must have a sufficient strength-to-density ratio in order to support itself but still be able to support large payloads. One of the first serious papers on space elevators (Pearson 1975) did some rough calculations on the effect of strength-to-density ratio on the feasibility of the design. Because the tension will vary through the length of the cable, in order to achieve constant stress, the cross-sectional area will be tapered exponentially from thinnest at the Earth's surface to thickest at GEO. Simple calculations also show that the smaller the taper ratio, the easier it will be to launch to orbit, as the minimum cross section stays constant. A stronger material will allow for a smaller taper ratio.

Back in 1975, the best material available was graphite whiskers. Using graphite whiskers would require a taper ratio of 10 and over 24,000 shuttle launches. (Pearson 1975) Obviously, this was totally impractical, and it seemed the idea was on hold pending the development of a stronger, lighter material. In 1991, the discovery of carbon nanotubes promised to be the answer. Further research has now confirmed that carbon nanotubes have the required strength-to-density ratio required for a space elevator. (Edward NIAC Phase II, Demczyk 2001) The work now is on putting the nanotubes into an effective composite that can be fashioned into a cable and developing techniques for mass-production of useful nanotubes. As of 2004, composites were capable of only around 1 GPa, a mere 1% of the required strength. It is likely, however, in the next 5 or so years, that carbon nanotube composite technology will be mature enough to consider developing mass production techniques.

The next most pressing technological challenge is the power system that will drive the climbers. After the cable itself, the power system has been getting the most attention. The power system must be capable of powering all the climbers on the elevator from the surface to GEO. Above GEO, the climbers can fall down the rest of the cable. The most often proposed system involves beaming power using high power lasers from a ground station to photovoltaic (PV) arrays on the climbers. Fortunately, most of the technological issues with each individual component of the system have mostly been solved. Electric motors are well understood, and PV arrays have been tested to have sufficient efficiencies to reasonably allow for their use. In order to beam the power through significant distances of atmosphere, the laser beam must compensate for atmospheric distortions. Adaptive optics has been use for ground-based telescopes for years now and in fact, an adaptive optics system in this application is easier than one for observing (Edwards NIAC Phase I).

Many of the other technological challenges are related to the initial deployment. Current plans for deployment involve maintaining the structure in tension by lowering the cable from GEO. This requires that the cable and initial support structures be launched to GEO by conventional rockets. This would require only a few launches from currently available launch vehicles (Edwards NIAC Phase I) instead of 24,000 Shuttle launches as initially suggested (Pearson 1975). As the International Space Station (ISS) has required dozens of launches thus far to complete, this puts the deployment well in the range of currently available technology. GPS could used to guide the deployment. A beacon placed on the end of the cable could receive location information from GPS and broadcast its location to assist in the capture at the surface. A commercially available rig could be used as a base station and anchor for the cable. (Edwards NIAC Phase I)

Edwards put forth a plan in his NIAC Phase I report for a 10-year construction timeframe, assuming all technical issues were settled before the start. In his Phase II report, he stands by that timeline, saying that, as technical challenges go, the space elevator "can be operational in 15 years." Since the timeline for finishing basic research needed for the only non-commercially available component of the project, the ribbon itself, is projected to be within a few years, it certainly seems like a possible timeline. However, it is the most optimistic timeline, as should be considered a lower bound. It seems that now technical challenges might not be as relevant as economic or political issues.

One might think that a project as ambitious as a space elevator would require an unprecedented level of economic investment. However, according to Edwards, the technical costs of the system can be estimated at around US$6.5 billion. He acknowledges, however, that non-technical costs could contribute to overrun. This is certainly non-trival, but compared to some other projects and put into perspective, it's not that outrageous. NASA's annual budget is around $16 billion. The total cost to date of space shuttle program is around $145 billion, and uses around $5 billion per year. The ISS has cost NASA around $50 billion in non-shuttle funding so far, with other space agencies such as Russia's and the ESA contributing comparable amounts. Thus, even assuming a cost overrun on par with the Big Dig in Boston, arguably one of the worst managed mega-projects in recent times, of about five times, that brings the estimated cost to around $30 billion. This is also estimated to be the total cost, spread over the lifetime of the project, which puts it at costing less than the shuttle program in the worst case.

The other side of the economics is the risk and return on investment. Having a short, large return on investment with low risk is critical to gathering investment for this project. With the current, basic design, allowing for the need for maintenance and self-repair, the capacity of the elevator is estimated to be around 1000 tons to GEO each year with a cost of $200/kg (Edwards NIAC Phase II). Using conventional rockets, costs of going to GEO are around $20,000/kg. At about 5,000 kg per launch, with a total of around 100 launches per year worldwide, it amounts to about 500 tons delivered to orbit each year. By reducing prices to orbit, the owner of a space elevator could increase the demand to bring it to the space elevator’s maximum output. At this rate, even making $1000/kg, this would amount to revenue of about $1 billion annually.

There are three basic methods for funding the space elevator project. It can funded privately, using only private investors, such as Bangkok’s Skytrain project. It can funded publicly through a government, or group of governments, such as in the case of the Space Shuttle program or ISS. Or, it can funded by both in a public-private partnership. According to Edwards (NIAC Phase II), the best option for the space elevator will be a public-private partnership. The time scale for payback on investment is too long for venture capitalists, but the possibility of a return on investment makes it somewhat appealing. Governments have non-financial reasons for supporting a space elevator. As the space elevator would fundamentally change transportation to orbit and allow for stable and serviceable communications, it would create unprecedented opportunities for military support and civilian infrastructure.

This also brings to light some of the political issues that the space elevator program may encounter. Since the space elevator will exist at all altitudes, numerous government offices would have jurisdiction and force certain requirements. These agencies and offices include the DOT, FAA, DOD, FCC, NASA, EPA, and the Coast Guard. There are also many treaties that would be applicable, including the Outer Space Treaty.

Additionally, any country in possession of a space elevator would have a huge strategic asset. With quick, continuous, access to GEO, the space elevator would allow for numerous new possibilities. While unlikely, kinetic energy weapons could be place on the elevator and dropped and targeted at enemies. Observational drones could also be dropped on command and deployed to areas of interest. Point to point, narrow beam communications could provide militaries with unmatched networking abilities. Thus, even if the elevator is privately funded, it is clear that a space elevator would be strategic resource and likely defended from attack using militaries on the surface.

In the case that the elevator is funded by a multinational collation, as with the ISS, issues of jurisdiction and rights-to-use become important. While these issues were solved for the ISS, the space elevator would make these issues much more relevant.

Since the elevator would be an investment with real returns, unlike the ISS, issues of dividing profits and sharing costs would need to be worked out.

With only one large technical challenge exists, namely the ribbon design and construction, many economic and political issues are now becoming the focus of attention. The technical challenges will likely be solved within five years. However, finding financing and getting approval from the appropriate political offices are likely to delay construction far longer. However, as space access is becoming more valuable, and as private companies are investing in space technology, the demand for access to space will continue to increase. Eventually, it will easily be economical to construct a space elevator. The increase in interest in the space elevator project is clear. With challenges at the X Prize Cup and Space Elevator Games, development is proceeding and the technical challenges are being worked out. Meantime, people like Dr. Edwards are pushing on the economical and political front. While a projection of 15 years is optimistic, it seems that it will almost certainly be done within 50 years.