UNLOCKING THE POTENTIAL OF SPACE ELEVATORS

AN INTERNATIONAL ACADEMY OF ASTRONAUTICS STUDY

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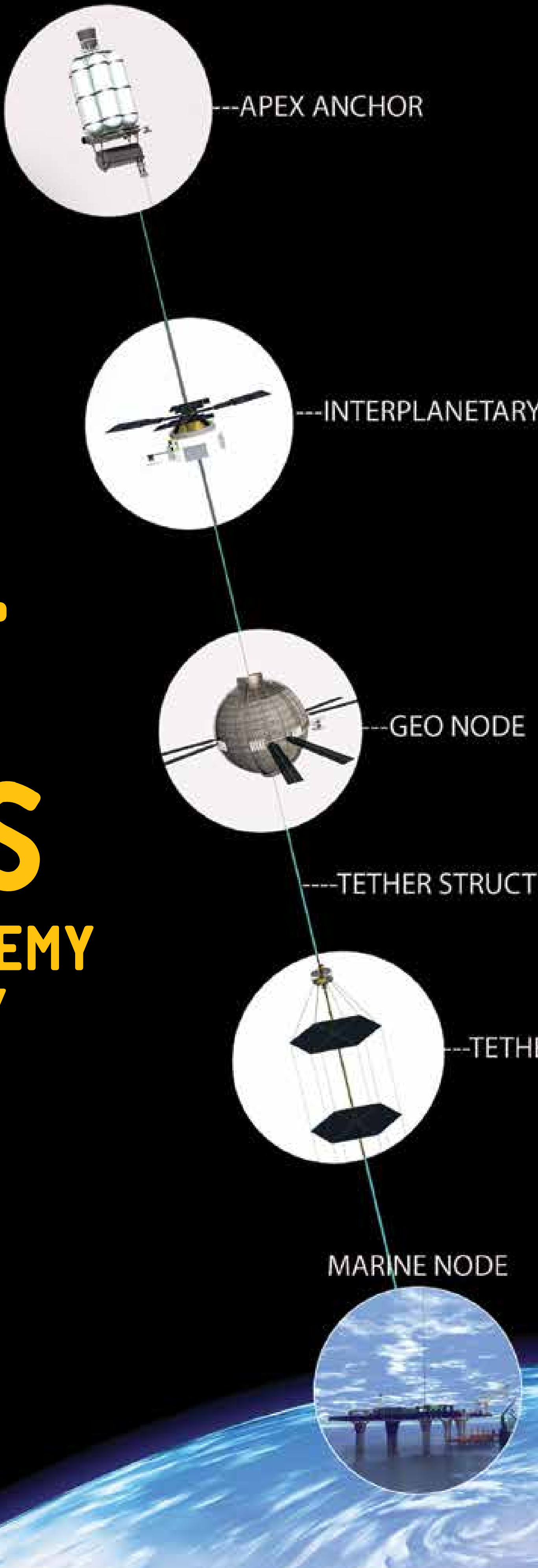

This is an artist's concept of the space elevator infrastructure. Once the system is in operation, the satellite payload would flow from its manufacturer to an ocean-going vessel to the Marine Node, up the space elevator, to the geostationary node or to the release point appropriate for its mission, all controlled by headquarters and its primary operations center.

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What would happen to your space business if the price of access to geosynchronous Earth orbit (GEO) was only $500 per kilogram? What would happen to your spacecraft design if “shake, rattle, and roll” was not part of the requirements? What would happen to future exploration efforts if we could “toss” missions toward their destinations without massive fuel consumption? What would happen to the space arena if we had routine, daily lifts of 14 metric ton payloads to GEO and beyond? These questions and more drove the International Academy of Astronautics to conduct a four-year study assessing modern day designs of a potential space elevator. Forty-one experts from around the world studied the issues and analyzed the rationale for this transportation infrastructure and concluded that space elevators are a feasible option.

The algorithm for success is simple: Reduce the price for access to GEO to $500 per kilogram while changing the model to: daily, routine, smooth riding, less dangerous, environmentally sound, open size/mass criteria, and mission enabling.

Here’s how it happens. Place a large satellite in LEO with a reel of seed tether; gain altitude to GEO with efficient engines; deploy the seed tether up and down, keeping center of mass at GEO; build the tether using multiple (>200) buildup climbers; establish a Marine Node, Apex Anchor, and Headquarters; and then initiate operational tether climbers of 20 metric tons (six metric tons for the climber, 14 for payloads to GEO).

There were, of course, some items of concern. Here are a few that were identified.

Carbon Nano-Tube (CNT) Research

The research showed that material strength properties would be available in the laboratory between 2015 and 2016. The design of the macro-tether could be tested in the late 2020s. The major hurdle for a successful space


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The space elevator tether climber is inside the atmospheric shielding protective box as it leaves the Marine Node.

elevator is material availability with strength-to-weight ratio far better than steel. CNT material, in the laboratory, has been grown in centimeter lengths with sufficient strength to hold a space elevator against the gravitational field. The projections are that: a) the material will be available by 2015, in the centimeter to meter length, with appropriate strength to achieve operational space elevators, and b) growth to thousands of kilometers of woven strands of this material could be available during the late 2020s.

Tether Dynamics

The study showed the dynamics of the 100,000 km tether were stable; however, the specific characteristics need to be simulated and understood to a greater level of detail. The chapter on dynamics describes a space elevator tether's motion anchored on the surface of the Earth with a large mass at the Apex Anchor. The analyses then added ribbon climbers to the dynamics and showed both extra motion and damping.

Tether Climbers

There will be a variety of climbers. Operational climbers are defined as the commercial version of a spacecraft taking customer payloads to altitudes such as LEO, GEO, and Solar System trajectories. It will also return objects to disposal orbits or to the Earth's surface. The ascent requires power to climb while the decent from GEO and ascent past GEO requires braking as gravity or centrifugal forces dominate. The variety of operational climbers will surprise even early believers. There will be tether weavers, repairers, and safety inspectors along with logistical trams, commercial climbers, human rated climbers, science climbers, hotels, and launch ports. Some ideas are:

- A tether climber will have 20 metric tons gross weight with six metric tons vehicle and 14 MT cargo.
- There could be a total of seven tether climbers on a space elevator at any one time.
- There would be one launch per day for a seven-day trip time to GEO.
- A tether climber is no more than a spacecraft with a special propulsion unit of electrically driven wheels instead of fuel-consuming engines.

Atmospheric Protection

Space elevator operations will be similar to current approaches for space infrastructures. The following new concept represents a simplification of movement from the surface location (Marine Node) to a safe altitude. The first 40 km of climb requires protection from atmospheric hazards, such as wind, lightning, and rain. As such, a large, very light, CNT-based, protective "box" with its own motor and gripper apparatus will surround the tether climber, its payloads, and power-receiving apparatus. The power source for the protective box could be of various sorts; but, this report assumed a lightweight tether power cord, probably made of carbon nano-tubes. This separately powered "box" lifts and protects the loaded space elevator tether climber during its transition through the atmosphere. The operations team loads the climber into the protective box and then initiates its rise from the Marine Node platform. Once it is outside the atmosphere (current assumption is at 40 km), the climber "ascends out of the box." The box is then returned to the Marine Node by descending on the tether to ready itself for its next lift.

Mitigation of Threats in Space

There are many associated risks; but, all of them seem to be manageable with appropriate mitigation techniques. The environmental threats to a space elevator are not significantly different from historical threats to orbiting spacecraft, given the differences in motion—orbiting around the Earth versus rotating with the Earth.


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The tether climber is exiting its protective box above the atmosphere and is preparing to deploy its solar cells to initiate power for the climb to GEO and beyond.

Similarities will be obvious for human transportation and when designing for the atmospheric portions of the space elevator. The large scale of a space elevator infrastructure crosses many environmental regions that increase complexity. Electromagnetic and radiation effects on the space elevator tether and climbers must be studied in detail. The study estimate is that the electric and magnetic fields and currents will not affect operations; rather, they could actually enhance them. The threat from LEO space debris is manageable with relatively modest design and operational procedures. For small debris, tether design will enable survivability; while, for tracked debris, evasive movements will avoid collisions.

Legal and Regulatory

The space elevator should be within the current legal framework of all three of the regimes it traverses: international waters, air, and space. The risk to the space elevator infrastructure from nation-state control when placing the base station inside its territory is too high to be acceptable. Therefore, the Base Node of the space elevator will be in the ocean beyond continental shelves and any exclusive economic zones of individual countries. In addition, the Marine Node must be flexible enough to not infringe upon any nation's rights of movement. As the space elevator is to be established stretching upward from the high seas at the equator, the undefined boundary between airspace and outer space is not a major concern. The tether must therefore be announced and visibly distinguishable within its airspace. The "Charter of Outer Space" established the principles governing the activities of states in the exploration and use of what is defined as outer space. The space elevator seems to fit within all these sets of precedents.

Technological Feasibility

The supporting technologies should be there when the tether material is available. Each of the technologies that would be necessary for space elevator development is assessed within the report with respect to achievability within a reasonable timeframe. The material of the tether will pace the entire space elevator development; but the other components are definable and achievable in the near future. Two key elements beyond CNT development are the refinement of lightweight materials for space missions and the development of higher efficiency solar arrays.

Financial and ROI

A space elevator infrastructure would open up the Solar System to government missions and commercial ventures similar to the initiation of transcontinental railroad infrastructures of the 1800s. This study chose to use a privately funded commercial venture approach, while recognizing that a fully funded government option was also feasible. The chosen approach lays out a four-step process for return on investment: Phase one is for pure research and is to be funded by entrepreneurs and government grants. The second phase is one where the total project is sized and projected with initial research conducted to lower individual risks.

The third stage of development would include building of space elevator infrastructures with private investors. The pairs of space elevators that were developed would then be sold to individual operators for business opportunities. The authors estimated that the first series of development would lead to three pairs of space elevators spaced around the world competing for payloads. At $500 per kg, business should be brisk. Market research showed that space elevator infrastructure companies will make major profits in the long run. As in most transportation infrastructures, the initial investments are massive and will require flexibility and creative funding; however, as the profit potential is so great, the money should be there.

After the conclusion that space elevators seem feasible, the authors laid out potential paths to making it a reality. They developed two potential roadmaps for space elevator operations: 2036 and 2055. These two thrusts were compared: a) assume tether material is space-qualified by 2030, leading to 2036 operations, and b) assume tether material is available two decades later, delaying deployment to 2055. As no one can reliably predict the future, this study chose to present both cases. Future roadmaps will lead to space elevators around the world, identifying and lowering risks, as well as moving technologies up the maturity hierarchy. Parallel prototype developmental programs must be established to lower risks and raise technology readiness levels. A successful research and developmental program will then enable a construction company to initiate construction of a space elevator infrastructure.

The 358-page study report can be purchased at: *http://www.virginiaedition.com/sciencedeck/spaceelevators.shtml*

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