Space Elevators: A Feasible Solution for Sending People and Goods into Space More Cost Effectively

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Abstract— The Present study focuses on the fascinating concept of Space Elevators. Object of this study is to get introduced with every aspect in Designing, Working & Construction of Space Elevators. It's a concept in which tether is used to uplift any type of cargo or personnel from Earth surface to an orbit in space. Such invention not only becomes the new path for heavy loads to get into space but also becomes a cheap one. Also from the top of it, loads can be launch in any desired direction. By this not only the cost of the launch through rocket gets reduced but also the personnel handling this launch i.e. reduction of human error too. Perfect suitable material for such operation is Carbon Nano-tube which hundred times stronger and ten times lighter then Steel. In coming 50 years, it might be possible that many space elevators are ready to launch the spacecraft in space. Its application is not just only limited to the launching but also it can help in carrying heavy payloads to International Space Stations. It simply can give access to space for scientific, commercial & military purposes.

Keywords— Space Elevators, Space-Towers, Geostationary Orbit, Space Cables, Tethers, Carbon Nano-tube, floating platforms.

INTRODUCTION

A concept which can make possible the fantasy of physical connection between Earth and Space. In Space it can be go high from LEO (Low Earth Orbit) to GEO (Geostationary Orbit), approximately ~ 100 to 23,000 miles. The most general description can be Space Elevator is a long tower attached with one end to earth and other long high in space. The concept first came from an inventive Russian in 1960.[1] Many science fictions even kept the insights of Space Elevators also. Its Intended use is literally a transportation of Payloads, personnel, power, etc. from earth surface to space. A recent patent filed by a Canadian company on the same concept in which a 12.4 miles long tower from the earth used to launch the spacecraft in space. Space Elevators can directly provide access to astronauts, which can help in mining asteroids, placing a satellite into an orbit. Through the introduction of this concept attaining the escape velocity by spacecraft to get to the orbit will not be a problem anymore. This concept reduce a major stage of getting into space i.e. launching through Rockets, which not only reduce the cost of the mission but also protect the environment from the harmful gases thrown out of exhaust nozzle of rockets. Sending things into space from the earth's surface is extremely expensive. Chemical rockets are complicated and dangerous as well as expensive to build and launch. Space elevators have shown the possibility of a simpler, safer and cheaper alternative. This is the main argument for developing an elevator that will take things from the earth's surface into orbit. So far technological and logistical roadblocks have been holding the concept of a space elevator from becoming a reality. The technology of carbon nanotubes is a ways away from becoming the 60,000 km tether for the elevator.[2] Finding the funding and manpower for building such a massive structure in itself will prove to be a logistical marvel in itself. If the understanding and utilization of carbon nanotube technology does not improve, and the needs for massive funding, manpower, and engineering genius are not met, there will be no space elevator.

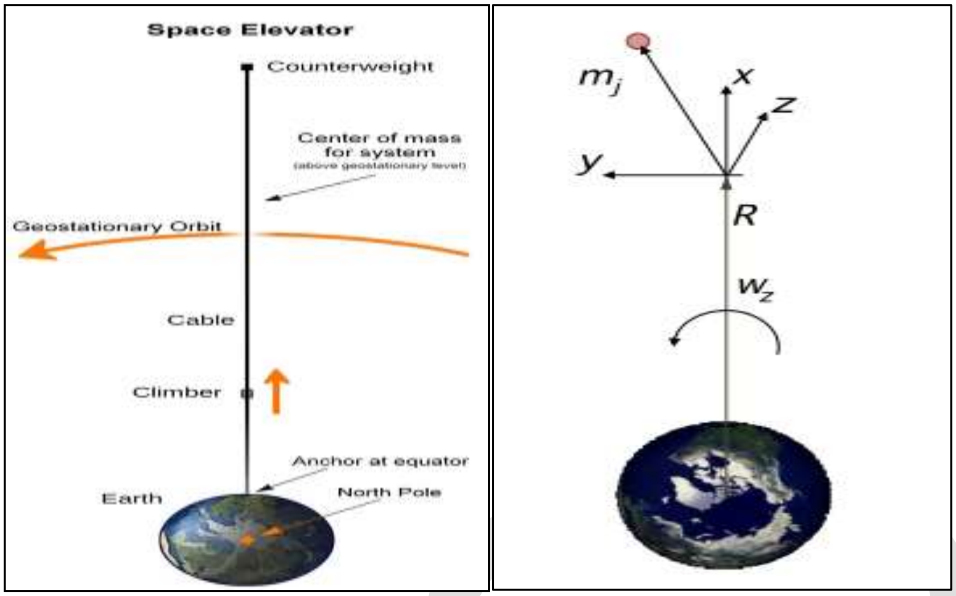

Fig 1: Space Elevator Methodology

Propellants used in rocket can cause the depletion of Ozone layer or can cause acid rain or can cause smoke-trails all over the sky. Space Elevators can directly be link to the International Space Station (ISS) or any other Space Station floating in the orbit, it helps astronauts in their researches. They don't have to depend or wait for the space organization to sanction a new rocket launch just for bringing some samples back. Surface labs can be directly connected to the labs setup in space. Another application of this concept in future is that, it can be direct link from the settlement in Space to the Earth surface.

BASIC CONCEPT

Main Principle behind the Space Elevator is the centrifugal force of earth's rotation. As it rotates, centrifugal force tends to align the cable/tower in a stretched manner. Basic Components that every design includes Base Station, Cable, Climbers, Counterweight.

1. ***Base Station:*** Generally Base Station categorize as Mobile or Stationary. Mobile are large ocean based vessels which maneuver in order to avoid high winds & Storms. Stationary Stations would normally be located in high altitude locations, like top of mountains or high towers which generally reduce the length of the cable.
2. ***Cable:*** CNTs are the strong candidates as a material for cable. The required strength of the cable will vary with its length. The cable should be made of a material with large tensile strength/mass ratio.
3. ***Climbers:*** Climbers are generally Elevators which climbs the cable. On elevator design, with cables as planner ribbons, most of the time rollers are being used to hold the cable with friction. Elevators must be placed on optimum time for minimizing cable stress & Oscillations and also to maximize the payload. Though often lighter climber being used so that several climbers climb at same time which not only increase the payload capacity but also lowers the stress acting due to extreme payload on the cables as well as climbers.

Apparently there are two major factors which affects the physics of Space Elevators:

1. ***Apparent Gravitational Field:*** Along with the rotation of the Earth, the space elevator cable rotates. Objects attached to cable will experience upward centrifugal force which opposes the downward gravitational force at that point. The actual downward gravity minus the upward centrifugal force gives the apparent gravitational field.
2. ***Cable Section:*** The cable material includes its design must be strong enough from the strength point of view so that it can support 23,000 miles itself. By designing any cable larger in cross-sectional area at top compared to the bottom, it can hold up longer length of itself. Due to this another important design factor in addition to the material is how the cross-sectional area tapers down from the maximum altitude to minimum at the surface. To maximize strength/weight ratio of the cable, the

cross-sectional area will needs to be designed in such a manner that at any given point, it is directly proportional to the force it has to withstand.

DEVELOPMENTS & BACKGROUND REVIEW

There has been lots of studies and theoretical researches done on Space Elevators. They were focused on its physics and some components like its optimal design.[3][4][5] But because of unavailability of proper material, this concept has been discarded. Then Carbon Nano-tubes (CNT) were discovered in 1991, which is hundred times more strong then steel and ten times lighter.[6] In CNT, atoms are structured in a particular pattern, same as of Geodesic domes. Moreover it is a very long chain of carbon atoms only. They are strong per kilogram than any other kind of material by a factor of 40, which means a fiber of CNT with a diameter of 1/8 inches could support a load of 45 tons.

Later in 1975, Pearson Physical base for designing & construction of Space Elevators. With Clarke, he stated that tower should be fabricated in both direction of Earth to Geostationary Orbit to maintain the gravitational balance of Structure. With the help of force derivatives, he calculated the tower must be minimum of 89,478 miles in order to be balanced state with Surface gravity, Earth's radius, Net weight of zero & period of rotation. He then proposed an exponent, area taper for the structure of 0.776r/h where r be radius of earth and h be characteristic height to which a uniform diameter of tower could built in 1g field. Proper materials can be classified from below relation:

$$h = \sigma/\rho g$$

Where, σ: Max material stress

g: Surface Gravity.

Graphite Crystals based Elevator is proposed by Pearson with σ of 46.5 GPa & density, ρ of 2200 kgm^{-3} which yield a solution with characteristic height, $h = 2150$ km & taper ratio of 10 without any kind of safety factor is applied. He stated that such structure would have certainly significant utility, like ascending payloads can be injected into space orbits directly without use of rockets. However, from construction point of view, still requirement of innovation in material as well as in space manufacture systems, programs, etc. and also there be requiring minimum of 24,000 spacecraft flights which is modified only for working in geostationary orbit.

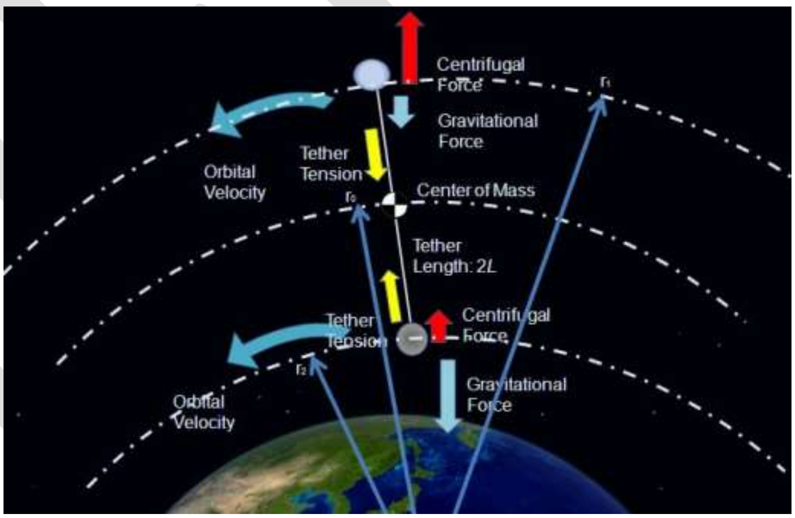

Fig 2: Orbital layering

In 1978, Arthur C. Clarke in his novel, *The Fountains of Paradise,* proposed that a space elevator can be constructed using a counter-balanced mass system and a cable. For Earth's spin rate and gravity such proposal requires cable of at least 23,000 miles long & a counter-balanced mass similar to mass of small asteroid. Later then such system could be constructed through launching cable in space or manufacturing it on site. Though there be some technological obstacles that must be overcome, including the manufacturing of cable with suitable strength or on-site construction. These obstacles have not been realized until Clarke proposed this concept.

In 1985, Lofstrom proposed *launch loop*, which is a 2000 km long cable structure fixed at both ends and at every 80 km vertically along its length.[7]

Later again in 2000, Edwards proposed a ribbon composed structure comprising 1.5 μm ribbons each with mass 5000 kg.[8] According to Edward, ribbon comprising CNT with tensile strength of 130 GPa requires 4 Titan IV/Centaur launches to deliver ribbons to GEO. These ribbon would be capable of holding a climbing payload of 528 kg with a safety margin of 2. After such 250 assents, the cable become capable of raising a 13,000 kg payload in every 5 days. This concept approach is quite better than other known. However, from his study Edwards found many challenges that one might face while engineering this design.

In 2000, Boyd & Thomas also proposed a design for space elevators in which a cable system is capable of transporting the payloads between orbital locations.[9] Basically in their design, payload moves between locations located at fixed orbital distance from the earth. Since the device is not attached to earth so there must be secondary means to attach the payload initially to the elevator.

Such studies keeps on going concluding all structures rely on innovation & development of materials to construct towers/cables of greatest strength. The best known is still CNT, but in 2006, Pugno argues that even presence of microscale defect alone will prevent the fabrication of cable with sufficient strength only if theoretical strength limit can be estimated in a microscopic cable.[10] He concludes that if elevator built based on today's design then it will break.

APPLICATIONS

A space elevator would be cheaper than using chemical rockets. To build the first space elevator it is projected to cost around 6- 12 billion dollars.[11] The cost of building any additional elevators is said to cost around 2 billion dollars each because the materials to build them could be sent up on the first elevator. In comparison the Saturn V rocket alone cost 6.5 billion dollars during its operation between 1964 and 1973. Also space elevators would be completely reusable. Once the elevator was built it would go until a part was broken or worn out. There would be no need to have expensive booster stages that would be dropped back down to earth and destroyed once used up. Once the space elevator was built it would be much cheaper to use continually without much maintenance.

The most expensive part of any space mission using chemical rockets is getting to Low Earth Orbit. This is because of the earth gravity and atmosphere. Because the fuel for chemical rockets weighs so much itself they have to carry a tremendous amount of fuel to be able to lift a relatively small payload into Low Earth Orbit. Also the whole time the rocket is also fighting air resistance until it leaves the atmosphere, which takes more fuel, which reduces payload and increases cost per kilogram of the payload. The Saturn V rocket, one of the most powerful rockets ever launched carried a payload of around 119,00kg into Low Earth Orbit and cost 1.1 billion dollars per launch, which comes out to around 8403 dollars per kilogram. The cost of sending a kilogram of payload into Low Earth orbit on a space elevator would be around $220 per kilogram. It is said that a space elevator could carry payloads of 11,193kg per climber and that up to eight climbers could be sent up the tether at once.[12]

Many times payloads need to be sent into what is called a geosynchronous orbit or a geostationary orbit. A geostationary orbit allows a satellite to follow a single point of the earth surface for its entire orbit. A geosynchronous orbit allows a satellite to oscillate from north south in a figure eight pattern over a specific area of the earth's surface. For instance satellites used for satellite TV need to have an orbit that allows them to send information to its consumers where they live. To achieve a Geosynchronous a transfer orbit is required to gain the additional altitude needed. This in turn takes much more fuel that reduces the overall payload by a third, and makes the cost per kilogram much higher. A space elevator would eliminate the fuel costs for getting a payload for this type of mission into Low Earth Orbit. Since there is no gravity and no air resistance in space cheaper more efficient types of rockets could be used to bring satellites into geostationary or geosynchronous orbits. Electrical and nuclear rockets that have extremely high specific impulses that do not weigh very much could be sent up on the elevator and used to put satellites into these orbits.

A space elevator could be much safer in some ways than using chemical rockets. The climbers would use power beamed from the ground instead of highly volatile chemicals. There would be none of the dangers that you have when you are using chemical rocket fuel. There would be no fuel that needed to be kept in a liquid state. You would not have to build a massive flame trench or have people standing three miles away to watch it lift off. There could be safety mechanisms that would grab onto the tether if something went wrong with the elevators propulsion system. When something goes wrong with a chemical rocket during lift off the payload is usually ejected or destroyed.

CONCLUSION & FUTURE SCOPE

Space elevators are not yet a feasible solution for sending people and goods into space. There are too many technological and engineering roadblocks. The challenges of building such a thing are far beyond anything that has been attempted before. The anchor for the elevator would be one of the most massive structures ever built and it would most likely has to be a ship that could move the entire elevator from the sea. A way to collect a giant asteroid and a way to attach this giant asteroid to the end of the tether needs to become a real life possibility for the elevators counterweight. The technology for wireless energy transfer needs to be greatly improved if the space elevator has any hope of being a more efficient way of getting things to space.

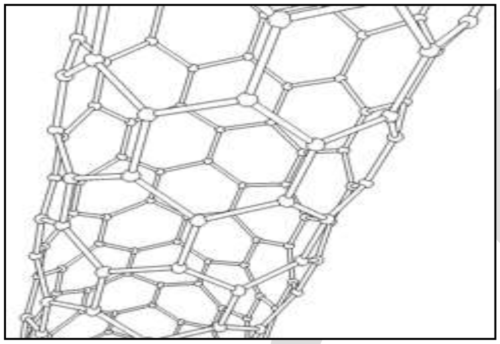

Fig3: Carbon Nano-Tube Structure

The technology for the carbon nanotube tether is far from being ready. Carbon nanotubes need to be made 66,000 km long and on a literally astronomical scale. Once this is accomplished a way to make this nanotube tether withstand the harsh weather and temperatures of the earth atmosphere as well as intense vibrations, radiation, satellites, meteoroids, and micrometeoroids would need to be found. The climber must endure these challenges as well but it must also be able to keep human passengers safe from them. The elevator must protect humans from intense radiation and the vacuum of space along with the challenges of the earth's atmosphere for days on end. These challenges are too much for the technology that we have at hand at this point in time. As Dr. Bryan E. Laubscher said, "As soon as we can build it, we should build it". But as of now a space elevator is not a feasible solution for sending things into space because we haven't built one yet. Therefore Space Elevators are only a sufficient but not a necessary condition for the viability of the space elevator as a practical transport system.

REFERENCES:

[1] Artsutanov, Y. 1960. V Kosmos na Elektrovoze, Komsomolskaya Pravda, (contents described in Lvov 1967 *Science* 158:946).

[2] Edwards B.C., The Space Elevator. Study conducted for NASA under NIAC program.

[3] Clarke, A.C. 1979. The Space Elevator: 'Thought Experiment', or Key to the Universe. *Adv. Earth Oriented Appl. Science Techn.* 1:39.

[4] Isaacs, J.D., Vine, A.C., Bradner, H., and Bachus, G.E. 1966. Satellite Elongation into a true 'Sky-Hook'. *Science* 151:682.

[5] Pearson, J. 1975. The Orbital tower: a spacecraft launcher using the Earth's rotational energy. *Acta Astronautica* 2:785.

[6] Iijima, S. 1991. *Nature* 354:56. *The Infrared and Electro-Optical Systems Handbook: Atmospheric Propogation of Radiation*, Vol. 2. 1993. Editor:Fredrick G. Smith. Bellingham Washington: SPIE Optical Engineering Press. 228.

[7] Lofstrom K. H., The Launch Loop: A low cost earth-to-high-orbit launch system, AIAA-85-1368, 21st joint propulsion conference, 1985.

[8] Edwards B. C., Design and deployment of a space elevator, *Acta Astronautica*, 2,785-799, 2000.

[9] Boyd R. R. and D. D. Thomas, Space Elevator, US Patent 6491258, Filing date: Dec 6, 2000, Issue date: Dec 10, 2002, (Assignee: Lockheed Martin Corporation).

[10] Pugno N., On the strength of the carbon nanotube-based space elevator cable: from nanomechanics to megamechanics, *J. Phys.: Condens. Matter*, 18, S1971-S1990, 2006.

[11] Chang, Kenneth. "Not Science Fiction: An Elevator to Space - New York Times." The New York Times - Breaking News, World News & Multimedia. Web. 21 Nov. 2011.

[12] Quine B.M., Seth R.K., Zhu Z.H., A free standing elevator structure: a practical alternative to the space tether