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CISLUNAR ORBITAL TRANSPORTATION STUDY OF SPACE ELEVATOR APEX ANCHOR RELEASES

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Abstract

As humans increasingly begin to expand beyond the threshold of Low Earth Orbit (LEO), moving supplies and astronaut safety within the vastness of space can become daunting. Limited by Tsiolkovsky's Rocket Equation, rockets are inefficient at moving material off planet as only a small percentile of the rocket's launch pad mass reaches orbital space. While commercial enterprises have greatly increased the rate of rocket launches, a human emergency occurring far from Earth raises the question of how to send aid. Space Elevators are an additional solution to overcoming the initial constraints posed by rockets. In a simplified manner, a Space Elevator is a permanent infrastructure for moving large elevators (climbers) along a tether that extends from the surface of the Earth into space. This research looks at the volume of space between Earth and the Moon, otherwise known as Cislunar Space, and the benefits that a Space Elevator would contribute. Specifically, a safety for astronauts beyond LEO by means of the Apex Anchor (space station located at the top of the Space Elevator) as well as mass distribution to the Moon by means of the Space Elevator. Mathematical and engineering details for the Space Elevator's construction or orbits for payloads are referenced but not calculated in this study.

Keywords: Space Elevator, Cislunar space, Astronaut safety, Mass transportation

Acronyms/Abbreviations

Geosynchronous Space ("GEO")
International Space Station ("ISS")
International Space Elevator Consortium ("ISEC")
Low Earth Orbit ("LEO")

1. Introduction

Space elevators offer not only a path or road to space, but a transformational avenue of travel comparable to the expansion by railway network. The railway network that connected the USA did not only allow for a quicker and cheaper transportation of goods but created a vast number of towns and settlements along its path. Which resulted in the expansion of industry and settlements more than could have ever been expected. The Space Elevator will hold a similar if not greater opportunity than that of the railway with expansion off planet because of the size and potential that space holds. This paper focuses on the area of space between the Earth and the Moon, otherwise known as Cislunar space. For a better understanding of the size of Cislunar space, most human spaceflight and satellites have been in the LEO portion of space of around 2,000 km or less. GEO of around 36,000 km from Earth and 384,000 km from the Earth to the Moon. These are distances from the Earth better known as altitude. However, the altitude only gives a single direction whereas the immensity of Cislunar space incorporates the entire volume of that region of space. As seen in Fig. 1 (not to scale) it is possible to gain an understanding of how as Space Elevator would appear in Cislunar space when pictured against the Earth and Moon.

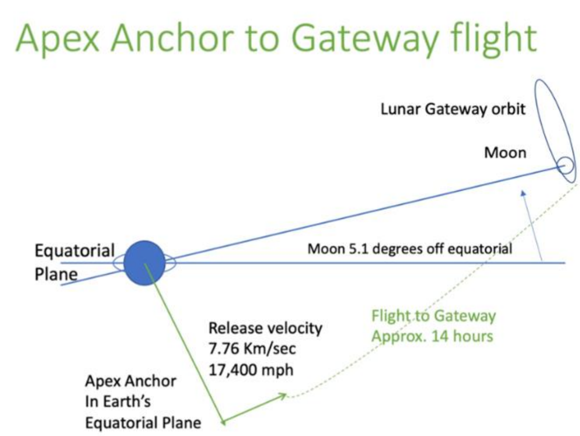

Figure 1: Example of Earth, Moon, and Space Elevator Cislunar space [1]

Cislunar space is important for future installations of human ingenuity. Some of the upcoming projected and theorized projects are the Lunar Gateway with Moon bases, ISS & upcoming Orbital Reef, Sunshades for controlling global temperature, and Space Solar Power to name a few. Each of every one of the future space endeavours will require large amounts of mass to be moved off planet. The gravity well that we call home to, Earth, creates a wonderful habitat for humans to thrive in. However, to leave the planet and build off world will require major movement of resources that are greater than that which rockets can realistically, economically, and environmentally provide. The Space Elevator can offer a transformational path to space with daily, environmentally friendly, and routine departures from an Earth Port. As well as provide large amounts of movements of mass into space and offer emergency safety for astronauts from the Apex Anchor.

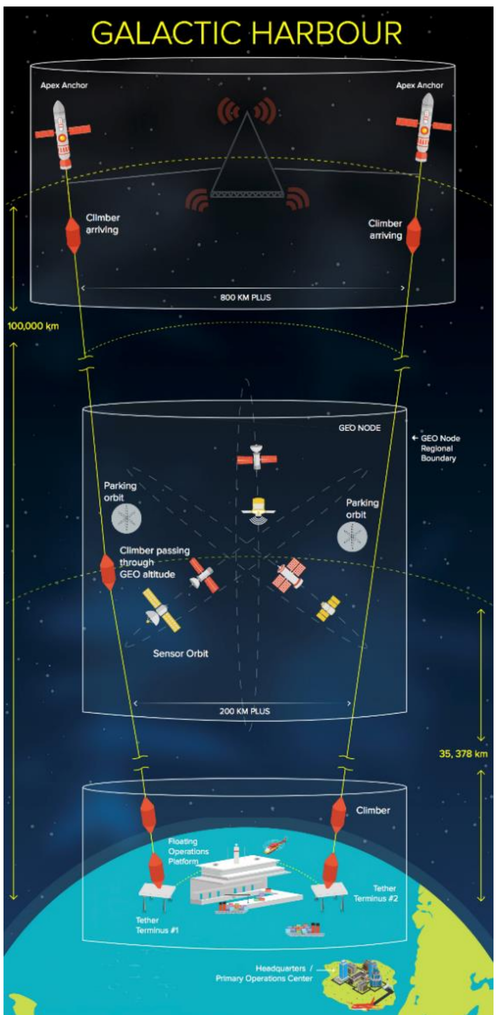

Figure 2: The Space Elevator illustration with its components. [2]

1.1 *Space Elevator Description*

Space elevators are relatively simple in quantitative design, as they are easily separated into four main components as can be seen in Fig. 2. Beginning with an Apex Anchor which sits at around 100,000 km altitude and is the starting point for building the space elevator as well as the final terminal for the transit. The Apex Anchor acts as the counterweight at the end of the tether and as a space command point. Capable of reeling "up & down" the tether to move out of the way of space debris and equipped with thrusters to move the tether out of the way of space debris.

The tether is the guideline for the space elevator and extends from the surface of Earth at the Earth Port, through the atmosphere and beyond GEO to the Apex Anchor. Current material for the tether that is under manufacturing testing is single crystal graphene. Crystal graphene was the breakthrough needed to solidify Space Elevators as another viable means to space. Current experiments and research are leading to the manufacturing process that will enable the crystal graphene to be made. The tether will be made from "12,333 layers of single crystal graphene 4 microns thin near Earth" Graphene super-laminate by Adrian Nixon, and will then taper to 14 microns near GEO. While currently still under development, the material will be ready for use by the Space Elevators initial operations time. [3,4]

Returning to the components of the Space Elevator, the basic purpose of the tether is a means for the tether climber to ascend into space. The tether climber is the component of the space elevator that is transporting the mass from the Earth Port along the tether to its destination. As the tether climber ascends the tether it gains momentum and releasing at various points along the tether allows for quick and efficient transportation of the climber and its cargo.

Finally, the Earth components of the Space Elevator would include the Earth Port, and the headquarter of operations. The Earth Port will act as the harbour for the sea-level portion of the space elevator, where cargo is delivered from arriving ships onto the tether climbers. Ideally there will be six Space elevators running in near tandem at three different Oceans. For trade and cargo distribution optimization, two Space Elevators will be located at the Pacific, Atlantic, and Indian Oceans. Comparatively to how trains have multiple tracks running parallel to allow for better flow of transportation. With an active network of Space Elevators large amounts of mass can be transported into space whereby the cargo can be sent to its destination. Recent Studies written by the ISEC include "Space Elevators are the Transportation Story of the 21st Century" written in 2020, "Space Elevators, the Green Roade to Space written in 2021, and an upcoming study on tether climber design and its impact on the tether, due to be released in 2023. Please see https://www.isec.org/ for more information regarding the studies, research, and a wealth of knowledge regarding Space Elevators and their future role in transforming space development. [5,6]

1.2 Tsiolkovsky Rocket Equation

Rockets are a quick and already designed method for reaching space and offer some great advantages. Such as moving humans quickly through radiation belts and being able to access multiple orbits using only thrusters. However, rockets greatest downfall are their inability to move beyond the limitations in the amount of mass that can be transferred into space per launch. Tsiolkovsky's rocket equation (1), gives the limitations that rockets have. That while our technology advances, there are restrictions with our environment that humans have yet, if not impossible, to overcome. Such as the amount of energy chemical reactions can produce and the gravitational pull from the body the rocket is launched from.

$$\Delta v = v_e \ln \frac{m_0}{m_f} = I_{sp} g_0 \ln \frac{m_0}{m_f} \qquad (1)$$

Δv (Maximum change of velocity of the vehicle)
m_0 (Initial mass)
m_f (Final mass)
v_e (Effective exhaust velocity)
I_{sp} (Specific impulse)
g_0 (Gravity)

As seen in Table 1 (following page), Rockets only provided 1% of the total launch pad mass to the Moon, less than 2% to GEO and a little more than 4% to LEO. While current rockets are in the process of reusability, thereby decreasing costs to the environment and resources, the amount of mass being sent into space on each rocket is still small. Space Elevators can overcome the abysmally small percentage of mass being moved into space. With their routine, environmentally friendly and efficient method of reaching space the mass movement problem can be overcome. [2]

With the current trend of rockets being the sole source of transportation into space, the cost on the environment needs to be closely monitored and addressed. While reusable rockets are a step in the correct direction for sustainability, the increased number of launches results in more damage to the atmosphere and other potential areas. A recent article "The environmental impact of emissions from space launches: A comprehensive review" [7] details how research into certain aspects of rocket launches have yet to be fully researched. It is however unlikely that the research will find that there is no harm to the environment from the increased number of launches and the different fuel types. Space Elevators however offer a green road to space as seen in the appropriately titled "Space Elevators, the Green Road to Space". [6] Fuelled by renewable energy from electricity via solar panels and other methods the only rocket fuel used would be when altering the trajectory of the tether climbers and slowing them down at their destination. Rocket fuel burnt in space holds no negative effects on Earth assuming they are harnessed in correct ecological practices.

It is important to take a moment and understand the need for dual space access with Space Elevators working alongside rockets. As can be seen in Fig. 3, it is the process of both rockets and Space Elevators working together to create a dual space access. A rockets quick ascension into space allows for minimal exposure to radiation and decreases the amount of time that astronauts need to wait for arrival to LEO. Current technology is advancing with rockets and the Space Elevator is not looking to remove rockets but to work alongside them. Without rockets Space Elevators do not have a chance to begin their construction and rockets will also renew the space race at the Lunar Gateway and Moon bases. Once Space Elevators are operational then mass should be routinely sent to space via the Space Elevators. Please visit www.ISEC.org and the list of references for more information regarding dual space access with rockets and Space Elevators. Perhaps the most prominent aspect of Space Elevators to show their advantages over rockets is the amount of mass that can be transported from Earth into space. [5]


Figure 3: Dual space access [5]

Table 1: Launch Vehicle Delivery Percentages to GEO

Launch Vehicle	Pad Mass	To LEO (with % of pad)	To GEO (est.) (with % of pad)	To Moon surface (with % of pad)
Atlas V	590,000	18,500 (3%)	7,000 (1.2%)	
Delta IV	733,000	28,770 (3.9%)	10,000 (1.4%)	
Falcon H	1,420,000	63,000 (4.4%)	26,000 (1.8%)	
Saturn V	2,970,000	140,000 (4.7%)		16,000 – 0.5%
Average		4% of Pad Mass	1.5% of Pad Mass	

Note: Data from web varies greatly - these numbers are representative only, ref. ISEC working documents summarizing information on web. [2]

2. Mass Transportation

All great projects built on Earth have required large amounts of resources, and space projects will have the same requirements but with greater difficulty to access those resources. In the future it may be possible to mine asteroids and harvest from gas giants for enough resources to supply outer space construction, however the current process is for rockets to move the needed mass. Space Elevators offer the better alternative to moving large amounts of mass into space to achieve the required masses needed for these great space projects. Some examples of space projects are given in Table 2. As a comparison, currently only around 26,000 tonnes have been sent into space since the beginning of the space race. [8]

Table 2: Projected Space Projects

Project Name	Mass Required in Space (in tonnes)
Space Solar Power	3,000,000
Moon Village	500,000
SpaceX Colony	1,000,000
L-5 O'Neill Colony	10,500,000
L1 Sunshade System	34,000,000 - 83,000,000

Mass in tonnes for potential projects in space. [8,9]

As seen in Fig. 4, the tether climber would ascend from Earth at the Earth Port and make its way towards the Apex Anchor. At the Apex Anchor would be multiple facilities such as storage, an assembly location, and emergency supplies depot all for helping allocate resources that ascend the Space Elevator.

The rate at which Space Elevators can send mass into space can be broken up into three main areas; how often can cargo be transported, how quickly can the cargo reach its destination, and how much cargo can be moved. An advantage of Space Elevators over rockets is how often and routinely tether climbers can be sent. While rockets need relatively strict weather conditions a climber can ascend into space where it will have no delays assuming it has sufficient power to move. Current design for the tether climbers use electricity gathered from solar panels attached to the climber with the potential to reach 7.8 km/s at 100,000 km. Therefore, in certain weather conditions the tether climber may face slower ascension times due to poor weather and the rotation of the planet away from the Sun. This is a minor inconvenience as poor weather conditions are at minimal altitudes and Earth's rotation guarantees daily doses of power from the Sun. Keep in mind that having multiple climbers across the globe allow for a highly designed routine transportation system capable of daily injections of mass into space.

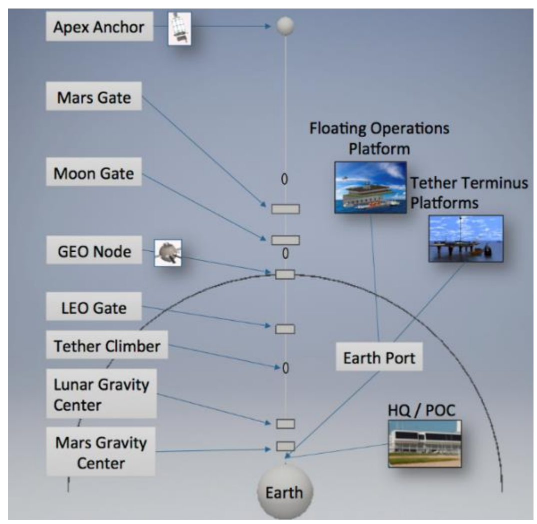

Figure 4: Structure of Space Elevator with Mars Gate and Moon Gate visible beyond GEO [5]

Ideal launch points have already been evaluated to reach popular destinations such as the Moon and Mars with the given names of the Lunar Gate Release Point and Mars Gate Release Point respectively and can be seen in Fig. 4. Launches towards Mars when launched at 100,000 km can reach Mars in as little as 61 days with many daily launches at less than 100-day arrival times depending on the location of Mars in respect to the Earth. However, releases from an altitude of around 57,000 km at the Mars Gate Release Point would be the most efficient for the fuel needed when slowing down and could be used for sending resupplies on a scheduled program. For comparison the shortest time duration to Mars were the Viking 6 and 7 spacecraft which were flyby missions and took 155 and 128 days respectively to arrive. Daily launches from the Apex Anchor can reach the moon in about 14 hours whereas launching from the Lunar Gate at 47,000 km would be more energy efficient as it would require less fuel to reduce velocity for a small increase in travel time. [2]

The transformational ability that Space Elevators bring to Cislunar space are predominately laid forth when looking at the total mass that they can move as well as how often. Increases to the number of annual rocket launches is a substantial improvement over previous years, however rockets will struggle to meet the demands of future space projects as researched by ISEC in their working documents summarizing information on the web as seen in Table 1. For how much mass rockets move and how much mass is needed see Table 2.

Current projections show each climber capable of sending 14 tonnes of cargo. With a total mass of around 20 tonnes per climber and the climbers being able to be used (not sent to a parking orbit or burned up upon re-entry) in space give them a great advantage over rockets. Initial expectations for cargo transportation is at around 30,000 tonnes per year up to 170,000 tonnes per year once all six Space Elevators are fully operational. [2,8]

3. Cislunar Mission of Apex Anchor

The general mission for the Apex Anchor is to be the final base of operations prior to deeper space. As described earlier, the Apex Anchor will have multiple facilities, this section will focus on the emergency applications and the reasons for needing a rescue vehicle.

3.1 Logistics Support to Full Arena

In Cislunar space where the distances are vast, aid will take long periods of time to arrive and launching rockets from Earth could waste precious time needed for the safety of the astronauts. Also, while the number of rocket launches are increasing, the current availability of backup resources being ready for launch with the needed supplies is still minimal. Therefore, having the capability for quick deployment from the Apex anchor increases the need for Space Elevators.

3.2 Safety for Astronauts Beyond LEO

Space is vast and dangerous to human life so a large benefit from Space Elevators are the Apex Anchors located in space near the end of the tether which can release rescue vehicles to astronauts in need of assistance. It is important to first establish some of the dangers that can occur in space. Due to the nature of space, there exists multiple dangers beyond simply the hostility that space itself holds. That is, the expansive vacuum where humas are unable to survive without the aid of specialized suits and spacecraft. Other dangers exist for astronauts as well and which are of greater importance for this paper. They are the dangers to astronauts from delay of resources, space debris and system failures of rockets or habitation units.

The lifeline of the ISS and future instalments of space habitations, such as the Lunar Gateway and multiple Moon Bases, will come from rockets launched from Earth. While the ISS currently has a safe supply of resources and a routine of resupplying, there are still risks to receiving the resources on time. With astronauts projected to live lives further and further from Earth, the risk of resources not arriving becomes greater. Delays to launches due to weather can lead to projected launches being pushed further into the future where the window for reaching specific regions of space can be small. Missing such windows of opportunities could lead to severe rationing of supplies and in some cases death if the missing resources are critical enough such as air and water. Other potential issues with resources not arriving could be failures to the cargo spacecraft or missing the intended destination.

A rock being flung on a highway can be dangerous to drivers, however the car protects the passengers and usually the worst that happens is a broken window. In space, the same miniscule “rock” can cause tremendous and catastrophic damage due to the velocity that the projectiles can be moving. As seen in Fig. 5 the impact damage for an experiment from an aluminium sphere of 1.2 cm diameter weighing 1.7 grams moving at 6.8 km/s can greatly damage an 8 cm thick aluminium block and cause great destruction. The sphere used in the experiment is a representation for objects known as space debris which are a major concern for LEO spacecraft and may propose threats in the Cislunar region if not correctly curbed and managed. Sending a rescue vehicle from the Apex Anchor is one solution for rescuing astronauts whose spacecraft have been severely damaged by space debris. Please see the following reports for more details regarding space debris and Space Elevators. [10]

Figure 5: Impact crater from experiment of sending aluminium sphere into a block of aluminium. [10]

When Apollo 13 suffered a loss of oxygen due to an explosion the astronauts were far from aid and rescue. Due to the ingenuity of NASA Mission Control, the astronauts were able to abandon the mission and return to Earth safely. While explosions and mechanical or system failures in space are not common occurrences, as humans increase their presence in space the likelihood of issues occurring will increase. Technology is helping to prevent such issues, but inevitably as the number of humans in space increases so will the chance for disaster. Unlike the survival of the Apollo 13 astronauts there might come situations where return to the safety of Earth is not an option. In these situations, it will be through the aid of other spacecrafts bringing relief and support to ensure their safety. Such as the rescue vehicle provided by the Apex Anchor. [11]

Space Elevators offer a solution by being able to send aid directly from the Apex Anchor. Launching a rescue vehicle loaded with aid and supplies towards the marooned or in danger astronauts would be as simple as planning the trajectory and giving a small boost to the rescue vehicle. The aid and supplies would consist of life necessities such as: oxygen, water, power, habitat replacement, food, science instruments, fuel, and anything else that requires emergency assistance. The rescue vehicle could be prepared and ready for immediate launch at all times. As it does not require an allotted platform on Earth and the window of opportunities for launch are near limitless with the only factor being which launch time would be the quickest. This system of a rescue vehicle at the Apex Anchor can be seen as an umbrella of safety for any and all within Cislunar space. Add in the factor of an idealized tandem of six Space Elevators with Apex Anchors and the safety parameters within Cislunar space becomes more encompassing. While not discussed in the paper the Space Elevator can also quickly launch rescue vehicles and aid beyond Cislunar space quicker than any other form of current technology. Such as to Mars and the future development of the solar system.

3.3 -From Apex Anchor (Storage Depot)

While the mass transportation that a Space Elevator will provide is transformational, another key aspect that is currently being evaluated is the ability to provide support quickly and effectively to astronauts anywhere in Cislunar space and beyond. While rockets are a quick way to reach space, they require time to prepare for launch and windows of opportunity to reach certain destinations. Then once said rocket is launched, provides minimal amount of mass or in this case aid. The amount of time to prepare and launch, as well as the numbers of launch windows, and the total amount of aid that a Space Elevator rescue vehicle can provide outclasses rockets. The Apex Anchor could be used to send resupply missions to outposts and stations or as an emergency center capable of launching rescue vehicles with aid quickly and effectively to any astronauts whether they be in distress or as a scheduled mission.

3.4 -From Earth using rocket for comparison

With the Moon as a target for sending supplies in the near future, the quickest spacecraft to arrive to the Moon, without flying beyond, taking around 35 hours was Luna 2. It is important to recognize that Luna 2 weighed in at a mere 390 kg which would not supply much support in the form of cargo supplies. The Apollo missions to the Moon are perhaps the best human flight comparison for sending mass into deep Cislunar space. The shortest time to reach the Moon was Apollo 8 at about 69 hours and the longest at 86 hours for Apollo 17. Much depends on the launch date as the best window of opportunity lies when it will take the shortest amount of time to reach the destination. [12]

4. Conclusions

The transformation aspects that Space Elevators can bring to Cislunar space and beyond are only currently limited by our imagination. Such as how the railway expanded more than could have been imagined, so will the Space Elevator as a routine, efficient, ecological, and express pathway to space. Rockets will continue to fulfil their roles and send astronauts into space and may perhaps see some missions from Earth to rescue or send emergency supplies to astronauts in need. However, sending large amounts of mass and the advantages of sending supplies & emergency aid directly from the Apex Anchor are overwhelming apparent. Dual space access to space should not be overlooked as simple fantasy. Correct materials, technology, and engineering capabilities are already present, and a timeline has already been created for the construction of six Space Elevators. The next step towards full space access is within sight.

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