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Transportation Study of Release from a Space Elevator to Cislunar Space

DANIEL GRIFFIN
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Daniel Griffin, MSc student, KTH, Royal Institute of Technology, Stockholm, Sweden

Abstract—To leave Earth’s gravity well and ascend into Cislunar space takes ingenuity, and the engineering feats of many. Now to propel humanity further into space, rockets will need assistance to provide the large requirements of mass to be used for space structures. Tsiolkovsky’s Rocket Equation greatly limits the advantages of rockets and leaves an opening for Space Elevators to assist in a dual space access approach. By moving a large scale amount of mass routinely, efficiently, environmentally friendly and with daily launches towards space. Along with the apex anchor situated at 100,000 km for emergency assistance across all of Cislunar space, and to act as both storage facilities and a construction zone. Space Elevators are the railway to space and can supplement rockets by transforming how mass is transported to Cislunar space and beyond.

Keywords—Space Elevator, Cislunar Space, Mass Transportation, Astronaut Safety, Apex Anchor

Sammanfattning—Att lämna jordens gravitationsbrunn och stiga upp i Cislunar-rymden kräver upfinningsriktom och mångas ingenjörsprestationer. För att nu driva mänskligheten längre ut i rymden kommer raketer att behöva hjälp för att tillhandahålla de stora kraven på massa som ska användas för rymdstrukturer. Tsiolkovskys raketekvation begränsar i hög grad fördelarna med raketer och lämnar en öppning för rymdhissar för att hjälpa till med en dubbel rymd tillgång. Rymdhissar kan att flytta en stor mängd massa rutinmässigt, effektivt, miljövänligt och med dagliga uppskjutningar mot rymden. Apex-ankaret som ligger på 100 000 km kan fungera för nödhjälp över hela Cislunar-utrymmet och som både lagringsutrymmen och en konstruktionszon. Rymdhissar är järnvägen till rymden och kan komplettera raketer genom transformation hur massa transporteras till Cislunar rymden och bortom.

I. INTRODUCTION

Throughout human civilization there has always been a next frontier of transportation over the horizon. From wagons, boats, trains, cars, and planes to now space transportation. With the advancement of rockets, humans have begun to traverse our solar system using spacecraft. Such as with satellites used for global navigation systems and others for monitoring the weather. Perhaps two of the greatest feats for space have been the Apollo missions which saw humans take the first steps on the Moon. As well as the International Space Station (ISS) which culminates years of research from a multitude of countries working together for the sake of science. Currently with the Artemis program for the next Moon missions, as well as SpaceX and the Mars settlement there exist many ambitious goals for a rising space faring species.

The next step towards migration off our planet, into and beyond Cislunar space, appears to only be hampered by the process of leaving Earth’s gravity well. While rockets have performed amazing feats, the rocket equation hampers the amount of mass that can be moved into space per flight. Space Elevators offer an alternative ability to reach space and move large amounts of cargo.

A. Cislunar Space

Covering a volume from the Earth to the Moon, the size of Cislunar space can be difficult to comprehend. While most human space faring vehicles and satellites exist in low Earth orbit (LEO) below 2,000 kilometer, Cislunar space exists to around 400,000 kilometers. That is, most rockets, satellites and other objects sent into space have only existed within the realm of half a percent. As can be seen in Fig. 1, a general overview of the region within the vicinity of the Earth and the Moon is difficult to comprehend when exploring distances within Cislunar space.

B. The Space Elevator

The Space Elevator is a multidimensional transportation structure whose entirety can be divided up into six major components. Each component will be described briefly, with some explored in greater detail later on regarding their potential to Cislunar transportation and future development. Figure 2 shows the Space Elevator along with its components such as the Earth port, tether, tether climber, and the apex anchor.
1) **Earth Port:** Established as the primary port of entry from Earth, the Earth ports are a foundational building block for the Space Elevator. Ideally located in the ocean near the equator for international trade laws and international intent, the Earth port would facilitate incoming cargo from ships. Envisioned as a stationary or floating platform as seen in Fig. 2, cargo would be loaded into crates, or more ideally arrive in predetermined sized crates. Thereby the crates would be loaded onto the tether climber within the correct loading parameters, such as size and weight. Once loaded, the tether climber would begin its ascent. It would be possible to attach two separate Space Elevators anchors at the same location, allowing for one Earth port to facilitate two separate tethers. Depending on the quantity of “upward” bound cargo, a tether climber at both tethers could be used in conjunction, to increase the amount of daily cargo transportation to space. Once the space sector has become large enough to return cargo to Earth, then one of the tethers could be used during the decent while the other tether would be used for ascent.

2) **Tether:** Held in space by tension due to the centrifugal force from the counterweight (apex anchor) rotating with Earth, the tether is considerably the most defining aspect of the Space Elevator. Extending to an envisioned 100,000 km from the surface of the Earth, the tether is the supporting structure and guideline for the tether climbers to ascend along. Seen as the crutch to the development and implementation for the Space Elevator, recent research and industrial progress has shown that an attainable tether is within realistic reach. Such tether material candidates can be seen in Fig. 3, though it is possible for new materials to enter the race. Current manufacturing processes are limited in their speed and build length capabilities. To reach the desired 100,000 km length, a continuous rate of 1 m/s for more than three years will be required. As the process for manufacturing the tether material is improved, the costs of the material will also decrease, leading to an overall decrease in the Space Elevator’s construction costs. [5]

Additionally, the total length of the tether could be manufactured longer, from 100,000 km to potentially 120,000 km or even 150,000 km. Where the velocity of releasing a spacecraft at the apex anchor would be 7.76, 9.22, or 11.4 km/s respectively. While increasing the length may require additional resources, the payoff from the extra speed could be significant assuming that the demand requires it. Such as for sending cargo deeper into space and beyond our solar system. [25]

3) **Tether Climber:** The movement of cargo along the tether will initially comprise of the additional layers of material, strengthening the tether with each pass until the required number of layers is reached. This initial micro tether climber is already under preliminary testing in Japan with an experimental study using a hybrid roller. Small initial remote tether climbers will be required to build upon the original thin strand delivered from space to increase the load capacity of the tether. [29]

Once the tether is completed, large amounts of cargo can begin to be transported to space. With each tether climber weighing 20 tonnes, where 14 tonnes (70%) consist of the payload. The remaining 6 tonnes consist of the tether climber and its mechanisms, and can be reduced with advancements in technologies, along with variations in power supplies. There are different methods for which the tether climber can be powered. On board power supplies allow for movement during day and night, but are heavier and reduce the amount of cargo that can be carried on each climber. Solar powered energy from the Sun is another means of power that will be primarily used after ascending beyond the atmosphere. Another option is to beam the energy to the tether climber either from Earth or from space. A recent update for progress regarding a current study of space solar power shows that the technology is advancing, and that there is potential for the technology to power Earth based structures. More information regarding mass transportation advantages are explored later in this report. [1]

4) **Apex Anchor:** Situated at the end of the tether, the apex anchor’s primary responsibility is to act as a counterweight creating tension in the tether away from the Earth. This tension is required to create an adequate line for the tether climber to ascend. While originally only viewed as a counterweight, recent studies have shown that the apex anchor could have further uses. Such as astronaut emergency response and logistical support. [6]

Beginning with the initial satellite that lowers the tether towards the Earth, the size and weight of the apex anchor increase with the added layers and length of the tether. Current projections suggest that the mass can be increased by adding each tether climber to the original satellite, creating a collaboration of density large enough to be a counterweight.
The exact weight of the required anchor will be decided once the tether is in the final steps of design. Further analysis of how apex anchors can operate and provide assistance in Cislunar space will be discussed later.

C. The Approach

The vast region between the Earth and its Moon requires a transformation of approach to Cislunar transportation by leveraging both advanced rockets and Space Elevators. This dual space access strategy will change from single event launches of rockets, to a continuum of logistics with a train like approach due to daily launches from Space Elevators. This transformation in transportation infrastructure will enable robust growth of the Cislunar space, and economy with acceleration of mass delivery to vital locations. While Space Elevators will not be operational for the initial migration of humans to space, they offer a long term solution to moving large amounts of mass as compared with rockets. Space Elevators offer an environmentally friendly mode of transportation at inexpensive pricing both routinely and efficiently. By requiring power from only electricity, Space Elevators offer the green road to space without the need to burn propellants in the atmosphere.

II. GOALS FOR SPACE

There are various reasons for going into space such as for resources, exploration, science research, and future human habitations. The Artemis program, space solar power, and a Mars settlement are all programs that involve moving large amounts of mass into space.

A. Artemis

Since the Apollo Moon landings humans have not walked on the Moon. Now NASA along with many supporting countries and companies will reach for a more permanent human presence on Earth’s largest satellite. The program will consist of multiple Space Launch System rockets to work towards building of the Lunar Gateway. A human habitation unit in orbit that will house astronauts and act as the mission control over the Moon. To reach the Moon from the Gateway will be the Human Landing System which will transport the next generation of humans onto the Moon at the Artemis Base Camp. [7]

B. Equality into space

Promoting a diverse space endeavor by sending people of varying countries, ethnicity, or gender promotes to an encompassing culture that space is for everyone. Expanding upon the Artemis mission, NASA has explained its desire to put the first woman and person of color on the Moon. As more space habitations and missions in space increase, opportunities for various countries will open the door for the next generation of individuals from a multitude of backgrounds. This expanding diversity will promote equality and understanding that everyone deserves an opportunity to explore space.

C. Future Space Projects

Some potential projects that are envisioned for the future, or are currently under progress with their required mass needed for construction can be seen in Table 1

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Mass Required in Space (in tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Solar Power</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Moon Village</td>
<td>500,000</td>
</tr>
<tr>
<td>SpaceX Settlement</td>
<td>1,000,000</td>
</tr>
<tr>
<td>L-5 O’Neill Colony</td>
<td>10,500,000</td>
</tr>
<tr>
<td>LH Sunshade System</td>
<td>34,000,000 – 83,000,000</td>
</tr>
</tbody>
</table>

Each of these projects require large amounts of mass which eclipse current rocket capabilities. While mass movement will be discussed shortly, it is important to understand what each of these projects are. Space solar power utilizes the concept that in space solar arrays can be used to capture energy consistently without concern for planet rotation or weather. Life expectancy can also be increased due to minimal chances for damages, as compared to risks on Earth. One option is for a vast array of solar panels to be synchronized in rotation with the Sun over a city on Earth. Thereby allowing for energy to be transmitted via microwaves towards the cities’ power stations, to provide vast amounts of energy. Also, as previously discussed, space solar arrays could be used to power the tether climber.

The Moon Village expands upon the Artemis mission by having more than routine transits to the Moon for experimentation. Instead having a more permanent infrastructure established on the Moon, as seen in the Moon Village concept in Fig. 1. As stated by the Moon Village Association: “The Moon Village is not a literal village on the Moon, it is not an ISS on the Moon, and it is not a single science facility. Rather, it is a diverse community of projects carried out by stakeholders from different fields (for example, technical, scientific, cultural, economic)”. [11] Reaching this level of architecture would allow for unprecedented research on a physical body other than Earth. Micro gravity research as well as experience for the eventual transition to a Mars base.

SpaceX envisions a future of an established Martian settlement with the capabilities for return flights. By landing on the surface of Mars and using H2O and CO2 to refuel the Starship spacecraft this reality could be within reach. To begin the mission, a fleet of Starships will need to be
established in Earth’s lower orbit, and each supplied with enough resources for the mission. However, what has not been precisely mentioned for this dream to Mars, is the quantity of rocket launches that will be required to supply the fleet waiting in orbit. [12]

In 2019 Elon Musk spoke of abstract numbers of needing around a “million tons” of equipment and supplies to create a sustainable human population on Mars. Under the assumption that each SpaceX Starship is capable of transporting 100 tonnes of cargo, and that each Starship would need refueling (three to five Starship launches). Then for a fully operational system without any errors a minimum of 30,000 rocket launches would be necessary to reach the “million tons” goal. It should be noted that as of 2019, approximately 6,000 successful launches in total have reached space. While it is true the rockets have be used to send Hubble, James Webb Space Telescope, ISS and many satellites into space, the total amount of this mass is minuscule in comparison with how much mass is requested for future projects. See section V on mass transportation for more detail.

A. Rocket Equation

Tsiolkovsky rocket equation is considered the building block on which all rockets are fundamentally governed and restricted. Famously named after Konstantin Tsiolkovsky who derived the equation, and published his findings in 1903. The full rocket equation can be seen below in equation (1) with each variable appropriately explained thereafter. [28]

\[
\Delta v = v_e \frac{m_0}{m_f} = I_{sp}g_0 \ln \frac{m_0}{m_f}
\]  

- \(\Delta v\) is delta-v, the maximum change of velocity of the vehicle (with no external forces acting).
- \(m_0\) is the initial total mass, including propellant, also known as wet mass.
- \(m_f\) is the final total mass without propellant, also known as dry mass.
- \(v_e = I_{sp}g_0\) is the effective exhaust velocity, where:
  - \(I_{sp}\) is the specific impulse in dimension of time
  - \(g_0\) is standard gravity
- \(\ln\) is the natural logarithm function

With each variable in the rocket equation comes the understanding of the limitations for rockets. That is, the velocity of the rocket is completely dependent on three main sections. Firstly the \(g_0\) (standard gravity) with a value of 9.81 m/s², is unchangeable for the foreseeable future. Therefore, other areas of the equation must be examined to increase efficiency with the rocket equation. Secondly the \(I_{sp}\) (specific impulse), can be seen as the efficiency of the rocket. Currently, rockets use
chemical reactions for liftoff, however the total energy that can be obtained from chemical reactions is restricted. Lastly the mass of the rocket at initial and final stages are taken into account as a fraction, where the initial mass $m_0$ is taken over its final mass $m_f$. Initial mass includes the fuel needed for liftoff, but improvements to different types of fuels have increased the mass ratio.

Specific impulse is within human control, with progress in technologies and materials the mass of the rocket may become lighter. This however, is still greatly limited and shows how rockets can only provide small percentages of mass into space. The Space Elevator is a prime example of how the rocket equation can be beat by simply avoiding it. Gravity continues to be a decisive factor, but without the need to carry fuel, the amount of mass that can be transported is much larger than that of rockets.

**B. Rockets**

The history of rockets is quite extensive and will not be reviewed in depth here. It is however, important to note that modern rockets began at around 1900 and have since quickly developed from their older counterparts. The World Wars saw rockets developed for combat purposes. Then during the Cold War between the United States of America and the Soviet Union, the race to space was that of epic proportions taking rockets from close range missiles to that of space flight. While it can be said that some of the technological advances were for intercontinental ballistic reasons, it is also true that the advances in the rockets was to reach for the stars. In 1957, the Soviet Union successfully deployed the first human made Earth satellite known as Sputnik 1. [3]

Current manufacturing and engineering processes design and build rockets to be as efficient as possible, however most of the mass from rockets is propellant. Where the propellant takes about 85% of the total mass, leaving 15% remaining for the structure and payload. While improvements in material will reduce the mass of the rocket, the amount of propellant required is still a much larger factor. The fuel for rockets has become an increasing dilemma for the environment. [2]

**C. Rocket Environmental Impact**

As the sole method for moving mass into space, it is important to monitor the impact that rockets have on both the environment on Earth, and the impact in Space. Unlike the Space Elevator which does not produce any byproducts from chemical reactions, rockets require the use of propellants which produce emissions. As seen in Table V in the appendix, various propellants each with corresponding emissions products can be seen. Rockets such as the Falcon-9, Ariane 5, and the Space Shuttle have all used these propellants with each fuel type having advantages in thrust and storage, but disadvantages with their emissions. During the launches of the space shuttles, both solid and liquid fuel engines were used. This is because solid fuels are easier to store, have design simplicity and are very reliable. However, the exhaust from using solid fuels are more harmful for the environment. [4]

Beyond the use of fuels and their release into the atmosphere, there is also concern for material acquisition to build the number of rockets that would be needed to match the mass desired for space projects. While reusable rockets save on the precious resources, an increase to the number of launches will continue to have an increasing impact on natural resources. Ensuring that resources are acquired and recycled based upon guidelines to ensure sustainability is imperative to a successful space industry.

Within Cislunar space, rockets have the potential to add debris and increase the chances for impact. While current chances are small and often only briefly considered, with increases to the number of global launches the total amount of debris is expected to increase. This paper understands the size of Cislunar space and that when looking beyond LEO the chances of space debris impacts are minuscule, however it is important to regulate debris and create a system for the future, as humankind expands beyond the immediate vicinity of Earth.

**D. Alternative Options**

Rockets have been the tried and tested method for reaching space, however they are not the only option. Some theoretical methods are Spin Launch which uses a high level of centrifugal force to launch an object into space. Another option being the sky hook which would sit in space and rotate down towards Earth to “pick up” objects. Perhaps the most intuitively straightforward method other than rockets, is that of the Space Elevator which offers a dual space access approach along
with rockets. An illustrated example of this dual space access approach can be seen in Fig. 6.

IV. EMERGENCIES IN SPACE

As humans enter space, life become drastically different. One cannot simply open the window for a fresh breeze or head to the local hardware store for replacement parts. Therefore, it is of greater importance to consider the possibilities for when life altering events may occur. Such dangers to astronauts include damage from space debris, failures of the habitation unit or spaceship, and delays in delivery of resources.

A. Dangers of Space

1) Debris: Space debris is a topic of great concern for LEO satellites and space missions travelling through LEO. A comparison for space debris is a rock being flung into a windshield of a car, and creating a crack that expands into a greater issue. One example for space debris can be seen in an experiment to shoot a small object at high speeds at another object. The amount of damage that small components travelling at high speeds can inflict can be readily seen in Fig. 7. Where an aluminum sphere with a diameter 1.2 cm and weighing only 1.7 grams collided with a larger 18 cm thick block of aluminum. Due to the sphere traveling at 6.8 km/s a large impact crater was created. This type of damage could be catastrophic in a space environment, where containment of a pressurized system is paramount for astronaut safety. As well as cause an unpredictable amount of damage to any systems on board the spacecraft or habitation units. While the experiment used a small sphere, space debris can come in many shapes and sizes. [18]

In May of 2022, an impact site on the Moon was discovered, and it is now believed to be from space debris. Possibly from an upper stage of a Chinese rocket. While denied, this collision creates a larger issue than simply having space debris. That issue being unknown or unclaimed space debris. Currently space debris in LEO is tracked via radar and telescopes from the Earth, but companies and countries declaring when they have accidentally added space debris can help with tracking. As humans expand further into space the chances for equipment to be lost, faulty, or miss trajectories to occur increase. Therefore, openness when creating space debris is important. Knowing where objects in space are can allow for space stations and spaceships to move in order to avoid collisions. With the Artemis program, there is the Lunar Base and the Lunar Gateway to consider, as well as any incoming spaceships. Understanding the locations of any space debris around the Moon improves the chances for safe and successful missions. While currently the total amount of space debris near and around the Moon is very minimal, it would be ignorant to assume that more will not be added as a human presence is increased.

Regarding the Space Elevator, the apex anchor is a key factor for helping the tether to miss potential space debris in LEO. While the tether band is very thin which greatly reduces the chances for impact, there is a higher possibility as the tether climber moves through LEO. The apex anchor itself is in little potential harm from space debris due to its distance from Earth. A key feature of the apex anchor is the ability to move either towards, or away from the Earth, which creates movement along the tether in order to avoid space debris in LEO. For more information regarding Space Elevators and space debris please see International Space Elevator Consortium (ISEC) and their research on the topic. [20]

2) Delay in Resources: Humans while tenacious can be a fragile species in space relying upon a near constant supply of oxygen, food, water, housing within a shield from radiation, and a relatively small parameter of temperatures. In space aboard the ISS, routine shipments from Earth are required to maintain human habitation. When humans eventually progress beyond LEO, the shipping parameters become more crucial as it takes much longer to reach specific destinations. Therefore, delays in scheduled resupplying missions can be detrimental to human life.

The current process for resupplying the ISS is performed by the private sector via rockets. These missions can involve an exchange in personal aboard the space station as well as bringing critical supplies and equipment. Rockets can be at the mercy of untimely weather conditions or face setbacks to launch dates. There is also the possibility of rocket malfunctions either partially or critically which can cause delays in the mission timeline. These delays will only become more prominent the further humankind reaches beyond the Earth and LEO.

Imagine a situation where astronauts are living on the Moon or at the Lunar Gateway, and a resupply mission misses its target destination. While perhaps an unlikely scenario, but not beyond reason. Due to the time it takes for rockets to be prepared, launch windows to be available, and weather permitting, crucial time could quickly elapse. A solution to this issue would be to use a Space Elevator to send routine supplies. As well as the apex anchor being available in either emergency situations or depending on configuration, as a supply hub.

Fig. 7. Impact crater where aluminium sphere was shot at high speeds towards an aluminum block. [18]
3) Failures to Systems: Due to the strict building parameters for rockets, typically involving large amounts of propellant, system failures can be devastating. As humans progress further from Earth, system failures to a spacecraft or habitation unit become increasingly important. A simple issue with the oxygen storage could result in astronauts suffocating or needing to heavily regulate movement until emergency assistance can arrive. An example of this occurred in 1970 during the Apollo 13 mission. Due to a series of events a switch caused an oxygen tank to explode while the mission was in progress, with astronauts aboard at over 300,000 km from Earth. Due to quick thinking from NASA and astronauts aboard, the mission was salvaged from disaster into a safe trip home. \[21\]

It is easily conceivable to imagine similar scenarios where the outcome would not have been as favorable, or future situations where system failures could occur. Losing a water filtration system, carbon dioxide removal failure, or even simply food going bad are situations that can by typically remedied quickly on Earth. But, as humans depend more on artificial habitation units further from Earth, the more humans need to prepare for emergency situations.

B. Space Emergency Regulations

Space law was designed with the intent for separate spacefaring countries and states to work in harmony in the harsh environment of space. During 1967 a rescue agreement was voted upon and passed by spacefaring entities. Known as RES 2345 (XXII), it provided security and aid to astronauts regardless of their origin. Specifically Article V expresses how “States Parties to the Treaty shall regard astronauts as envoy of mankind in outer space and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of another State Party or on the high seas”, from the United Nations Office for Outer Space Affairs. Creating these laws to protect astronauts will become of greater importance, as the number of humans in space increase, and the chances for emergency situations rises. \[22\]

Historically, astronauts have been primarily sent to LEO and the ISS. With the Apollo missions and the upcoming Artemis program, more astronauts will be entering potentially dangerous situations. To help astronauts on the ISS, there is an escape vehicle attached to the space station in the form of a recent supply mission. These shuttles are not permanent fixtures, however they can be used in dire situations. In situations less dire where escape may not be required, rockets launched from Earth can bring aid. As the number of human settlements in LEO increase it may become possible where emergency rockets are prepared and ready to launch on short notice. Where the emergency missions become more difficult are the further the astronauts become relative to Earth.

C. Potential Rocket Response from Earth

Beyond LEO and deeper into Cislunar space where rockets take longer to reach due to large distances, space rescue can take on new meaning. The L-5 O'Neill Colony, and with earlier time scale the Lunar Gateway, need to have procedures in place for emergency situations. While it may be possible for the ISS to send a response, due to propellant amounts a rocket launched from Earth may be quicker and have the ability to send more supplies.

For comparison, the Luna 2 mission launched in 1959 required 35 hours to reach the Moon. This number would need to be adjusted for rescue missions as the Luna 2 mission was an impact mission, which did not require the slowing process that an emergency mission would require. A more reasonable comparison for rockets launching from the Earth would be that of the Apollo mission. In particular, the Apollo 8 mission which reached the Moon in about 69 hours and the longest Apollo mission, Apollo 17 at 86 hours. It is conceivable that a rocket launched from Earth with a destination of the Moon would have similar results, however the amount of time does not take into count launch windows and readiness of rockets. \[23\]

With SpaceX and their desire to go to Mars, emergency vehicles launched from Earth could take as long as seven up to nine months. The lengthy time period for aid launched from Earth is a culmination of orbital analysis that determines the best launch windows for reaching Mars. The possibility that the amount of time could extend beyond allowance exists. Therefore another option for emergency assistance for Cislunar space, with emphasis beyond LEO is needed. \[24\]

When launching rockets from the Earth for emergency situations many factors can contribute to delays or inadequate response times. Assuming that a rocket was fully prepared for launch there are windows of opportunities that rockets need to limit the transit time as well as being dependent on weather factors. It is however, highly unlikely that rockets will be prepared and equipped for immediate launches. Since the emergency vehicle loaded with appropriate supplies can be launched with great velocity at any time without restrictions to weather, the apex anchor offers a reliable alternative solution for offering assistance in space.

D. Apex Anchor Emergency Assistance

Located at the end of the tether the apex anchor offers unique attributes that are currently non existent in Cislunar space. When the apex anchor is used as a multipurpose facility beyond a simple counterweight, the options for a storage facility with attached emergency response vehicle are easily comprehensible. Storing required emergency supplies, life necessities, and aid such as propellant, water, oxygen, food, scientific instruments and replacement parts. As well as any other commodities that could be requested to keep in storage. Each of these emergency supplies can be released from the apex anchor and inserted into an orbit that will quickly reach the intended destination. By being released at 7.76 km/s from the apex anchor this form of assistance is proportionally quicker than launching from the Earth. Figure \[8\] demonstrates the relationship between launching from the apex anchor within Cislunar space with the Moon as the destination. \[25\]

With rockets needing potentially crucial amounts of time to send aid, the apex anchor offers the solution of reaching the
Moon in as little as 14 hours. As humans expand into Cislunar space and develop different habitation units and facilities, the chance for emergency situations to occur increases. A rescue vehicle with appropriate emergency supplies could be docked and prepared for various emergencies with near readiness for launch. Without a gravity well and weather to hinder launch, the apex anchor could be an immediate response unit sending aid to astronauts in danger. Where the only needed response is a trajectory adjustment to reach the destination with important aid. 

While beyond the Cislunar region of space, Mars is an ideal candidate for human progression into space. Launching from the apex anchor could have help with reaching Mars in as quickly as 61 days. A much shorter time schedule than rockets and without the need for windows of opportunity. This is due to being able to release into a trajectory ellipse by using the Earth’s rotation instead of from a typical Hohmann transfer. With the ideal situation of six Space Elevators as seen in Fig. 8, each with its own apex anchor, every location within Cislunar space and potentially beyond could be quickly and efficiently reached. The apex anchor would create an umbrella safety net over Cislunar space with the fastest available assistance into deeper space.

V. COMPARISON OF ROCKETS AND SPACE ELEVATORS

Space exploration without rockets will almost certainly never exist. Rockets provide a durable means of transportation that can be specialized for each individual mission using thrusters. This specialized method of transportation is perhaps the greatest advantage that rockets provide over other means of space travel. However, this advantage becomes a disadvantage once within a gravity well. The amount of fuel required for moving mass into space on a rocket greatly overshadows the minuscule amount of mass that can be sent into space on each rocket. As discussed in previously, due to Tsiolkovsky’s rocket equation, there is not a possible way to greatly increase the amount of mass moved into space on rockets. Currently, the total mass delivered to space is only around 26,000 tonnes. A small amount compared with the launch pad masses as shown in Table I. Space Elevators can fill the gap needed to move large quantities of mass into space nearly effortlessly, and with minimal impact to the environment thereby creating a sustainable road to space.

A. Moving Massive Amounts of Mass

Humans have long moved cargo from place to place by different methods. The wheel revolutionized transportation as did the domestication of animals. Then sailing ships allowed for greater amounts of mass movement with steam engines greatly increasing the rate of transport. Railways and Space Elevators are perhaps the closest for comparison in how they change the course of mass movement. As the railway allowed for quick access to large amounts of cargo, settlements and towns sprang up along its path for increase to trade. The Space Elevator will allow a passage for supplies which in turn will create an avenue for people to explore the reaches of space and expand beyond our planet.

The transportation of humans and cargo into space has been solely achieved through the use of rockets. Rockets are unfavorably inefficient at moving large amounts of mass, but they do offer a quick entry into space which is ideal for human transportation. Table I details how different rockets have performed at mass transportation based upon their mass at the launch pad, and the amount of mass that they have carried to their destination in space. As can clearly be seen the amounts carried to LEO offer the highest percentages from around 3–5%, then Geostationary Orbit (GEO) from 1–2% and finally the lunar surface of less than .5%. From a transportation point of view these numbers are quite horrendous. Imagine a plane or train that would arrive with only a small percentage of its cargo. This inefficiency would almost certainly mean the end for that mode of transport. Rockets fill a special niche for quick access to large amounts of cargo, settlements and towns. As can be seen in Table I, the required amounts of mass needed for major space projects are immense. Requiring
TABLE II  
LAUNCH VEHICLES WITH DELIVERY PERCENTAGES* 

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Pad mass (kg)</th>
<th>To LEO (with % compared to pad mass)</th>
<th>To GEO (est.) (with % compared to pad mass)</th>
<th>To Moon (with % compared to pad mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlas V</td>
<td>590,000</td>
<td>18,500 (3%)</td>
<td>7,000 (1.2%)</td>
<td>16,000 (&lt; 0.5%)</td>
</tr>
<tr>
<td>Delta IV</td>
<td>733,000</td>
<td>28,770 (3.9%)</td>
<td>10,000 (1.4%)</td>
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</tr>
<tr>
<td>Falcon H</td>
<td>1,420,000</td>
<td>63,000 (4.4%)</td>
<td>26,000 (1.8%)</td>
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</tr>
<tr>
<td>Saturn V</td>
<td>2,970,000</td>
<td>140,000 (4.7%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>4% of pad mass</td>
<td>1.5% of pad mass</td>
<td></td>
</tr>
</tbody>
</table>

Data from web varies greatly - these numbers are representative only, ref. ISEC working documents summarizing information on web. [25]

hundreds of thousands to millions of tonnes. Rockets need assistance to do the heavy lifting. With each climber weighing around 6 tonnes, and the payload at 14 tonnes, the tether climber will weigh a combined 20 tonnes that is moved into space daily. A single tandem Space Elevator (two tethers using the same Earth Port) will initially move 28 tonnes per day for 365 days giving a total of over 10,000 tonnes annually. This however jumps up dramatically in the ideal initial situation with six Space Elevators, where the annual mass transported becomes more than 30,000 tonnes per year. After maturity to the Space Elevators, a combined annual amount of 170,000 tonnes is reached. This will allow for not only the future capabilities of moving large amounts of mass off Earth for space projects, but can eventually be used to return cargo to Earth as well. [27]

Emergency assistance is not the only form of aid that the apex anchor can provide. Foreseeable failures or delays in resources could see astronauts calling upon the aid of the apex anchor to deliver vital cargo to different regions of Cislunar space. A storage facility, built at that apex anchor could allow for large amounts of resources such as oxygen, water, power, habitat replacement, food, science instruments, fuel, and anything else that would be needed in space. The cargo could be on scheduled deliveries from Earth to the storage facility where the supplies could either be held for when needed or as a staging point. Similar to modern distribution buildings, one could image simply ordering supplies or packages. The process would involve either ordering from Earth and having the supplies shipped directly (an entire tether climber) or to have it unpacked, prepared and sent on smaller spacecraft to its intended destination.

As rockets become more environmentally friendly with their reusable fuselages with hopes for entire rockets being reusable, there is still the concerning issue of how much mass they can move per launch. The percentage of the cargo that a rocket sends to space is alarming, and simply increasing the number of launches will put strain on both resources and the environment, from an excessive number of launches. Due to being environmentally friendly, efficient and with a routine launch schedule, Space Elevators can fill the niche in a dual space access venture with rockets and move the large amounts of cargo.

B. Best Time to Launch

Rockets can be launched any time of year, and at any location, assuming reasonable weather that does not hinder the launch. However, major launch sites are typically located near the equator to take advantage of the Earth’s rotation, thereby requiring less propellant. Then, depending on the inclination and destination for the payload time slots are selected. [8]

Due to the orbits of the planets around the Sun, and the Moons around planets, there are optimal windows of opportunities to reach outer space destinations; at the quickest and most fuel efficient times. However, these times are not daily or weekly occurrences though they do occur at regular intervals. This restriction of launch dates is only limited by the amount of fuel needed to send something to the destination and the amount of time it would take to arrive. Space Elevators can greatly increase the number of launch dates to daily occurrences.

Launching to Mars from Earth can take between seven to nine months whereas launching from the Space Elevator can take as little as 61 days with an average in the upper 70’s. As seen in Table [III in the appendix, flight time from the apex anchor during July of 2035 can vary depending on which Space Elevator is used for launch. The dates selected are merely examples as launches towards Mars could be routine and sent daily. Launches towards the Moon from the apex anchor are routine, with transit times as little as 14 hours as seen in Table [LV]

It is however not always optimal to launch from the apex anchor since the amount of propellant needed to slow the vehicle increases as the launch velocity increases. Therefore,
as seen in Fig. [10] there are two separate gates along the tether known as the Mars Gate and Moon Gate. At an altitude of 57,000 km the Mars Gate has its release point, which would most efficiently reach Mars with the least amount of propellant needed. Likewise the Moon Gate sitting slightly lower at 47,000 km could be used to send supplies towards the Moon. While the release points would require a longer duration of travel time to reach their intended destinations, it may be beneficial for certain supplies. Another option is to have scheduled deliveries that are spaced apart to allow optimal arrival at their destination such as at Mars or the Moon. [10]

C. Construction in Space

Rockets provide a means for components of larger space objects to be packaged into smaller pieces, sent to space, and then assembled using automated systems. While this process could be repeated using the Space Elevator, there are other options. For example entire large satellites could be assembled to fit within the standard tether climber, or larger pieces could be sent separately and then assembled using automated systems upon their arrival. Another option is to send a custom tether climber which could carry and entire satellite such as something similarly sized to the Hubble telescope or James Webb telescope. An interesting feature of the apex anchor is to have a construction facility for assembling satellites or spaceships at the apex anchor. By using the low gravity at the apex anchor of 0.2g, assembly can be easily accomplished and new designs for space fairing vehicles which previously needed to exit Earth’s gravity well created.

D. Environmental Impact

Another advantage for the Space Elevator is the environmentally approach to using only electricity for power. As well as each component from the tether climber sent into space would be designed either for use on arrival, or to add additional weight to the anchor. Space Elevators are dependant on rockets for quick ascension to space, primarily for astronauts. Therefore, a dual space access approach as seen in Fig. [6] offers a solution for optimizing the best of rockets and Space Elevators.

VI. CONCLUSION

Since the first space race between the Soviet Union and the United States, rockets have been the sole source of transportation to space. With emerging technologies and materials, Space Elevators are ready to enter a new space race for companies and governments competing for space access. However, Space Elevators will not be opponents to rockets but rather work together as a dual space access network enabling massive amounts of cargo to be transported to space. As humans expand and increase their numbers in Cislunar space and beyond, the apex anchor offers emergency assistance to all in space. As well as creating a location for growth with storage and construction facilities. Space Elevators offer an environmentally safe, efficient, routine, and heavy lifting option, within a Cislunar space encompassing emergency umbrella alternative. Into the far foreseeable future rockets will continue to launch astronauts from Earth and into space while capturing our imaginations. However, similar to how new technologies changed the course of history for movement of mass, so will Space Elevators.

ACKNOWLEDGMENT

The author would like to thank advisor Dr. Gunnar Tibert of KTH for his patience and willingness to offer any assistance when needed. As well as thank Dr. Peter Swan for his knowledge of Space Elevators, expanding my understanding of the space arena, and imparting life advice that is taken to heart.
### TABLE III

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<th>Date</th>
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<td>Moon</td>
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<td>Atlantic #1</td>
<td>Moon</td>
<td>14</td>
<td>+14</td>
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<tr>
<td>Every Day</td>
<td>Atlantic #2</td>
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<td>14</td>
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### TABLE V


<table>
<thead>
<tr>
<th>Propellants</th>
<th>Main emission products</th>
<th>Significant launch vehicles and launch systems associated with this propellant</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Al/NH₃CIO₄± HTPB (solid) | HCl, H₂O, CO₂, NOₓ, Al₂O₃, soot | Titan II (0), Titan IIIA/C/D/E (0), Titan IV-B (0), Delta II (0), Space shuttle (0), Ariane 5 ECA/ES (0), Atlas V (0), H-IIA/IIB (0), GSLV (1), PSLV (0, 1, 3) | • Easy to store  
• High propellant density  
• Relative design simplicity of engine  
• High thrust | • Relatively large environmental impact  
• Low specific impulse relative to LREs  
• No throttling or shut down |
| LOx/LH₂ | H₂O, H₂, OH, NOₓ | Space shuttle (1), Saturn IIV (2), Delta IV (1, 2), Titan IIIE (3), Atlas IIIV (2), H-IIA/IIB (1, 2), Ariane 1/2/3/4 (3), Ariane 5 ECA (1, 2), Ariane 5 G+, GS, ES (1), GSLV (3) | • Low environmental impact due to water vapour exhaust  
• Highest specific impulse | Requires cryogenic storage due to extremely low boiling point of LH₂ (~252.87°C)  
• Low density  
• Difficult to handle due to temperature requirements and explosion risk |
| N₂O₄/UDMH ± N₂H₄(hypergolic) | H₂O, N₂, CO₂, NOₓ, soot | Delta II (2), Titan II, Titan IIIA/B/C (1, 2, 3), Titan IIID/E (1, 2), Titan IV-A/B (1, 2), Long March 1-4 (1, 2), Proton (1, 2, 3), Ariane 1/2/3/4 (1, 2), Ariane 5 G+, GS, ES (2), GSLV (0, 2), PSLV (2) | • Can be stored for long periods  
• Relative design simplicity of engine | • High toxicity  
• Difficult to handle due to safety concerns |
| LOx/RP-1 (kerosene) | CO₂, H₂O, CO₂, OH, NOₓ, soot | Delta II (1), Titan I (1), Atlas III (1), Delta III/I (0), Saturn IIV (1) Falcon-9 (1, 2), Atlas V (1), Soyuz (0, 1, 2), Electron (1, 2), Angara (0, 1, 2) | • High propellant density  
• Relatively easy to handle  
• More affordable than LH₂ | • CO₂ and black soot emissions contribute to climatic warming |
REFERENCES


[22] Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space (1967).


