Expanding the possibility of future research over interplanetary distances through the utilization of the Modern-Day Space Elevator

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Abstract:

This research provides an in-depth look into the utilization of the Modern-Day Space Elevator as a transportation tool for scientists and their scientific equipment. The Modern-Day Space Elevator would grant the ability to bypass the inefficiencies associated with the rocket equation and could provide an unmatched efficiency when moving mass to orbit. The development of this transportation infrastructure would prove to be invaluable for the scientific communities of Earth. The Modern-Day Space Elevator has been extensively theorized amongst the members of the International Space Elevator Consortium (ISEC) and is in the process of moving into the engineering phase of development. This transportation structure is paramount for all scientific communities of the world and could offer a paradigm shift in moving mass to orbit, where the next frontier of study will occur.

1.0 Introduction:

Since the launch of the Russian spacecraft, Luna 1, from the surface of the Earth, all spaceflight has been chaotically propelled via rockets. Current theory proposes an expansion in our method in achieving spaceflight in a clean and efficient way: the Modern-Day Space Elevator. The development of the Modern-Day Space Elevator would allow for substantial, widely applicable scientific opportunities to both local and interplanetary destinations. Mass-to-orbit and payload volume would no longer be constraints for research purposes as the Space Elevator would allow for an efficient, routine, and green movement to Geostationary Earth Orbit and beyond. This paper explores the advantages of utilizing the Modern-Day Space Elevator as a tool for scientists. This infrastructural tool enables a wide range of study for an ever-expanding audience. The unmatched efficiency of the Modern-Day Space Elevator, coupled with its green and frequent release opportunities, opens the doors of previously untouched science and kick starts the expansion into the solar system.

1.1 History of Interplanetary Travel:

For as long as humans have been bipedal, we have been looking to the stars beyond our planet. A slow progression of scientific advancement has paved the way for modern civilization. Humanity watched the stars and the Moon and dreamt of walking among them, and so we did. On July 20, 1969, Neil Armstrong became the first human to stand on something other than Earth. However, before humanity took the first step on the Moon, we sent probes. It took the work of thousands of scientists and engineers to complete flybys, impacts and orbits around the Moon before we were able to even think about sending mankind to walk on its surface.

In the 21st century, we have landed rovers on Mars and sent space probes that have completed scientific analysis to every planet in our solar system, and we have not even scratched the tip of the iceberg. These instruments have always ridden on rockets for better or for worse, as indicated in Table 1.1 [1 Siddiqi]. A large portion of these interplanetary missions have ended in lost spacecraft and all have suffered from widely inefficient methods for moving mass to orbit.

Robotic rovers and satellites collect a wide variety of data where a human would otherwise perish. They are the "eyes and ears" of scientists. These tools have allowed scientists to study the universe around them despite not being able to collect data firsthand. With the advancements in robotic engineering we can now build highly sensitive telescopes, advanced robotic rovers, and fine-tuned data collection satellites. Despite their complexity, engineers have produced scientific instrumentation that remains relatively small. However, this equipment is required to ride inside a dramatically chaotic launch sequence. The sophisticated equipment selected is constrained by their vehicle, due to the limits on the payload volume and by the inefficiencies of the rocket equation.

The Modern-Day Space Elevator has the potential to drastically increase the capability to send these probes. These massive spacecrafts could reach any target in the solar system while reaching their destination with high velocities and minimal fuel consumption.

Table 1.1: Launched Interplanetary Spacecraft

Launched Spacecrafts for Interplanetary Travel by Destination (as of 2023)		
Destination of Spacecraft	**Successful / Semi-Successful Missions**	**Attempted Missions**
Sun:	12	14
Mercury:	4	4
Venus:	26	39
Mars:	25	43
Jupiter:	6	6
Saturn:	4	4
Neptune:	2	2
Uranus:	1	1
Beyond the solar system:	5	5
Total:	**85**	**118**

Table 1.1 shows the total spacecraft missions to each major body in our solar system as well as the few that have left our solar system and are now travelling through interstellar space. These include partial successful missions as well as fly-by information [1 Siddiqi].

This table is used to show the quantity of unmanned spaceflight in and around our solar system. Note this does not include the Moon and is geared toward interplanetary flight.

Over the last 65 years, since the spacecraft Pioneer 0 unsuccessfully launched in 1958, humanity has sent less than one hundred spacecrafts beyond our local orbit to probe the solar system around us and only a handful to study beyond our solar system. Each probe would have been assembled on the ground and then packaged atop of a rocket in hopes of escaping the Earth's gravity well. For each mission the mass-to-orbit ratio is less than one percent of launch mass reaching Geostationary Earth Orbit (GEO). This has left researchers with a terribly inefficient method of moving scientific equipment throughout the solar system.

2.0 The Modern-Day Space Elevator saves us from the tax of the Rocket Equation:

The biggest challenge of using rockets as our only means of extraplanetary transportation is undoubtedly the rocket equation. Rockets provide rapid movement at the expense of fuel and stability. A rocket can quickly move through the radiation belts in Earth's upper atmosphere but expends almost all its fuel to do so.

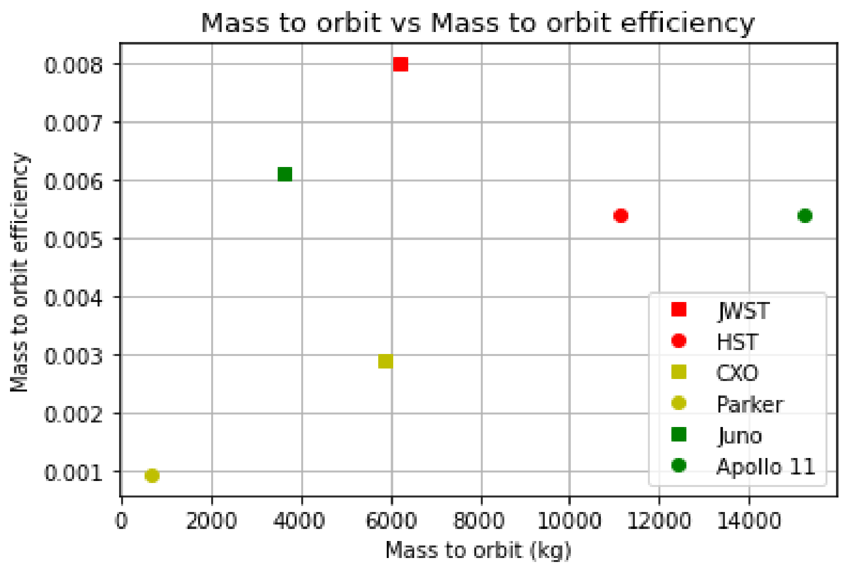
The Modern-Day Space Elevator allows for easy access to every major body in the solar system and various altitudes around Earth. Due to the nature of the placement of the space elevator (equatorially) an excess velocity of 7.76 km/s can be achieved [3 Swan]. This combined with the correct time of release from the Apex Anchor, either prograde or retrograde to the planet, opens the totality of the entire solar system for study.

Table 2.1: Efficiency of Launched Vehicles

Efficiency of Launched Vehicles					
Spacecraft	**Spacecraft weight (kg)**	**Launch Vehicle**	**Launch Vehicle Mass on Pad (kg)**	**Mass to Orbit Efficiency**	**Target Destination (km)**
James Webb Space Telescope:	6,200	Ariane 5:	770,000	0.0080%	1,500,000
Hubble Space Telescope:	11,110	Space Shuttle:	2,030,000	0.0054%	540
Chandra X-ray Observatory:	5,860	Space Shuttle:	2,030,000	0.0029%	139,000
Parker Solar Probe:	685	Delta IV Heavy:	733,000	0.00093%	16,270,000
Juno Space Probe:	3,625	Atlas V:	590,000	0.0061%	778,000,000
Apollo 11:	15,200	Saturn V:	2,822,000	0.0054%	238,855
Space Elevator Initial operation capacity (14 tonnes/day):	14,000	*Modern-Day Space Elevator (single tether):*	20,000	70.0000%	100,000
Fully operational Galactic Harbor (84 tonnes/day):	14,000x6	*Modern-Day Space Elevator (six tethers):*	20,000	70.0000%	160,000

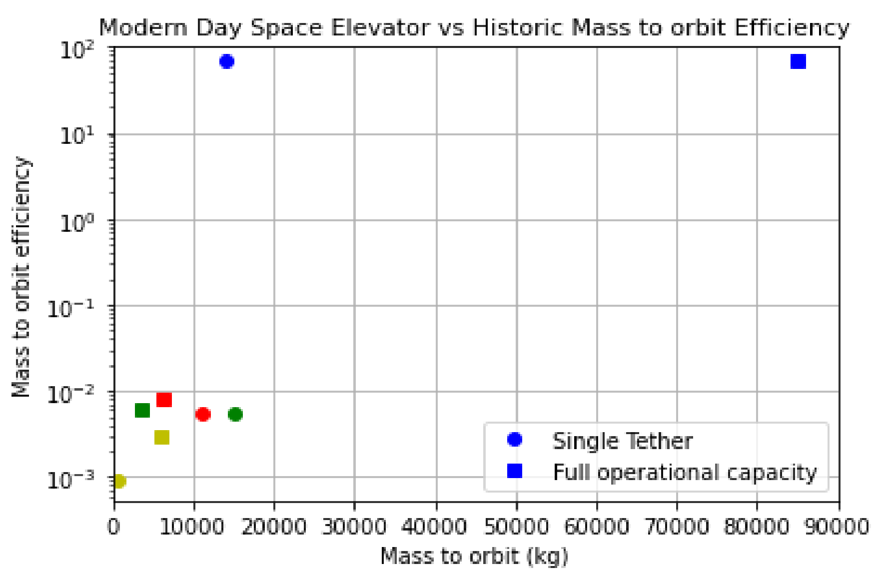
Table 2.1 shows the efficiency of various missions as well as their target destination. These numbers were all recorded through the NASA data archives as general approximations. This data is further used in graphs 2.1-2.2 to show the mass to orbit efficiencies.

Graph 2.1: Historic Spacecraft Launch Efficiency



The graph above illustrates the relationship between the mass to orbit payload and the corresponding vehicle efficiency. The data points have been selected as 'recent' popular missions that contributed significantly to the scientific communities of Earth. The raw data can be seen in Table 2.1.

Graph 2.2: Unmatched efficiency of the Modern-Day Space Elevator



This graph illustrates the unmatched efficiency of the Modern-Day Space Elevator. All data points from Graph 2.1 are presented with the additional information concerning the Modern-Day Space Elevator. The mass to orbit efficiency is the main drawback of the rocket equation that is circumvented by the space elevator. The fully developed Galactic Harbor has six times the capability of a single tether and at fully operational level can increase the mass to orbit payload capacity beyond what is depicted. Careful to note the logarithmic scaling in the efficiency.

During the development of the James Webb Space Telescope, NASA had valid concerns regarding the vibrations of the Ariane 5 rocket. Engineers feared that the violent vibration would damage the James Webb on ascent. The modern high-tech telescope had three hundred forty-four single-point failures, a large swath of these failures being associated with the launch vehicle. To account for this, the James Webb Space Telescope took twenty years to be fully developed and went massively over budget to $10.8 billion USD. The telescope had to be folded and put through rigorous testing before it was launched leading to further delays.

The Modern-Day Space Elevator doesn't have these same single-point failures and excels at transporting massive tonnages to Geostationary Earth Orbit. With dual space architecture in mind [2 Swan], rockets are used as means of transportation to Low Earth Orbit and the Modern-Day Space Elevator grants access to higher altitudes. Once above the Earth's gravity well the Modern-Day Space Elevator can utilize its apex anchor as a rendezvous point for rockets and larger structures.

3.0 No limits on size or weight:

Mass-to-orbit is the ultimate challenge for space travel. The Modern-Day Space Elevator is essential to achieving an efficient, routine, and green method of moving material into orbit. This infrastructural tool introduces incredible opportunities to the scientific community of Earth. With releases from the elevator being routine and anywhere in the solar system being the destination, an enormous amount of scientific research becomes readily available. Alongside a dual access space architecture [2 Swan], the space elevator becomes a tool of infrastructure no different

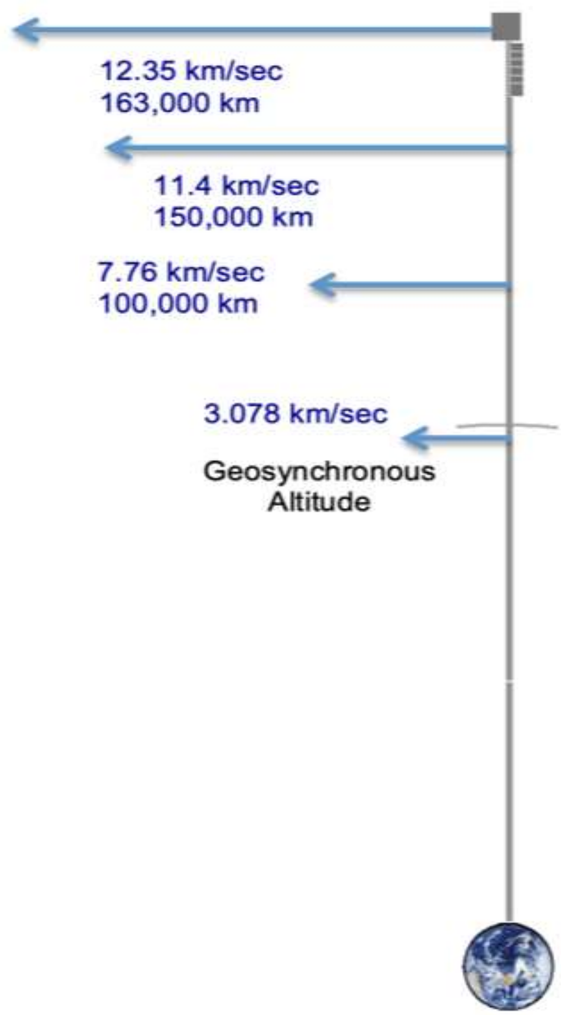


Fig. 1 Assembly Above Gravity Well

than railroads or canals. Moving mass to orbit becomes no more difficult than moving a shipping container across the Atlantic Ocean.

With the location of the apex anchor being above the gravitational well, the opportunity for larger structures to be assembled is facilitated. The International Space Station weighs four hundred sixty-two tonnes. In a scenario with a functioning initial space elevator [3 Swan], all components of the International Space Station could be lifted to GEO in thirty-three days. Each component could be collected at the apex anchor and assembled at GEO, with an effective gravity of 0.2% Earth gravity. The placement of the apex anchor would allow for the unique opportunity to assemble logistical or scientific instrumentation above Earth's gravitational well and then have the capability to accelerate beyond Earth's orbit and reach anywhere in the solar system.

Table 3.1: Comparison of Launched Space Structures to the Modern-Day Space Elevator

Comparison of launch vehicle assemblies			
Space Structure:	**Total Weight (tonnes):**	**Amount of Mission:**	**Average weight of Mission (tonnes):**
International Space Station:	450	30	15
I.S.S. as Initial M.D.S.E:	450	33	14
I.S.S as Fully Operational M.D.S.E.:	450	6	14x6
Tiangong Space Station:	70	3	22.9
T.S.S as Initial M.D.S.E.:	70	5	14
I.S.S. as Fully Operational M.D.S.E.:	70	5	14

Table 3.1: When comparing the total weight of the space stations to the required number of missions to complete, the Space Elevator is comparable to the current methods of transportation but would move mass to orbit every day.

The Modern-Day Space Elevator excels as a permanent infrastructure to be used as a tool alongside rockets in a Dual Access Architecture [2 Swan]. The unmatched efficiencies of the Modern-Day Space Elevator make it an invaluable tool for scientists, as it allows for more frequent and safer transportation to Geostationary Earth Orbit and beyond. As the space elevator would be a permanent infrastructure, it operates every single day as a means to orbit. This presents the opportunity to build massive projects above Earth's gravitational well. The limiting factor of a structure like that of the International Space Station will be the production time of modules. The transportation logistics become simpler when you aren't riding on top of a controlled explosion.

The violent movement of a rocket launch is unmistakably absence from the movement of the space elevator. The movement to

Geostationary Earth Orbit is a gradual climb along the tether and becomes exponentially easier to move as the gravitational attraction is proportional to the radius squared.

$$F = G\,(m_1 m_2)/r^2$$

$$F \propto 1/r^2$$

Cargo loaded at the Earth Port can be moved in specialized containers, depending on the needs of the scientific equipment, and then moved into Geostationary Earth Orbit and beyond without the fear of a rocket exploding on launch or failing to release. This eliminates the restriction on volume of the equipment as missions can either:

1. Choose to assemble in an orbit, such as GEO, above Earth's gravity well, then release into orbits towards chosen orbital parameters or planetary destinations.

   or

2. Use specialized containers to house the mission and then move the mass into chosen orbit with release from the tether climbers.

The unmatched efficiencies of the Modern-Day Space Elevator allow for an incredible amount of solar system research to become readily available. A fully operational Modern-Day Space Elevator would open a new age to the scientist of Earth. Even when remaining within our atmosphere, The Modern-Day Space Elevator can provide easy access to varying altitudes around our planet, atmospheric data is always valued. This infrastructural project could substantially enhance the capabilities of scientists here on Earth in a wide variety of fields.

4.0 Fast Transit:

Within the first few minutes of a rocket launch, a massive amount of weight has been shed in the expenditure of fuel. By the time a rocket has reached Geostationary Earth Orbit, 95% of the initial fuel volume has been spent. This leaves very little fuel to expand its apoapsis or correct the orbital plane. Space probes have gotten around this problem by using Hohmann transfer orbits and gravity assists from nearby planets to reach their destination. Detours over interplanetary distances this large come at the cost of time, as spacecraft flight paths are selected years in advance to consider all possible opportunities.

The Modern-Day Space Elevator has the capability to send massive spacecraft, containing large amounts of scientific equipment, to anywhere in the solar system with virtually no fuel consumption. This flight time is not a matter of years, but of months. The unmatched efficiency allows for a free 7.76 km/s [3 Swan] release velocity at the 100,000-kilometer release point, without burning any fuel. This free velocity tremendously helps space travel times, with as low as a 61-day travel time to Mars [3 Swan]. A travel time such as this would allow for an enormous amount of research to be conducted and for practical applications to be demonstrated at a light-speed pace. The outer solar system is no longer barred by distance and travel time. Probes sent out to the gas giants and their moons could arrive within a year after release. The previously untouched scientific opportunities of the solar system would become readily available to researchers.

Daily releases from the anchor can move massive amounts of scientific equipment to any location in the solar system. A more diverse group of organizations can access the previously unstudied corners of the solar system. With a fully developed Galactic Harbor system [3 Swan], over 170,000 metric tonnes per year could be moved into orbit, this possibly leading to one continuous project. This substantially exacerbates the possibilities for research teams.

When going beyond the Apex Anchor, located at one hundred thousand kilometers, additional velocity is gained. At an altitude of one hundred sixty thousand three kilometers a free velocity of 12.35 km/s velocity can be gained. This extreme velocity, with the correct time of release can generate velocities capable of leaving our solar system. An enormous amount of scientific data, that has previously been untouched, becomes available.

5.0 Conclusion:

The development of a Modern-Day Space Elevator system would provide tremendous benefit for the scientific communities of Earth through the unmatched efficient, routine and environmentally conscious movement to Geostationary Earth Orbit and interplanetary destinations. These opportunities can impact a multitude of professions, from Geologists to Cosmologist and everything in between. The Modern-Day Space Elevator is beyond a hypothetical strategy and should be seriously considered as an additional method of moving scientific mass to orbit. With its unparalleled efficiency, the space elevator aims to assist the development of space travel and scientific exploration as a permanent infrastructural project that would open the entire solar system to be subject of study. Utilizing the space elevator as a “bridge” to Geostationary Earth Orbit and beyond, it offers the potential for massive projects to be constructed above Earth’s gravitational well and a 7.76 km/s free velocity to any destination in the solar system. The Modern-Day Space Elevator is a legitimate endeavor that could change the way we view the solar system. Indeed, the development of this transportation infrastructure would prove to be invaluable for the scientific communities of Earth.

References:

[1] Siddiqi, Asif A, Beyond Earth: A Chronicle of Deep Space Exploration, 1958-2016. NASA History Program Office, 2018.

[2] Swan, Peter Space Elevators, the Green Road to Space. International Space Elevator Consortium, 2021.

[3] Swan, Peter Space Elevators are the Transportation Story of 21st Century. International Space Elevator Consortium, 2020.

Figures supplied by the International Space Elevator Consortium.