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Fast Transit to Interplanetary Destinations

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Abstract

The unique characteristics of Space Elevators with a rapidly moving Apex Anchor (7.76 km/sec) enable remarkable opportunities for off-planet missions. This combination of three major strengths (massive movement of mission support equipment - a tremendous opening up of launch windows - shorter travel times) will ensure constant support to missions beyond Geosynchronous altitude. The daily release of payloads towards Mars (and other interplanetary destinations) from the Apex Anchor imparts tremendous velocity with very little drag from Earth's gravity. Periodic fast transit to Mars lowers this time to 61 days. This occurs several times during the two-year orbital dance. In addition, the concept of one launch window every two years is collapsed to multiple launches every week towards Mars. Adding these two characteristics of space elevators to the routine, daily and massive movement of cargo ensures that human missions off-planet will have the supplies needed to prosper and grow. Can you imagine?

- 61 days to Mars several times each 26 months
- multiple releases per week towards destinations (no 26 month window restriction)
- massive movements towards interplanetary destinations every day.

***1.0 Introduction**:* This paper will discuss the latest developments and strengths of space elevators for the movement of cargo to Mars and the rest of the solar system. Research by the International Space Elevator Consortium and the Arizona State University showed that there were remarkable insights into how the space elevator can enhance movement off-planet. The basic concept of future capabilities is that when planetary spacecraft rises to the Apex Anchor by electricity (vs. rocket fuel consumption) the increase in energy is vast. For the baseline space elevator with a 100,000 km long tether, the velocity at release is 7.76 km/sec, or three times the velocity of a rocket insertion towards Mars. As such, the orbital paths chosen to reach Mars are all high-energy ellipses crossing to the Martian orbit much faster than traditional Hohmann transfers. The first image shows this rapid cross over from the Earth's circular orbit to Mar's orbit (minimal estimated as 61 days).

1.1 ***Background:*** This insight into the strengths of space elevators has increased the body of knowledge as shown by the list of yearly study reports accomplished by ISEC and four year study reports by the International Academy of Astronautics and the Obayashi Corporation.

Table 1, Study Summaries, ISEC

Year	***Title of ISEC Yearly Study Reports*** ***(www.isec.org/studies)***
2021	Design Considerations for the Space Elevator Climber-Tether Interface - just starting
2021	Beneficial Environmental Impacts of the Space Elevator - in work
2020	Space Elevators are the Transportation Story of the 21st Century
2020	Today's Space Elevator Assured Survivability Approach for Space Debris
2019	Today's Space Elevator, Status as of Fall 2019
2018	Design Considerations for a Multi-Stage Space Elevator
2017	Design Considerations for a Software Space Elevator Simulator
2016	Design Considerations for Space Elevator Apex Anchor and GEO Node
2015	Design Considerations for a Space Elevator Earth Port
2014	Space Elevator Architectures and Roadmaps
2013	Design Considerations for a Space Elevator Tether Climber
2012	Space Elevator Concept of Operations
2010	Space Elevator Survivability, Space Debris Mitigation

Table 2, Study Summaries, IAA & Obayashi Corporation

Year	***Title of Yearly Study Reports***
2019	The Road to the Space Elevator Era - IAA
2014	Space Elevators: An Assessment of the Technological Feasibility and the Way Forward - IAA
2014	The Space Elevator Construction Concept
	IAA - International Academy of Astronautics (https://iaaspace.org) Obayashi Corporation (https://www.obayashi.co.jp/en/news/detail/the_space_elevator_construction_concept.html)

1.2 ***Interplanetary Strengths:*** During the last two years, the ISEC research focus has been "to the Moon and Mars." As the research on this topic began, Associate Professor Matthew Peet, of the Arizona State University, joined the discussions and oversaw student research projects to apply their "orbital classroom lessons" to life. As the research into high velocity pathways to Mars (and initial studies towards Venus) matured, many factors combined to show the remarkable improvement in movement to Mars by leveraging the space elevator as inherent release velocity. (see later section in paper) During the discussions between ASU and ISEC, many conclusions surfaced leading to the most exciting findings that space elevators enable a tremendous flexibility in flights towards Mars. The three main conclusions are reflected in the mission needs for supplying cargo, equipment, food, and supplies for human Martian colonies. These would be;

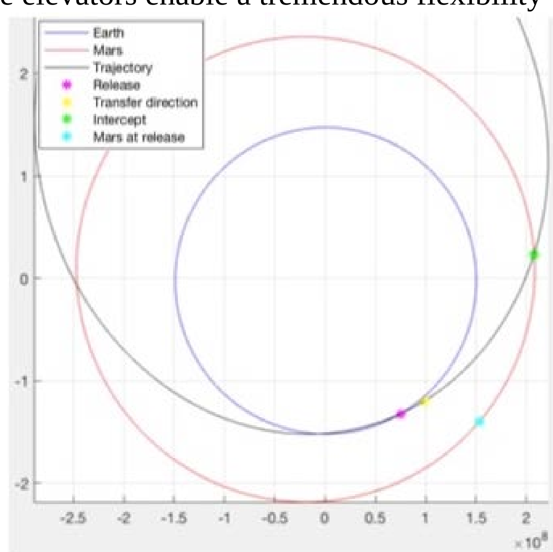

Figure 1, "Cutting the Corner"

- <u>Fast Transit to Destination:</u> From Earth to Mars in as little as 61 days with an average somewhere outside three months.
- <u>Daily Departures:</u> Releases from the Apex Anchor towards Mars can

be accomplished every day of the year. Several, during the 26 month repeating cycle, are close to 61 days flight time while some are over a year. This is all due to the changing orbital dance between the two planets. However, there is NO 26 month long waiting for opportunities to launch towards Mars. Departures can occur each day of the year across the 26 month restriction of the Hohmann launch window. No one cares if the hammer you deliver takes 400 days to get there, so long as you ordered it 400 days ago. Indeed, the fast transit times will probably be saved for high priority items that need to get there soonest. Logisticians supporting the Mars colony can set up a train schedule with releases from multiple space elevators towards Mars - as needed.

- Massive Cargo Movement: The Initial Operational Capability is planned for 14 tonnes of cargo released each day from each space elevator, or 5,110 tonnes per year. After the first space elevator is completed, there should be competition to construct several around the equator. As such, the estimate is that within five years, there will be six x 5,110 or 30,000 kg/year capability. This will grow as tether strength is upgraded and competition develops for space elevator enterprises. This most recent ISEC report projects a capability of roughly 170,000 tonnes per year by the middle of this century. One must compare that to the 2018 delivery of mass of somewhere short of 1,000 tonnes to all orbits for all customers.

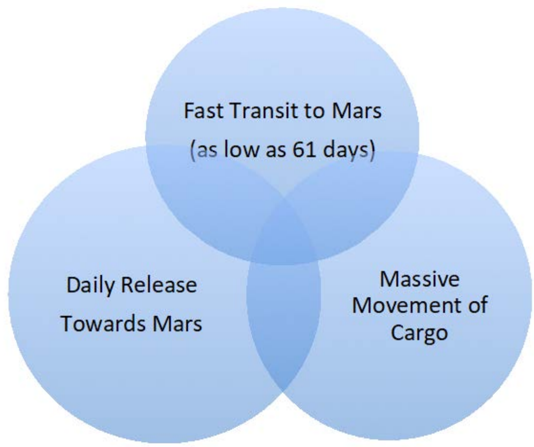

Figure 2, Newly Recognized Strengths

1.3 *Appropriate Space Access Architecture for Mars:*

The year 2020 seems to be unique in many ways - including isolation across the globe; however, the space arena has come together and started to focus on movement off planet. NASA's push for female boots on the Moon by 2024, the Chinese rover on the far side of the Moon, UAE's spacecraft bound for Mars, and the push for a colony on both the Moon (Moon Village) and Mars (SpaceX), all reflect the amazing transition towards "beyond GEO." However, this reach for the stars will be extremely difficult in the arenas of energy and design complexity if it only uses a rocket architecture. The basic rocket equation has been controlled. However, it still consumes mass to achieve orbit. Historically, we have been very successful - at great cost to liftoff mass and complexity of mission. As the Human race has decided to go off-planet, the limitations of the rocket equation for delivery of mass to mission destinations must be lifted. Future space architectures must develop a more permanent infrastructure using the strengths of reusable rockets and space elevators. Racing through the Van Allen Belts using rockets for humans is a necessary characteristic of this new architecture while the movement of massive amounts of equipment and cargo should be the missions for space elevators.

Combining these architectures into a single concept for movement of people and equipment will enable the dreams of many to be reached. Expanding the current rocket based access to space to include space elevators will enable a robust movement off-planet which will enable the creation of a spacefaring civilization.

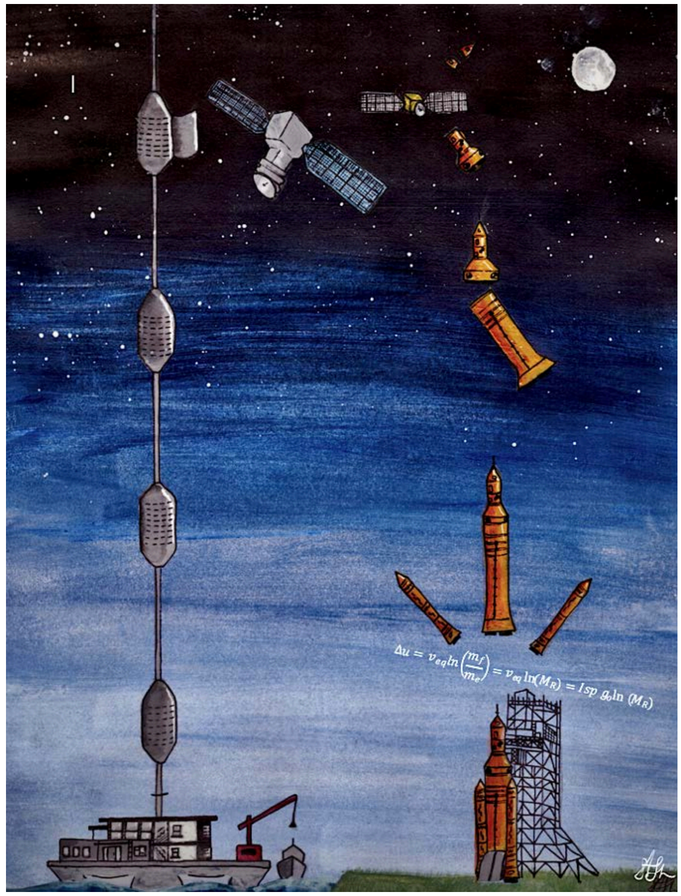

Figure 3: Combined Architecture for Mars (Amelia Stanton image)

When envisioning future movement off-planet, three major programs surface that demonstrates the demand from customers. These results are explained in greater detail in the ISEC yearly study report entitled "Space Elevators are the Transportation Story of the 21st Century."[1] These three missions are monumental in their promise for the human condition with exploration within our solar system and improving our health on Earth. Elon Musk[2] stated that he requires one million metric tonnes of supplies to develop his colony on Mars. Another customer requirement was shared by Dr. John Mankins[3] with his prediction of what is needed to supply 12% of the electricity demand for customer by 2060. This mission to eliminate hundreds of coal burning plants will require five million metric tonnes to geosynchronous orbit. The third mission referenced in the research is a Moon Village. Their mission need is roughly 500,000 tonnes to the Lunar surface. The following chart shows the customer needs while estimating the time it would take to fulfill them using a mature space elevator architecture.

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[1] Swan, P., C. Swan, M. Fitzgerald, M. Peet, J. Torla, V. Hall, Space Elevators are the Transportation Story of the 21st Century, lulu.com, 2020.

[2] Musk, Elon., Quotation from CBS's Sunday Morning Show, 21 July 2019.

[3] Mankins, John, The Case for Space Solar Power, Virginia Edition Publishing Co. Dec 2013.

Table 3.3,[4] Reference Destinations - Mars, GEO & Moon

Reference Mission	Metric Tonnes to Destination	Comment	Years to Fulfill Customer Demand using Space Elevators
Space Solar Power	5,000,000	Power to 12% of the Earth's population in an environmentally friendly manner.	29.4 years
Mars Colony	1,000,000	Supporting a Colony with logistics has been underappreciated in the movement off-planet	5.9 years
Moon Village	500,000 estimated	Developing and supporting a colony of residents will require massive movement from Earth	2.9 years

Note: Mature Space Elevator supplying 170,000 metric tonnes per year (2050 time period)

A vision that surfaced during the writing of the ISEC 2020 study on Interplanetary Mission Support showed three Galactic Harbours distributed around the equator. This provided six space elevators with daily fast transits and massive movement of cargo.

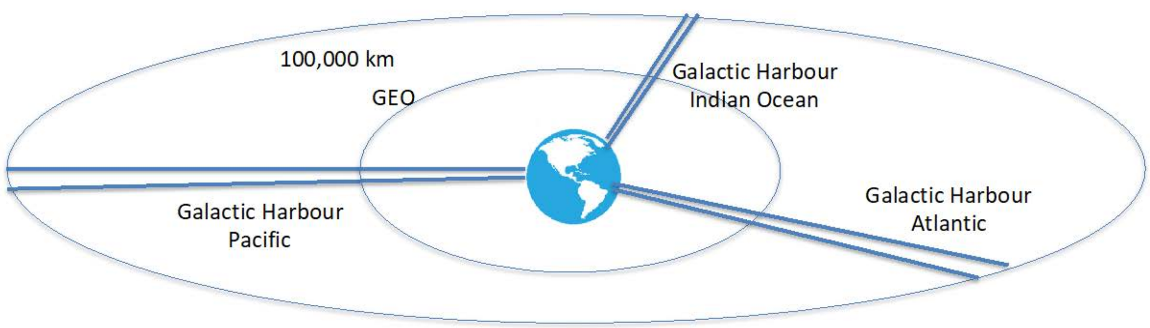

Figure 4, Three Galactic Harbours - A Vision At the Horizon

2.0 Promise for Planetary Scientists - any mass, anywhere, daily: The remarkable "throw capability" of space elevators has facinated so many visonaries, but they didn't follow-up with the numbers. ISEC's recent work at the ASU has shown that the release velocities of long tethers enables scientific research that has not been conceived of until now. The new "Promise for Scientists," is simple:

"Any scientific payload mass to any destination in the solar system with daily launches available!"

4 Swan, P., C. Swan, M. Fitzgerald, M. Peet, J. Torla, V. Hall, Space Elevators are the Transportation Story of the 21st Century, lulu.com, 2020.

The establishment of space elevators with routine (daily) departures, high velocity at release, the ability to assemble multiple segments of spacecraft at Apex Anchors and to accomplish those traits with low-cost is a game changer. Scientists can plan on sending their large/complex instruments to any planet in our solar system on daily schedules. If one compares today's remarkable achievements, there are normally three launches to Mars every 26 months and one or two launches to the other planets each year. Over the period 1960 - 2010 there were over 150 probes to the Moon and planets (less than 3 per year).

With the research conducted at ASU, the assumption was that the length of the tether was 100,000 km. Further analyses show that the velocity is significant if the reach of the tether grows significantly. This look into the future capabilities of space elevator release velocities with longer tethers shows some surprising results: at 163,000 km, the probe released would exit the solar system, without burning rocket fuel at all. The chart shows the various options of releasing to gain velocity.

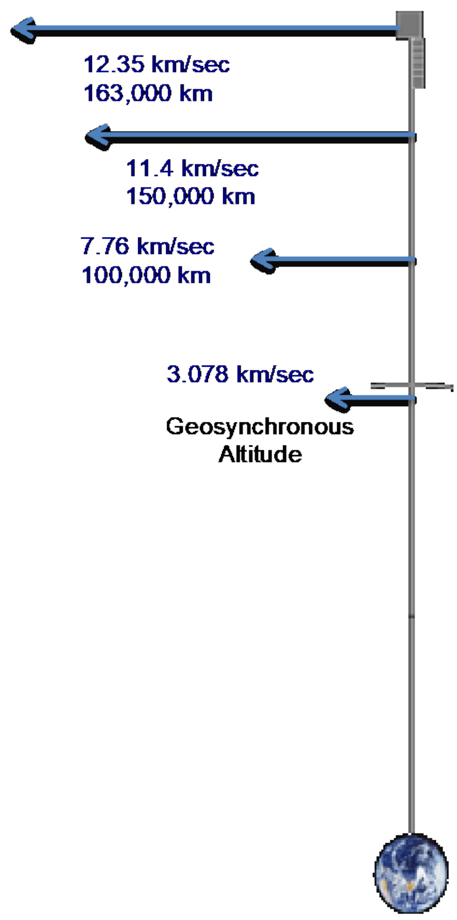

Figure 2, Launch Geometries[5]

3.0 Galactic Harbour Baseline Capability:

The Galactic Harbour, as shown in Figure 3, imagines two space elevators reaching from the surface of the ocean to the Apex Anchor at 100,000 km altitude. This is a unification of a tremendous transportation infrastructure and a remarkable arena for future enterprises. When inexpensive access to space is combined with routine, Earth friendly liftoffs, and daily characteristics, the strengths become obvious. New enterprises will leverage the ability to refuel and assemble spacecraft - or repair them in place. This volume of space will encompass the Earth Port through the geosynchronous region towards the Apex Anchor with two tethers and multiple tether climbers simultaneously.

Customers will insert their cargo at one "pier" and release it from another at a designated altitude, thus imparting sufficient velocity to gain the desired orbital destination or interplanetary send off. The development of robust enterprises within the Galactic

[5] Torla, James and Matthew Peet, "OPTIMIZATION OF LOW FUEL AND TIME-CRITICAL INTERPLANETARY TRANSFERS USING SPACE ELEVATOR APEX ANCHOR RELEASE: MARS, JUPITER AND SATURN," International Astronautics Congress (IAC-18-D4.3.4), Washington D.C., 2019.

Harbour emphasizes the complementary nature of an architecture with rocket portals and space elevator infrastructures - each with their own strengths.

Figure 3, Galactic Harbour

4.0 Results from ISEC Research at ASU:

In the spring of 2019, ISEC (Dr. Swan) lectured about the space elevator to the orbital class of ASU's Associate Professor Matthew Peet. This collaboration initiated research in assessing the strengths of releasing payloads at the Apex Anchor for interplanetary missions. Several students, led by James Torla, were excited about examining a new concept and delving into unique orbital challenges looking at high speed travel to Mars and Venus. This discussion focused upon the Mars results examining the potential impact of a Space Elevator Apex Anchor release of cargo for permanent habitation on Mars.[6] The question, when looking at it from a Space Elevator perspective, became "can the Galactic Harbour infrastructure do daily launches with a variety of flight times and distances

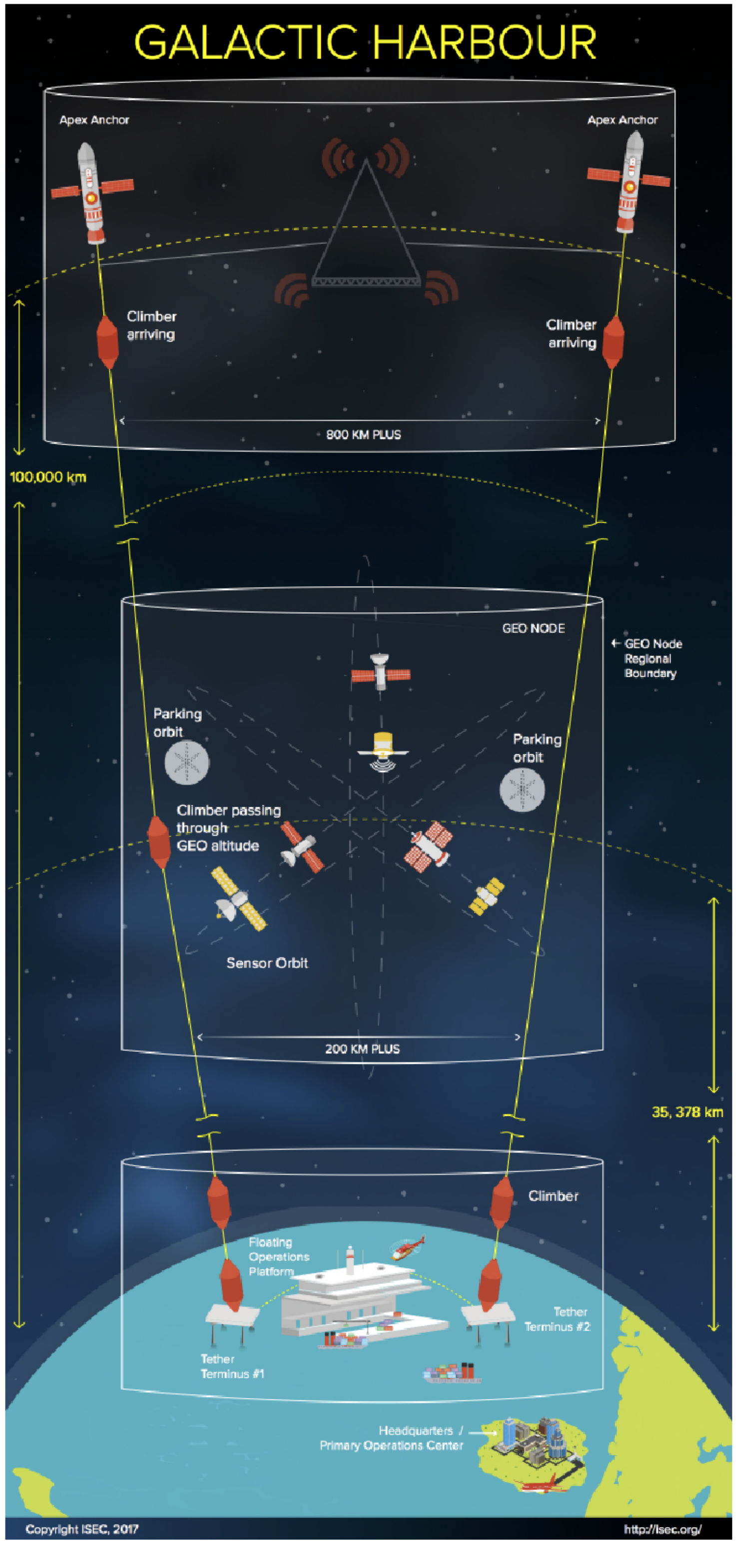

Figure 1 Galactic Harbour (2017)

[6] Torla, James and Matthew Peet, "OPTIMIZATION OF LOW FUEL AND TIME-CRITICAL INTERPLANETARY TRANSFERS USING SPACE ELEVATOR APEX ANCHOR RELEASE: MARS, JUPITER AND SATURN," International Astronautics Congress (IAC-18-D4.3.4), Washington D.C., 2019.

to Mars?" The research was conducted over the semester and extended through a "honors" presentation in the fall. The results of the study lead to the following conclusions:

- Release from the Apex Anchor opens up daily trips towards the Moon and Mars.
- Release from an Apex Anchor enables rapid transit to the Moon (14 hours) and Mars (as short as 61 days).
- Multiple Galactic Harbours are shown as the transportation vision of the future supporting significant missions at GEO and beyond.
- Massive movement of payload cargos enables these missions.
- Routine (daily), safe, environmentally friendly, inexpensive, with continuous massive movement of cargo will enable movement off-planet.
- Movement off-planet will require complementary infrastructures, such as rockets and Galactic Harbours, each with their own strengths.
- Permanent Space Elevator Transportation Infrastructures will move massive amounts of cargo in support of off-planet missions.

4.1 Future Research:

Between the research conducted by ASU and the ISEC, the future of interplanetary flights from space elevators is coming into focus. The students, led by Dr. Peet, are going to investigate both the orbital characteristics of flights to multiple locations and the release options from space elevators. Increased velocity through new release techniques will assist the opportunities for reaching far more planets and even solar system escape. Some of these research initiatives are:

- Apex Anchor to Mars (with a receiving Space Elevator rendezvous)
- Apex Anchor to the Moon (with a receiving Space Elevator rendezvous)
- Trips to the Inner Solar System - Venus and Mercury as well as smaller solar orbits.
- Science missions to the outer planets
- Science missions leaving the solar system (with inherent escape velocity from a 163,000 km altitude Apex Anchor)
- Alternative approaches to gaining extra velocity - trebuchets and/or slide release

5.0 Combined Architecture: The logical approach is to combine the architectures for rockets of the future and space elevators to ensure the best of each is leveraged. This comparison (shown in the next two tables) of strengths leads to some eye-opening conclusions.

Table 3, Strengths of Rockets and Space Elevators

	ry of 100% of the pad mass to anywhere on the space elevator defeats the traditional rocket equation.

Table 4, Shortfalls of Rockets and Space Elevators

	l is required with rockets attached to space systems, making it possible, but not optimum.

The bottom line is that a combined architecture for access to Mars should consist of both rockets and space elevators. Some basic insights into the problem show:

- Rockets should be emphasized for the movement of people
- Rockets have tremendous support for LEO and MEO destinations
- Space Elevators should be leveraged for GEO and beyond
- Space Elevators should deliver of cargo and equipment to the Moon and Mars, in other words:

Vision of the Future: On to Mars with
Rockets to Open up the Moon and Mars and
Space Elevators to supply and build up the colonies.

6.0 Conclusions and Recommendations:

The combined research from ISEC and ASU provide some focus for the next steps. These studies have reached some conclusions:

- There must be a change of vision for any interplanetary activity. When there is a permanent infrastructure to provide delivery inexpensively, timely, routinely, environmentally friendly, and daily, there must be early support of its development. The new revelations of fast transit, massive support and daily departures for Mars opens up a robust future for human exploration.
- Complementary architectures must be developed leveraging the strengths of both rockets and space elevators to implement future visions, including SpaceX's Mars colony, the Moon village, and Space Solar Power infrastructures.
- Mission development for GEO, Lunar and Mars programs must begin to understand the magnitude of their desires. Elon Musk's million tonnes of support equipment establishes a remarkable goal - which can be achieved with a complementary transportation infrastructure moving people by rockets (fast through radiation belts) and space elevators (moving massive amounts of cargo).

The next steps have been formulated from many inputs: engineering estimates; customer needs; complexity of designs; and, short-falls in information and data. Each of the items listed next should be initiated in the near term by setting goals and identifying who will take on the challenge.

<u>Near Term Initiative #1</u>: Create a Space Elevator Institute. There are many questions to be answered during the initial phase of a development program for mega projects which include: How will space elevators fit in the emerging mosaic of space? Who will look and formulate preliminary answers in the fields of materials research? dynamic simulations? funding profiles? investor opportunities? international partnerships? international policy and treaty understandings; and, who will assess the great needs for the migration of humans off-planet?

<u>Near Term Initiative #2</u>: Support further research at Arizona State University. Much of the previous work by students in 2019/20 helped us to understand the magnitude of the new capability of release from the Apex Anchor at 100,000 km. The focus was essentially on Mars with some quick looks at Io. The new research, starting in the fall of 2020 should expand the orbital work to refine the questions and tabulate answers for several destinations (continue work on Mars; but, add Venus, Io and then the outer planets - or even escape from the solar system). Additional looks at release physics and new concepts could increase the potential velocity and decrease transit times with radical new opportnities. Another concept could be that there needs to be space elevator to space elevator matching velocities to enhance delivery of cargo at various destinations.

<u>Near Term Initiative #3</u>: Support further research into the application of the newly developing materials field of 2D physics. This series of materials have great promise for extreme strength and the ability to manufacture long lengths of sheets of material.

The Awakening

A NEW Space Transportation Paradigm has emerged. Ideas brought forward in a recent study report,[1] and this paper, are presented in clear and understandable ways, showing that a revolutionary concept is becoming realizable. The envisioned cooperative and collaborative operations between rockets and space elevators will benefit mankind into the next century. This architecture, with space elevators and rockets as a remarkable Earth to Space Transportation Infrastructure, provides logistics support to future missions throughout our solar system. This is a path to fully support interplanetary travel occurring by the second half of this century. This paper has highlighted the following realizations:

- Space Elevators can be accomplished because we now have a tether material
- Space Elevators ENABLE Interplanetary Missions
  - Fast Transit to Mars (as short as 61 days, with variations out to 400+)
  - Can release towards Mars EVERY day (no 26 month wait)
  - Can move massive amounts of cargo (170,000 MTs/year to GEO beyond)
- Space Elevators are Environmentally Friendly
  - Space Solar Power replaces 100s of coal power plants
  - No rocket exhaust to contribute to global warming
  - No additional space debris
  - Opens up remarkable commercial enterprises at Earth Ports, GEO Regions and beyond
- Offer to all future scientists
  - Any size science experiment
  - Any solar system destination
  - Releases every day towards multiple research destinations

How can this be possible? Simple - a working Space Elevator defeats gravity and the traditional rocket equation. Massive payloads to the Apex Anchor - raised by electricity - to be released at 7.76 km/sec towards destinations; daily, routinely, safely, and robustly all while being environmentally friendly. Combined with rocket architectures, future missions to GEO and beyond can be robustly supported.

Rockets to Open up the Moon and Mars
Space Elevators to supply and build up the colonies.

Pete Swan
9 August 2020

[1] Swan, P., C. Swan, M. Fitzgerald, M. Peet, J. Torla, V. Hall, Space Elevators are the Transportation Story of the 21st Century, lulu.com, 2020.

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