



***Space Elevators Enable
Interplanetary Mission Support
Terms of Reference***

International Space Elevator Consortium 2020 Study

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Space Elevators Enable Interplanetary Mission Support Terms of Reference 2020 ISEC Study Topic

Introduction: This is the transportation story of the 21st century. Reliable, routine, safe, and efficient access to space is close at hand. Space Elevators within the Galactic Harbour are an essential part of the global and interplanetary transportation infrastructure. In the community of off-planet movement with NASA's newest move to put boots on the Moon by 2024, space elevators must be added into the discussions. Daily, routine, inexpensive, and massive movement of payloads towards the Moon and Mars is a strength of the Apex Anchor - especially with, high velocity and daily launch windows. This study will start the discussion about the strengths space elevators have with respect to future missions to the Moon, Mars, asteroids and beyond. To a large extent, in the orbital characteristics arena, this study will leverage research accomplished at Arizona State University on the Lambert Problem and fast transits on direct elliptical orbits.

The reality is that when humanity decides to go to the Moon, Mars, and beyond, there will be a tremendous need for logistics support [mission support equipment] as well as the transportation of people [especially at low cost and routine/daily]. The question on ISEC's table is: How do the strengths of space elevators enable missions to the Moon and Mars. I think it is obvious that when we can ship 14 metric tons of payload x 6 Apex Anchors daily with 14-hour transit times to the Moon (Initial Operational Capability - IOC- is 14 MT around 2035 with Full Operational Capability-FOC- of 85 MT by 2050) a permanent human presence becomes possible. Of course, there will be a need for trajectory corrections and landing deceleration propulsion [also needed by rocket driven missions]; so, fuel and rockets will be required as part of the 14 metric tons at IOC. However, 14 metric tons delivered daily, routinely and safely towards Moon (and or to Mars) is an amazing capability. This problem, to the Moon, can be defined and discussed pretty easily. Missions to Mars need to be analyzed to show non-traditional (non-Holman Transfer) orbital options with high energy, fast transit characteristics. The puzzle is how to best support Mars missions with our tremendous strength of daily release and massive movement [14 MT x 6 or so per day].

Assumptions: The following assumptions will establish the initial conditions of the study. (to be refined over the study)

Growth of Space Elevators: Space elevator expectations between the ISEC and JSEA have been estimated to have an IOC in 2035 and FOC in 2040. The growth of multiple Galactic Harbours are expected to be supported by both countries (as a launch capability) and by industry (as a center for massive enterprise growth).



Initial	First Space Elevator	2035
Operational	First Galactic Harbour (Mid-Pacific)	2036
Capability	Second Galactic Harbour (Indian Ocean)	2037
(IOC)	Third Galactic Harbour (Mid-Atlantic)	2038
Full	First Space Elevator	2040
Operational	First Galactic Harbour (Mid-Pacific)	2041
Capability	Second Galactic Harbour (Indian Ocean)	2041
(FOC)	Third Galactic Harbour (Mid-Atlantic)	2042

Operational Pace: The assumption has always been that space elevators would liftoff one payload per day. This was due to simulations and loading of each tether. Further analyses must be accomplished to go beyond this for normal operations. However, interplanetary mission support routinely allows the alignment of release location and target orbital characteristics once a day.

Slow down at Rendezvous Location: The assumption is that the payload mass would include orbital rendezvous rocket motors to slow down and orbit the target planet with spare fuel to maintain the required mission orbit or land on the surface. This assumption is standard on all interplanetary probes and missions. Of course, there are other approaches such as aero-braking and direct landing.

Compatible Infrastructures: Space elevator infrastructures will be compatible with rocket launch infrastructures and will be complementary in mission support. One concept circulating is that rockets would handle people and Galactic Harbours would handle logistic support.

Baseline Infrastructures: ISEC baselines for Space Elevators, and by extension the Galactic Harbour, include the following characteristics: 100,000 km tether resulting in an Apex Anchor at that altitude, IOC payload capability, initial space elevator in mid-Pacific (2035) with a Galactic Harbour growing out of that with two tethers (space elevators) by 2036. Each of the major segments (HQ/POC, Apex Anchor, Galactic Harbour, and tether) would be supporting missions of one lift-off a day of 14 MT. Expansion of Apex Anchor capabilities must be initiated to support this aggressive capability.

Operational Needs at Destinations: ISEC is working with other organizations to identify projected needs at designated locations for logistics support. Suggested needs will be discussed with key mission support requirements identified. Three missions are shown and must be heavily researched. There are many other missions that would be

greatly enhanced by leveraging space elevators' strengths, such as space mineral resource mining from asteroids, Moons or planets. However, the three chosen to use as baseline mission support are:

- **Space Based Solar Power:** “Space based solar power can solve our energy and greenhouse gas emissions problems. Not just help, not just take a step in the right direction, but solve.”¹ This collaborative study must look at the massive payloads needed to be delivered to the GEO belt if this mission is endorsed. Space Based Solar Power deserves to be evaluated as a mission which would require massive space mission support. The impact on humanity for this mission is critical and should be included in the sizing of future mission support infrastructure. The estimate is 5,000,000 MT to support 12% of Earth's population.
- **Lunar Village:** European “togetherness” towards a Moon Village suggests a massive support effort is required. Continuous power will be one of the toughest problems while supplying food, air and temperature control will tax any logistics system. Delivery from Earth will be needed during the initial phases with a gradual movement to more and more in-situ resources. (need numbers here - big research)
- **SpaceX Colony:** Supporting a 100,000 person colony on Mars is the vision of SpaceX and the plans are being formulated today. Mr. Musk stated that he initially needs 1,000,000 Metric Tons of support for his Colony.² The question is how does one deliver one million tons of anything to the surface of Mars? How does the 26 month launch window effect delivery?

Impact of Radiation Doses: Although the two weeks to GEO and another week to Apex Anchor will ensure that our payloads will be in the radiation belts for a considerable time, the savings in the short duration flights to Mars should be offset. Therefore, a study of radiation exposure should be started. Slow transit through Van Allen Belts vs. fast transit through inner solar system radiation environment must be analyzed and compared.

Starting Point: This study has been authorized by ISEC to illustrate the tremendous strengths of space elevators when asked to support Lunar and interplanetary missions. The starting point will illustrate four main points (Identified by Arizona State University research) and then support them or throw them out. In addition, the study will be looking for new concepts where space elevators can aggressively support movement off-planet - to the Moon and beyond. These four main points are:

Major Tenant ONE: There would be a release point each day towards each interplanetary target (no 26 month wait for a launch window).

Major Tenant TWO: There would be optimum release days with rapid transit to target locations (e.g. Mars in as few as 77 days).

¹ Mankins, John, The Case for Space Solar Power, Virginia Edition Publishing Co. Dec 2013.

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



Major Tenant Three: Fast transits and 365 days of available for releases each year results from fast transits enabled by release from the Apex Anchor at roughly 7.76 km/sec.

Major Tenant FOUR: Massive movement of logistics can be achieved by releasing daily from space elevators. (yearly estimate at IOC of: 30,660 MT with 3 GHs, and estimate at FOC of: 186,150 MT with 3 GHs)

Background: The envisioned Missions to the Moon and Mars are of incredible size and scope as well. There is a lingering taint to some discussions that these two behemoth efforts [space elevators and missions to Moon/Mars] can only exist in sequence; first one, and then the others. However, what if it were found that one needed the other? Specifically, what if interplanetary missions were not possible without an operating Space Elevator? OR What if the scope and complexity of Interplanetary Missions made currently envisioned Space Elevators inadequate in some way? There are probably a dozen variations to those questions and the study team's position is that those variations should be documented in a thorough way and subsequently investigated.

To work the problem of movement to Mars we talk about:

- Earth's sphere of influence [1 million kms] with Mar's sphere of influence [600,000 kms]
- 'Windows' only every 26 months due to the need for Holman transfers [minimum energy path] and the position of Earth vis a vis Mars
- Heavy rockets needed to get the energy to: reach LEO [11 ++ km/sec] plus Mars transfer trajectory [3.6 km/sec or so]
- Velocity when escaping the Earth's sphere of influence through rocket trajectory [2.94 km/sec at 1 million kms radius]
- Added to Earth's velocity around the Sun, it is sufficient to go into Holman transfer towards Mars
- Roughly 5 km/sec is needed to slow down and go into circular orbit around Mars [400 km altitude]

Several of the "big questions" are:

- Question: How often can we expect to deliver payloads to Mars from Space Elevators' Apex Anchors? What are the launch windows? - weekly or daily?
- Question: What are the transit times when departing the Earth's sphere of influence with three times the energy of chemical rockets? [non-traditional approaches - Lambert's Solution]

- Question: With those two discussions initiated, the concept of multiple tons of mission support logistics going to Mars (or the Moon) per day is remarkable. How will that change the approach to supporting human movement off-planet?

The study thrust is: How do we address this problem of interplanetary mission support logistics from space elevator's perspective? A few of the questions are:

- What speed are you going at the sphere of influence of Earth when released from 100,000 km at 7.78 km/sec?
- When you are going that fast at the sphere of influence, how long does it take to get to Mars
- We have to rearrange our thinking as Holman transfers are NOT in play. Elliptical orbits around the sun at great speed - Lambert Problem Solutions
- Assumptions: Six operational space elevators with each able to "raise" 14 Metric tons of payload per day and, guessing, late 2030's to early 2040's operational, with growth to FOC payloads of 85 MTs each by late 2040's.

So the question become, when looking at it from a space elevator perspective, "Can we do daily launches with a variety of flight times and distances to Mars?" We can not only go direct, as expected but we could go by way of Venus or loop around the Moon for gravity assist to "bend" the orbits. There are many possibilities; but, with all the extra velocity, the trips are shorter and can go on various orbits. So what does it mean with respect to the big picture? One area of study must include the planetary incoming velocity and how to slow down for rendezvous and landing?

The breakout of this study could follow the following preliminary outline.

- Introduction and background on currently planned support to Moon and Mars (supplied by rockets) - description of projected needs, such as mass to Mars per year, capabilities (via rockets vs. SE) vs. needs
- Historic orbits to Mars and the Moon with supply schedule
- Background on Galactic Harbour and Space Elevators with assumptions for study, with remarkable capability to provide massive payloads to Mars, daily and routinely.
- Approach Breakout: New energies are available at Apex Anchor; Lambert Problem definition; calculations for paths to Mars [daily, covering a 26 month period]; Analyses of Lambert approach to transit times and departure opportunities; and, Summary of results. The focus will be Mars with discussions on other planetary objectives such as Jupiter's moon Io.
- Analyses of Results: how often can we go to Moon and Mars from the Apex Anchor? What are the transit times? fastest transit? average transit? Concerns for these flight paths?
- Conclusions & Recommendations

Study Lead: Pete Swan Study Members: Michael Fitzgerald, Matthew Peet, James Torla, Dennis Wright, Jerry Eddy, + +



Our schedule for this study is as follows:

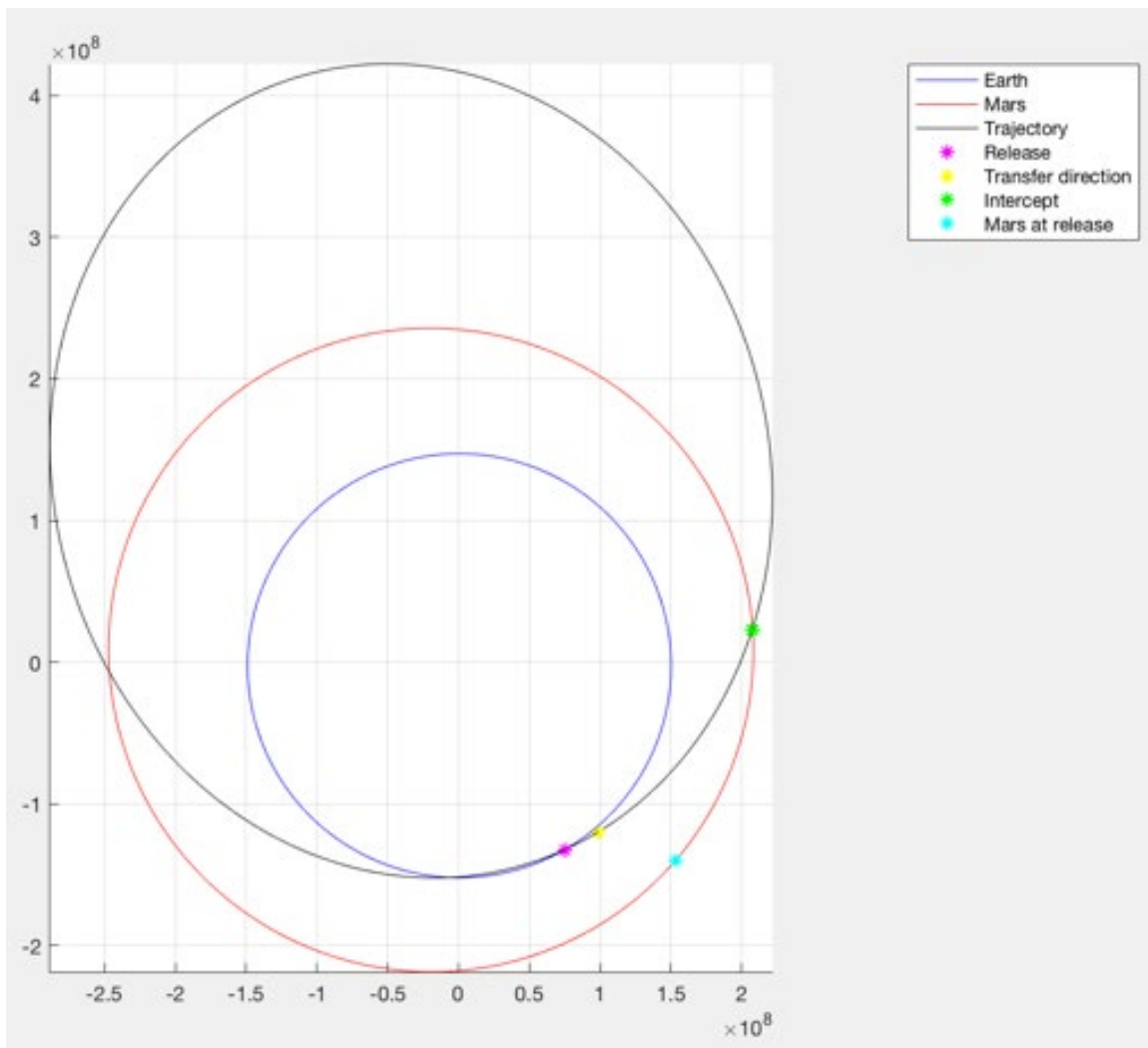
- August 2019 — Study authorized at Board of Directors meeting (lead Pete,+Fitzer+ASU+)
- Aug-Sept 2019 — Topic announced at the yearly conference with mini-workshop for brainstorming - initial team formed
- Sept 2019-Dec 2019 — Team formalized and initial outline of study topics - with responsibilities designated
- Jan- May 2020 — Specific items discussed, analyzed and studied - chapters written - topics submitted to ISEC yearly conference
- May 2020 — Preliminary presentations given at space elevator sessions at ISDC on topics - mini workshops to discuss proposed concepts from within individual chapters
- Sep-Dec 2020 — Draft of final document.
- Oct 2020 - presentation and papers at IAC Dubai
- Jan-Feb 2021 — Review of final report within team
- Feb-Apr 2021 — ISEC Review of final document (red team and internal acceptance)
- May 2021 — Publish study report

Goal for ISEC: We need to insert ourselves into the conversation and demonstrate the unique strengths for new discussions. We have been focused on Earth missions, now we have movement towards the Moon and Mars. Interplanetary mission support is an important future mission for space elevators. We would ENABLE robust mission support to off-planet. We need to explain the concept in good engineering terms. One of this year's outreach goals is to become more involved in discussions about moving off-planet. Some themes that could be stimulating!

- The space elevator will enable missions to the Moon and Mars!
- Only space elevators can provide the real requirement of mass to Mars and the Moon
- Colonization on Mars cannot happen without the logistics support of space elevators!
- Launch Windows to Mars every 26 months - be Damned! [my favorite]

Remember: This is the transportation story of the 21st century. Reliable, routine, safe, and efficient access to space is close at hand. Space Elevators and Galactic Harbours are an essential part of global and interplanetary transportation infrastructures.

Peet-Torla Transit to Mars 76 days: Associate Professor Matthew Peet of Arizona State University, in collaboration with Dr. Peter Swan, supervised the algorithmic development and processing of data, including numerical solution of Lambert's problem. - James Torla was the student lead





This is the transportation story of the 21st century. Reliable, safe, and efficient access to space is close at hand. The Space Elevator is the Galactic Harbour, and an essential part of the global and interplanetary transportation infrastructure.

**Bus Schedule for Interplanetary Transportation
when departing from Galactic Harbour Apex Anchor**

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/1/2035	Indian #1	Mars	87 days	9/26/2035	
7/1/2035	Pacific #1	Mars	86 days	9/25/2035	
7/1/2035	Pacific #2	Mars	84 days	9/22/2035	Fast

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/8/2035	Indian #1	Mars	81 days	4/14/2035	
7/8/2035	Indian #2	Mars	81 days	4/14/2035	
7/8/2035	Indian #1	Mars	80 days	4/13/2035	Fast

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #1	Mars	79 days	10/2/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Indian #2	Mars	79 days	10/1/2035	
7/15/2035	Pacific #1	Mars	78 days	9/30/2035	Fast
7/15/2035	Atlantic #1	Mars	190 days	1/21/2036	
7/15/2035	Atlantic #1	Mars	182 days	1/13/2036	
7/15/2035	Atlantic #2	Mars	173 days	1/4/2036	
7/15/2035	Atlantic #2	Mars	164 days	12/25/2035	
7/15/2035	Atlantic #1	Mars	154 days	12/15/2035	

Bus Schedule, from Apex Anchor 2035

Date	Departure	Destination	Flight Time	Arrival	Comments
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #2	Mars	77 days	10/7/2035	Fastest
7/22/2035	Pacific #1	Mars	223 days	3/1/2036	

Bus Schedule, from Apex Anchor 2035 to Moon

Date	Departure	Destination	Flight Time	Arrival	Comments
every day	Indian #1	Moon	14 hours	+ 14 hours	
every day	Indian #2	Moon	14 hours	+ 14 hours	
every day	Pacific #1	Moon	14 hours	+ 14 hours	Fast
every day	Pacific #2	Moon	14 hours	+ 14 hours	
every day	Atlantic #1	Moon	14 hours	+ 14 hours	
every day	Atlantic #2	Moon	14 hours	+ 14 hours	