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Interplanetary Mission Support from Galactic Harbour Apex Anchor

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Abstract

As humanity expands off Earth, the need for support increases at a tremendous rate. The mass per day required to be delivered to the Moon, Mars and other destinations will stress out the current rocket based approach unless something revolutionary is supported. A Space Elevator allows the growth of humans off-planet to accelerate with three major improvements: - massive movement of mission support equipment - a tremendous opening up of launch windows - shorter travel times. With Mars as the destination of a recent Arizona State University research study, their results show that the delivery time for supplies from the Earth can become very short. In addition, the concept of one launch window every two years is collapsed to multiple launches each week towards Mars. The essence of this change is the tripling of kinetic energy at the Earth's sphere of influence(SOI) compared to rockets entering the Hohmann transfer ellipse. The resultant increase in energy is enabled by the release from 100,000 km altitude Apex Anchor rotating with the Earth. These potential and kinetic energies result in a hyperbolic orbit departing the Earth. This ASU study was aimed at determining "time of flight" from Earth to Mars when departure angle and energy at the edge of the SOI reflected the strengths of having space elevators at the Equator. This paper expands beyond the recognition of daily departures to Mars with tremendous energy and addresses the opportunities available for massive logistics support.

***1.0 Introduction**:* This is the transportation story of the 21st century. Reliable, routine, safe, and efficient access to space is close at hand. Space Elevators are Galactic Harbours, and 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 included in the discussions. The key to any support infrastructure is daily, routine; inexpensive, and massive movement of payloads towards the Moon and Mars. These are strengths of Apex Anchors; especially with, high velocity and daily launch windows. This paper provides impetus for discussions about the three major attributes when departing from the Apex Anchor and the other strengths space elevators have with respect to future missions to the Moon, Mars, asteroids and beyond. To a large extent, in the orbital characteristics area, this study will leverage research accomplished at Arizona State University on the Lambert Orbital Solution and fast transits on those direct elliptical orbits.

The reality is that when humanity decides to go to the Moon and Mars, there will be a tremendous need for logistics support [mission support equipment] as well as transporting people [especially at low cost and routine/daily]. Mission logistics support describes all the extra mass that needs to be delivered to the intended destination. For this paper, movement of humans will be accomplished by rockets well past the Initial Operational Capability of the space elevator. People movement on the Space Elevator will arrive in time, but well after IOC (roughly 2037 for IOC). The logistics support needed by humans beyond Low Earth Orbit starts with everything required to stay alive and enable mission support. Much will accompany the first flights of humans to the Moon and Mars. However, mission support equipment will be required to enable humans to prosper with pre-positioning of supplies and equipment; equipment that accompanies the human missions; and, post arrival mission survival and enhancement equipment and supplies. Indeed, we will learn to live off the land (in-situ resources); but, humans will always need enormous quantities of support infrastructure delivered to wherever they go. The question to ask is: How do the strengths of space elevators enable missions to the Moon and Mars? Can a release from the Apex Anchor of 14 metric tons daily, routinely and safely towards Mars (and or the Moon) be supported as an amazing and required capability? Missions to Mars need to be analyzed to show non-traditional (non-Hohmann Transfer) orbital options with high energy, fast transit, characteristics. The puzzle is how to best support Mars missions with a Space Elevator's tremendous strengths of daily release and massive movement [14 MT x 6 space elevators per day]. One interesting twist within this analysis is that Elon Musk recently established a baseline of needs on Mars by the mid to late 2030's.

One Million Tons to Mars to Support my Coloney!

Elon Musk, 21 July 2019, CBS Sunday Morning Interview

Is it a coincidence that Mr. Musk asked for delivery of a million tons of support infrastructure for his colony on Mars? I think not! It is obvious to anyone studying the recent commercial off-planet movement that there is a crying need for routine, daily, inexpensive, environmentally friendly, safe, and massive payload capability access to space. It just so happens that Space Elevators and Galactic Harbours epitomize those strengths. The International Space Elevator Consortium (ISEC) believes:

Space Elevators Enable Interplanetary Mission Support.

2.0 Galactic Harbour Baseline Capability: Galactic Harbours will be spread out along the equator during the late 2030's with an estimate of three being operational by 2040, with each Galactic Harbour having a pair of Space Elevators. The first image shows the arrangements from the Headquarters in a distant city, to the Earth Port and then to GEO and Apex Anchor Regions. This paper will look at two strengths that are inherent to the fact of a permanent infrastructure, routine massive lifts and rapid travel.

Routine Massive Lifts:
Each Space Elevator Climber will carry 14 metric tons of payload to GEO and beyond with departures every day, or 84 MTs per day (14 x 2 SE x 3 GH) around the globe. This would happen 365 days a year, or 30,660 MTs per year to GEO and beyond. As each tether capacity would probably double each four years, before long the carrying capability of Galactic Harbours would be roughly 100,000 MTs per year. The main question being asked is how many rocket launches are required to support movement off planet? The baseline Initial Operations Capability Space Elevators will not be carrying people; so, their missions are strictly logistics support to missions at GEO and beyond - including interplanetary. If you think in today's world for a parallel example, such as planes for people and rail or sea for logistics, you will start to understand the strengths of space elevators for support to interplanetary missions. The strengths of a space elevator are:

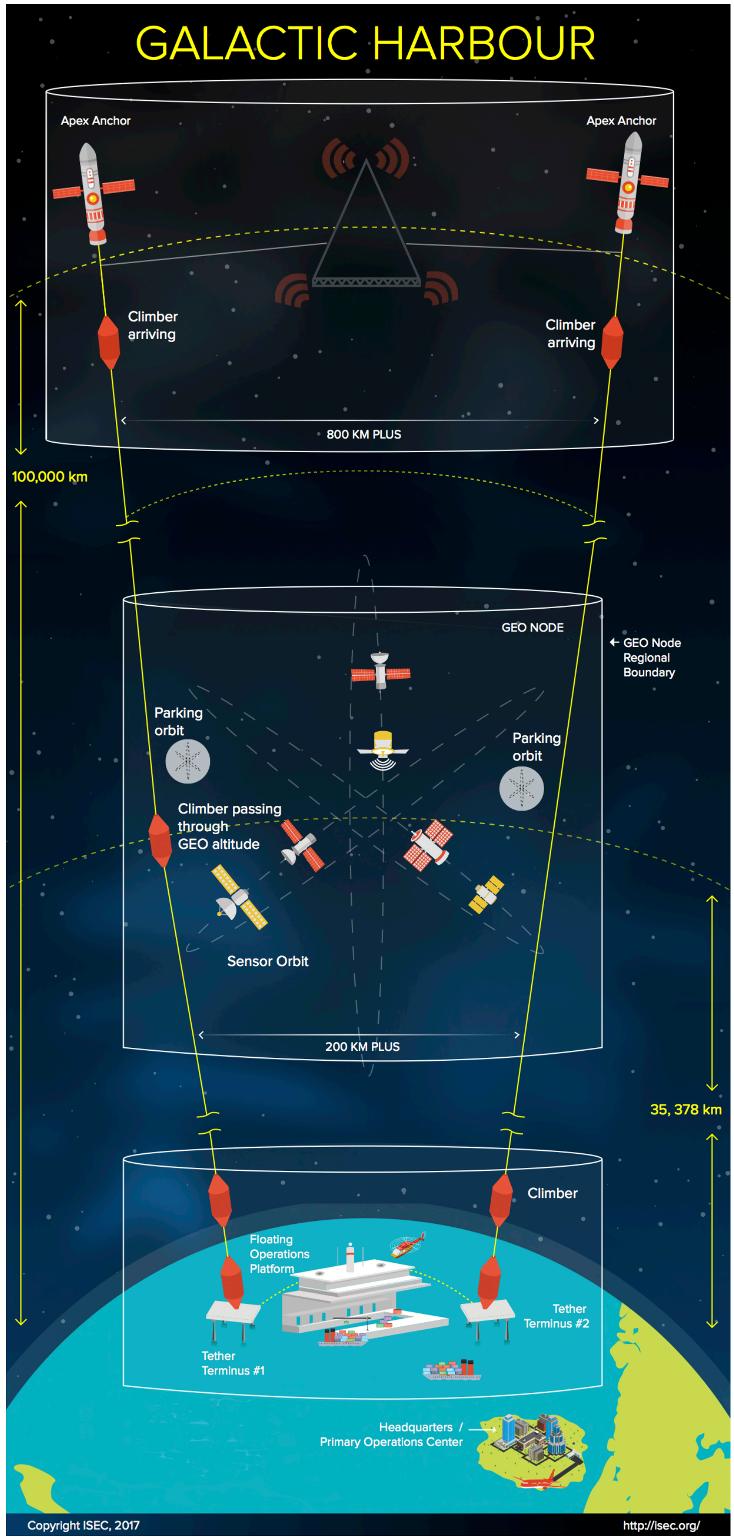

Figure 1 Galactic Harbour (2017)

- Routine [daily] access to space
- Revolutionarily inexpensive [<$100 per kg] to GEO and beyond
- Commercial development similar to bridge building
- Financial numbers that are infrastructure enabling
- Permanent infrastructure [24/7/365/50 years]

- Multiple paths when infrastructure matures
- Massively re-usable, no consumption of fuels
- Environmentally sound/sustainable - will make Earth "greener"
- Safe and reliable [no shake, rattle and roll of rocket liftoff]
- Low risk lifting
- Low probability of creating orbital debris
- Redundant paths as multiple sets of Space Elevators become operational
- Massive loads per day [starts at 14 metric tons cargo loads]
- Opens up tremendous design opportunities for users
- Optimized for geostationary orbit altitude and beyond
- Does not leave debris in LEO
- Co-orbits with GEO systems for easy integration

The bottom line for Galactic Harbours, and missions within the solar system, is that humanity's hopes and needs to expand beyond the limited resources and environment of our own planet can be realized. Space Elevators are the enabling infrastructure ensuring humanity's growth within and beyond our solar system. Currently, the Case for Space Elevators is laid out as:

Point One: Space Elevator Transportation Infrastructure - if you ship 100 tons of mission support equipment from the Earth Port; 100 tons show up in proper orbit. No rocket equation eating up launch pad mass.

Point Two: Interplanetary Mission Support - Departs daily from Apex to Mars (no 26-months wait between launch windows) with rapid transit (77 days best time) plus other solar-system destinations.

Point Three: Inexpensive, routine, and environmentally friendly daily departures from the Galactic Harbour's Earth Port.

Point Four: Single Crystal Graphene shows remarkable potential as a tether material, half-meter single molecule already made in the lab in 2D form.

During the International Space Development Conference in June of 2019, four themes were presented and discussed at length. The themes are descriptive of todays understanding of Space Elevator status as of the Fall of 2019 and are presented here:

- ***Theme One***: Space Elevators are closer than you think!
- ***Theme Two***: Galactic Harbour is a part of this global and interplanetary transportation infrastructure
- ***Theme Three***: Space Elevator development has gone beyond a preliminary technology readiness assessment and is ready to enter initial engineering validation testing -- leading to establishment of needed capabilities.
- ***Theme Four***: The magnitude of Space Elevator Architecture demands that it be understood and supported by many.

***3.0 Three Apex Anchor Strengths will Enable Interplanetary Missions**:* The demand for supplies and support equipment will be remarkable as colonies off-planet are developed. There are several benefits from Space Elevator transportation infrastructures: first, there is the tremendous load capability; second, is the remarkably fast transits that are available; and third, the departure dates can be every day of the year.

3.1 Massive Movement to Mars Movement of people and mission payloads by rockets has been remarkable with trips to the Moon and delivery of constellations of communications and navigation satellites. However, all these successes have leveraged burning rocket fuel, leveraging the rocket equation. Defeating gravity costs enormous amounts of energy with the reality being that delivery to mission orbit consumes both fuel and often the vehicle providing the delivery. A quick comparison of rockets to Space Elevators should explain the strengths of a permanent infrastructure for access to space. The following chart shows some examples of the delivery techniques when using the rocket equation. The average mass that gets to Low Earth Orbit from a rocket is only 4% of the mass that started on the pad. The average to GEO is only 1.5% of the pad mass while getting to the surface of the Moon is only 0.5% of launch pad mass. OOPS - To deliver a 1 kg pizza to the Moon surface (assume includes cheese), the mass at the pad would have been 200 kg. The strength of the Space Elevator is that it is a permanent infrastructure delivering supplies to orbit. If you wanted to deliver a 1 kg pizza to the Moon thru the infrastructure, you would put 1 kg on the tether climber.

Table 1: Launch Vehicle Delivery Percentages to GEO

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

Note: data from web varies greatly - these numbers are representative only

In addition to delivery benefits (factor of 200 to one) the space elevator also has a capability of adding energy to the payload by raising it up (potential energy) and then releasing it at velocity (rotational energy from the planet). To gain those two energy characteristics, the space elevator plans on using solar power. This increase in energy at departure from the Apex Anchor allows payloads to reach their destinations more rapidly and with departures every day of the year (some days have quicker pathways to Mars than others however). In addition to the efficiency of a permanent infrastructures, departure opportunities are far more frequent - ensuring movement of more supplies and equipment. Todays rocket launches average less than 100 per year from around the world. (2018 - 114, 2017 - 90, 2016 = 85, 2015- 86, 2014 - 92, 2013 - 81 with several failures every year). If we compare the delivery mass to GEO (similar to Space Elevator strength and beyond), the rough number is 10 MTs for each launch vehicle (less than half of what it can deliver to LEO). This is compared to the delivery of 14 MTs each day by the space elevator x 3 Galactic Harbours (x2 tethers per) or 84 MTs per day.

Table 2: Number of Rocket Launches vs. Galactic Harbour Lift-Offs

Type	Lift Average (Metric Tons)	Number per year	Total Mass to Interplanetary (MTs)
Individual Heavy Launch Vehicles	10 per launch	87 (average last 5 years)	870 MTs if all went to single mission
Galactic Harbour Transportation Infrastructure	6 tethers x 14 MT = 84 MT per day	every day towards Mars and Moon 365 per year	84 x 365 = 30,000 MTs if all went to single mission

The table shows a comparison of Today's average rocket capability per year (of 870 MT to GEO and beyond) with Galactic Harbours of 30,000 MTs per year. The comparison uses total capability to lift off the ground towards the Moon and Mars - so no other misssions would be accomplished. In addition, the launch numbers are for current launchers and the future will have more robust reusability and maybe even larger capacity with Blue Origin's New Glenn and SpaceX's StarShip. Even if we double or triple the numbers, the difference is still tremendous because the space elevator is a permanent transportation infrastructure with no wastage from the catastrophic rocket equation.

3.2 Rapid Transits (as low as 77 days): During the the 2019 International Space Development Conference it was shown daily launches towards Mars will occasionally arrive within 77 days. This ASU study showed that launches towards Mars could occur every day of each year without the penalty of waiting for the traditional 26 month launch window. Research at Arizona State University, sponsored by Associate Professor Matthew Peet, lead to the conclusion that mission support from Galactic Harbours is an enabling factor in humanity's expansion off-planet.

Release Velocity - The next chart summarizes a variety of altitudes associated with various architectures for Space Elevators (historic). This paper uses 100,000 km altitude, or 106,378 km radius from center of Earth to Apex Anchor. With this altitude (or potential energy) and tip velocity (or kinetic energy), the release towards the Moon or Mars would be 7.76 km/sec.

Table 3: Height of Apex Anchor Alternatives

Length (kms)	***Author***	***Speed (Km/sec)***
96,000	Obayashi (2013)	7.466
100,000	Edwards (2002), IAA (2013 & 2019)	7.757
120,000	Knapman (2019)	9.216
144,000	Pearson (1975)	10.966
150,000	ASU alternative (2018)	11.403

In addition, with this release velocity, the direction could vary from the traditional perigee release of a Hohmann transfer to one where the vehicle enters a very large trajectory ellipse at an angle off of the Earth's velocity vector.

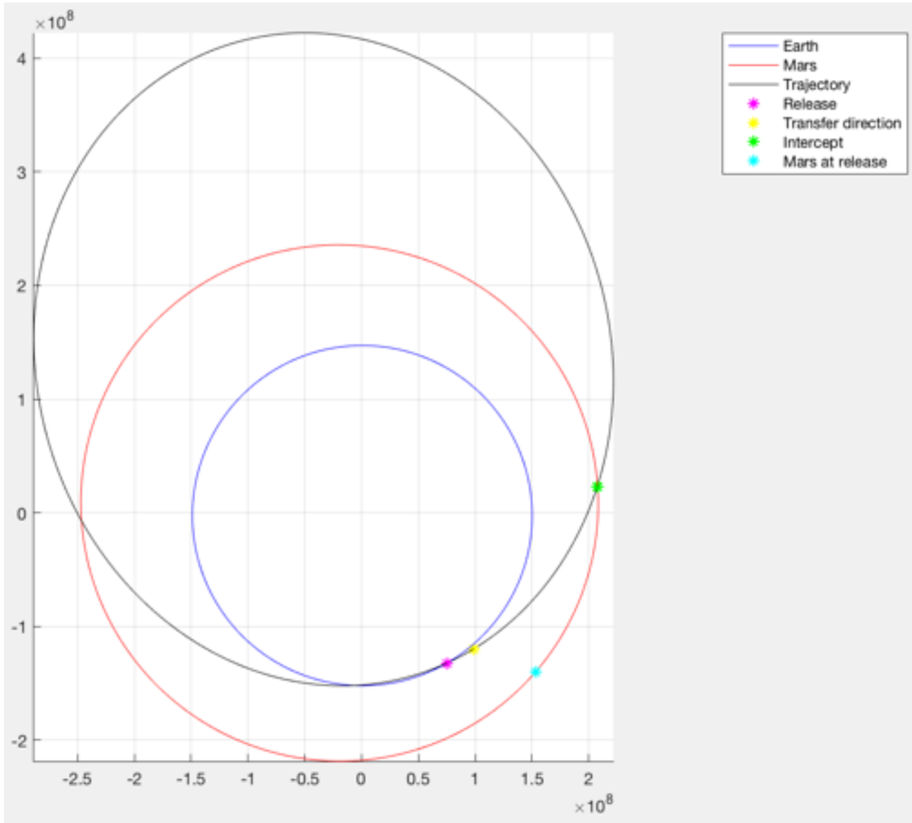

Figure 2: Fast Transit (77 days to Mars)

This enables a tremendous variety of flight paths. The image below illustrates the minimum transit flight of 77 days to Mars. Associate Professor Matthew Peet supervised the algorithmic development and data processing by James Torla, including Lambert's numerical solution. - James Torla was the student Lead Arizona State University[1].

As the reader can see in the next table, there are many rapid transits that are close to 77 days, but there are also longer routes when the two planets don't line up correctly. The reality is that a space elevator can send logistical support along the route to the Galactic Harbour and then release it at the appropriate time to have it fly to Mars and be delivered on time.

3.3 Bus Schedule to Mars - Daily Departures:

When you have a permanent transportation infrastructure in place, the scheduling of asset movement is routine - like taking a bus to Mars. This "bus schedule" example below was spread out across the month of July 2035. It shows the flight times, arrival days and gives everyone the confidence that their support equipment will arrive on time.

[1] Totla, James, Optimization of Low Fuel and Time-Critical Interplanetary Transfers using Space Elevator Apex Anchor Release: Mars, Jupiter and Saturn, presented 2019 International Astronautical Congress, Washington D.C. Oct 2019.

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Bus Schedule for Interplantary 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	

Figure 3: Bus Schedule for Delivery to Mars

***4.0 Demand for Logistics Support**:* The demand for logistics support has not been separated from human deployment to the Moon and Mars. This single approach in launch support drives the reliability of every vehicle to human rating. When we are talking about humans to space (to the ISS, to the Moon, to Mars or a free floating colony) you are talking about a tremendous amount of support equipment delivered to their destinations. The concept of a Moon Village is remarkable and it is encouraging that people are working towards that, but how much do we have to bring from Earth to house, feed, oxygenate, and entertain humans. One question still to be addressed is what are the demands to support people on the Moon and Mars. If done by rockets, the inefficiencies would dominate the numbers. When Apollo went to the Moon, they landed the lunar lander (and ascent vehicle) on the surface (only 0.5% of total mass of the Saturn V on the pad at liftoff). Now, modern rockets are better at efficiencies and re-usability; however the rocket equation still dominate and the answer can probably not get better than 5% of total mass on pad at departure towards the Moon. To make it even worse, it takes so many launches and safe landings before we can support people on the surface of the Moon. "NASA is currently planning a series of 37 rocket launches, both robotic and crewed, that will culminate with the 2028 deployment of the first components for a long-term lunar base."[2]

If one were to take the hugely successful cruise ship analog, one could say that it takes 12 metric tons per person to support them for one week. The number comes from a massive vessel (100,000 tons weight) with lots of humans (8,500 guests and crew). Not sure this is a good parallel; but, it illustrates the tremendous needs of humans to live their daily lives. The real question is how much support does an individual need when going to Mars or the Moon, on-average? The demand should be spread out to areas such as - preliminary living for the explorers, upgrade capabilities to include scientists-engineers-builders, and then continuous demands to maintain the colony as a full time environment. These numbers need to be quantified to enable realistic planning. As colonies form, the need for support will increase at a tremendous rate. The mission support mass per day required to be delivered to the Moon, Mars and other destinations will over stress any rocket architecture as well as being exorbitantly expensive. Space Elevators allow mission support growth to accelerate with three major improvements:

- inexpensive and routine (daily) massive movement of mission support equipment
- tremendous opening up of launch windows (daily to weekly towards Mars)
- while reducing travel times (fast transits as short as 77 days)

Another interesting aspect of the movement to Mars by Elon Musk is that he plans on his StarShip having a capacity to move 100 people (100 to 200 is sometimes quoted) at a time towards Mars with a capability for an extra 100 MTs of support equipment. That turns out to be only 1 MT of supplies for each person for the next two years (remember they are still on launch window restrictions with rockets). Of course the explorers will be smaller groups with larger portions of supplies and housing. If we go back to Elon Musk's statement of 1,000,000 tons of supplies for his colony, then we will need to provide a massive movement of support equipment from Earth to Mars. With Mr. Musk's calculation, the extra supplies for each StarShip would take 10,000 trips. In comparison, if we used the initial operational capability of 6 space elevators (3 Galactic Harbours), the delivery of 1,000,000 MTs would take 34 years. However, as our system will grow, the real estimate using the full capability of future space elevators, would be more like 5 years to supply the full million tons. Permanent transportation infrastructure is the answer, if the need is to support a colony on Mars or even the Moon.

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[2] http://www.astronomy.com/news/2019/05/moon-village-humanitys-first-step-toward-a-lunar-colony

5.0 Conclusions and Recommendations:

The dominant question becomes, when looking at it from a Space Elevator perspective, "Can we do daily lift-offs with a variety of flight times and distances to Mars?" We not only could 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 so many possibilities — with all the extra velocity, the trips are shorter and can use multiple trajectories.

The Space Elevator community needs to insert itself into off-planet conversations and express its unique strengths and opportunities. It has been focused on Earth missions, the discussion should now become movement towards the Moon and Mars. Interplanetary Mission Support is an important future mission for Space Elevators. Galactic Harbours will enable robust mission support off-planet. There are needs to be explained within the concept in engineering, financial and programmatic terms. Some conclusions from this analysis could be stimulating!

- The Space Elevator will enable missions to Moon and Mars!
- Only Space Elevators can deliver the requirements of logistics equipment and supplies to the Moon and Mars
- Colonization on Mars cannot happen without the logistics support of Space Elevators!
- Launch Windows to Mars every 26 months - be Damned! [my favorite]

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This is the transportation story of the 21st century.

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