Huge Fast Spacecraft Travelling Our Solar System

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DOI https://doi.org/10.59332/jbis-076-07-0247

Can you imagine a large space system leaving from an Earth space elevator in excess of 12.34 km/sec, ensuring quick travel within our solar system? How about if it had an additional 10 km/sec assist from a slingshot release with the ability to gain another 15 km/sec by doing gravity assists along the way? The total concept being discussed is fast enough to allow travelling around our solar system within months instead of decades. However, there is more for those seeking answers beyond Earth – how about the ability to send multi-hundreds of tonnes along this path in a huge space system with fuel for rendezvous and landing along the way? How? Forget the Rocket Equation! You assemble a large spacecraft above the gravity well of the Earth, add velocity to it by virtue of the Earth's rotation and then release it with extra velocity as if from a giant slingshot. An extra-long space elevator could achieve these goals by 2038. This story should be told as part of future opportunities for space exploration and science. Solar system travel, and even into interstellar regions, becomes reality with space elevators designed to assemble massive satellites and enable high velocity releases.

Keywords: Space elevators, Neptune, Apex Anchor, Interplanetary

1 INTRODUCTION

Space elevators will open up the heavens for humanity because they lift massive payloads off our planet with unmatched efficiencies. The transformational characteristics of space elevators revolutionize the way we think about going somewhere "out there." The development of permanent space transportation infrastructures results in several significant improvements in capability. The programs of today estimate massive logistics needs (geosynchronous orbit (GEO) missions such as space solar power – three million tonnes and Mars logistics support – one million tonnes) while still relying on rocket deliveries. From future Earth based electrical power needs (estimates double today's) to a desire to move off planet, humanity's future demands for delivery to space are extraordinary. These capabilities will support 12% of the global baseline electrical needs by 2050 (replacing coal burning plants) [1] and assist SpaceX's desire for settlements on Mars [2]. To reach these numbers using rockets (at less than 2% delivery statistics – and 20 to 50 tonnes capability to GEO) something like three launches a day are required. This exorbitant demand for rockets – burning fuel in our atmosphere – would be extremely hazardous to the environment. A leap into this bright future for humanity by using rocket launches alone is counterproductive. We must build upon the concept of a dual space access strategy combining the strengths of both advanced rockets and space elevators [3]. Fig. 1 illustrates this leverage of the future concept of cooperation and competition in delivery. A permanent space access infrastructure will enable massive space systems for exploration and planetary science to reach our solar system destinations in remarkably short trip times.

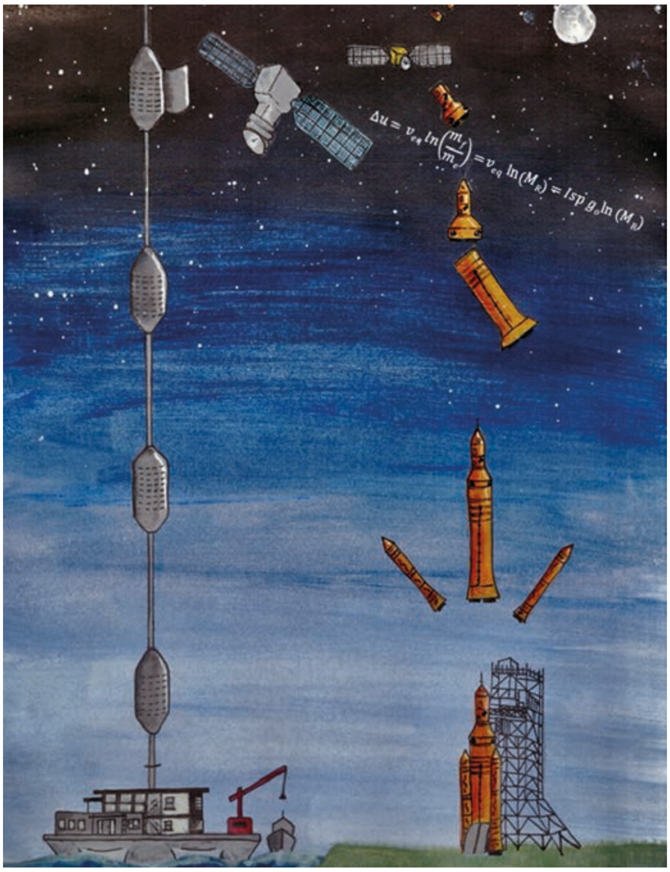

Fig.1 Dual Space Access Strategy (illustration by Amelia Stanton).

1.1 Proposed Neptune Mission Concept

The proposed mission concept for this research project is to illustrate revolutionary interplanetary approaches for a human trip to Neptune, after 2050. A recent article by 73 authors and 26 organizations covered the mission science and major design aspects of a similar concept (robotic only), using today's rockets, entitled "Neptune Odyssey: A Flagship Concept for the Exploration of Neptune-Triton System" [4]. This mission is proposing a 2031 launch (on SLS) for a 12-year cruise to investigate Neptune and Triton environments.

The proposed concept for space elevator supported missions would be human, less than 300 days to Neptune [optimum path with longer trips depending on orbital alignments], stay for a year and then use nuclear propulsion to return to Earth with a few gravity assists along the way. Indeed, for this to happen, space elevators would have to have a huge spacecraft released at extreme velocities with the ability to support humans and have propulsion throughout the trip. There are two characteristics of space elevators that are not obvious; however, they revolutionize space transportation and can enable just such a mission. These are assembly above the gravity well and extreme velocity releases.

1.2 What is a Space Elevator?

Space Elevators are a transportation infrastructure that is ecological and "beats the gravity well." Its overriding strength is that it supplies massive amounts of cargo to GEO and beyond in an environmentally friendly manner [Initial Operational Capability – 30,000 tonnes per year]. By using electricity to raise its payloads to "toss" towards their destinations, the space elevator is a "Big Green Machine." It not only does not consume fossil fuels to raise itself, but it also enables tremendously difficult missions that are not fully realizable with traditional rockets (or even the newer reusable ones).

Space elevator transportation systems consists of six major segments.

Earth Port: A complex located at the Earth terminus of the tether, on the ocean at the equator to support its functions with tether termini, headquarters, and logistics center.

GEO Region: The complex of space elevator activities positioned at 35,786 km altitude includes central main operating platforms, "parking lots," fueling stations, assembly garages and tug boats.

Apex Anchor: A complex of activity located at the upper end of the space elevator providing counterweight stability for the space elevator and a large garage for assembly of space systems, repair and refueling.

Tether Climbers: Vehicles able to climb or lower themselves on the tether, as well as releasing or capturing satellites for transportation or orbital insertion.

Tether: 100,000 km long woven ribbon with sufficient strength to weight ratio to move logistical in a timely manner.

Headquarters and Primary Operations Center: Locations for the Operations and Business Centers will probably be at multiple locations including the Earth Port [5].

1.3 Permanent Transportation Infrastructure

If one thinks in transportation terminology, access through space would be like building a bridge after centuries of using boats to cross a river. The concept enabling this revolution is simple:

Rockets to open up the Moon and Mars with space elevators to supply and grow the settlements. In addition, space elevators will enable green missions moving massive logistics while releasing advance rockets to move people rapidly through the radiation belts. This approach is compatible and complementary while leveraging the strengths of both inside a dual space access strategy.

During the research into the "Space Elevators are the Green Road to Space" study report [6], the idea developed that rockets and space elevators should be complementary and cooperative [3]. As such, the ability of space elevators, as the green road to space, will enable most missions to be achieved in much shorter timelines. In addition, when one includes the newly identified strength of space elevators of "assembly at the top of Earth's gravity well," the solar system opens up.

By lifting satellite segments (at roughly 14 tonnes each at initial operations) and assembling them above the gravity well, solar system science missions can become quite large and are then released with tremendous energy towards our outer planets every day of the year. In addition, these garages at 100,000 km above Earth will act as logistics centers for cis-lunar activities or even astronaut rescue centers for storage of equipment, oxygen, water and food deliveries for emergencies. The 14 hour travel time from apex anchor to lunar orbit, with daily releases, would enable "quick responses" to emergencies.

1.4 Understanding Transformational Characteristics

The transformation of space access created by the space elevator's permanent infrastructure operations will be similar to moving from small boats crossing a large river to a permanent infrastructure such as a bridge moving traffic daily, efficiently, routinely, safely, inexpensively, and with little environmental impact. Permanent space access transportation infrastructures exhibit these strengths:

(a) Unmatched efficiencies with daily, routine, safe, and inexpensive delivery of logistics payloads,
(b) Unmatched massive movement (initial operational capability (IOC) at 30,000 tonnes/yr with full operational capability (FOC) 170,000 tonnes/yr) [7],
(c) Unmatched velocity (starting at 7.76 km/s at 100,000 km altitude enables rapid transits to the Moon, Mars and beyond) [8],
(d) Ensures environmentally neutral operations as a green road to space [6],
(e) Reduces rocket fairing design limitations,
(f) Assembly at the top of the gravity well, and
(g) Transforming the economic strengths of strategic investment, ubiquitous access, and uninterrupted exchange of resources [9].

1.5 Space Elevators beat the Rocket Equation

The Tsiolkovsky rocket equation defines the characteristics of rocket launches while showing the restrictions of delivery statistics. The explanation of the rocket equations relates to the definition of rocket propulsion from Wikipedia:

A device that can apply acceleration to itself using thrust by expelling part of its mass with high velocity can thereby move due to the conservation of momentum [10].

The Tsiolkovsky rocket equation (Fig. 2) still responds to

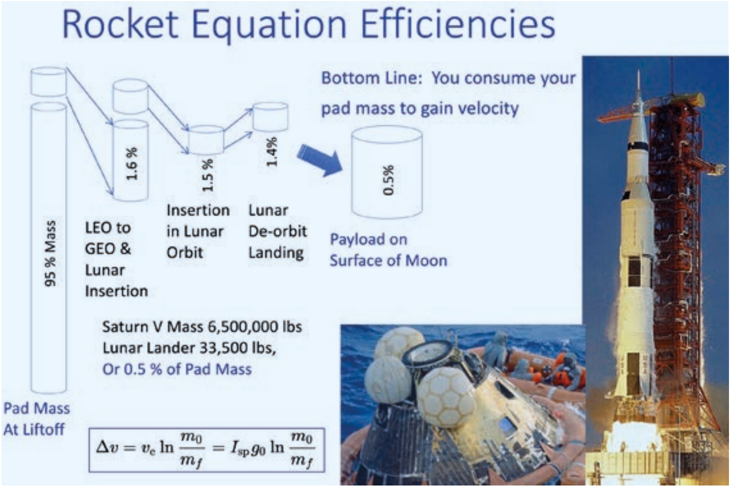

Fig.2 **Apollo Efficiency.**

that critical factor called gravity; and, it is unaffected by either efficiency or cost factors. The Earth's gravity numbers have a consistent impact on effectiveness of rockets at liftoff and flight – draconian!

Conundrum of Rockets: The conundrum of rockets is the simple realization that the delivery of mass to its destination is an insignificant percentage of the mass on the launch pad. Fig. 2 shows the breakout of delivery statistics for Apollo, a glaring example is the delivery of a half percent of the launch pad mass to the surface of the moon for Apollo 11. It is up to 2% for delivery to geosynchronous orbit and woefully small for delivery to Mars' orbit, much less Mars' surface. Space elevators efficiently deliver 70% of the mass at liftoff (the other 30% is the tether climber and will be reused repeatedly) to GEO and beyond by leveraging electricity.

2 MODERN DAY SPACE ELEVATORS

"The idea of a space elevator has captured the imagination of scientists and engineers (as well as writers and artists) for some 125 years and been the subject of studies by Russians, Americans, Europeans, and Japanese. The concept has been extensively refined and developed over the last few decades. All these diverse insights have led to refinements and modifications of the various components making up the entire system (its architecture). To date, there have been eight such architectures." [11] The future of space elevators will grow through a Galactic Harbour architecture approach. Galactic Harbours are the volume encompassing an Earth Port while stretching up in a cylindrical shape to include two space elevator tethers outwards towards apex anchors. "The case for space elevator architectures has grown stronger over the last five years as candidate materials for its tether have been tested successfully" [12]. The estimate is for three commercially competitive Galactic Harbours to be built during the developmental phase between 2035 and 2043, as shown in Fig. 3. When you assess humanity's movement to GEO and beyond, there is a demand for a permanent transportation infrastructure that can move massive logistics to GEO and beyond with environmentally-friendly operations.

This Galactic Harbour concept has an "Unmatched Efficiency" of liftoff to GEO and beyond. The efficiency of space elevators is in the range of 70% of liftoff mass arrives at its destination. The need for high efficiency delivery of logistics support to all of humanity's movement off planet is important to recognize. The development of modern-day space elevators focuses on the following statements: (a) space elevators are ready to enter engineering development [13, 14], (b) space elevators are the green road to space [6], (c) space elevators can join advanced rockets inside a dual space access architecture[3], and (d) the capability of space elevators dwarfs advanced rockets rapidly because of its unmatched efficiency of delivery, environmentally friendly operations, and the ability to beat the rocket equation [3].

3 NEPTUNE MISSION CONCEPT

In the case of solar system missions, a single space elevator would be chosen as support infrastructure which would lift 5,000 tonnes per year at the start [thus 30,000 tonnes when reaching Initial Operations Capability with six space elevators] and then move up to 28,000 tonnes per year per space elevator when fully operational [15]. This capability to support the interplanetary exploration and science projects will revolutionize the conceptual approach to those missions. This paper is proposing an aggressive mission for humans to have a round trip to Jupiter with a space system capable of supporting a decade long mission. The high release from a space elevator will ensure velocity to reach Jupiter while the design of massive nuclear

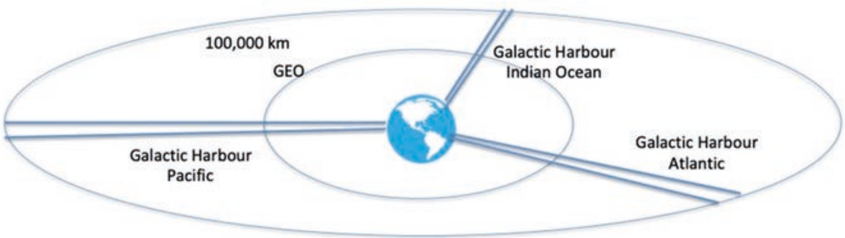

Fig.3 **Three Galactic Harbours. (Swan image)**

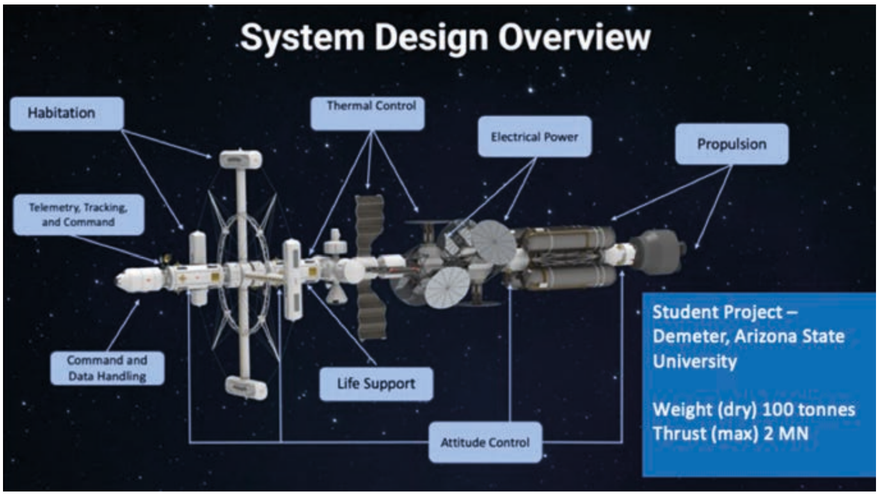

Fig.4 Mission Concept Space System [16].

propulsion will ensure a return trip. The concept is as follows:

3.1 Mission Spacecraft: During an academic review of a student project (capstone class on space system designs – Professor Boehmer at Arizona State University) a student team presented the space system image defining their concept in Fig. 4 [16]. This Space Train resulted in a human occupied tour of the solar system with nuclear power, nuclear propulsion, rotating human habitat, and plenty of extra mass capacity to bring along any number of experimental payloads to investigate the region around the trip path. The students have allowed the author to use their image and discuss the capabilities of their remarkable work.

Using their design, with the addition of the release from a space elevator, the vehicle would travel for less than 300 days to reach Neptune, slow down and rendezvous, investigate the region, send smaller science mission spacecraft to assess the environment, and gather science before returning home with gravity assists and massive propulsion [16]. The design shows nuclear propulsion and power with a rotating crew habitat for living inside an artificial gravity environment. Their mass estimate was a 100 tonne space system. However, for the space elevator design supported mission, the mass could be as big as required, but definitely at least 10,000 tonnes. The following paragraphs show off a mature space system assembled at the apex anchor garage and how permanent space infrastructures enable such a mission.

3.2 Extreme Velocity

When leaving from the science length space elevator (163,000 km long), the inherent velocity is 12.35 km/sec released in the direction needed every 24 hours. Fig. 5 shows the variation of velocities from space elevators: GEO (3.1 km/sec – matching the orbital characteristics there), 100,000 km altitude (7.76 km/sec – enabling flights to Mars with no rockets), and 163,000 km altitude (12.35 km/sec – fast enough to leave solar system with no rockets). The key is that this is initial velocity and the addition of nuclear rockets will enable rendezvous and landing along with the ability to increase the velocity while travelling. In addition, there are several mechanical methods to increase the velocity off the tip of the rotating tether with an increase in the velocity of approximately 10 km/s [17, 18]. For the mission concept being discussed, the increase should lead to a velocity towards Neptune in the range of 25 km/s, thus 273 days to Neptune (with one gravity assist). This ability to depart from above the gravity well at great speeds will revolutionize support to exploration and science beyond GEO.

3.3 Assembly above the Gravity Well

A significant capability when looking at space elevators is the ability to assemble space systems of any mass above the gravity well. When the tether climber delivers its payload to the apex anchor garage, assembly can begin for huge spacecraft required for significant missions beyond Earth. After less than two years of assembly in the apex anchor garage, the resulting mission spacecraft could be 10,000 tonnes leaving at 25 km/s to reach Neptune in 273 days [19]. This large science and human mission would have tremendous capability along the way and at Neptune. This is made possible by the two factors – rapid release and assembly above the gravity well. Fig. 6 shows the concept of an assembly plant at the top end of the tether. These are the transformational characteristics that can make a difference when talking with potential customers. We change the paradigm in all things space (at GEO and beyond) and need to expand upon this concept.

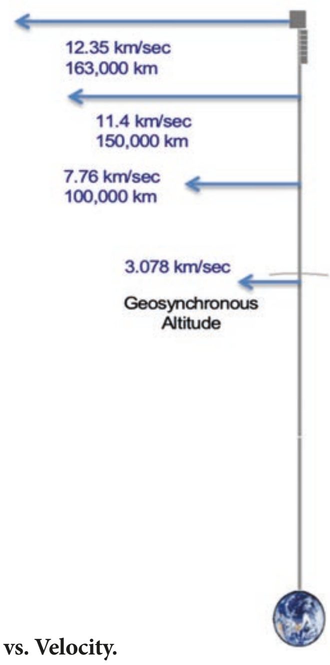

Fig.5 Altitude vs. Velocity.

4 CONCLUSIONS

The previous discussions have laid out an approach for understanding space elevators' characteristics as a transformational space access system that is indeed a permanent infrastructure. The concept has matured into the modern-day space elevator and is ready to begin development. This recent level of understanding has surfaced because there are now several basic materials that should mature into satisfactory tether material [12].

There will be a massive change of vision for interplanetary movement when delivery of mass is efficient, inexpensive, timely, environmentally friendly, daily, and supportive. It turns out the revolutionary transportation capabilities of space elevators open up immense possibilities and ensure humanity can "bring with them" the essential elements for survival and aggressive growth. This new vision of space elevator architectures will change the thinking for off-planet migration – we **can** bring it with us!

A discussion of various mission needs, when analyzing logistics support for destinations, will start the critical discussions of "how much carrying capability" is required by each supportive infrastructure: when, to where, and their priorities. In the past, the rocket approach restrictions valued lightweight and compact designs of support equipment while the space elevator permanent infrastructure will enable mass to be moved to desired destinations easily. The driving function for infrastructure design becomes a description of the customers' needs, not light weight designs. Massive movement of support logistics can occur daily to any solar system location with "on-time" delivery a standard.

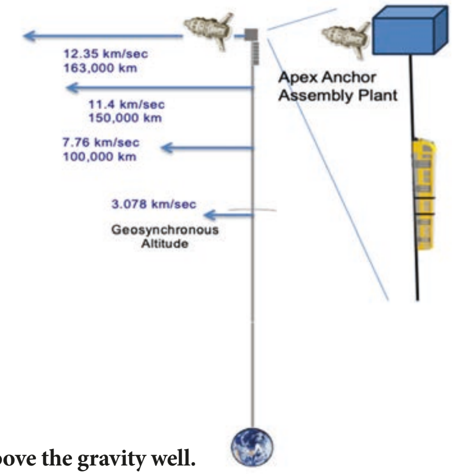

Fig.6 Assembly above the gravity well.

An interesting insight in parallel with this analysis says that planetary scientists can be offered as much mass as they require for any of their missions. There will be zero restrictions for scientific instruments going to any place in the solar system - including the survival from the shake, rattle, and roll of rocket launches. If you cannot include it in one 14 metric tonne payload capable tether climber, you can assemble parts at the apex anchor garage and release them daily towards any destination.

But let us also remember the question: why space elevators? The answer: unmatched efficiency, speed and mass movement with a permanent space transportation infrastructure that is environmentally friendly! (70% vs. 1% to Moon). Now the science and exploration communities can make their space system as large as they need and reach their destination quickly!

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Received 25 August 2023 **Approved** 28 September 2023