Space Sustainability while Transforming Access to Space – Modern-Day Space Elevators

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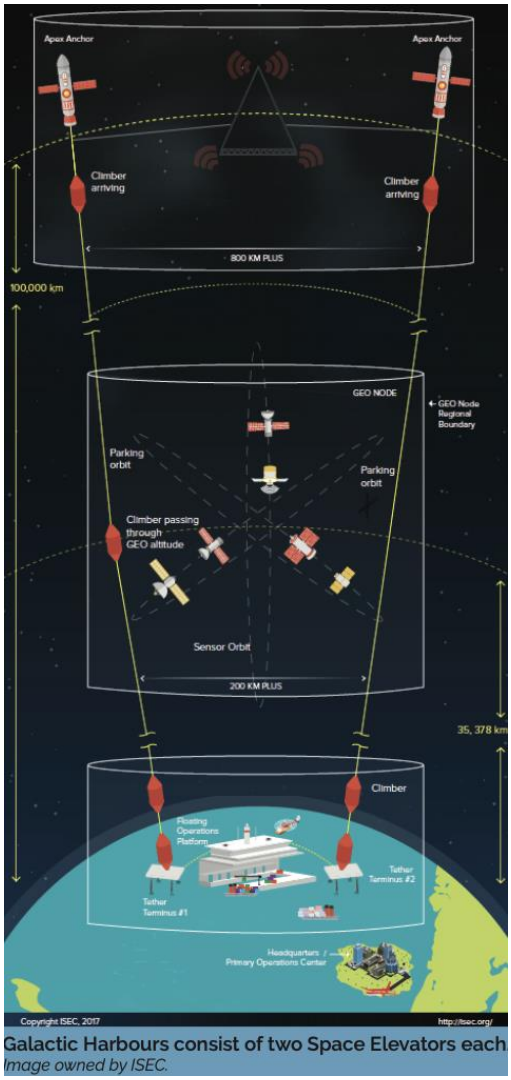
ABSTRACT

Sustaining the environment of space and improving the health of the Earth are major missions of future Modern-Day Space Elevators. The remarkable strengths of a permanent space access infrastructure will result in not only a "Green Road to Space" [no burning of rocket fuel in our atmosphere, and no debris left along the path to mission destinations] but routine, daily, safe, inexpensive and massive logistics operations. Not only will the fully operational capacity of six space elevators deliver 173,000 tonnes to GEO and beyond per year; but, it will accomplish this with a delivery statistic of 70% of the pad mass will reach its mission destination. These strengths emphasize the capability to monitor Earth and support humanity's needs but also take care of the space environment with its operational strengths. This combination ensures full Space Sustainability. This discussion will share the developmental plans for space elevators and then explain the remarkably transformational characteristics of Modern-Day Space Elevators which will lead to Space Sustainability.

1 Introduction

Modern-Day Space Elevators will be the Logistics Giant enabling the movement off planet as a starting point for our robust and exciting future. The first generation of space elevators will ensure that humanity can leap off Earth with a robust 170,000 tonnes per year with daily, routinely, safely and with inexpensive operations. This future will enable cities to grow on our Moon and settlements to blossom on Mars with thousands of dwellers. There will be no match in capacity nor efficiency as Modern-Day Space Elevators will provide 70% of the mass at the Earth Spaceport to their destinations such as geosynchronous, lunar or Martian transfer orbits. This compares to the rocket equation that delivers only 4% of the pad mass to low-Earth orbit, 2% to GEO, and 1% to lunar and Martian orbits.



Galactic Harbours consist of two Space Elevators each
Image owned by ISEC.

Figure 1: Galactic Harbour Architecture

This SRI 2026 World Congress has several missions to ensure the "Quality of Life on Earth and Beyond." Some of the individual goals of this Congress are to rethink our mission, promote civilization's expansion into space, connect aerospace and new space companies and individuals, as well as accelerate technologies for civilian space growth. As the authors look into the future of moving off planet, we believe Modern-Day Space Elevators will support those goals; but, they will also expand our reach through their transformational and revolutionary aspects while defeating the rocket equation.

Modern-Day Space Elevators will greatly enhance the sustainability of space AND support the betterment of Earth. The key to space sustainability is the fact that elevators, as bridges to space, will literally become the "Green Roads to Space" as they do not burn rocket fuel in the atmosphere nor leave debris along their path to mission destinations. In addition, by providing massive satellite components to geosynchronous (and beyond) many missions essential to Earth's sustainability will be fulfilled;

such as, energy sources (space solar power), weather warnings, navigation support and improved communications around the globe can actually be realized.

2 Modern-Day Space Elevator Architecture

The full operational characteristics of Modern-Day Space Elevators have been described often (see body of knowledge at www.isec.org). Figure 1 of a Galactic Harbour emphasizes the strengths of two tethers stretching vertically from an Earth Spaceport towards a GEO Spaceport and then continues up to Apex Anchor Spaceports. The concept for early development is to have three Galactic Harbours distributed about the equator with commercial and/or government competition between each as driving factors for rapid development. Tether climbers leave the Earth Spaceport routinely, daily, safely, inexpensively while being the Green Road to Space with approximately seven-day trips to GEO Spaceports and then another ten days to Apex Anchor Spaceports. The majority of the first ten years will be supporting the "outgoing" logistics for our customers with future growth into "downward" operations and then in the distant future human transport. Initial customer support will be focusing upon the GEO region and CIS-Lunar growth leading to the transport of massive payloads to Mars settlements. During this early time period, Galactic Harbour operations teams would develop a Dual Space Access Strategy with advanced rockets enabling humans to ride through radiation belts rapidly and logistics requirements heavily supported by space elevators.

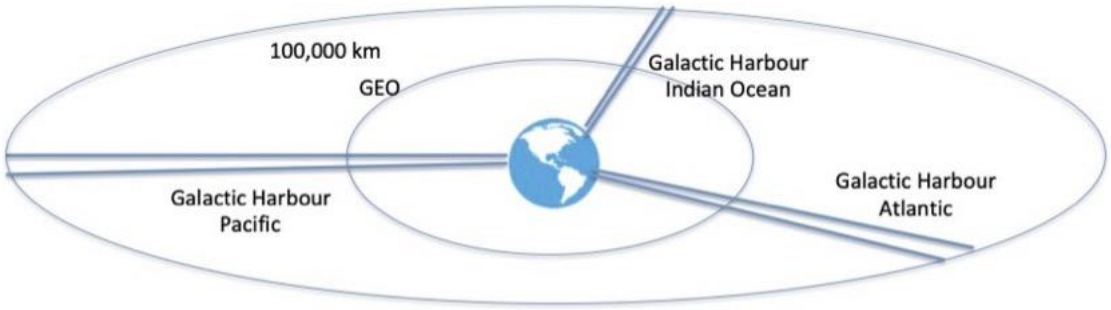


Figure 2. Global Layout of Galactic Harbours

3 Space Elevator Strengths

When looking at the characteristic of Modern-Day Space Elevators, it is obvious that the transition to permanent space access infrastructure is natural. Their major strengths are transformational, but there are many more revolutionary characteristics inherent in this approach to lifting payloads. As space elevators have the inherent strengths of bridges, it is easy to compare small boats crossing a big river to the bridge to space with space elevators. The essential strengths of Modern-Day Space Elevators are shown with the list below:

- Green Road to Space (no burning of rocket fuel in atmosphere and no debris left along their path)
- Permanent bridge-like characteristics: daily, routine, inexpensive and safe
- Massive delivery of customer requirements with initial capability of 30,000 tonnes per year to GEO and beyond growing to 170,000 tonnes per year when the architecture is mature [note; humanity only lifted 20,000 tonnes to orbit between 1957 and about 2020]
- Revolutionary delivery statistics of 70% of pad mass to GEO and beyond [note: the rocket equation limits delivery of only 4% of pad mass to LEO – 2% to GEO – and only 1% to lunar orbit]
- Daily releases to Mars transfer with tremendous velocity (7.76 km/sec) from above the gravity well (no 26 month wait for planetary alignment). Recent studies conducted at Arizona State University, with Professor Peet as the lead, resulted in transit time as low as 61 days to Mars with an average of around 140 days.[1]
- Assembly of larger space systems at spaceports enables huge spacecraft released for future missions. This includes storage and assembly. Each spaceport has the strengths of "truck stops" which include – acceptance or release of payloads, storage of space systems. Assembly of very large space systems and then, of course, refueling and repair as required.
- Elimination of rocket restrictions such as payload fairing sizes and volume.

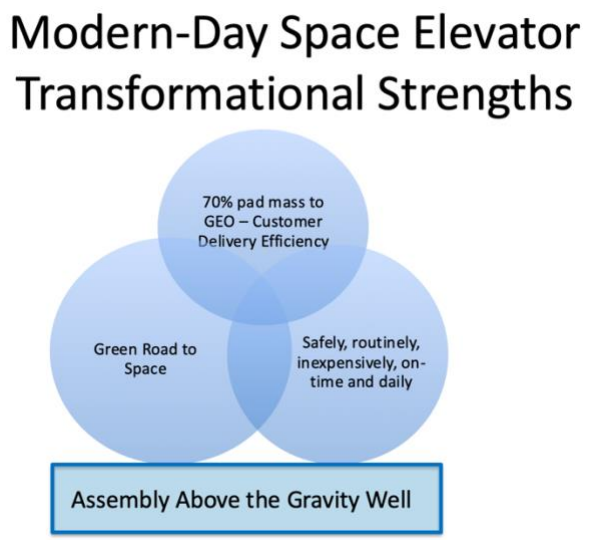


Figure 3. Transformational Strengths

3.1 Modern-Day Space Elevator Sustainability Characteristics

When the capability exists to create large space systems by assembly at GEO and Apex Anchor spaceports, the restrictions of rockets dissapeaar. The ability to assemble huge space systems above the gravity well and then release them at tremendous speeds opens up our solar system without restrictions of size, mass, and velocity. The tip of the space elevator [Apex Anchor spaceport] is traveling at 7.76 km/sec while it is above the gravity well – resulting in tremendous energy for very large spacecraft enabling space to space transportation concepts not even thought of as yet. When mature, Galactic Harbour infrastructures will deliver 170,000 tonnes of space systems to anywhere in our solar system each year resulting in capacities not even dreamt of by rocket designers as their rocket equation limits them to less than 1% of the pad mass to our moon or planets or free space (L-5) concepts.

Space elevators create opportunities with massive delivery of material, and they will enable that delivery to be accomplished anyplace in our solar system in a timely manner as they originate above the gravity well where we are already traveling at the speed of the planet Earth and have our own additional velocity from the rotation in addition. All this will be accomplished on a Green Road to Space saving the Earth's atmosphere while conserving our space environment.

When analyzing the vision of Space Sustainability ["responsible, secure, resilient and peaceful use of space to ensure the long-term viability of space activities."[2]], the concept of a permanent infrastructure ensuring environmentally friendly operations with tremendous delivery efficiency and massive delivery capability, the implications are that Space Elevators must be initiated to help save the environment and enable humanity to move off planets in the very near future.

One of the key elements of Modern-Day Space Elevators is the ability to operate as this Green Road to Space with no debris left behind nor burning rocket fuel inside our atmosphere. Tether climbers lift mass to the customer's destination with electricity and the assembly of larger space systems along the path with high velocities [not created by rockets] when released. Of course, the newly assembled space system would have added rocket motors for tasks like rendezvous, station keeping, landing or trajectory updates. This leads naturally to the realization that Modern-Day Space Elevators will be major contributors to the global emphasis of space transportation infrastructures leading to "Space: Driver of Space Sustainability" – the newly proposed United Nations Sustainability Goal #18. This Green Road to Space will not only contriubute through its movement of huge logistics from Earth to destinations at GEO and beyond; but, it will enable so many space programs impacting everyday life on Earth ensuring success across the hopes of the planet and enabling missions not achievable by rockets. Specifically, space elevators will have direct positive impacts upon the following UN Sustainable Development Goals:

7 Affordability and clean energy

9 Industry, Innovation, and Infrastructure

11 Sustainable Cities and Communities

13 Climate Action

16 Peace, Justice & Strong Institutions

17 Partnerships for the Goals

The emerging concept of Orbiting Data Centers has tremendous potential for helping humanity with massive data movement, storage, and analysis in locations that are better aligned with operational needs and sustainability on Earth and in Space. As LEO concepts mature towards geosynchronous (or Apex Anchor) locations for these data centers, the strengths of permanent infrastructures leaps out in front of any other options. The ability to assemble these data centers at GEO Spaceports will leverage Green Road to Space

characteristics while creating these huge space structures in a benign environment with massive support infrastructure. The continuous solar environment would enable gathering of power and help moderate the temperature issues with the vacuum and cold of space. Permanent infrastructures will also enable many operational needs such as maintenance or improvement of capabilities through assembly in orbit. The capability to lift massive components and then assemble them at GEO will leverage the strengths of these permanent infrastructures. In addition, they will provide customers the needed analysis and communication. The beneficial elements of space elevators for GEO locations of massive orbiting data centers focuses around high capacity of available energy, low-cost transportation, assembly in orbit for rapid implementation, and continuous logistics from a permanent location at GEO Spaceports. In addition to the benefits related to mass, energy, assembly, and communications, there are additional advantages to Artificial Intelligence and High Power Computing (AI/HPC) data centers located at the Apex Anchor:

- **Lifecycle operations**: Data centers need hardware refresh, repair, and software upgrades; space elevators are uniquely suited to service that ongoing logistics and sustainment tempo.
- **Decision assurance**: Orbital compute power can be dedicated to run trusted climate models, formulate disaster response, provide a secure communications hub, and formulate planetary-defense missions at the Apex Anchor. This approach increases data security and confidence in sensitive operations in support of the UN SDGs and other common benefits.
- **Apex Anchor as a trust hub**: The Apex Anchor can be considered a persistent platform integrating logistics, energy, secure compute, validation, and response coordination.

3.2 Apex Anchor Data Centers: Trusted Compute Infrastructure for Sustainability

This new concept of Modern-Day Space Elevators as orbiting data centers for AI/HPC, secure storage, and real-time data processing strengthens the sustainability value proposition. Growing demand for AI computation and data-intensive services is increasing pressure on terrestrial data-center infrastructure, including land use, power availability, cooling, and water consumption. Space-based data centers remain an early-stage concept, but they are increasingly relevant to discussions of sustainable infrastructure, resilient communications, and space-enabled decision support.

Modern-Day Space Elevators could change the feasibility of such systems by addressing several of the largest barriers to orbital data-center deployment: mass, cost, assembly, maintenance, and refresh cycles. Data centers are not static assets. They require periodic upgrades to processors, memory, storage, networking systems, thermal-control components, and power electronics. A permanent Green Road to Space would allow modular data-center elements to be transported to GEO and beyond, assembled in orbit, serviced over time, and upgraded as technology evolves. This is a different paradigm from launching isolated, self-contained spacecraft that must perform for years with limited physical access.

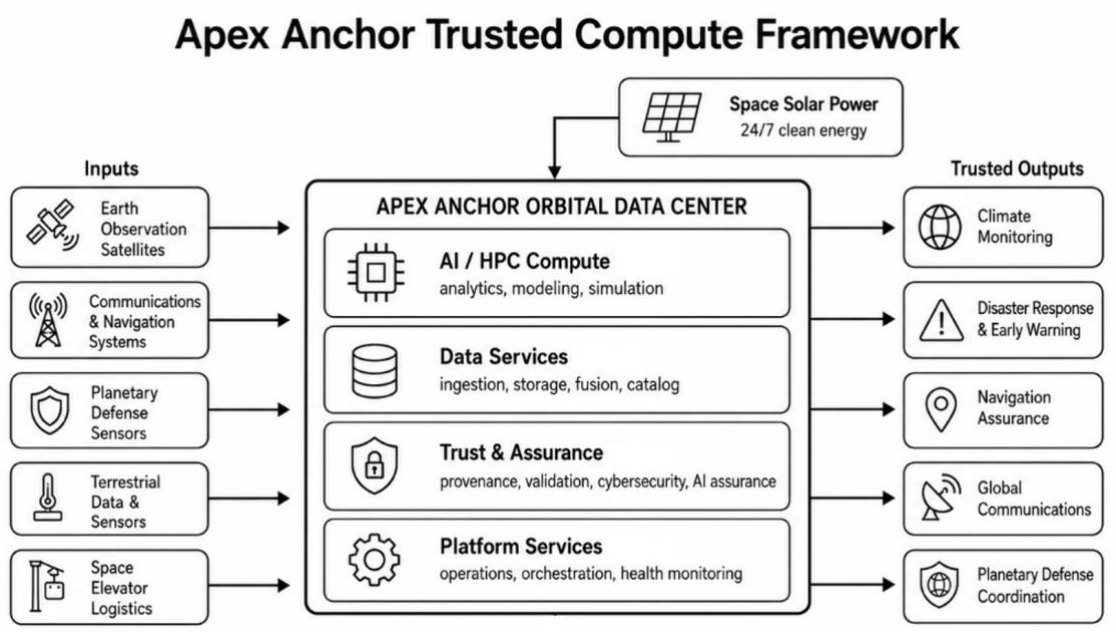


Figure 4. Decision-assurance flow enabled by Space Elevator infrastructure

Persistent logistics and orbital compute convert raw space and Earth data into validated, high-confidence information products for climate action, disaster response, navigation, communications, and planetary defense. This permanent Space Elevator infrastructure will enable decision-assurance as well as robust operations.

This capability also strengthens the connection between Modern-Day Space Elevators and the UN SDGs. Orbital data centers and trusted compute infrastructure support industry, innovation, and resilient infrastructure. High-integrity climate and disaster response data support sustainable cities and climate action. Secure, auditable, and shared information systems support stronger institutions and international partnerships. In this sense, the Space Elevator is a transportation system and an enabling infrastructure for sustainable energy, trusted data, and better decisions on Earth and beyond.

4 Conclusions

Permanent infrastructures, such as bridges, can deliver 70% of the mass on the pad to GEO and beyond leading to the conclusion that Modern-Day Space Elevators will enable industry to expand rapidly towards the stars. Going to GEO, the Moon and Mars will become routine, daily, inexpensive and have the characteristics of Green Roads to Space, thus ensuring Space Sustainability. With these promises, major investments should be initiated ensuring the goals of SRI are fulfilled. Permanent infrastructure establishments will ensure fulfilment of the SRI Goals for 2026 World Congress:

- Raise awareness of the current risks to civilization and culture
- Promote accelerate civilian space development
- Debate the priorities in space policy, philosophy and strategy
- Build coalitions to advance industrialization and settlement beyond Earth

Looking at the permanent characteristic of Modern-Day Space Elevators, it is obvious that the transition to space elevators is natural and inevitable. Their major strengths parallel the goals of this World Congress at many levels.

Indeed, the establishment of Galactic Harbour architectures will greatly improve the “Quality of Life – On Earth and Beyond!”

REFERENCES

[1] Swan, Peter, Fitzgerald, M, Swan, C, Peet, M., "Fast Transit to Interplanetary Destinations," 2020 International Astronautical Congress - CyberSpace Edition

[2] Space Sustainability: A View from the Global Space Industry,” 000 IAF IRC Sustainability White Paper_2024_09_15

Body of Knowledge of Modern-Day Space Elevators at www.isec.org