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Today's Space Elevator Status

Peter Swan* Cathy Swan & Michael Fitzgerald*****

*International Space Elevator Consortium, Paradise Valley, Az, USA dr-swan@cox.net.
**SouthWest Analytic Network, Inc. Paradise Valley, Az, USA dr-swan@cox.net.
***Galactic Harbours Assoc., Rancho Palos Verdes, Calif. USA._Michael.Fitzgerald@cox.net

Abstract

The Space Elevator has developed significantly over the last ten years; and indeed, 2019 was a ”break-out” year. We have made the leap from thinking about future concepts to the realization that an aggressive proposal for early developmental activities must be initiated. A phase change in Space Elevators has occurred with several elements from: Space Elevator to Galactic Harbour; wishing for a material for the tether to having one successfully tested; an immature plan to a preliminary positive assessment of each technology within each system segment; and, quiet discussions in small groups to advocacy across the world. The placement of the Space Elevator inside the international and strategic mosaic of space will ensure that the exploitation of this tremendous new access to space will be leveraged. The strategic mosaic of space is taking form. It is composed of trade, enterprise, research, and exploration. The ability of the Space Elevator to be a logistics giant will ensure that this movement off-planet will result in an economic engine on (and near) Earth. The beauty of this future for a space transportation revolution is that it is fast approaching. The Space Elevator community is rapidly arranging to meet it with enthusiasm and knowledge. Movement off-planet will demand low cost access to space. The Space Elevator will provide that as a daily, routine, massive, and environmentally friendly infrastructure that will resemble ”train operations.” This infrastructure for transportation leads to a prediction: The Space Elevator will be the Transportation Story of the 21st Century!

1.0 Introduction: We believe that the Space Elevator program has developed its concept to such a degree that it is ready to initiate engineering testing! This document illustrates the status of the Space Elevator project as of the Fall of 2019. "Show-me" is the methodology of this paper. This is to emphasize the fact that the Space Elevator community is ready to proceed to engineering testing. In addition, we recognize that this is not a space project -- it is a transportation infrastructure. In fact, there is much to be said for the statement:

"The Space Elevator will be the transportation story of the 21st Century."

An interesting change in thinking has occurred. The International Space Elevator Consortium sees the future, but knows that the space elevator is no longer a "future project" but one that should be initiated in the near term. This phase change in Space Elevators has several elements, to include movement from:

- Space Elevator to Galactic Harbour
- Wishing for a material for the tether to having one successfully tested
- An immature plan to a preliminary positive assessment of each technology within each system segment
- Quiet discussions in small groups to advocacy across the world.

One of the statements the space elevator community uses is "show me." This is a critical point in that we have shown great progress and are ready to start significant testing of several components of a full up Space Elevator. Recently, the Japanese launched an in-orbit test vehicle to experiment with "up-down" movement of a climber on a tethered satellite. The vehicle was launched to the ISS and then released from there. The problem with space systems is that they are difficult missions in a harsh environment. While this particular mission was not a success - we are off and running with in-orbit testing of space elevator concepts.

1.1 Case for Space Elevators: To fully understand the motivation for this paper, one must understand that the Space Elevator community believes it is ready to start a program. The following chart points out the main thrusts of our "Case for Space Elevators."

Case for Space Elevators

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.

www.isec.org

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 tether material, half meter single molecule already made in the lab in 2D form.

Chart 1 - Case for Space Elevators

To support these four points about where the Space Elevator is today, there is a list of strengths of a Space Elevator transportation infrastructure inside a Galactic Harbour. [the baseline is expected to have two Space Elevator tethers inside a Galactic Harbour with roughly three Galactic Harbours dispersed around the equator.] These strengths are:

- 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

2.0 Where is the Space Elevator - Today? The Fall of 2019 seems to be the "breakout year" for the concept with so many activities culminating during the conferences (International Space Development Conference - NSS - June; International Space Elevator Conference - ISEC - Aug; and, International Astronautical Congress - IAF/IAA/IISL - Oct.). Expansion of this paper's concepts are in "Today's Space Elevator."

2.1 Where is the Space Elevator - Today? Over the last ten years the following big activities have occurred:

- ISEC produced eight year-long studies with resulting reports.
- The International Academy of Astronautics produced two study reports supporting the concept.

Year	Study Title	Organization
2020	Interplanetary Mission Support (in development)	ISEC
2019	Road to the Space Elevator Era (four year long)	IAA
2019	Today's Space Elevator	ISEC
2018	Design Considerations for Multi-Stage Space Elevator	ISEC
2017	Design Considerations for Space Elevator Modeling and Simulation	ISEC
2016	Design Considerations for GEO Node and Apex Anchor	ISEC
2015	Design Considerations for Earth Port	ISEC
2015	Space Elevator: An Assessment of the Technological Feasibility and the Way Forward (four year long)	IAA
2014	Space Elevator Architectures and Roadmaps	ISEC
2013	Design Considerations for the Tether Climber	ISEC
2012	Space Elevator Concept of Operations	ISEC
2010	Space Elevator Survivability and Space Debris Mitigation	ISEC

Note: IAA - International Academy of Astronautics: ISEC - International Space Elevator Consortium

Chart 2: Space Elevator Studies Conducted

- The Obayashi Corporation conduced an independent study that focused upon humans on the Space Elevator and massive movement of space based solar satellites to GEO.
- Internal ISEC assessments were provided within a series of Chief Architect's Notes.
- The agendas of major international space agencies are aligning to target human presence and/or settlements on the Moon and Mars.

2.2 Galactic Harbour Concept Development: Recently, the development of Space Elevators has grown to include connections with the total transportation infrastructure around the globe, realizing that the movement to space is only the next step towards three-dimensional infrastructure support. The image shows the concept of a payload being delivered by boat or plane to the Earth Port and then deployed up one of the Space Elevators to a desired orbit - to the GEO Region, to the Apex Anchor, or to Interplanetary trajectories. The strategic approach for the movement of payloads because:

Our "strategy" is to link the Space Elevator Transportation System to the Space Elevator Enterprise System within a unifying vision: … the Galactic Harbour.

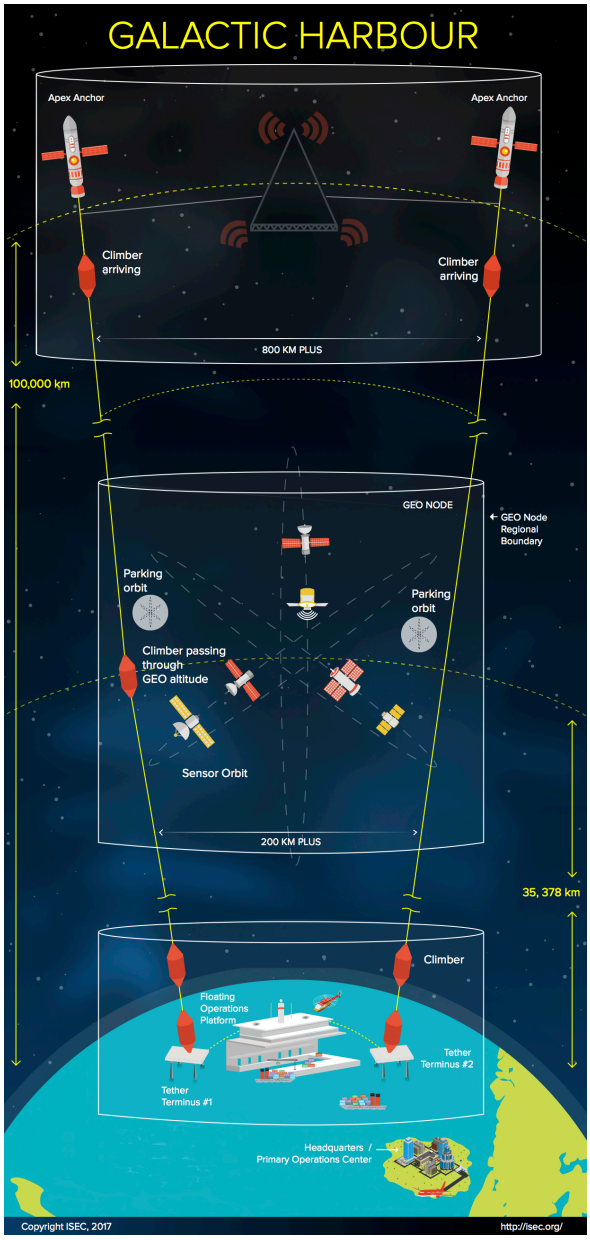

Figure 1 Galactic Harbour (2017)

2.3 Tether Material Available: Recently, the presentation of the newly discovered single crystal graphene in a single molecule 0.5 meter long and 0.1 meter wide format amazed the world. The realization that this approach could result in the continuous growth of material longitudinally leads to the statement that this material and this approach could produce very long - very strong material which is perfect for Space Elevators. As there are two materials that have been shown to have these properties (single crystal graphene and single crystal boron-nitride) the future is bright for Space Elevator tethers. The estimates are for

long lengths of single crystal graphene of 130 GPa linear tensile strength with a density of 2.2g/cc, or approximately 59 mega-Yuri specific strength. This should more than suffice for Space Elevator tethers of the future. So, we wait for further development of the material that has been produced in the laboratory. The good news is there is a tremendous demand for it throughout the commercial materials industry. The costs to develop will be spread between the touch-screen market, aircraft and spacecraft structures arena, and so many other commercial users. Recently, Nixene Ltd. stated:

> *"Joint planning between ISEC and Nixene Ltd anticipates the development testing and deployment of the Space Elevator tether within the next decade or two at a cost of $30bn."*

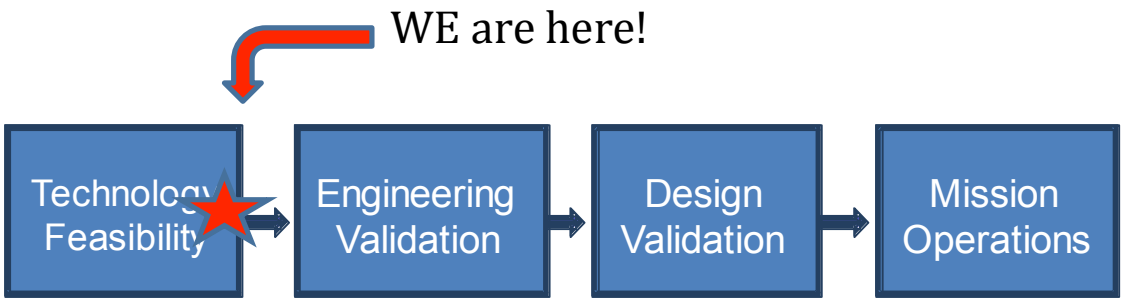

Figure 2, Space Elevator Development is HERE

2.4 Engineering Development, Where are We? The technology development approach is to build around a set of well-defined demonstrations, inspections, tests and simulations to move the concept forward. When one follows this lead, the technology development matches a tried and true sequence of phases. The engineering teams around the Space Elevator and Galactic Harbour development believe that we are very close to exiting the technology feasibility phase. This will require quite a bit of testing at the sub-system and system level for each of the major segments of the Space Elevator. This complexity is normal for all mega-project developments and is well understood. The rationale for exiting the first phase boils down to the readiness assessments as described for the phase one exit criteria, different for each mega-project. More details are shown in the recently published study report, ***Today's Space Elevator***. (available on www.isec.org)

- Document technology readiness state and determine if the technologies are State of Art (SOA) or State of the Industry (SOI) or State of the Market (SOM)
- Establish readiness level rationale for all portions of the program. Given that the technology availability has been demonstrated, the level of readiness can be established for each program segment.
- Set success criteria regarding engineering validation – the second phase. Prudent acquisition planning calls for early design reviews. “Show me” means a lot at this point.

3.0 Next Steps for Galactic Harbours: Today's space world is so different than the one we grew up with. The beauty of today is that we have tremendous forces that quickly moved space project developments forward. Human spaceflight off-planet is focusing on returning to the Moon with NASA vocally pushing for 2024 as "boots on the Moon to stay." A tremendous objective and reasonable when understanding the engineering strengths across America, European Space Agency, Japanese Space Agency, Chinese Space, and others. These forces are peaking with the motivation to be there in the first wave of activity, soon after the start of the coming decade. This new mosaic of space will include so many diverse projects with huge goals and remarkable people attempting large "moon-shots." However, the new players are disrupting the flow on "natural" approaches to space. The commercial world is leaping out into the challenges and showing very successful components of a space mosaic. Elon Musk has already stated that he wants a colony on Mars within his lifetime (he is 48) -- numbers vary from 10,000 to 100,000 people within that time frame. His approach is to develop a large rocket that can transport over 100 passengers on voyages of over eight months to Mars. This is remarkable and game changing until you realize that he is not alone. Jeff Bezos has developed rockets on his own and will be moving people to space within four months. He also has shown his Blue Moon lander that will handle massive amounts of payload versus previous government concepts. He will get the Blue Moon lander to the surface by launching on his own rockets, New Glenn. These two are only the tip of the iceberg. There are approximately 25 billionaires participating in various space projects. The combination of government and commercial space projects going to the Moon is exciting. However, they are still constrained by the rocket equation. The Space Elevator will provide a much better alternative for moving supplies and other mission essential equipment - not people just yet; however, inexpensive, routine/daily, environmentally friendly, and safe transportation will be a winner.

3.1 Need to be Included: The discussions today about movement off-planet have not included Space Elevators in any meaningful way. This needs to be changed as the Galactic Harbour brings so much to the "party." The first mission of the space elevator community is to reach out beyond our own groups and touch the large off-planet space movement. The Space Elevator MUST be included in the discussions occurring about big projects moving forward with tremendous energy and backing. The strengths of the Space Elevator are so tremendous, these projects cannot move a foot or as far without including a permanent transportation infrastructure. The simple statement is that Space Elevators will ENABLE interplanetary mission support at reasonable costs and remarkable characteristics. Discussions about space projects going to GEO and beyond must have participation and contributions from the Space Elevator community.

3.2 Establishment of a Space Elevator Institute: Recognition of the availability of Space Elevators in the not-too-distant future should lead the space community to recognize that we need an academic institute addressing its various needs. The creation of a Space Elevator Institute will help the community address, and

orchestrate responses to, critical questions, issues, and topics. This Institute would research major questions and ensure they are investigated leading to discussions within the larger space community, not just the Space Elevator community. There are two major thrusts that can be leveraged to start an institute:

1) Transportation Baseline Studies: There are many trades that need to be addressed in the near future to ensure that the current (IAA and ISEC) baseline is reasonable and should be supported moving forward. These studies would include:

- Engineering concerns in the atmosphere
- Choice of material and tether approach
- Design of initial deployment satellite
- Develop an engineering simulation capability to represent Space Elevators

2) Lead the Investigation into Chosen Topics: This pursuit of knowledge will be crossing engineering (to pursue engineering trades) and research(to pursue basic topics) arenas such as:

- Location of Earth Port
- Geosynchronous Orbit designation
- Space Debris mitigation, communication and coordination
- GEO Region monitoring and coordination
- Quantify interplanetary mission support needs
- Develop mission based simulations to represent daily operations
- Mechanical, thermal and electromagnetic properties of the bulk tether material
- Effects of magnetospheric fields and solar radiation on tether motion and climbers
- Characterization of possible perturbations of tether motion and estimation of their effect relative to stable tether oscillations
- Alternative types of tether-gripping mechanisms such as linear motors
- Alternative types of radiation protection such as active shielding.

4.0 Conclusions and Recommendations: This quick summary of the status of Space Elevator development has been to layout an understanding for the reader that the Space Elevator/Galactic Harbour concept is ready to be included inside major discussions on movement off-planet (be it GEO or interplanetary). The Space Elevator community is ready to engage.

The concept of a Space Elevator Institute has been developed because the community believes it could supply critical analyses on this important topic. Its mission would be:

> "Leverage the understanding of Space Elevators and Galactic Harbours to combine space and transportation futures into a common thread within the mosaic of space!"

The reality is that the future in space is remarkable in its strengths and diversity of projects. The movement off-planet will demand a parallel effort (in addition to rockets) for efficient, low-cost, environmentally friendly, routine, and daily, access to space. The key here is a permanent infrastructure enabling daily massive movement of mission support equipment, supplies and life-support equipment.

The Space Elevator will be the
Transportation Story of the 21st Century

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