Space Elevator Transportation System
SEATTLE 2018

AGENDA

1. Review Progress during 2017
2. Theme for 2018 ➔ “The Space Elevator Transportation infrastructure is closer than you think”!

Michael Fitzgerald
ISEC Chief Architect
August 2018
The Main Message 2017 - The year of change

The Galactic Harbour is the unification of Transportation and Enterprise

Space Elevator Transportation System is the ‘main channel’ in the Galactic Harbour.

- GEO Node
- Earth Port
- Apex Region
- Climbers
- Tethers
- HQ & Ops Center

Businesses flourish as part of the Space Elevator Enterprise System

- Business support to Operational Satellites
- Interplanetary Efforts within reach
- Power and Products delivered to Earth
- Research
Overview

The New Message in 2018

• By the middle of this century, we expect to have an operational Space Elevator Transportation System as part of a burgeoning Galactic Harbour

• The International Space Elevator Consortium lays out seven basic technology readiness statements that validates 2018 theme: The Space Elevator Transportation infrastructure is closer than you think.

• IN Support:

  The Chief Architect presents the seven point preliminary Technology Readiness Assessment, and connects those seven points to the next steps of engineering development for the Space Elevator’s Transportation System; the Main Channel.
Preliminary Technology Readiness Assessment

1. The Earth Port is buildable with today’s available technologies and engineering expertise.
2. The Headquarters / Primary Operations Center is buildable today.
3. The Tether Climber is similar to a today’s satellites, and ISEC sees no technology challenge to the construction of the Climber.
4. The GEO Node and Region technology needs are understood and ISEC assesses that the most of the GEO Node’s Transportation System components can be built now.
5. The Apex Anchor will be a challenge. Its role is key to the building of the Space Elevator, but it is neither a technological nor engineering obstacle. The Apex Anchor can support the Space Elevator Transportation System; and could be built in the near future.
6. The Tether material is the pacing item for the development of the Space Elevator. Currently, there are at least three viable materials that could mature into the needed “strong enough and long enough” material for a Space Elevator Transportation Tether; 100,000 kms long and strong enough to support multiple Climbers.
7. The other voiced challenge to the Space Elevator Transportation System faces is collision avoidance. ISEC, and others, have studied the issue, and collisions are much less likely than most think. Even so, the Space Elevator Transportation System will be advised of approaching debris; even debris smaller than a pebble – in sufficient time to avoid it. Further, the Space Elevator Transportation System will work with the FAA’s Space Traffic Management program ensuring that the Tether operates only within uniquely assigned space locations. This traffic management approach will keep other operating space systems safely separated from the Elevator.
Space Elevator Transportation Infrastructure
-- Architecture Engineering 101 --

Stages of “Maturity”

Our Technology Development Strategy
– our Maturity program -
What are we doing?

Phase One Technology Feasibility & Readiness

1. **Document technology readiness state.** Determine if the technologies are State of Art (SOA) or State of the industry (SOI) or State of the Market (SOM). “SOA” means that only one industry member holds the critical technology; “SOI” means that a few competent industry members can play; and “SOM” means that the technology is widely available and widely used.

2. **Establish readiness level rationale for all portions of the Program.** Given that the technology availability has been demonstrated (SOA v SOI v SOM … etc.) the level of readiness can be established for program segment, component or subsystem. This taxonomy of readiness will be well understood by, and documented in an official readiness assessment per segment; using the rationale set here.

3. **Set Success Criteria regarding Engineering Approach Verification.** Prudent acquisition approaches call for an early preliminary design review (PDR). The PDR is an examination to show that the projected engineering approaches are valid. In this consideration “engineering verification” means that we can build it. If the technology exists, it can be included in a design based purely upon technology maturity. If a component is SOM, SOI or SOA, or is a TRL level 6, some engineering verification information is needed to get through the process. “Show me” means a lot at this point.

ISEC Position Paper # 2014-1; “Space Elevator Architecture and Roadmaps”;

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What are we doing?

Phase Two -- Engineering Approaches.

This Phase will begin soon after a worthy milestone. Seek a wide range of engineering objectives from various members of the industry. Some efforts might reflect a competitive construct of one segment’s envisioned solution, while another effort might be a more collaborative activity. This Phase two activities are driven by six major activities:

1. **Determine if it can be built:** This is the fundamental question. Describe the segment concepts envisioned and assess the various engineering approaches being considered. Ask industry if the engineering approach is valid and does it incorporates the results of an ongoing technology maturation effort.

2. **Examine Industry’s technology maturation approaches:** Review a sample of these roadmaps in industry. It will be clear from the roadmaps that the range and number of needed engineering verification tests are substantive.

3. **Assess schedule & technical risk:** This assessment needs to be very real. Multiple tests, and simulations are the path to ISEC program success; and they are the basis of a long sequence of engineering and design judgments. Conducting the numerous tests, resulting in the proper test data and performance insights is in itself a risky set of ventures. However, proceeding without thorough testing would be beyond risky.

4. **Delineate “On Ramp” Criteria:** Based upon the information on emerging technologies that will not be mature in time, they should be deferred. This is not simply delay; but rather a considered approach of when that capability is (“really”) needed and whether subsequent maturity and testing will be manifest.

5. **Set criteria and standards regarding Design Validation:** By the end of Phase Two ISEC should be able to determine whether or not the Space Elevator can be build by determining the efficacy of specific design approaches. Those design criteria and design standards need thorough evaluation for the sake of technology, schedule and/or cost risk.

6. **Baseline Technical Performance:** By the end of Phase Two, the performance of the envisioned concept can be predicted and will be “baselined.”

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Space Elevator Transportation Infrastructure -- Architecture Engineering 101 --

Stages of “Maturity”

Our Technology Development Strategy
– our Maturity program –
The Space Elevator Transportation System

ISEC’s preliminary Technology Readiness Assessment:
“Start along its Verification demonstration roadmap” …
Pathways demonstrating Technology Readiness for Engineering Verification

- Marine Node Segment
- Tether Segment
- Climbers Segment
- APEX Anchor Segment
- HQ&POC Segment
The Space Elevator

Next Steps

• Technology Feasibility ➔ Pass
• Engineering Verification ➔ Does it work?
• Design Validation ➔ Does it do its mission?
• “…..its closer than you think!”
Catalyzing force
The need to solidify the view into a new plan of action

• In 2017 ➔ The complex inter-relationships of the elevator system AND the future enabled enterprises needed to be resolved; if only to temper apoplexy.

➢ Separate systems identified – a Transportation System and an Enterprise System
➢ “Separate but not segregated” paradigm to be enforced; cross system awareness avoids a ‘bridge to nowhere’ outcome.
➢ Collaborative involvement with Space Industries and other Space Elevators essential
➢ Overall Unifying, Operational View needed … The Galactic Harbour
The preliminary Technology Readiness Assessment

Topic #1
The Earth Port is buildable with today’s available technologies and engineering expertise.
Pathways demonstrating Technology Readiness for Engineering Verification

- Marine Node Segment
- Tether Segment
- Climbers Segment
- APEX Anchor Segment
- HQ&POC Segment
“Space Elevator Columns” are part of the FAA’s Automatic Dependent Surveillance—Broadcast.

Surface of the Earth (ocean)

Bottom of the ocean (variable)

Earth Port underwater security zone (80-100 km diameter)

Atmosphere to approx. 40 km

Ocean water depth 4 to 5 km

Earth Port Boundary

To (From) GEO NODE

Tethers

Climber

TTP Alpha

Floating Operations Platform

TTP Beta

Earth Port at IOC

Space Elevator

Earth Port

Node
The Marine Node Pathway

Earth Port

4 Culminating Demonstrations

Earth Port
Marine Node
Segment Planning Phase

MN# a  MN# b  MN# c  MN# d

MN# 1  MN# 2
MN# 3  MN# 4

MN# b
MN# 1  MN# 2
MN# 3  MN# 4

MN# a  MN# c  MN# d

Earth Port
The Marine Node Pathway

Fitzer 17
The Space Elevator Earth Port Validation Checklist

Functional Requirements  (see ISEC Position Paper 2015-1)

• Connect “H to V” Transportation Chain (shipping and air cargo)
• OGV fleet: tug/barge, hi-speed ferry, long range amphibious and
• Service Craft: off-shore service vessels, harbor tugs, patrol craft, helicopters, seaplanes, drones,
• “City at Sea” including: cargo handling terminal, shops and storage, communications and control center, marina and crew support facilities, client and visitor services....security
• Meteorological and oceanographic monitoring equipment and facilities with wave attenuation system
• Three platforms: Floating Operations Platform (FOP), 2 Semi-submersible Tether Terminus Platforms (TTPs)
• Earth Port will also have responsibility for tethers and climbers to 40km
Key Earth Port Functions

• Horizontal to Vertical Transshipment of the Climber and/or the Payload at the MSSE platform
• Tether Horizontal move management
• RIRO operations
• Human support within the Earth Port
• Payload capture & Movement control (vis the lower altitudes)
• Power provision to the Earth Port
MN #1  Tether Terminus  (RIRO operations)
This demonstration will show that the tether can remain attached to the reel in/reel out housing with the IOC number of climbers attached. The reel in/reel out function will operate at IOC speeds to help manage tension and avoid space debris.

MN #2  Position Management
This demonstration will show that the FOP can maintain its position to the IOC accuracies in the presence of wind, current, and tension. The demonstration will include movement of the platform at IOC speeds to avoid space debris.

MN #3  Attach and Detach
This demonstration will show the ability of the climber and the tether to attach and detach climbers to/from the tether

MN #4  Power
This demonstration will show that the FOP can supply power to the climber for the initial ascent through the earth’s atmosphere
The Earth Port is buildable with today’s available technologies and engineering expertise.

Devil’s Advocate
The preliminary Technology Readiness Assessment

Topic #2
The Headquarters / Primary Operations Center is buildable today.
HQ / POC
Pathways demonstrating Technology Readiness for Engineering Verification

- Marine Node Segment
- Tether Segment
- Climbers Segment
- APEX Anchor Segment
- HQ&POC Segment
HQ / POC Major Functions

- Mission Planning
- Activity Planning and Development
- Mission Control
- Data Transport and Delivery
- Navigation Planning and Analysis
- Spacecraft Planning and Analysis
- Payload Planning and Analysis
- Payload Data Processing
- Archiving and Maintaining the Mission Database
- Systems Engineering, Integration and Test
- Computers and Communications Support
- Developing and Maintaining Software
- Managing Mission Operations
- Financial Management
The HQ/POC Segment

Composed of a number of operations centers

- Primary Operations Center
  - An Ops Center of the Ops Center
  - Overall View of the operating status
- Transportation Operations Center
- Payload (Satellite) Operations Center
- Climber Operations Center
- Tether Operations Center
- GEO Node Operations Center
- Marine Node Operations Center
- (Apex Anchor Operations Center)

Description Each of these centers are amalgams of the needed communications, tracking, forecasting, and monitoring tools. The concept presented is that the Space Elevator Transportation System keeps track of things from product delivery, to the insertion of the satellite into proper orbital position. Positive control of all aspects. The day to day transition approach seemed to be rolling handover – a la flight control centers

Challenge The challenge in this segment is demonstrating how the several centers can share information and notification between and among themselves. A fine software and modeling challenge. Building that operations modeling scheme is the challenge; especially forecasting how such a thing can be upgraded or modified with minimal operations breakdown.

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HQ / POC Demos

The HQ/POC will be successful when it can:
• Communicate with every node
• Control the tether
• Control the Marine Node
• Control the Apex Anchor
• Control System Center of Mass
• Manage System Models
The HQ / POC Pathway

A full range of Integration testing will be conducted concurrent with the Culminating Demos during Far Term activities. Essentially, this testing will validate that all the pieces work together. 4 prime examples are shown.

Stabilization
Telemetry
Payload exchange
Operations

Near Term
Mid Term
Far Term
To IOC And Beyond

Marine'Node!
Tether!
Tether" Climber!
APEX'Anchor' Node!
HQ&POC" Segment!
The Headquarters / Primary Operations Center is buildable today.

Devil’s Advocate
The preliminary Technology Readiness Assessment

Topic #3
The Climber is similar to a today’s satellites and much like the space shuttle. ISEC sees no technology challenge to the construction of the Climber.

SKIP’s Comment: See Ops Concept...
we note that the climber is just another satellite.
We will leverage the 50 plus years of satellite operations
Pathways demonstrating Technology Readiness for Engineering Verification

Demo Demo Demo Demo Culminating Demo

Demo Demo Demo Demo Culminating Demo

Demo Demo Demo Demo Culminating Demo

Demo Demo Demo Demo Culminating Demo

Marine Node Segment

Tether Segment

Climbers Segment

APEX Anchor Segment

HQ&POC Segment
# Tether Climber Demos

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<td>Mid</td>
<td>The Climber can provide power for IOC Climber mass and payload below 40km</td>
<td>TBD</td>
</tr>
<tr>
<td>TR-3</td>
<td>mid</td>
<td>Climber can survive environment up to 40km</td>
<td>Actual environment needs capable tether: Analysis can buy down risk</td>
</tr>
<tr>
<td>TR-4</td>
<td>near</td>
<td>Climber can provide SWAP and data interface</td>
<td>None</td>
</tr>
<tr>
<td>TR-5</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> The Climber is able to climb at IOC speeds carrying IOC payload</td>
<td>Needs capable tether</td>
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<tr>
<td>TR-6</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> The Climber can reduce speed to safe level and can park</td>
<td>Needs partial length tether</td>
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<td>TR-7</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> The Climber can withstand the earth and space environments while carrying the IOC payload</td>
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<td>TR-8</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> The Climber is able to stay on the tether when moving at IOC speeds and parked</td>
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Devil’s Advocate
The preliminary Technology Readiness Assessment

Topic #4
The GEO Node and Region technology needs are understood and ISEC assesses that most of the GEO Node’s Transportation System components can be built now.
Pathways demonstrating Technology Readiness for Engineering Verification

The Culminating Demos for the GEO Node need to be defined.
The GEO Node and Region technology needs are understood and ISEC assesses that most of the GEO Node’s Transportation System components can be built now.

**Devil’s Advocate**
The preliminary Technology Readiness Assessment

Topic #5
Pathways demonstrating Technology Readiness for Engineering Verification

- Marine Node Segment
- Tether Segment
- Climbers Segment
- APEX Anchor Segment
- HQ&POC Segment
The Apex Anchor will be a challenge. Its role is key to the building of the Space Elevator, but it is neither a technological nor engineering obstacle. The Apex Anchor can support the Space Elevator Transportation System; and could be built in the near future.
## Apex Anchor Demos

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<td>AA-1</td>
<td>mid</td>
<td>Reel-out tether</td>
<td>AA-6</td>
<td>mid</td>
<td>Design flexibility for customer construction and assembly</td>
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<td>mid</td>
<td>Reel-in tether</td>
<td>AA-7</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> Recover from anomalies beyond expectations</td>
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<td>mid</td>
<td>Stabilize the initial tether situation – center of mass control</td>
<td>AA-8</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> Customer payload release and capture</td>
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<td>AA-4</td>
<td>near</td>
<td>Simulate normal modes [no climbers], deployment, multiple climbers, solar/lunar effects.</td>
<td>AA-9</td>
<td>far</td>
<td><strong>Culminating Demo:</strong> Customer payload and space tug refueling</td>
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<td>AA-5</td>
<td>near</td>
<td>Illustrate thrust profiles to enable stabilization</td>
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The preliminary Technology Readiness Assessment

Topic #6
The Tether material is the pacing item for the development of the Space Elevator. Currently, there are at least three viable materials that could mature into the needed “strong enough and long enough” material for a Space Elevator Transportation Tether; 100,000 kms long and strong enough to support multiple Climbers.
Pathways demonstrating Technology Readiness for Engineering Verification

- Marine Node Segment
- Tether Segment
- Climbers Segment
- APEX Anchor Segment
- HQ&POC Segment
The Tether Pathfinder Demos

Pathfinder Demonstration

It is pretty clear at this point that a Pathfinder demonstration – or even a set of such – will likely be the sensible course for the deployment of a shorter ribbon from a satellite, and the movement of the climber along the same ribbon.

This concept would be one of the early demonstrations, lending confidence that the four culminating demonstrations would be successful. Preliminary discussions have led to an idea focused upon a preliminary “test flight” of a 1,000 km tether, at 2,500 km altitude center of mass, with deployment from a satellite and with tether climbers. This could be accomplished within the near future as it would not require the operationally capable tether strength, but would require a full understanding (modeling) of a 1,000 km tether demonstration.
The Tether Culminating Demos

**Tether simulation challenge** –
The Roadmap and Architectures team recognizes the intimate and dynamic relationship amongst the forces in space near the geosynchronous altitude, near Earth, and due to the moon, the sun and the tether climber aboard the Tether. The challenge is to build the set of models within the simulation of these dynamic interrelationships. In addition, one must establish the models as the basis for the vitally needed operations model used by the HQ/POC to monitor and control the Space Elevator system. The Operations simulations demonstration must be a rigorously accurate link between the Space Elevator and the space environment.

**Tether Deployment challenge** –
The straightforward idea of dropping the Tether from a satellite to the Marine Node for initial deployment is a lot more involved than initially appears. The tether first released will likely be a thinner, lighter version of the operational ribbon. This process is the same notion of throwing a string across the canyon to pull the rope across to then pull the cable across. A similar sequence is envisioned here. However, the tether must drop through a variety of space environments over a huge distance.

**Climber capable Tether Operations demonstration** –
This culminating demonstration is the quintessential activity of the Space Elevator. It will show the movement of a climber along the long and strong tether, because it has the grip and power to do so.

**Tether Repair demonstration** –
The final culminating demonstration is to show how the ribbon can be spliced and repaired.
# Tether Climber Demos

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Preliminary Technology Readiness Assessment

The Tether Material 6

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The preliminary Technology Readiness Assessment

Topic #7
The other voiced challenge to the Space Elevator Transportation System faces is collision avoidance. ISEC, and others, have studied the issue, and collisions are much less likely than most think. Even so, the Space Elevator Transportation System will be advised of approaching debris; even debris smaller than a pebble – in sufficient time to avoid it.

Further, the Space Elevator Transportation System will work with the FAA’s Space Traffic Management program ensuring that the Tether operates only within uniquely assigned space locations. This traffic management approach will keep other operating space systems safely separated from the Elevator.
The Operations (HQ/POC) Pathway

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Stabilization
Telemetry
Payload exchange
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Culmination Demos!

To IOC And Beyond

Marine'Node!
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