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The Technical Maturity and Development Readiness of the Galactic Harbour

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Abstract

In the last six years the technical maturity and engineering substance of the space elevator has solidified and become organized; most notably as the Galactic Harbour. This progress represents a powerful momentum, not only for the Galactic Harbour but also for establishing enterprise in space and enabling interplanetary missions. ISEC's Technology Development and Maturation approach has melded with a better definition of the Space Elevator engineering solution(s). The authors will review the progress specifics and discuss the likely destinations of this emerging technology momentum. The 2014 publication of ISEC's "Architecture and Roadmap" Report removed the shroud of mystery and myth from the Elevator's scope and complexity. The Elevator's technological basis was no longer a mystery. ISEC's "Design Consideration" documents published between 2013 and 2017 delineated the technology needs and engineering approaches for the Tether Climber, the Earth Port, the GEO Region, and the Apex Anchor. An Architecture simulation tool was selected. The last technology hurdle - strong material for the tether – was conquered. This technology and engineering momentum portray space elevator mission diversity as likely; almost certain. The Galactic Harbour will support enterprise activities along the GEO belt, factories and solar power generation near GEO, efficient interplanetary departures from the Apex and arrivals at GEO, product and materials returns to the Earth Port. All this, closer than you think! The authors will review the technical and engineering readiness of the Galactic Harbour. The review will substantiate the architecture's readiness to be developed and built, and project how the Galactic Harbour will be the essential support to interplanetary missions foreseen for the rest of the century.

1.0 Preface and Introduction: In the last six years the technical and engineering information about the space elevator has solidified and become organized; notably as the Galactic Harbour. The Galactic Harbour vision portrays the Space Elevator beyond the notion of a space project. Rather, the Galactic Harbour is a nexus of trade, enterprise, exploration and even escape to interplanetary. The Harbour portrayal conjures up mental snapshots of cruise ships departing, container ships arriving, explorers arriving in the New World and more. "Earthbound" has a new meaning; because humankind will no longer be earth bound. By the end of this century, it will be "Earth Bound" … meaning headed toward Earth. Recent technical progress represents a powerful momentum not only for the Galactic Harbour but also for enterprise in space and interplanetary missions. ISEC's Technology Development and Maturation approach has melded with a better definition of the Space Elevator engineering solution. The authors will review the progress specifics and discuss the likely destinations of this emerging technology momentum.

The 2014 publication of ISEC's "Architecture and Roadmap" Report removed the shroud of mystery and myth from the Elevator's scope and complexity. The Elevator's technological basis was no longer a mystery. ISEC's "Design Consideration" documents published between 2013 and 2017 delineated the technology needs and engineering approaches for the Tether Climber, the Earth Port, the GEO Region, and the Apex Anchor. An Architecture simulation tool was selected. The last technology hurdle - strong material for the tether – was conquered. This momentum of technology and engineering portrays space elevator mission diversity as imminent.

The Galactic Harbour will support enterprise activities along the GEO belt, factories and solar power generation near GEO, efficient interplanetary departures from the Apex and arrivals at GEO, product and materials returns to the Earth Port. All this, closer than you think! The authors will review the technical and engineering readiness of the Galactic Harbour; and project how the Galactic Harbour can be the essential support to the interplanetary missions foreseen for the rest of the century.

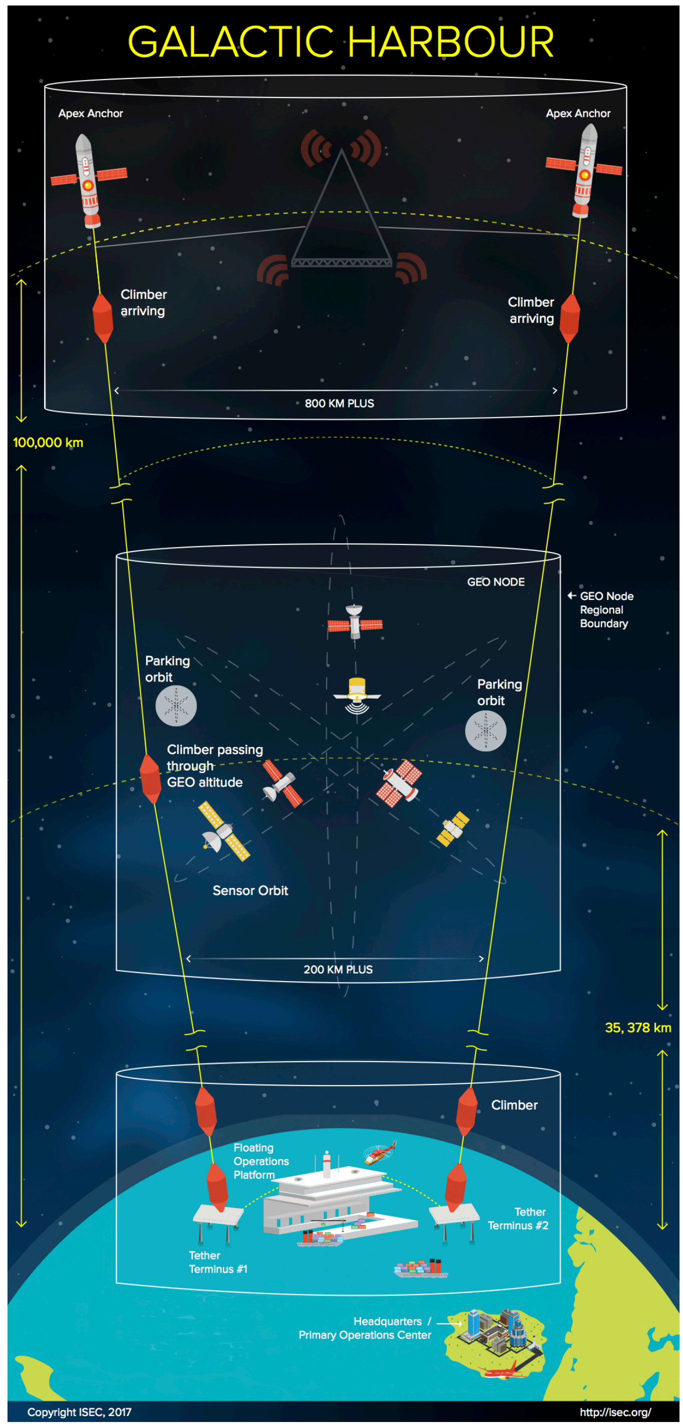


Figure 1 Galactic Harbour (2017)

1.2 From Circumstance to Strategy to Plan: The Space Elevator is coming. It is closer than you think. It will be here by mid-century; like 2045 – maybe earlier. It will be here, during our time. During our time! WOW!! Crazy, eh? Well, tell that to the Chinese and the Japanese. Their Space Elevators are part of their respective country's strategy for energy, science, trade and even a geo-strategic position. In each case their "circumstance" levied a need for a Space Elevator. Their respective circumstances gave birth to a strategy; and then plans emerged. Circumstance – Strategy – Plan.

The International Space Elevator Consortium (ISEC) saw this happening and even played a part. ISEC began by imagining a Space Elevator and thinking about what it would take … It seems evident that within the envisioned Space Elevator Architecture, and its two primary components – a Space Elevator Transportation System and a Space Elevator Enterprise System; a number of new entities and new technologies would be required. After all, we never have had a Space Elevator before!! Further, new engineering approaches would need to be instantiated and validated; and even new materials need to be developed and then applied to the engineered foundation of the Space Elevator Architecture.

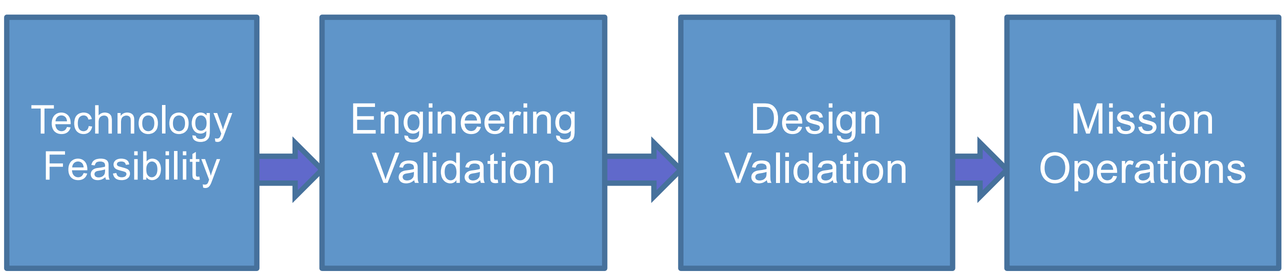
1.3 Circumstance …During the Summer of 2013: ISEC took a deep breath and tried to assess whether a Space Elevator was needed. In our case, ISEC saw the need in broad generalities. Leaving the planet was going to happen. Enterprise opportunities were clear and abundant at geosynchronous; factories, communications, research, and more. Nominally, a Technology Development Plan was needed. To get to that plan, the Space Elevator Consortium could base its path to the initial operating architecture based on a technology development strategy of "Show Me". In our view, the "Show Me Strategy" begins early; with set of well-constructed demonstrations, simulations, and experiments. It was felt that a successfully executed strategy would convince funding sources (e. g. industry members or foundations) that our vision was worth it. In short, a funded strategy is a plan. Further, demos, simulations, and experiments would give the team the experience needed for the coming developments of the Space Elevator. The small team from ISEC set out to uncover the paths of activities which would lift ISEC's activities from technological feasibility to engineering viability by examining the entirety of the Architecture and determining what ought to be simulated, demonstrated or examined by experiment. This experience will later support validated design activities, and offer empirical mission assurance information; heady stuff. As time progressed, ISEC focused on the Space Elevator Transportation System… seeing that as the enabler of enterprise involvement.

All efforts need not be successful, nor would they be abandoned. For those not yet mature technologies or engineering approaches, inclusion could be planned for later in the program; after operations begin. The Show Me Plan must include a series of development steps that will enable their inclusion via a later "on ramp". Given all that, with the results of the early demos, simulations, and experiments, the ISEC has the basics to assess Space Elevator Transportation System technology maturity risk. By extension, the approach was to examine the technology needs for the Space Elevator Transportation System and the technologies for the Enterprise Systems would follow. By talking to industry and other subject matter experts, ISEC could judge where things stand in terms of risk versus mission satisfaction. The judgments were simple – Do we need it, and can we build it? Technology maturity risk determination is a positive control aspect of any program; especially a program that has never been attempted before.

Given attainment of sufficient technical maturity across all elements of the concept, the technologies are then blended into the program's risk management approach, including approaches to "buy down" the risk at a pace consistent with program execution, program schedule, and cost. The distinction made here between technology maturity risk and the program's risk management approach is a subtle but important one. The assessment of an item's technology maturity gains its access to the program; if not mature then the technology is not part of the program or goes on to a later "on ramp". Once part of the program, the item goes to the program's risk management program (starting in Phase 2); where it's engineering, design, and mission value progress are monitored closely- through the latter stages of the Development Roadmap portrayed below.

The ISEC Technology Development Strategy emulates the approaches used in industry; and begets the ISEC Technology Development Roadmap

2.0 Space Elevator Transportation System – Development Phases : The ISEC Development Plan will extend the investment thinking of industry's Science and Technology Plans; sometimes referred to as Industry Research and Development (IRAD); to mitigate future risk by developing and demonstrating new capabilities.



The ISEC Development Plan has a Technology Development Strategy based on a constant & recurring attitude of "show me" → manifested in a taxonomy of tests, demonstrations, simulations, and experiments that reward success with admission to the next set of tests, demonstrations simulations and experiments; an iterative approach to program risk removal.

The roadmap depicts a continued inspection of the technical veracity of ISEC progress toward meeting the mission objective. Frankly, this approach has been in place for some time; about 13 years. But in the last six years or so, ISEC saw the need to codify and compare the metrics of technology readiness with the variety of "show me' techniques available. The ISEC Technology Development Roadmap – based on "show me" … is marked by four Phases, as shown. The roadmap has two intermediate destinations; the preliminary Technology Readiness Assessment (at the end of Phase One), and the start of Engineering Validation (Phase 2).

2.1 From a Technology Development Roadmap to the ISEC Technology Development Plan: The ISEC Technology Development Roadmap becomes the ISEC Technology Development Plan with the identification of the specific approaches necessary to execute the Strategy. In this context, the Plan will be executed in four Phases; from now through Operations. Substantive funding and Industry involvement is needed; starting with Engineering Validation.

2.1.1 Phase One ➔ Assess Technology Feasibility.: This Phase is well underway. In fact, for the Space Elevator Transportation System; it is essentially complete. The ISEC team has been assessing the technology feasibility situation since 2006. In recent times, the team has established an open dialog with several current and former members of the space industry and learned a great deal about the technologies being matured into engineering approaches, and those that will be available later. During Phase 1, ISEC program team has:

Determined readiness state ➔ Determined 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.

Established readiness level rationale (e. g. TRLs) for all portions of the Program. ➔ Given that the technology availability has been demonstrated (SOA v SOI v SOM … etc.) the level of readiness could be established for program segment, component or subsystem. Generally, TRL level 5 or 6 at the segment level would be expected for entry into design development (the Plan's phase 3). The show me based taxonomy of readiness is well understood as we approach the beginning of Phase 2 and readiness will be documented by Industry in the official Technology Readiness Assessment later in Phase 2.

Set Criteria regarding Engineering Validation. ➔ Modern acquisition approaches call for a Preliminary Design Review (PDR) during the Engineering Validation phase. This review is really an examination to show that the projected engineering approaches are valid. In this consideration "engineering validation" means that we can build it. If the valid technology exists, it cannot be included in a design based purely based on technology maturity. If a component is SOI or SOA, or is a TRL level 4, some engineering validation information is needed … within the PDR process. "Show me" means a lot at this point. These Engineering Validation efforts could begin now and progress through all segments of the Space Elevator Transportation concept.

2.1.2 Phase Two ➔ Validate Engineering Approaches:

This Phase begins soon after preliminary TRA is reached. The ISEC team will assign a wide range of engineering validation objectives to various members of the industry base. These have been called by some … "sanity samples". Much of this information is likely to be competition sensitive, but broad insights will be gathered to loosen funding sources. Industry involvement is mandatory!! The Phase Two activities are driven by six major activities:

1. **Can it be built?** ➔ This is the fundamental question facing the ISEC team before it approaches Space Elevator Transportation System design. The ISEC team intends to describe the engineering approaches it envisions and examine determine the engineering approaches being considered by industry. The ISEC team will then ask industry to show how their engineering approach is valid and incorporates the fruits of the ongoing technology maturation.

2. **Examine Industry's Program Roadmaps.** ➔ ISEC members saw a sample of these IRAD roadmaps during interactions with industry. It was clear from the samples that the range and number of needed engineering validation tests and demonstrations is substantive.

3. **Assess schedule & technical risk**. ➔ This assessment is very real. The multiple tests, demonstrations 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 --- but proceeding with the program without that thorough testing would be beyond risky; even foolhardy.

4. **Delineate On Ramp Criteria.** ➔ Based on the information emerging through risk assessment above, ISEC will collaborate with industry re deferring certain functionalities (e. g. "late incorporation") or redefining the basic schedule. Setting on ramp targets for late incorporation is not simply delay; but rather a considered approach of when that capability is ("really") needed and whether subsequent maturity and testing will be fruitful.

5. **Set criteria and standards re Design Validation ➔** By the end of Phase Two ISEC evolves from determining that industry can build it to determining the efficacy of specific design approaches. Those design criteria and design standards need thorough evaluation for the sake of technical, schedule and/or cost risk. These criteria and standards are to be assessed in Phase Three; using design validation information.

6. **Baseline Technical Performance ➔** By the end of Phase Two, the performance of the envisioned concept can be predicted and will be "baselined" into a system performance specification.

2.1.3 Phase Three and Four ➔ Technology Development Plan: Phases 3 and 4 are part of the ISEC Technology Development Plan; but, become the Industry Prime contractor's System Engineering Plan for the Space Elevator Transportation System development program. The outlined activities of each Phase are included here for the sake of completeness. The efforts taken by the ISEC team to get the needed technologies matured (Phase One) and then assessed to be "engineering valid" (Phase Two) must not be left behind as some bureaucratic process. The judgments and efforts of Phases One & Two move forward into the program's subsequent Phases; - amplified by a System Engineering Management Plan, a Test and Evaluation Master Plan, a Risk Management Plan; and other discrete engineering process efforts – ultimately delivering on the promise and vision of those predecessor efforts.

Phase Three ➔ Validate Design Approaches –

1. Service the Risk Buy down
2. Measure Design versus Performance Baseline
3. Baseline Technical Performance Measures
4. Establish Basis for Mission Assurance assessments

Phase Four ➔ Assess Mission Operations Success – Phase Four

1. Establish Performance Envelopes for the operational system
2. Terminate Risk Management Program
3. Conduct Risk Monitoring with Good Tools
4. Examine "On-Ramp Items"
5. Baseline Operational Performance Measures

3.0 The Space Elevator Transportation System Concept: This portion of the paper will show the baseline of the transportation system, three Adjunct Elements of the Space Elevator and answer the question: Where are we NOW?

3.1 Space Elevator Transportation System – Concept Baseline : The Space Elevator Transportation System is the core of our vision. This is what ISEC is declaring is ready to enter Engineering Validation. It is the transportation system that will provide affordable and reliable access to space. We see the transportation system made of six segments. The Earth Port, The Apex Anchor, The GEO Region, The Climber, The Tether, and the Headquarters / Principle Operating Center (HQ/POC). The HQ/POC is embedded in the Earth Port and has an expansion element on land nearby; in the Access City. Each of these six pieces must be described in explicit and finite terms with ascribed engineering performance; based on detailed "show me" efforts to be conducted in Phase 2 of the ISEC Development Plan: How strong the Tether, how fast the Climber, how mobile the Earth Port, and how aware the HQ/POC; and more. From our experiences, baseline building is a hit and miss iterative process; a bootstrap miracle. Baselines are built by trial and error mixed with sweat and tears. ISEC expect to publish the FIRST Engineering validated baseline by the middle of Phase #2.

3.2 The Space Elevator Transportation System Baseline: The Space Elevator baseline is shown as the sum of the parts, as of the Fall of 2019:

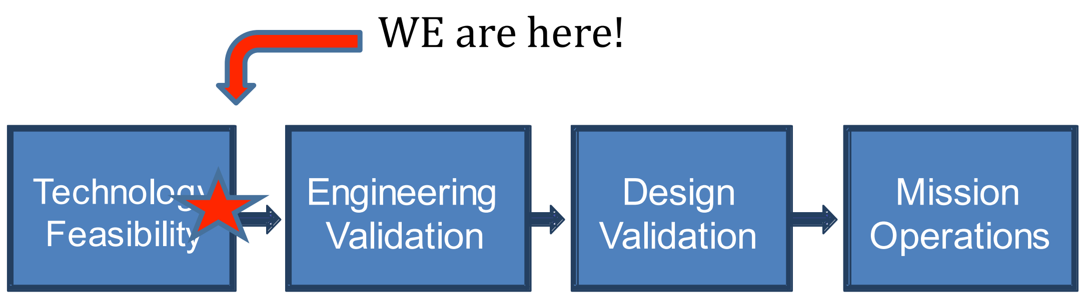
1. One Earth Port
   a. Floating Operations Platform
   b. Two Tether Termini
   c. The Access City
2. One GEO Region provides support to a range of space based enterprises:
   a. Space Based Power collection
   b. Space Based Factories
   c. Satellite Repair
   d. Satellite Refuel
3. One Apex Region
   a. Interplanetary Departure support
4. One HQ/POC
   a. a major portion collocated on the Earth Port FOP
   b. A substantial portion of the HQ/POC
5. Two Tethers
6. 14 operating Tether Climbers

3.3 Three Adjunct Elements are recognized as part of the overall Space Elevator Transportation Baseline:

1. Space Debris Adjunct (Mitigation) -- The Space Elevator will establish a close operational relationship with the space debris mitigation systems that will operating near Earth within the next decade. The space debris "chair" will be a permanent member of the HQ/POC, and be charged with supporting or providing awareness, warning, active defense, passive defense, and (if needed) recovery after a debris event.
2. Space and Surface Object Adjunct (Situational Awareness)

3. Client Support and Management Adjunct

4.0 Where are we, now? In the last year, the International Space Elevator Consortium assessed that basic technological needs are available, and each segment of the Space Elevator Transportation System is ready for engineering validation.



The Space Elevator and Galactic Harbour Concepts are ready for Prime Time

Because of the availability of a new material as a potential solution for the Space Elevator tether, the community strongly believes that a Space Elevator will be initiated in the near term. The ISEC position:

1. <u>The Galactic Harbour Earth Port</u> ➔ ready for an engineering validation program
2. <u>Space Elevator Headquarters / Primary Operations Center</u> ➔ ready to start an engineering validation program
3. <u>Tether Climber</u> ➔ Engineering model assemblies needed -- then start an engineering validation program
4. <u>GEO Node</u> ➔Engineering discussions and demonstrations with key members of industry are needed along with collaboration / outreach with certain government offices.
5. <u>Apex Anchor</u> ➔ Engineering discussions and various simulations are needed. Near term collaboration with engineering organizations and academia should begin follow-on outreach to key members of industry and government. Engineering validation follows.
6. <u>Tether material</u> ➔ Prime material candidate is identified; and, production demonstrations are needed.
7. <u>Collision avoidance</u> ➔ Architectural engineering definition is being finalized. Candidate concepts are identified. On orbit performance demonstrations are needed.

The summer of 2019 was a turning point in the visibility of Space Elevator development and the future of movement off-Earth towards the Moon and the planets. The study , "***Today's Space Elevator***," was recently completed and represents the status of the space elevator transportation infrastructure as of the Fall of 2019.

- **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 the Space Elevator Architecture demands that it be understood and supported by many.

5.0 Conclusion: The conclusion from the analysis going into this paper is that there is a solid case to proceed. Proceed ahead with the Space Elevator development.

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.

And indeed, ISEC believes:

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

References ***(note: all ISEC reports are on www.isec.org in pdf for free)***

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