A Space Elevator for the Far Side of the Moon

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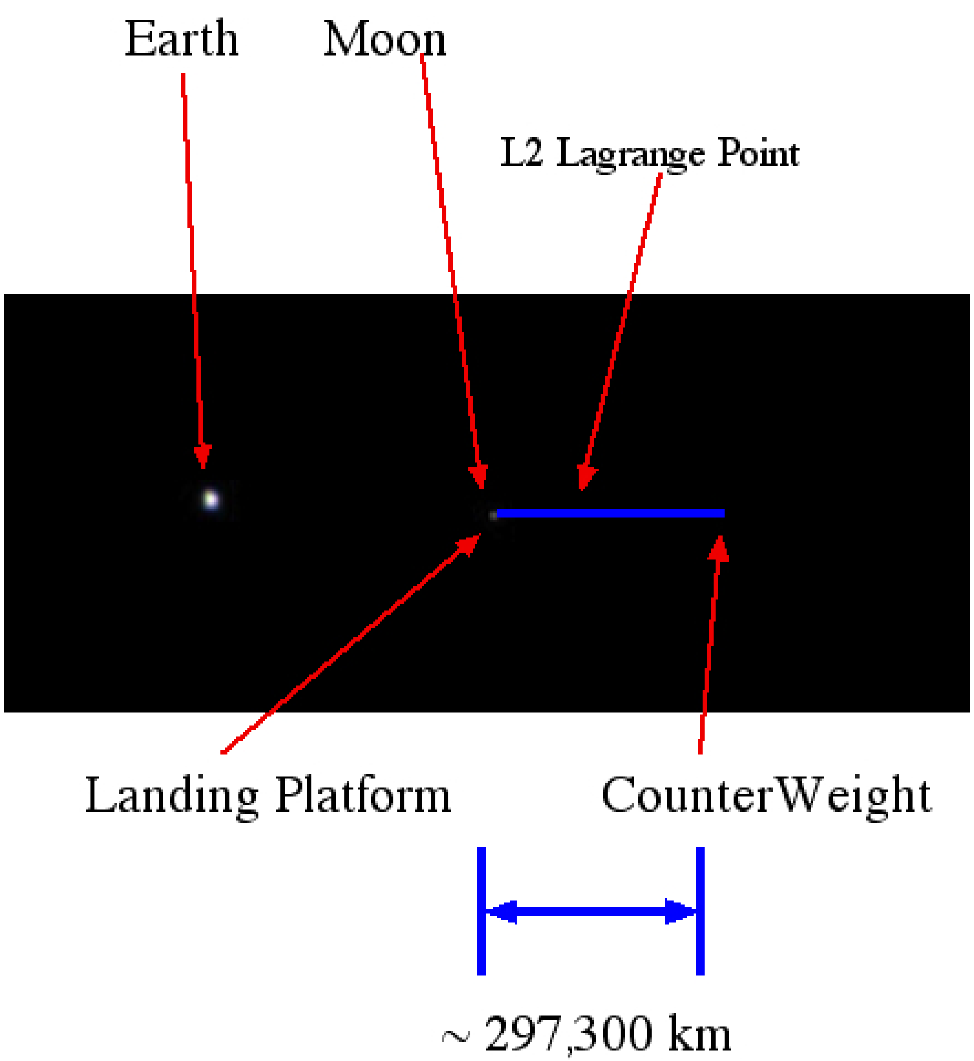
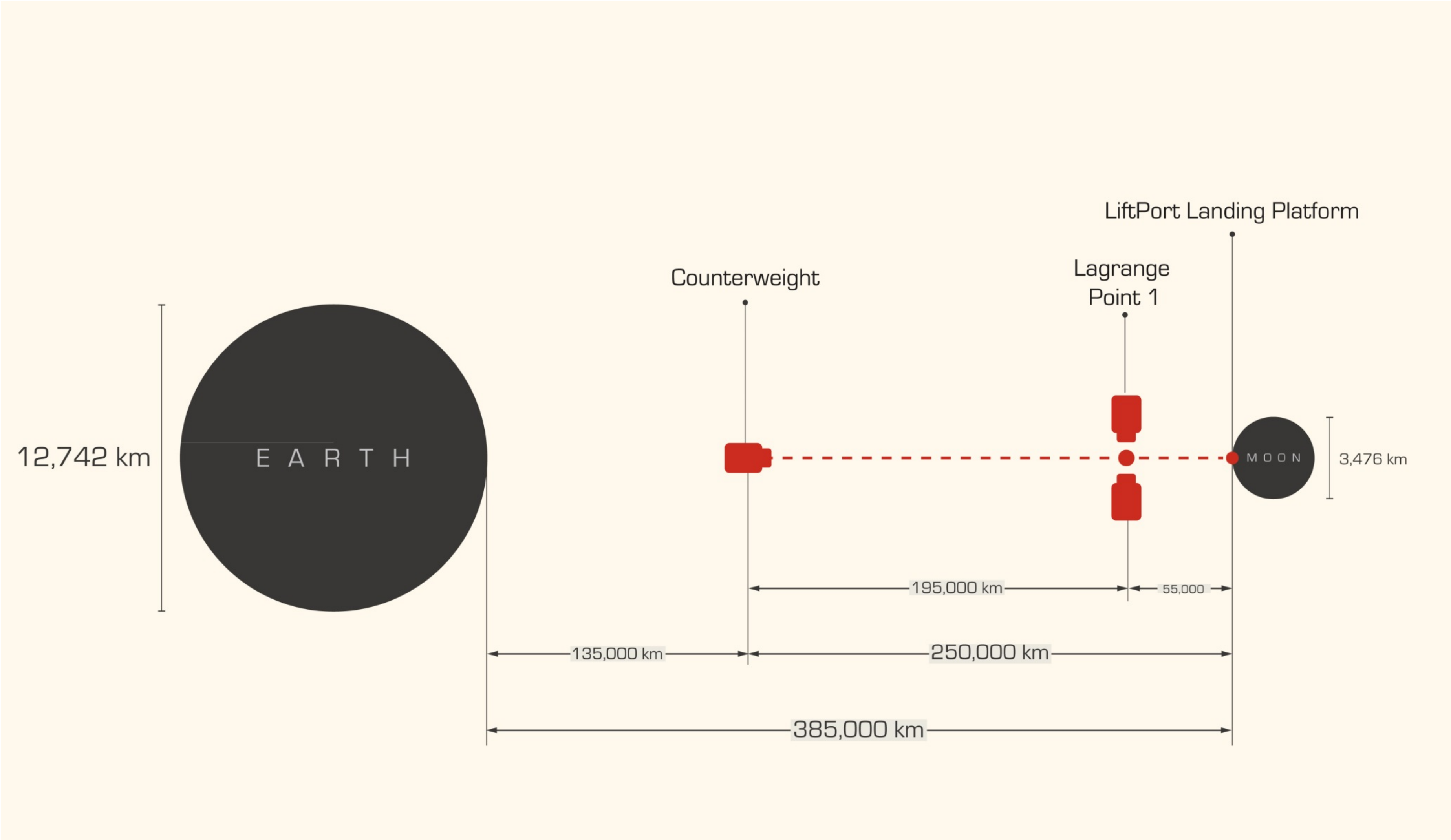
What is the Lunar Space Elevator Infrastructure (LSEI) ?

- Lunar Space Elevator (LSE) is a tether reaching upwards from the surface of the Moon to a Lagrange point [EML1 or EML2].
- The tether is kept taut by a counterweight CW.
  - The opposing force is the gravitational tidal force of the Earth, not rotational centrifugal force.
  - This tidal force balances against the gravitational force of the Moon, so that the entire LSE is in a dynamically stable Earth-Moon orbit.
  - The simplest LSE are from the Lunar center (the Near-side Elevator) or the Lunar Antipodes (the Far-side Elevator LFSE).
- The large Earth-Moon distance means that either a very long tether or a very large CW is needed to obtain sufficient tension.
  - Any prototype LSE will be weight limited, and so will be long.

The LFSE (to scale)



Nearside LSEI Configuration using existing industrial materials



LSEI offers game changing cost reduction

- Rockets deliver 3x more to EML1 than surface
- Current commercial pricing of lunar soft landing, i.e. Astrobotic = 12x TLI $/kg
- Hence LSEI offers 3X to 12X times reduction in soft landing cost versus chemical rockets
- LSEI offers approx 1000X cost reduction for sample return versus chemical rockets
- Throughput: >100 kg every few days,
  - >5 tonnes per year [up and down]

Investment Payback Time Period

- Assume 12X ratio of Astrobotic pricing: then 48 tons LSE at EML has same transport cost as 4 tons on surface
- 48 tons LSE has 100 kg payload capacity
- Therefore 4 tons / 100 kg = 40 payload cycles
- Assume 5 days per payload life cycle, Then: 40 cycles = 40x5 = 200 days Payback time period

Concept Validated by NASA/NIAC in 2005

LUNAR SPACE ELEVATORS FOR CISLUNAR SPACE DEVELOPMENT

Phase I Final Technical Report
by
Jerome Pearson, Eugene Levin, John Oldson and Harry Wykes

Research Subaward No.: 07605-003-034

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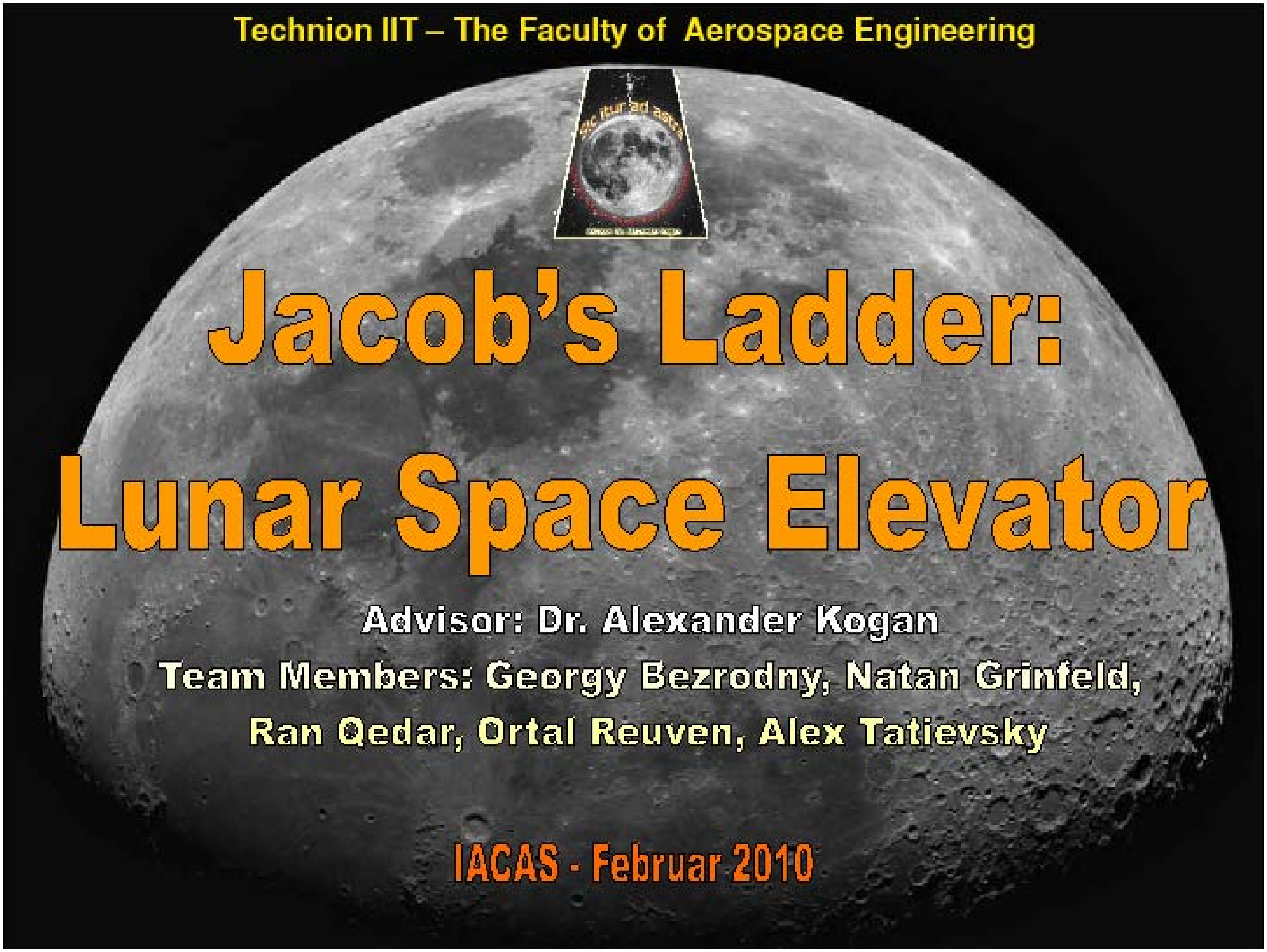
STAR, INC.

Concept studied by Technion Team in 2009



Youtube Video

- https://youtu.be/MktwUqAOboQ

Major Components of either LSEI

- The Counterweight (CW) helps to keep the string taut and shortens its length.
- LSEs pass through the Earth-Moon Lagrange Points (EML) 1 or 2.
  - EML-1 for the Near-Side, EML-2 for the Far-Side.
- An object can be in orbit at these Lagrange points and “hang” stationary between the Earth and Moon, or above the Far-side.
  - The LSE will be deployed from the appropriate EML, extending string both towards and away from the Moon in a balanced fashion. Material can also be stored there.
- The Landing Platform (LP) is attached to the string. It has to be embedded in the Lunar surface firmly enough to anchor the elevator. Once it lands, it is referred to as the Landing Station (LS).
- All 3 locations (CW, EML and LP) can and should be instrumented, both for science and to monitor the elevator’s performance.
- Support of surface operations requires the ability to transfer material to and from either LEO or GSO and the EML.

The LSEI is also good science

- In the prototype, a small solar powered climber can be lowered to the Lunar surface, scientific instruments will be deployed and the climber be loaded with surface samples.
- The climber will then climb back to a sample return capsule, located at the EML Lagrange point.
- The climber plus sample return capsule will be taken to a suitable altitude above EML for return to Earth.
  - Sample return from a Near-side LSE requires no expenditure of fuel.
  - Sample return from a Far-side LSE requires a powered return capsule.
- That is actually a LFSE safety advantage - if the elevator breaks, the counterweight does not fall to Earth.

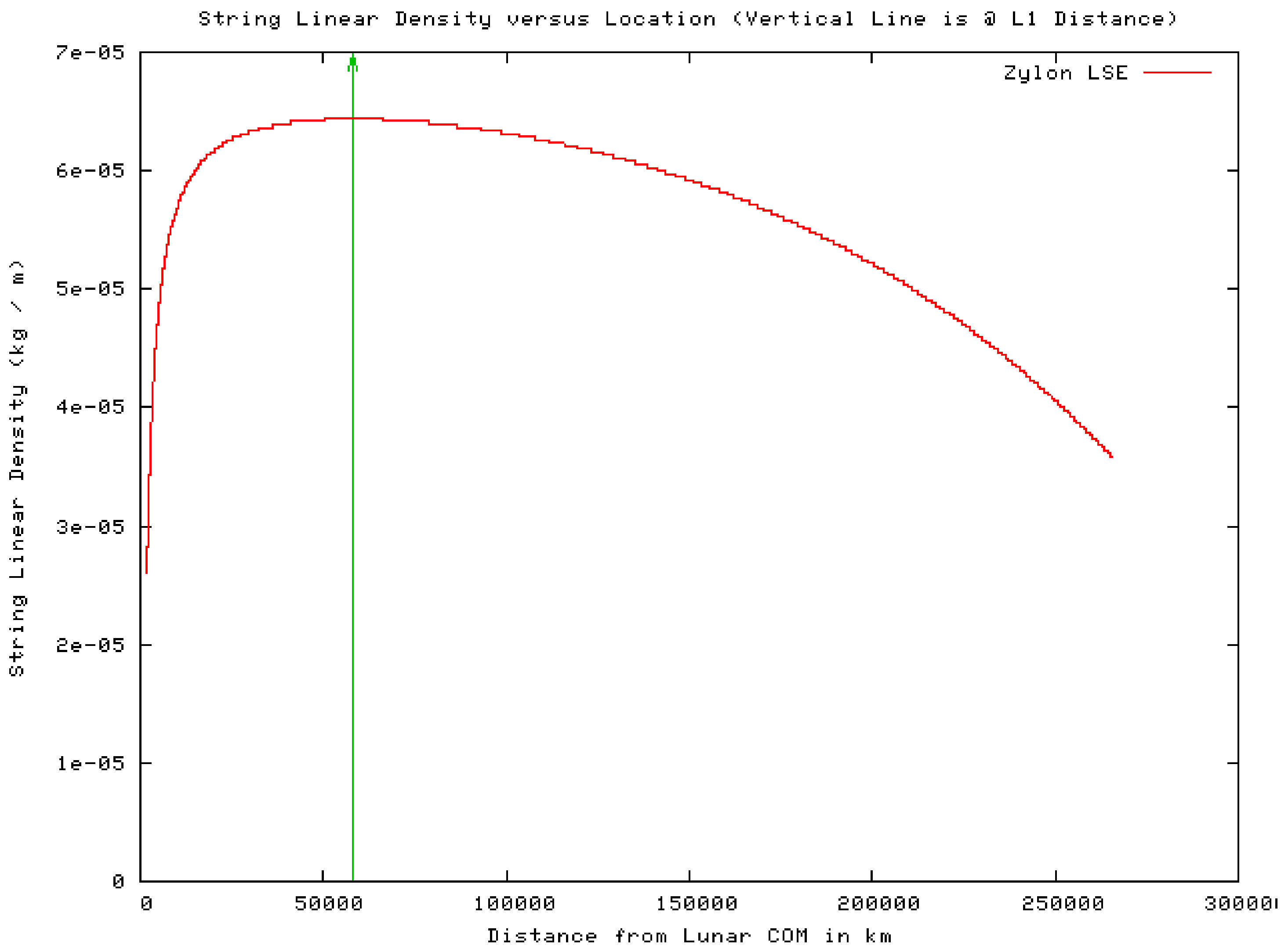
LSEI : The Lunar Space Elevator Infrastructure Prototype

- The prototype would be the first piece of a reusable lunar exploration infrastructure and an international space infrastructure asset. Cost ~ EU 1 Billion for 100 kg capacity.
- The first launch would deploy a climber carrying a microrover to provide lunar sample return without a dedicated lunar lander.
- A Lunar Far Side Elevator (LFSE) would offer many advantages for a first deployment.
  - A LFSE could offer: real time communications and monitoring; Radio Astronomy; opening up the entire Far Side for exploration and exploitation.

Materials Selection

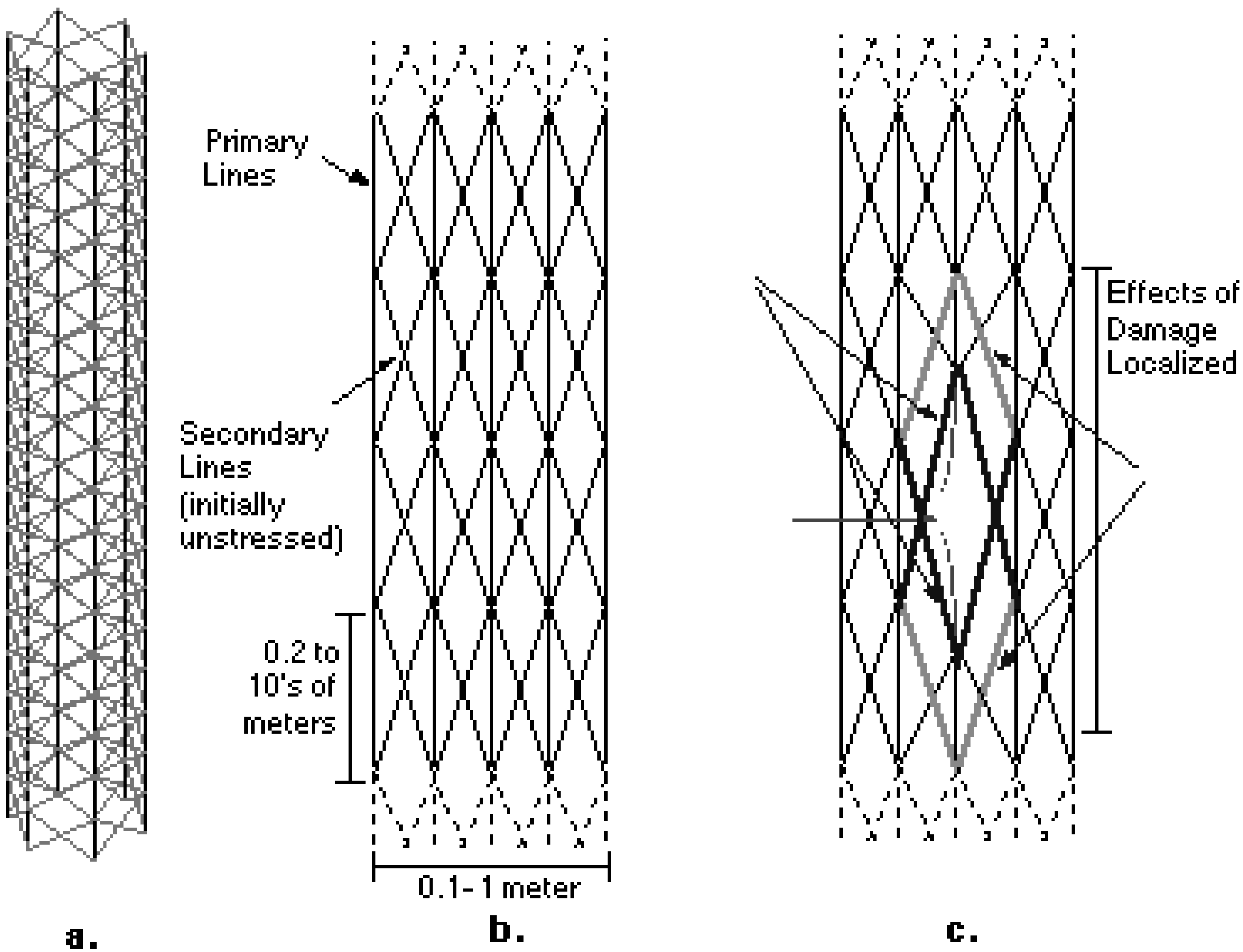
- Of the existing tether materials considered, Kevlar, Spectra 2000, M5 [from USA], and Zylon PBO, Zylon provides the best performance.
  - Zylon [from Japan] is **commercially available** and would require no technology development.
  - Determining whether this is in fact the best material to use for LSEI mission would be an engineering goal of the proposed work.
  - Dyneema [from Netherlands] has similar performance to Zylon..
- Carbon Nanotubes would provide better performance, but are **not** necessary and their availability will **no**t be counted on.
- The Zylon current prototype design was scaled to fit within a single SLS launch and to serve as a baseline for discussion. It is
  - 278,500 km in length
  - Total Elevator mass = 48,700 kg
  - Total String mass = 41,800 kg
  - Total taper = 2.5 : 1

The optimum taper for the full LSE



Need to tolerate micrometeroid impacts

- The Hoytether™, illustrated below, is a tether structure composed of multiple lines with redundant interlinking that is able to withstand many impacts. 2 impacts per year expected. Will repair continuously



Which Side ?

- Both have advantages.
- The Near-side LSE has a little higher performance, and very straightforward sample return.
- The Far-side LSE would support Radio Astronomy, explore new terrain and would offer a communications platform / relay tower that could open the entire Far-side to exploration and exploitation.

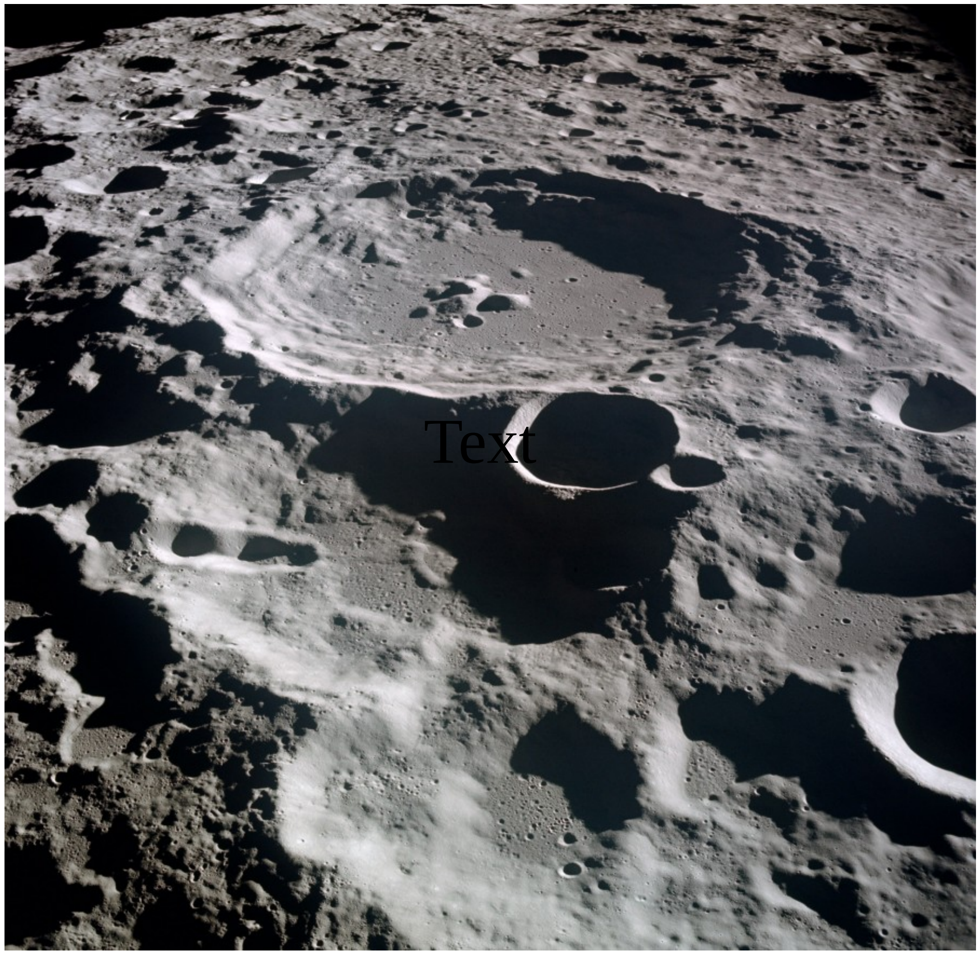
Comparison of the 2 LSE

Lunar Elevator	LSE-EML1 NearSide	LSE-EML2 FarSide
String	Zylon PBO	Zylon PBO
Length	278544 km	297308 km
Total Mass	48,700 kg	48,700 kg
Surface Lift Capacity	128 kg	110 kg
Total Taper (in area)	2.49	2.49
Max Force	517 N	446 N
Landing Site	0° E 0°N	180° E 0°N

The Far-side Landing Point

- The EML-2 landing site is near Lipskiy Crater, just North of Daedalus Crater in very rugged and heavily cratered terrain in the Lunar Highlands.
- Ideal location for Radio Astronomy observatory
- This region of the Moon is totally unexplored, at least as far as surface sampling is concerned.
- It is also part of the rim of the South Pole–Aitken Basin crater
  - There is no question of the importance of sampling the Far Side Highlands.

A view from the Far-side Elevator



Apollo 11 picture of Daedalus Crater almost directly above the LFSE Landing Point

Communications with the Far Side

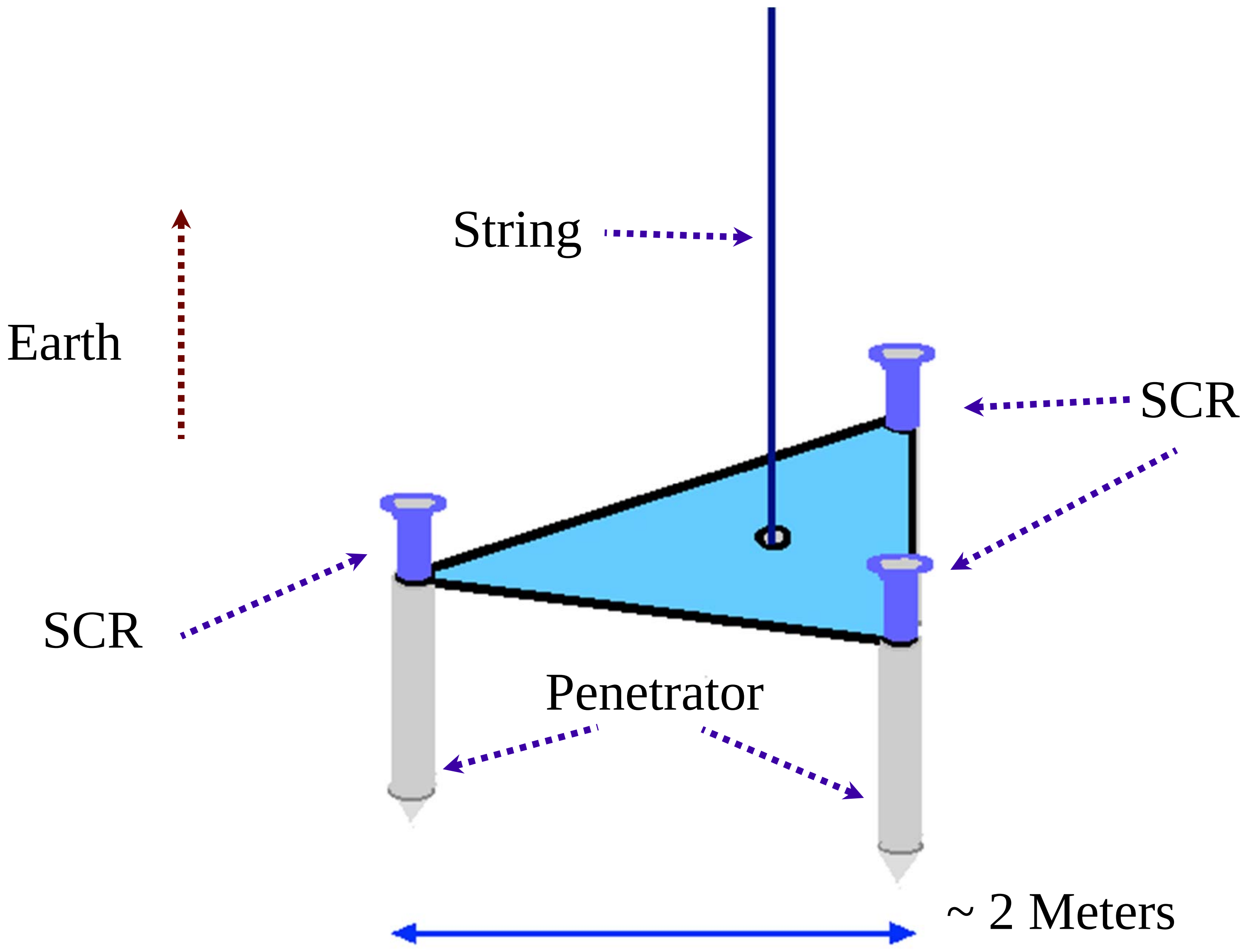
- A LFSE is an enormous communications mast.
  - Any location on the Far Side that sees the Sun would be able to use the LSFE as a relay.
  - The EML2 is 64516 km from the Lunar COM
    - From that distance, the Moon radius subtends 1.54°
  - While the Earth would not be continuously visible, TDRS or other geosynchronous satellites would be, so real-time continuous relays could be set up from Earth to anywhere on the Far Side.

LSE Deployment :
Anchoring the Elevator on the Moon

The Landing Platform

- The Landing Platform is permanently attached to the end of the elevator string and will anchor the elevator on the Moon.
  - the mass of the Landing Platform + any equipment has to be < 120 kg ***at landing***. Once it is down, it doesn't load the elevator, and equipment can added.
- In the current design, the LP is a 1 meter equilateral triangle with 3 penetration anchors on the vertexes, and 3 LLR retroreflectors.
  - Total weight ~ 100 kg
- The LP carries a microrover for immediate deployment to the Lunar surface.
- The LP would have room to carry equipment provided by partners. For example, the penetration anchors might be instrumented to measure heat flow or a seismometer might be deployed.

Landing Platform with Anchor (schematic)

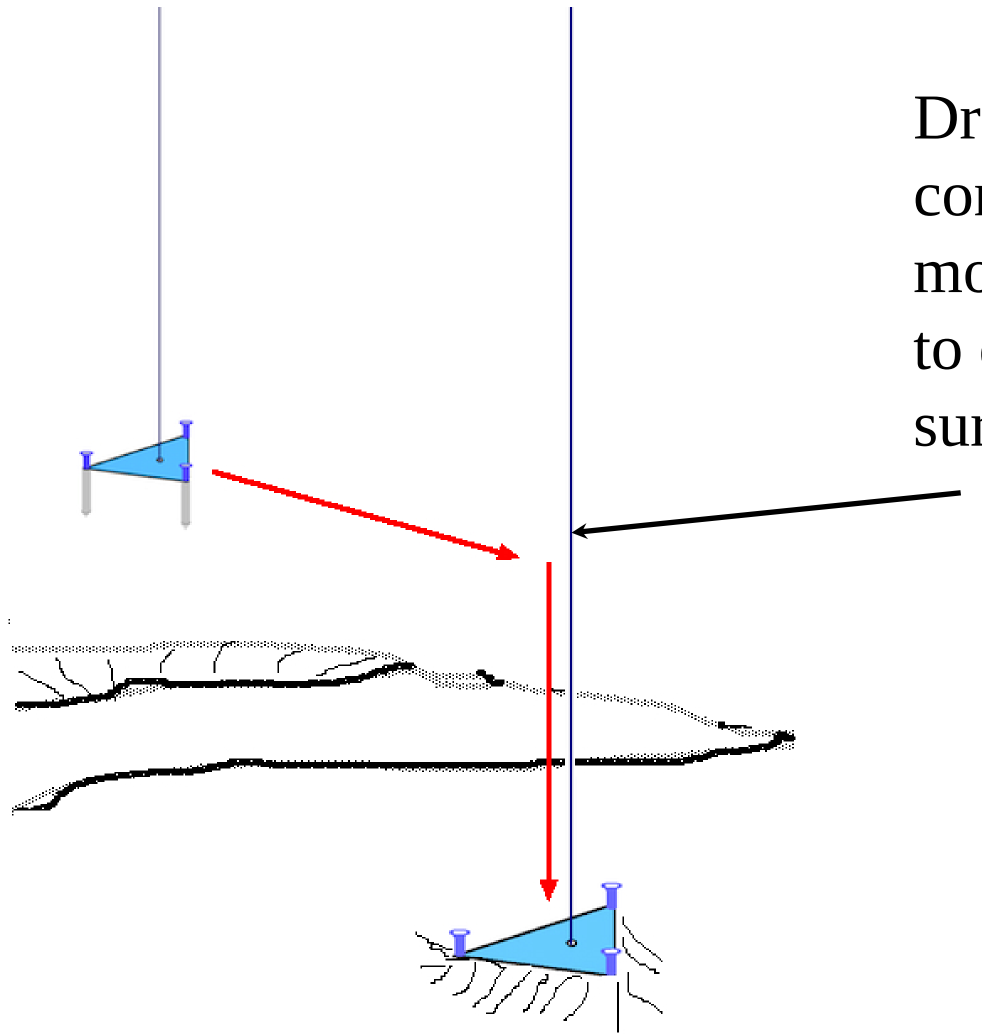


Landing Platform Penetrators

- The Landing Platform will need anchoring penetrators to hold it onto the surface.
- Despite its size, the forces are quite low, and vertical tension is highly unlikely to exceed 1000 Newtons at the surface.
  - That implies an anchor ~ 1 meter deep, with barbs or flukes to hold onto the soil.
- To penetrate to one meter requires a velocity of ~ 10 meters / second, based on prior Lunar experience (Apollo, Luna).
- Two possible solutions to do this
  - run the cable out at 10 meters / sec at the surface. That is likely to lead to excess cable at the surface once the platform lands, which could get tangled or cut.
  - Hang at 30 meters, image the surface, let go when there are no rocks directly below. This will take a loop or reel on the LP with about 30 meters of cable (~8 grams).

Avoid craters, rocks, etc. at 30 meters with stereo imaging.

The ability to dwell just above the surface before committing to a landing site is crucial. With typical pendulum mode velocities of 10-100 meters / day, it shouldn't require waiting too long.



Drop when convenient, use momentum of drop to drive LP into surface.

Dedicated Climber for Sample Return

- A 40 kg dedicated climber could return up to 40 kg of Lunar samples in the first month of deployment
  - Subsequent months could return up to 1000 kg of samples / year.
- This dedicated climber could also carry down 40+ kg of equipment, such as a seismometer or drop penetrators, for subsequent deployment.
- We propose that this climber only operate below EML 1, and that a separate climber be dedicated for operations above EML 1.
  - As a detail, the first sample return climber should have a means of collecting a surface sample even if all Landing Platform and rover equipment failed.

A solar powered climber

- Coming down from the EML requires brakes, not energy. Climbing up to the EML requires power.
  - 2,696,686 Joules / kg for EML-1
  - most of this is expended relatively close to the Lunar surface.
- Suppose that the design climb velocity at the surface is 5 m/sec.
- Then, the peak power requirement, at the lunar surface, is 8.2 W / kg
- Assuming electrical motors with 90% efficiency, and no other losses, a 40 kg climber would require 700 watts at peak (plus whatever is required for command and control and other non motor uses).
  - We assume 1500 watts for a 20 kg sample return.
- Once the climber gets up above about 5000 km, its load has decreased to the point where you could send another one.
- The LSEI, with two dedicated climbers, each lifting 20 kg every lunar month, could return ~ 500 kg of lunar samples **per year**.

EML1 and Manned Deep Space Flight

- The “Global Exploration Roadmap” of the International Space Exploration Coordination Group includes, as part of its “Asteroid First” mission track, a Deep Space Habitat at EML.
  - http://www.nasa.gov/pdf/591067main_GER_2011_small_single.pdf
- Key features include
  - The early deployment of the deep space habitat to the Earth-Moon Lagrange points , allowing demonstration of habitation and other critical systems in a deep space environment.
  - With an in-place LSE, the Deep Space Habitat could also be used to assist in the transport of equipment to the Lunar surface, and the return of Lunar samples

The LSE and Manned Deep Space Flight

- A LSFE and a manned Deep Space Habitat at EML2 would allow for a number of synergies.
  - Astronauts at the DSH could examine, classify and sort lifted lunar samples, and select those to be send back to Earth.
  - Unwanted samples could be added to the radiation shielding.
  - Astronauts at the DSH could teleoperate rovers on the Lunar surface with minimal delay (thus allowing for faster roving).
  - Astronauts could add and service equipment for a pico-gravity physics lab at EML2 itself.
    - Any physics or astronomy that can be done at the ISS can be done better at EML2

Future Work and Roadmap

- More engineering analysis and risk reduction is needed
- Detailed task plan and roadmap available, includes:
  - Control of tether deployment process
  - Dynamic analysis including handling of Coriolis forces
  - Dynamic analysis of changes in center of mass
  - Maximize payload throughput, moving heat shield attachment
  - Trajectories for delivering payloads to Earth
  - Tether material UV degradation mitigation
  - More detailed design of surface attach fixture interfaces
  - Static charging by solar wind
  - Electric power supply to robotic climber
  - Methods of station-keeping

Conclusions

- The LSEI is viable using existing industrial materials
- The LSEI reduces soft landing cost SIX fold [at least]
- The LSEI reduces sample return cost 1000 X

- The LSEI offers a means of
  - Getting to the Moon much cheaper than chemical rockets, using currently available technology.
  - Continuing access to the Lunar surface, plus sample returns and a Lunar transportation infrastructure, ***for the cost of a Discovery Class mission***.
- This anticipates using existing fibers - while even a modest improvement in fiber technology would bring substantial improvements in payload capacity, the LSE does not require this.
- The LSEI offers a path to a man-rated LSE and a Phobos-anchored Mars elevator.