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First Space Elevator: on the Moon, Mars or the Earth?

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Abstract: The ability to move massive amounts of materiel and people will enable space colonization. The needs of the people and their habitats will drive logistics loads to levels never achieved before in the space arena. Key to this enabling technology is the space elevator. With today's materials, space elevators can be built around the Moon and Mars because of the lesser gravity well inherent in the planets. However, the biggest issue is raising mass against Earth's gravity to begin colonization. Engineering trades will be compared with cost and logical requirements associated with a movement of population off of the Earth and toward the Moon, Mars and beyond. The concept of an infrastructure to move mass into and around space greatly simplifies, and dramatically lowers cost of, the logistics tail. So the question is: Where will the first space elevator be constructed? The Moon, Mars, or here on our home planet?

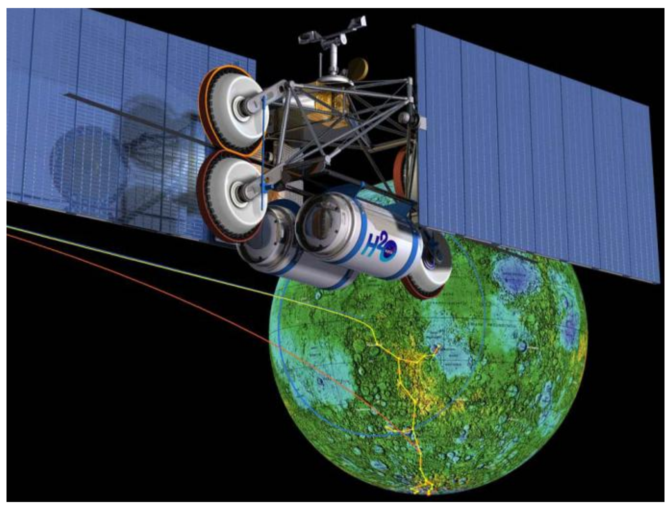
Introduction: At the beginning, we must address three belief systems for this analysis to become meaningful:

- Space Elevators are Feasible
- Human Colonization [or movement off of the Earth] is a necessity for global health and survival of the Human Race.
- Financial and environmental factors will be significant factors in human endeavors well into the future.

Rotating bodies with huge masses can enable space elevator transportation infrastructures. Each environment is unique and drives designs for various system architectures; however, the basic physics are consistent across different masses, number of orbiting moons, depth of atmosphere, or access to energy. This paper will first describe all three concepts, as presented by many people (see references) and compare each to the needs and desires of humanity's expansion above the atmosphere. The vision that is often placed in front of the audience is:

> An affordable, robust, and routine transportation infrastructure to and around space from a planet [or Moon] must be realized to enable colonization off-planet.

Figure 1, Lunar Space Elevator



This vision is applicable in all three locations; around the Earth, around the Moon, and supporting Martian transportation. The following concepts will be discussed in this paper:

- Earth's based space elevator.
- Lunar space elevator.
- Martian space elevator [Phobos version]

After the discussion of the three space elevators, a comparison of their various aspects will be laid out to show the relative value. Should we first do the lunar, the Martian or the Earth space elevator?

Basic Concept: The basic concept for a space elevator around a rotating planet [or Moon] deals with the properties of gravity and centripetal force. The long ribbon is connected to the surface of the orb [simple case at the equator] under the synchronous location [each planet has a location where the forces are equal when the velocity is correct in a circular orbit such that the location stays exactly above a spot on the equator]. This location is perceived to be stationary with respect to the equatorial location underneath it; however, it is traveling at a meaningful velocity to "stay" there. The ribbon goes well beyond this point to balance the ribbon's mass and its gravitational pull--below synchronous--with the rotational energy of the mass above the geosynchronous location. This matching of tension, below and above the synchronous location, enables the "firm basis" upon which to place a transportation infrastructure. The simple concept is a long ribbon with climbers going up and down the ribbon moving materiel "off-planet" and "return-to-planet." There are many excellent books and articles on space elevators that go into the basics to include the International Space Elevator Consortium website [www.isec.info] [and *Space Elevator Systems Architecture*[1].]

Figure 1: Dr. Edward's Modern Space Elevator[2]

Basic Designs - Lunar: Jerome Pearson [inventor of the Earth Space Elevator[3]] published a paper entitled "The Lunar Space Elevator" with Eugene Levin, John Oldson, and Harry Wykes.[4] This paper describes two space elevator alternatives for Lunar transportation demands. His analysis of the physics showed that there could be a space elevator on both the near and far side of the Moon. Instead of using rotational locations, such as the GEO point on the Earth, the basic concept utilizes the Lagrangian points around the Moon. In all two body dynamics problems when one object is in orbit around another, there are five locations positioned around the two objects that are stable [or marginally stable]. The L-1 position is the gravitational stable location between the larger body and the orbiting body. The L-2 stable position for the Lunar Earth region is on the far side of the

[1] Swan, Peter A. and Cathy W. Swan, Space Elevator Systems Architecture, Lulu.com, 2007.

[2] Swan, Peter A. and Cathy W. Swan, Space Elevator Systems Architecture, Lulu.com, 2007.

[3] Pearson, Jerome. "The Orbital Tower: a spacecraft launcher using the Earth's rotational energy." Acta Astronutics, vol. 2, pp 785-799. Pergamon Press, 1975.

[4] Pearson, Jerome. Levin, Oldson, & Wykes. "The Lunar Space Elevator," IAF 2004.

Moon at a very great distance. The logical location for a transportation system is the use of the gravitational equality location on the near side of the Moon, or L-1.

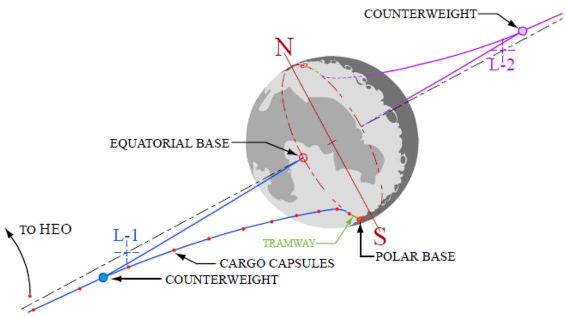


Figure 3; Lunar Space Elevator[5]

This location is approximately 58,021 +/- 3183 km from the center of the Moon toward the Earth. The variation is due to the slightly elliptic orbit that the Moon has around the Earth. Figure 3 shows some of the options that engineers have proposed for a lunar space elevator project. The concept is one where climbers would ride up to the top using electrical energy with wheels propelling the motion up and down [very similar to the Earth's space elevator basic design].

Basic Designs - Mars: Mars has some unique aspects that make space elevators much more challenging. The beauty of the environment is that it is 6/10's the gravity of Earth so the gravity well is not quite as deep. While the Moon has no atmosphere, Mars has a slight one that can be leveraged as a break or as one for "aeronautical flight." In addition, the value of a transportation infrastructure could easily be visualized when the concept of colonization or scientific development becomes a reality.

There is one tremendous issue that is a driver in the design of a Martian space elevator – Phobos. This moon is very close to the surface of the planet and has equatorial crossings multiple times per day. As a result, a Martian space elevator cannot be built using the traditional design of a point on the equator past the synchronous location because of the routine crossing of the potential locations with a large moon body. As this is the dominant physical characteristic of low Martian orbits, the design of a space elevator must be adapted.

The current idea is that the concept of space elevators is applied to the moon Phobos such that there is a space elevator projected up from Phobos away from Mars and another down towards the surface of Mars. The incoming spacecraft would rendezvous with the upper elevator and slide down to the surface of the moon. The payloads would then be transported to the Mars facing surface where they would get on the lower elevator for the trip towards the surface. As the moon is traveling at a reasonable velocity, the tether end is not attached to the surface, but dragged through the atmosphere.

The payload is dropped into the upper atmosphere for an easy transfer to the surface using either wings or parachutes. The key is that the velocity of the lower end point of the Martian space elevator would be travelling at a significantly reduced velocity to the incoming payload from Earth on its traditional hyperbolic orbit.

Note: A recent presentation by Gaylen Hinton at the 6th International Space Elevator Conference showed how the traditional approach to space elevators could be adapted to the Martian arena by having the terminus at a north/south latitude thereby enabling the ribbon to trail above/below both Phobos and Dimos in latitudinal locations.[6]

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[5] Pearson, Jerome. Levin, Oldson, & Wykes. "The Lunar Space Elevator," IAF 2004.

[6] Hinton, Gaylen, "The Colonization of Mars via a Martian Space Elevator," 6th International Space Elevator Conference, Redmond Washington, Aug. 2010.

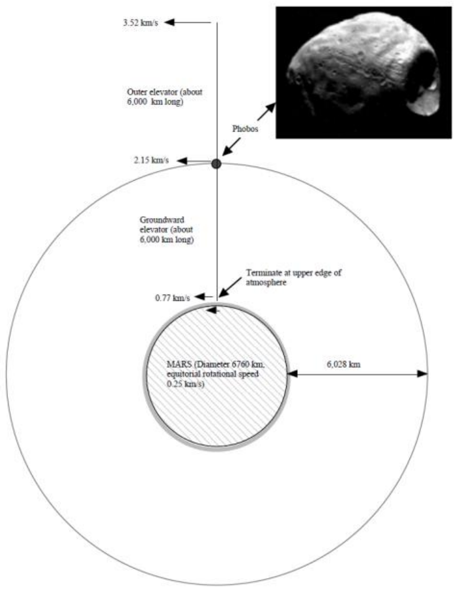

Figure 3: Mars space elevator on Phobos[7]

Basic Designs - Earth: The modern day space elevator, as described by Dr. Edwards in *The Space Elevators*[8], has many strengths. For the purpose of this paper, and so that engineers can trade against a somewhat real design, the general characteristics include:

- Length: 104,000 km, anchored on the Earth with a large mass floating in the ocean and a large counterweight at the top end
- Width: One meter, curved
- Design: Woven with multiple strands to enable localized damage; and curved to ensure that edge on, small size, hits do not sever the ribbon.
- Cargo: The first few years will enable 25 ton payloads without humans (radiation tolerance is an issue for the two week trip) with five concurrent payloads on the ribbon for travel to GEO.
- Production: The space elevator can, and will, be produced in the near future because the human condition demands it and the materials are almost ready to enable the construction today.
- Construction Strategy: The first space elevator will be built the tough, and only, way – from GEO – then once the gravity well has been overcome it will be replicated from the ground up leading to multiple elevators appearing around the globe. This redundancy will reduce the magnitude of the impact if one is lost.

Definition of Needs: The definition of need is essentially "lower cost to orbit." This is the driving force of space exploration. The rocket equation is exorbitant in cost of product to orbit. This would be true at any one of the locations; but, it is especially true where the gravity well is greatest, i.e. the Earth. Currently the cost of launching a kilogram to low earth orbit is somewhere around $40,000. This does not get it to Geosynchronous or to Lunar orbit, just to a low Earth orbit (LEO). You have to add another $15,000 per kg for those locations. In addition, bringing anything back from the Moon or Mars today requires that you take the fuel with you to return. That would mean that each kg of fuel would be very expensive and the resulting return of mass especially exorbitant. Cost is the driver; but, there are many other benefits from space elevators. They could be:

- Routine operations
- Large payloads can be handled
- Very little rock and roll at launch
- Design constraints on shape are reduced
- Continuous operations will enable commercial operations

Technology Challenges Compared: The development of all the components of a space elevator [minus the ribbon] is routine. We have built boxes before. We have built solar cells and electric engines that work in space. We have built radiation tolerant equipment. The components of a space elevator can be manufactured on all three solar system bodies today; and, will not, except for the routine space development issues, pose problems. However, the ribbon is another issue. The requirement for ribbon strength [in the tensile arena of lbs per

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[7] Weinstein, Leonard. "Space Colonization Using Space-Elevators from Phobos," NASA Langley.
[8] Edwards, Bradley C. and Eric A. Westling, The Space Elevator. BC Edwards, Houston, Tx, 2003.

square inch or GPs or Myuri] for the Earth Bases Space Elevator is too great for today's material. The requirements are in the range of 40 to 70 Myuris. This is beyond the strength of current production materials; however, it has been shown to exist in scientific settings, under pristine conditions, in lengths of up to ten cm. The growth of the new material in strength to weight ratio is encouraging and could be available in XX years. [no one knows what XX is; however, optimists say two to three years for material to come out of the lab and into manufacturing]. On the other hand, the ribbon dynamic demands for the space elevators on both Phobos and the Moon are within current materiel capabilities. [M5 and Zylon both have capabilities greater than required. They both have the characteristic of around 5.7 MYuri[9]. Indeed, the material exists; but, it still must be "outfitted" for the space environment and tested to ensure it maintains its capacity over time in the harsh environment.

Timeliness Challenges: The puzzle on timing is that we could probably make a very good start at designing a Lunar or Martian space elevator with today's materials. The problem is that we are not slated to get to those locations for another 20 years, or so. With the new policy of going to an asteroid or Lagrangian point to prepare for the exploration of Mars, the need for those space elevators has been slipped to the right. In my experience in space development, engineers need a "practice ground" to test out the environment for future exploration. I believe that means we need to colonize [or staff up research facilities] on the Moon in order to prepare for Mars. The rationale boils down to three major engineering challenges we need to practice prior to 1000 day commitments on a Mars trip. Those are power [need nuclear power, not just RTGs, but reactor support], protection from radiation [one of the good aspects of having lots of electrical power], and an ability to provide artificial gravity during the long cruise to Mars [we do not know how to handle 8 ½ months of free fall on the way to and return from Mars].

The second puzzle in the timeliness arena is that we NEED the space elevator around Earth for an enabling, inexpensive, access to orbit infrastructure; but, the material is not available to meet the ribbon strength requirements. The biggest gravity well (and the initial kickoff for all exploration activities) is on the Earth and requires the greatest strength in materials.

Total Assessment: Jerome Pearson expressed the argument for Lunar Space Elevator First:

"The lunar space elevator will also be a stepping stone to the Earth space elevator. Lunar space elevators do not require super-strength materials, and do not endanger all Earth satellites. Lunar space elevators are twice the length of the Earth space elevator, but because of the moon's much smaller mass they can be constructed of existing materials. In addition, there are few satellites in lunar orbit, no man-made debris, and fewer meteoroids are expected. The Earth space elevator and the lunar space elevator both need traveling vehicles to carry cargo along their ribbons of material, and they are both orders of magnitude longer than any structure yet constructed in space. For these reasons, the lunar space elevator is an excellent test bed for examining many of the technology challenges of the Earth space elevator, including the dynamics and stability of long structures in space, control of the lateral and longitudinal oscillations, and the vehicles climbing rapidly along their great lengths."[10]

Total Assessment: the argument for Mars Space Elevator First – The Martian space elevator will be the second or third one built as it is so far away and we are not scheduled to be there for another 20+ years. In addition, the expense of getting to Mars will ensure that human missions are in the future with robotic systems filling the void for the foreseeable future. These would be too hard to operate remotely for establishing an infrastructure to enable massive movement of equipment and people. As such, the Mars space elevator will wait for the people

[9] "Lunar Space Elevator," Wikipedia, 7/17/2010.

[10] Pearson, Jerome. Levin, Oldson, & Wykes. "The Lunar Space Elevator," IAF 2004. Pg 8.

and then be developed to "enable colonization" in the Martian zone.

Another professional in the space arena stated: "My thoughts while walking were Mars is the farthest away and should be deferred until after we learn how to live and prosper on the moon. I think most of what we think we will need to get to Mars and to live on Mars will need to be demonstrated and the moon is the best place to do it.

- it is closer
- it has lower gravity
- it is easier to understand
- it is the easiest to supply/resupply
- it will be the easiest to exploit

"My thoughts on Mars is that it is just too hard. We will be a very long time just getting man to Mars let alone learning how to live there and building a space elevator there.

- Mars is so far away, it is hard to communicate with it, time delay
- Mars is so far away, there can be no timely help from Earth, folks are on their own.
- the trip to Mars is so long, we will need to do a lot of work learning how to support man on a space journey of that duration, years.
- we do not know how to keep man self supporting in space for a week let alone years

Bottom line, Mars is just too hard to do first. And, if you try to do Mars first, you will end up doing a space elevator from the moon first anyhow just to get ready to do Mars."[11]

Total Assessment: the argument for Earth Space Elevator First –

If one is to move beyond Low Earth Orbit in a manner compatible with expansion of the human race off planet, or colonization, an infrastructure is essential. The space elevator will be the "to orbit" infrastructure as it will be low cost, readily accessible, and open to all.

Development of a space elevator is directed at the cost of access to space. The current and historic approach of launching satellites has become more refined, but is still described as "Building rockets… always on the edge of chaos."[12] This approach has two serious handicaps: only a small fraction of launch mass on the pad gets to orbit; and, the fuel and structures are all consumed. These handicaps lead to large inefficiencies and tremendous costs. One goal of the space elevator is to leverage an initial investment in infrastructure into access to space and then take advantage of routine transportation modes. The parallel to a bridge is evident, as the climber only consumes renewable energy. This leverage should lead to $100 (US dollar) per kilogram in the near future; and eventually, to $8 per kilogram after multiple space elevators are operating. The rocket infrastructure will change to being one around planets (and returning to Earth). The parallel is true on both other worlds—the Moon and Mars. Consumption of fuel for propulsion does not make an infrastructure that is reusable and cost effective.

Conclusion # 1: First – conduct a complete point design for the Lunar Space Elevator. The rationale for this consists of three points:[13]

Point One: The case for doing a space elevator from Earth first (versus the moon) is the same as for Mars. Earth first is just too hard. Everything you need to do a space elevator on the Earth will need to be demonstrated first and the moon is the best place to demonstrate it.

- Earth's gravity is greater than the moon, making things harder.
- there are winds on the Earth that will make it hard to build a space elevator on Earth versus the moon with no winds.

[11] Adams, Dennis. Discussions during outing, August 2010, Fiji.

[12] Robert Sackheim, "Panel Discussion," The Space Elevator 3rd Annual International Conference, 30 June 2004, Washington, D.C.

[13] Adams, Dennis. Discussions with during Aug 2010 in Fiji.

- There are lots of things flying in the Earth's atmosphere that would be able to crash into a space elevator while around the moon there is/will be very little flying near the moon.
- There are lots of satellites flying around the Earth, both intentional satellites and trash, that could crash into an Earth based space elevator. There is/are very few satellites around the moon.
- There are/will be many humans on the Earth who would want to see the space elevator destroyed. There are fewer of those on the moon.

Point Two: A space elevator on the moon will require materials that are in common use today. Jerome Pearson states that the "materials for a space elevator on the moon exist today"[14] while the materials for a space elevator on the Earth will need a lot of development. The materials that are needed and selected for a space elevator, are much closer to realization for the lunar space elevator. This is because of:

- lower gravity
- lower atmospheric disturbances.
- the less stressing distances to build a SE to place materiel in moon orbit

Point Three: Another rationale supporting conclusion one is that the first space elevator to be built should have a high probability of success:

- a simple demo will validate the models, both dynamic and materials
- a simple demo will validate the manufacturing and assembly processes
- a simple demo will capture more political support; it will be seen as a simple stepping stone to a much greater project.
- a simple demo will flesh out and quantify the requirements and constraints.

Conclusion # 2: Second – Design and build the space elevator on the Earth FIRST. The rationale for this is that the greatest need is moving out of the gravity well that the human race has been in for eternity. This will ENABLE colonization. The second is that the business case supports a robust transportation infrastructure on the Earth to the Moon and beyond. The ONLY financially viable space elevator is one where the most usage will occur. The parallel to a railroad is obvious and must be followed. The technical achievement must be accomplished, even if it is much more difficult, because it will ENABLE movement off of the Earth.

George Whitesides stated… "Until you build an infrastructure, you are not serious."[15] The space elevator is designed to be ***THE*** space access infrastructure to orbit, the Moon, Mars and beyond.

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[14] Pearson, Jerome, Eugene Levin, John Oldson, Harry Wykes. "Lunar Space Elevators for Cislunar Space Development." Phase I Technical Report, NASA, May 2005. Pg 11

[15] Whitesides, George, "Panel Discussion," The Space Elevator 3rd Annual International Conference, 30 June 2004, Washington, D.C.

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