Space Elevator Stage I: Through The Stratosphere

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Abstract:

It is not necessary to wait for new materials to make a start on building the first stage of the space elevator. Using magnetic levitation, which is a proven technology, and using Kevlar as the main structural material, the first stage can be built from the sea upwards. It can support a large transfer platform at 50 km altitude so that payload, and eventually passengers, can board a climber on the main space-elevator ribbon when that becomes available. Stage I is based on the Lofstrom Loop (Launch Loop). It has the advantage that the problems of dealing with wind, cloud and electrical storms are isolated from the main ribbon. Strong winds are prevalent in the stratosphere, and the Lofstrom Loop is designed to cope with the weight of tethers needed. The structure stands on floating platforms at sea, and it puts no weight on the ribbon.

1. Introduction

The space elevator must pass through the Earth's atmosphere, where it must cope with the effects of winds, clouds and storms. It is preferable not to load the whole structure with the loads and buffeting entailed. It helps to choose a site near the equator where there are no recorded tropical storms, such as the area of the Pacific south west of the Galapagos Islands. It is still necessary to cope with wind pressure in the stratosphere. Using tethers for stabilization or increasing the tension in the space-elevator ribbon would cause strong variable forces that would have to be supported from the top.

The proposed solution is to use an adaptation of the Lofstrom Loop,[1] also known as the Launch Loop or the Space Cable,[2] as stage I of the Space Elevator. The launch loop is one of the concepts related to the space elevator outlined in a paper by Jerome Pearson.[3] Stage I will stand on *surface stations* floating 240 km apart. It will support a *transfer platform* 50 km above the Earth's surface. Stage I will lift payloads, and eventually passengers, to the transfer platform for onward travel up the space-elevator ribbon to geosynchronous orbit or beyond (Figure 1).

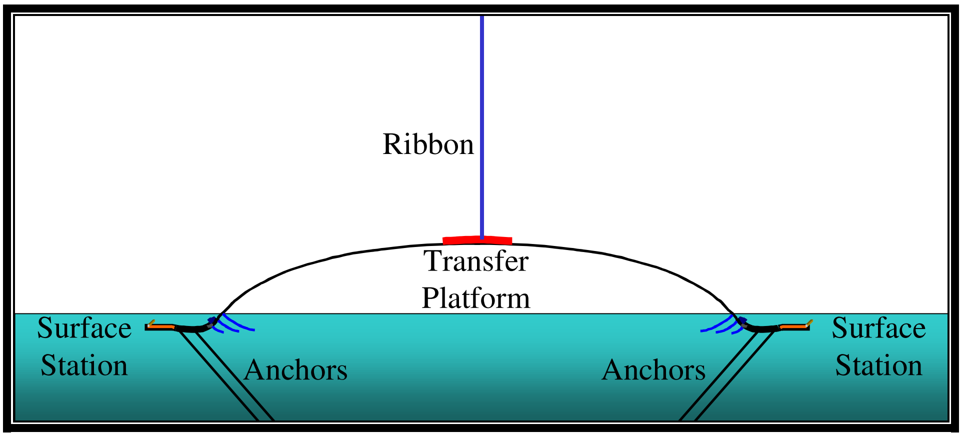

Figure 1 Space Elevator Stage I with surface stations and transfer platform

The Lofstrom Loop was designed to propel a vehicle directly into orbit electromagnetically, but the technology can be adapted to act as a high-altitude support structure. It is held aloft by fast-moving continuous belts called *rotors* traveling inside evacuated tubes. To minimize friction and energy

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consumption, they use magnetic levitation with permanent magnets stabilized with electromagnets. The levitation force causes the rotors to change the direction of their momentum vectors, which provides sufficient force to support the weight of the tubes and transfer platform. The rotors continue in an indefinite loop via the transfer platform from one surface station to the other and back again.

Previous work has shown that this structure is feasible using Kevlar as the main load-bearing material and Neodymium Iron Boron (NIB) in the magnets. Because these materials are available today, the space elevator stage I can be built now and so provide valuable experience of reaching space using a fixed infrastructure. Hence it can be stage I chronologically as well as the lowest stage physically.

To maintain stability in the presence of gusting cross winds, a technique called active curvature control transmits the forces to a set of tethers near each surface station. The support structures at the surface station are designed to accommodate the consequent movement of about 150 meters in any horizontal direction.

1.1 Advantages and Disadvantages

Stage I uses known technology and materials that are already available. It can therefore be built without having to wait for new materials. Initially, it can support astronomical telescopes and other scientific instruments 50 km high at a fraction of the cost of launching them into orbit. They will be easy to access for service and upgrade. Later, tourists will be able to visit the platform, and this will build experience and generate income that can be reinvested in the higher parts of the space elevator.

The platform can support power beaming to climbers using lasers or microwaves without the diffusion caused by the Earth's atmosphere and without blocking caused by clouds or storms.

The main disadvantage is an increase in conceptual complexity of the space-elevator project.

1.2 Stage I Variations

Research has been published on versions of the Lofstrom Loop as high as 140 km or as low as 300 meters.[4] The preferred altitude of 50 km is low enough to avoid significant risk of damage due to space debris but high enough that there is no risk of wind damage to lightweight solar panels that may power the climbers.[5]

Stage I can support more than one laser power transmitter at altitude. If the climbers use lightweight solar panels, only one transmitter is required and only at night. Having the transmitter at altitude eliminates the dispersion caused by the atmosphere and avoids clouds, although having it at sea level makes it easier to cool. It is advisable to place it away from the space-elevator ribbon so that the ribbon does not block the beam, even when being moved to avoid debris. The suggested altitude is 20 km; there is little atmospheric dispersion, but cooling is easier than higher up, and the transmitter can be 90 km from the ribbon.

The surface stations can be sited on land instead of the ocean. Alternatively, one station could be on an island or near a coast while the other station is at sea. Having at least one surface station at sea allows it to be moved, which makes erection of stage I easier.

It is possible to use a different shape for stage I by having the surface stations closer together, but the 240 km separation is easier to stabilize. Another design is to have four surface stations with the tubes forming a cross. A three-cornered arrangement is also possible, and both these arrangements help with stability. However, solutions are available to the problem of stability with two surface stations, and they avoid the significant cost of extra stations. The cross arrangement may be useful when moving the space-elevator ribbon to avoid space debris. Further work is needed on the speed and forces needed for moving the ribbon.

In work on the Space Cable, the continuous rotor is replaced by separate bolts. This has the advantages that (a) the spacing can be varied by a factor of three or more, which is helpful during initial erection on land, and (b) the bolts can be manufactured off site and are replaceable. The advantages of the rotor are that (a) it can be used as a large heat sink, and (b) it is less liable to sputtering and related problems if there should be a flaw in the vacuum through which it is traveling.

1.3 Following Sections

We look at where to locate stage I, which is to be the space elevator's anchor. That is followed by descriptions of the transfer platform and surface stations. After that, there is more detail on the technology.

2. Location

Erecting stage I at sea has some advantages, because the surface stations can be brought closer together as the tubes rise. On the other hand, siting it on land is likely to simplify the operational logistics. The location must be away from human habitation in view of the experimental nature of the project. We are dealing with novel technology. At the required scale, a very large amount of energy is stored in the moving parts, and stringent safety precautions must be taken.

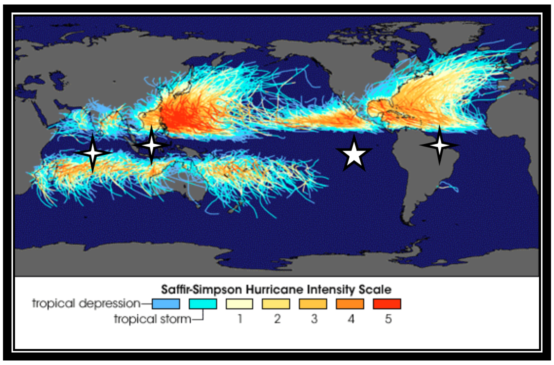

Figure 2 Recorded tracks of tropical storms over the last 150 years

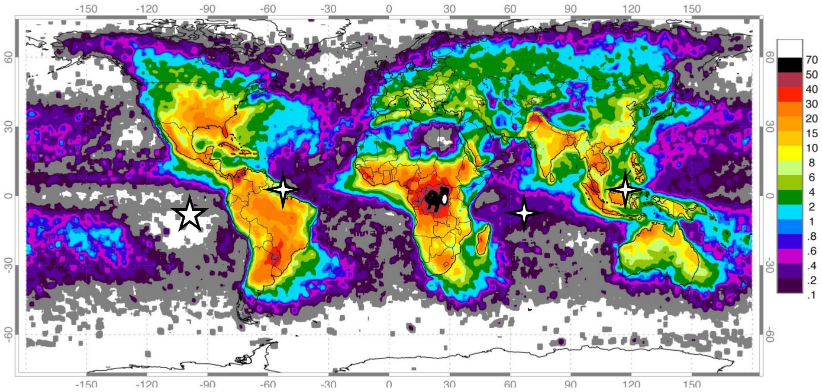

Figure 3 Annual rate of lightning flashes observed by NASA satellites: Apr 1995-Feb 2003

The equatorial area of the Pacific Ocean south west of the Galapagos Islands at longitude 100°W has particularly calm weather and is the favored site. Another possibility is the Salomon Islands, part of the British Indian Ocean Territory; this uninhabited atoll is at 5°S and 72°E. A surface station could be based on the largest island, Boddam, which is about 2 km long. The second surface station would be at sea.

Sites on land include French Guiana at 4°N and 53°W and Brunei at 5°N and 115°E. All four sites are marked by stars in Figure 2 and Figure 3.

2.1 Climate at Altitude

Cyclonic storms, i.e., hurricanes, tornadoes or typhoons, are rare at the equator. As Figure 2 shows, they have not been observed at all in the last 150 years in the zone south west of the Galapagos.

Electrical storms do occur at the equator and are very frequent in central Africa and elsewhere on land. However, Figure 3 shows that the rate of occurrence in the region west of the Galapagos Islands is extremely low, and it is less than one strike a year in the middle of the Indian Ocean. Stage I will carry a lightning conductor to carry electric currents to the surface so that they do not affect the main space-elevator ribbon.

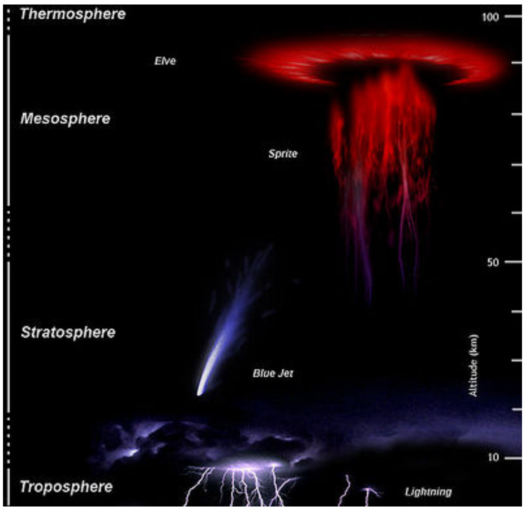

Figure 4 High altitude lightning and discharge phenomena

Some electrical phenomena occur at high altitude, as illustrated in Figure 4.[*] Blue jets occur in the stratosphere, up to about 50 km; sprites and elves are twice as high. Another phenomenon, the gigantic jet, was only discovered in 2001; they reach from the lower stratosphere up to 70 km. All of these are associated with electrical storms in the troposphere. Electrical breakdown above thunderstorms was first predicted in the 1920s, but the first documented visual evidence was obtained in 1989.

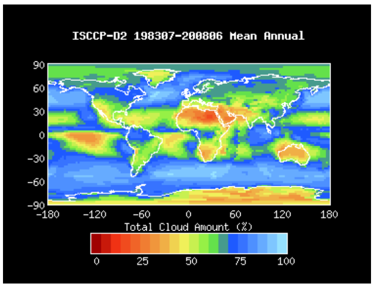

Figure 5 Global cloud cover from the International Satellite Cloud Climatology Project

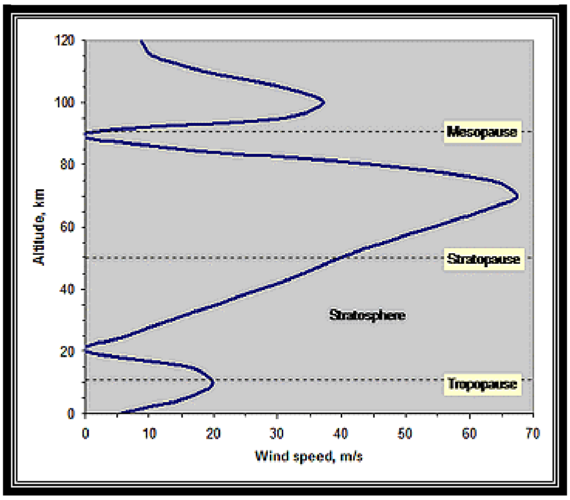

Figure 6 Average global wind speed against height

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[*] Source: en.wikipedia.org/wiki/Upper-atmospheric_lightning

Choosing a site with few electrical storms means that high-altitude electrical phenomena are also likely to be infrequent. Siting the transfer platform at 50 km altitude will still expose the main space-elevator ribbon to elves, sprites and gigantic jets, but carbon nanotubes will conduct the current to the transfer station, where it will be connected to the stage I lightning conductor.

Information is available on global cloudiness, which is important if laser power is to be beamed from the Earth's surface. In Figure 5, the blue areas are the most cloudy, and much of the equatorial zone shows a high percentage of cloud. Siting the power transmitter above the cloud level avoids this problem.

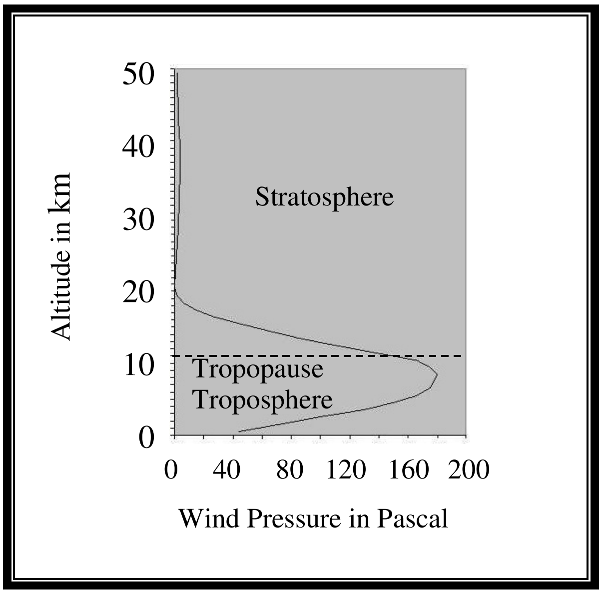

Figure 7 Wind pressure against altitude, based on average global wind speeds

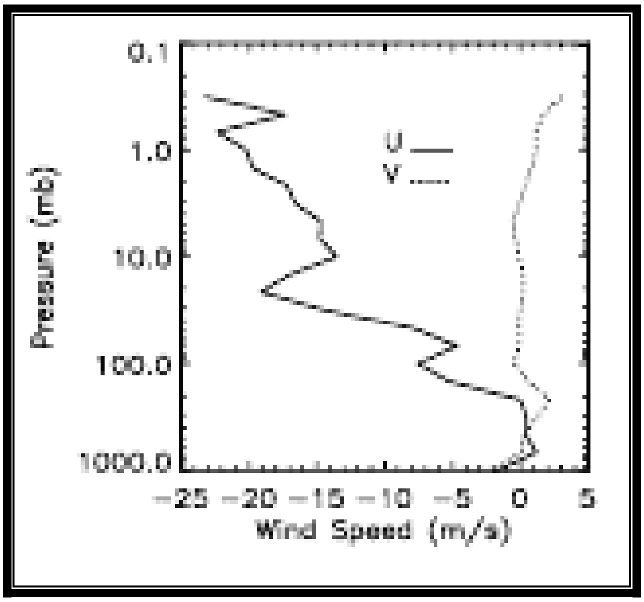

Figure 8 Wind speed against atmospheric pressure in the equatorial Western Pacific December-March 1991-92

Winds are a challenge to the space elevator. In temperate latitudes, jet stream winds can exceed 100 meters/sec between altitudes of 9 and 15 km.[6] Figure 6 shows global average wind speeds against altitude.[*] The high speeds above the stratopause are of little consequence because of the extremely low density. Figure 7 takes the atmospheric density ρ into account to reach an estimate of global average wind pressure ρv^2, where v is wind speed. Maxima may be four times as great as averages; that effect can be seen by multiplying the pressure scale by 16.

Near the equator, there are only seasonal jet streams over Africa near latitudes of 15° N or S, and they do not occur over the equatorial oceans. Figure 8 shows that equatorial wind speeds are generally more moderate than the global average,[7] although more detail is needed on the extremes.

Considerable design effort has gone into dealing with strong winds in stage I, based on the use of tethers supported by the rotor via magnetic levitation. This is a great advantage over the alternative of trying to support these forces directly from the ribbon.

3. Transfer Platform

The transfer platform is the anchor point for the main space-elevator ribbon. It handles automated cargo transfer and contains mechanisms to move the ribbon when required to avoid space debris. It also has facilities to hold several climbers. When we are ready to accommodate passengers, we expect that most of them will want to stop at the transfer platform to admire the spectacular view, much as most visitors to the Eiffel Tower like to pause at the intermediate stages. An observation lounge will be provided for them.

The tubes up to the platform vary in slope, and so a vehicle designed for passenger comfort could vary the tilt of seating areas. On the other hand, the climber that ascends the ribbon from the platform does not need that adaptation but does need to be suitable for micro gravity. The methods of supplying power are quite different: either the stage I vehicle draws power from the tubes and propels itself, or it is winched up. The climber ascending the ribbon may be powered either by ultra lightweight solar panels or by receiving power from a laser transmitter. To avoid wind damage, the lightweight solar panels should not be brought into the atmosphere but held at the transfer platform.

Therefore, it is proposed to have two different classes of vehicle: one for the vehicle traveling between the surface and the platform, and one for the climber going up and down the ribbon. Passengers and cargo will transfer at the platform.

3.1 Space Debris

The altitude of the transfer platform is chosen so that the risk of being hit either by space debris or a natural meteor is negligible. On the other hand, the space-elevator ribbon will be exposed to these hazards. It is designed to withstand collision with objects up to 10 cm. Larger objects can be tracked, and the ribbon must be moved to avoid them. One method of doing this is to pay out an additional length of ribbon and initiate a transverse wave from the platform. According to a recent study, up to 100 meters of ribbon may be required, which would permit lateral movement up to that distance in any direction.[8] It is sufficient to thrust the ribbon at the desired velocity using winches, so long as it is timed to set up a resonant traveling wave. It is not necessary for the winches themselves to pull the ribbon the whole distance.

3.2 Power Transmission

The transfer platform can support the power supply to the climbers, but it is preferable to place the laser power transmitter lower down. At 20 km altitude, the transmitter is 90 km away horizontally, which is far enough away from the space-elevator ribbon to eliminate any risk of being blocked by ribbon movement. 20 km is high enough to avoid the dispersion caused by the atmosphere and the risk of occlusion by cloud.

Of course, it is still possible to site the transmitter on the ocean surface, where cooling is straightforward, but cloud will sometimes occlude, and the atmosphere will partially disperse the beam.

A climber starting at dawn and traveling at 300 kph reaches an altitude of 3600 km after 12 hours, where it enjoys an additional 2 hours of sunlight to reach 4200 km. Initially, the power required is 16 MW.

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[*] Source: http://www.intercomms.net/AUG03/content/struzak1.php, credited to COSPAR International Reference Atmosphere at http://nssdc.gsfc.nasa.gov/space/model/atmos/cospar1.html

At 4200 km, gravity is reduced by 64%, and the power required is only 6 MW. Assuming 20% of the laser output is captured and converted into mechanical power, the laser beam output required is 30MW. We assume 2 MW of waste heat per MW output.[*] So we need 90MW of power, 60MW of which has to be disposed of in cooling. At a ratio of 3 kg/kW, the estimated weight is 300 tons.

This assumes that the climber can obtain the power it needs from the sun during daylight (ref. 5) using very lightweight solar panels. If such panels do not become available in time for the space elevator, there remains the solution of installing three laser transmitters emitting 50 MW of power each, sufficient to supply three vehicles at different points on the space-elevator ribbon, each traveling at 200 kph. On the same assumptions as above, the total power including losses is 450 MW, and the weight estimate is 1400 tons.

Cooling a laser at altitude can best be done with water lifted from the surface. The latent heat of boiling water is 2380kJ/kg, and so water is needed at 25 kg per second to dispose of the 60 MW heat produced by the 30 MW laser. Lifting water to 20 km at that rate requires an additional 5 MW of power.

4. Surface Stations

There is a station on the surface at each end of stage I, either on the ground or at sea. During startup, the surface stations accelerate the rotors. Thereafter, in continuous operation, each station turns round the rotors from the incoming tubes and sends them back through the return tubes. It can build up a reserve of speed, and hence energy, by allowing the tension in the tubes to increase so that it is non-zero at the surface. This also simplifies the task of maintaining stability.

In continuous operation, the incoming rotors arrive on the *ramp* that turns them to the horizontal. Then they proceed to the *ambit* that turns them around, after which they go back up the ramp. These are illustrated in Figure 9, in which the ramp is below sea level, and a submarine pipe brings the rotors back near the surface for the ambit and accelerator. It is possible to have the ambit submerged more deeply, thus shortening the pipe, but that would make servicing more difficult.

On land, some of the ramp is in a tunnel, some of it supported by a gantry and some of it supported by short *support tubes* (as distinct from *main tubes*). This represents a compromise between depth of tunneling and height of support tubes. The ambit and accelerator pair are at surface level or in shallow trenches. The details will depend on site conditions.

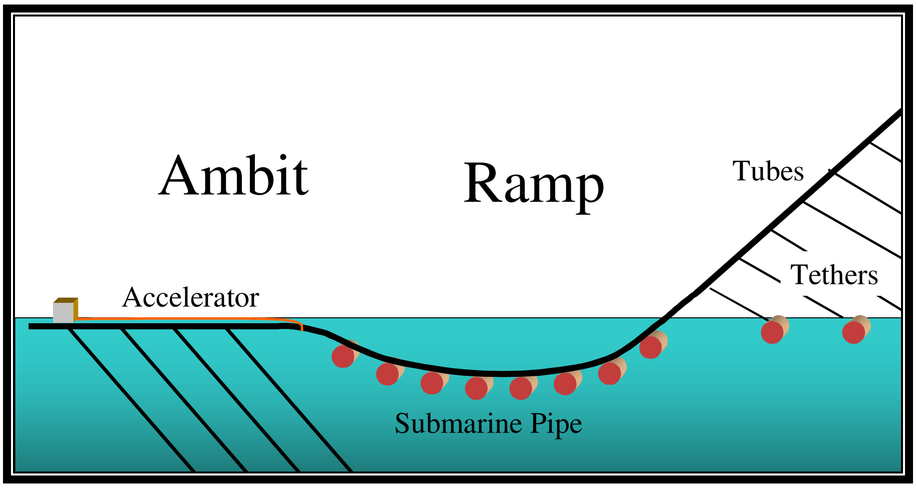

Figure 9 Side View of Ramp, Ambit and Accelerator Pair

As illustrated in the plan view (Figure 10), there is a large ambit to avoid deceleration and acceleration. This allows powerful magnets to be used in the ambit. These may be permanent or superconducting magnets. An ambit using permanent magnets is large but reliable. Powerful electromagnets are available, but they consume substantial power. Superconducting magnets cooled with

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[*] Jordin Kare, personal communication

liquid helium are preferred, because of their field strength. Where the Lofstrom Loop is used for launching to orbit, the rotor can become very hot, which risks warming the liquid helium but, in the space elevator stage I, the rotor will not absorb much heat, and so we can benefit from a compact ambit.

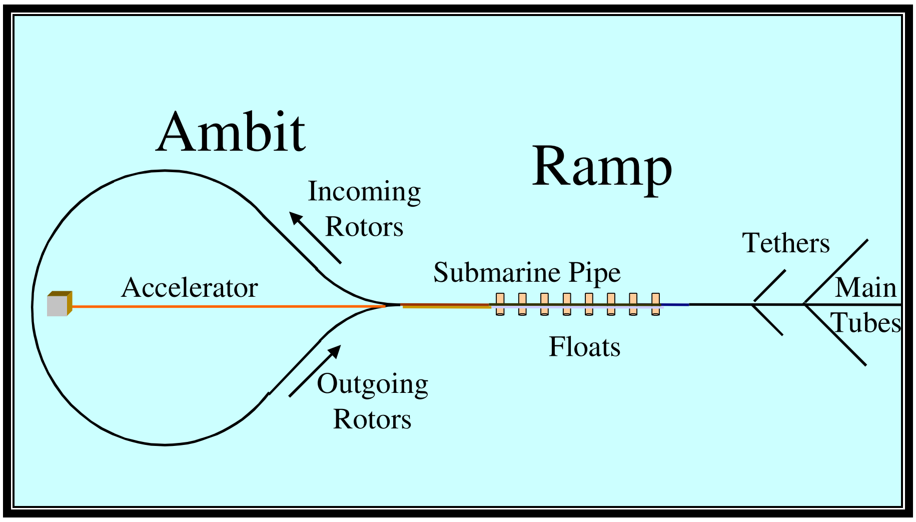

Figure 10 Plan View of Ramp, Ambit and Accelerator Pair

The force on a magnet of flux density B_1 with effective surface area A in a field B_2 is given by

$$F = \frac{B_1 B_2 A}{8\pi \times 10^{-7}}$$

Commercially available superconducting magnets can apply a 10 T (Tesla) field. Using this equation, we obtain a force F in the ambit of about 60 kN if A=100 cm^2, assuming an induced field in the iron rotor of 2 T. This result is confirmed by a simulation using *Finite Element Method Magnetics, Version 4.2*. The ambit radius is mv^2/F for a rotor mass m kg/meter and velocity v. If v is 3.5 km/sec and m is 3 kg/meter, the radius is about 615 meters. If NIB permanent magnets were used instead of superconducting magnets, the field strength would be about 1.2 T. Taking the induced field as 0.9 T, the force comes to approximately 4.3 kN, and the radius of the ambit would be 8.5 km.

4.1 Extent of the Ramp

The overall vertical extent of the ramp required is given by $2R\sin^2(\theta/2)$ for radius of curvature R and angle of inclination θ to the horizontal. To achieve the best radius, superconducting magnets are needed in the ramp, cooled with liquid helium. Now θ is 38°, and R is as for the ambit, giving a vertical extent of 145 meters, which is the required depth of the submarine pipe. Its length is roughly $2R\theta$ (θ in radians), which is about 860 meters. The angle of inclination of the main tubes can be varied by varying the buoyancy of the floats.

4.2 Facilities at a Surface Station

Apart from the infrastructure needed to support and operate the space elevator stage I, facilities include a floating airport capable of handling regional jets that link to the nearest international airport, which is at Quito in Ecuador in the case of the site south west of the Galapagos. A runway about 1200 meters long is suitable for this class of aircraft. Passengers will disembark from an airplane and transfer to a vehicle that is lifted up the tubes to the transfer platform.

The surface station floats and includes a floating dock for cargo and resupply as well as sufficient accommodation of reasonable quality for passengers and crew, bearing in mind that a flight could be cancelled or delayed as at any other airport.

5. Forces and Technology

The rotors traveling inside the evacuated tubes are able to support the weight of the transfer platform, as well as the tubes' weight, by changing the direction of their momentum vectors. However, this does not reduce their kinetic energy. The rotors lose kinetic energy due to residual friction and due to gravity. They make up the effect of gravity when they descend. The surface stations give them a boost to make up for friction losses.

Permanent magnets deflect them without affecting their speed, thus creating a force orthogonal to the direction of travel but without taking any of the rotors' kinetic energy. Because of the inherent instability of levitation by permanent magnets, electronically controlled electromagnets in the tubes are used to maintain a clearance of about 1 mm between the rotors and the tubes. Careful design of the permanent-magnet arrays and the electronics allows the currents in the electromagnets to be kept very small.

As illustrated in Figure 11, the levitation force at the top of the curve supports the weight of the platform and the greater part of the tubes. Lower down, the levitation force is not vertical, and it only supports part of the weight. Tension in the tubes supports the other component of weight. Because tension in a curve causes a net orthogonal force inward, the tension transmits the tube weight to the top.

If the mass density of a rotor is m kg/metre and it changes direction by an angle ϕ over a distance l, then the change in momentum is $mlv\sin\phi$, where v is the speed. This happens in the time the rotor travels the distance l, which is l/v seconds. Hence, the rate of change of momentum is $mv^2\sin\phi$, and this is the resultant levitation force. If ϕ is 5°, m is 3 kg/metre, and v is 3.5 km/sec, the force is 3.2×10^6 N (Newtons) per tube. Thus ten tubes would support 3100 metric tons weight. However, using permanent magnets, the available force is about 1600 N per meter per tube in addition to the 160 N needed to support the tubes themselves. Thus a 250-meter length with 10 tubes can support 400 metric tons. By contrast, suitably designed electromagnets can support 10000 N per meter per tube. A length of 300 meters is sufficient to support a 3000-metric-ton platform.

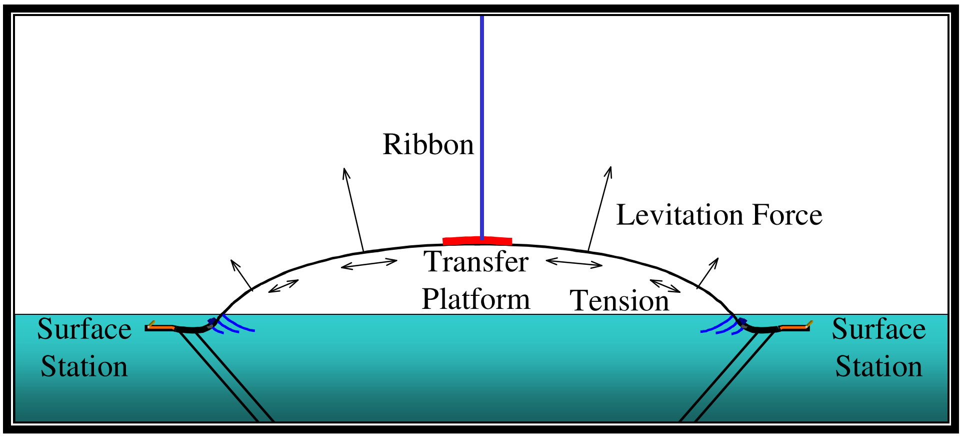

Figure 11 Shape of Curve indicating Tension and Orthogonal Forces

For the sake of redundancy, six pairs of tubes are used so that one pair can be quiesced and taken down for maintenance while the other five pairs continue to support the platform. Different numbers are possible, depending on the desired degree of reliability and the weight to be supported.

5.1 Winds and Stabilization

Cross winds and other disturbances will tend to cause instability. There is a natural stability in the vertical direction due to the effect of gravity offset by the curvature of the tubes and rotors. This stability is enhanced by adding moderate tension to the tubes to allow the necessary variations in the rotors' speeds without the structure sagging. Laterally, however, the structure is inherently unstable, and corrective measures are needed.

A technique has been researched called active curvature control (ref. 2). It uses electronic methods to correct for changes in curvature and adjust them so that they match the curvature required to counteract lateral forces. It is designed to maintain stability at higher altitudes by transmitting movements down to the Earth's surface. There are some practical implementation details still to be worked out. It requires the time derivative of curvature to be measured and the results to be acted on as the rotor passes at high speed. Assuming these details can be resolved, the complexity of the control problem is comparable to that handled by automatic systems on sailing vessels, although the scale and speed is much greater.

The maximum deflection due to wind is calculated based on previous work showing that a tube is subject to a maximum wind force of 50 N/meter.[9] Winds are significant at elevations up to about 12 km. At these elevations, the rotor speed is 3.4 km/sec and the maximum deflection angle is 0.8°. This translates to a maximum deflection near the surface station of 220 meters in any direction. At 3 km elevation, the movement is about 150 meters.

The alternative solution is to attach tethers at periodic intervals up the tubes. These tethers would be anchored at the surface and would inhibit lateral movement. Small-scale movements between tethers are suppressed by the natural stiffness of the rotors and tubes. The drawback is that the tethers add considerably to the overall weight that the rotors must support through magnetic levitation, and this load scales non-linearly with altitude.

If there were no stage I, the space-elevator ribbon would experience these wind forces. It would need similar tethers to keep it stable, which would require a substantial increase in ribbon strength.

5.2 Tethers below 3 km

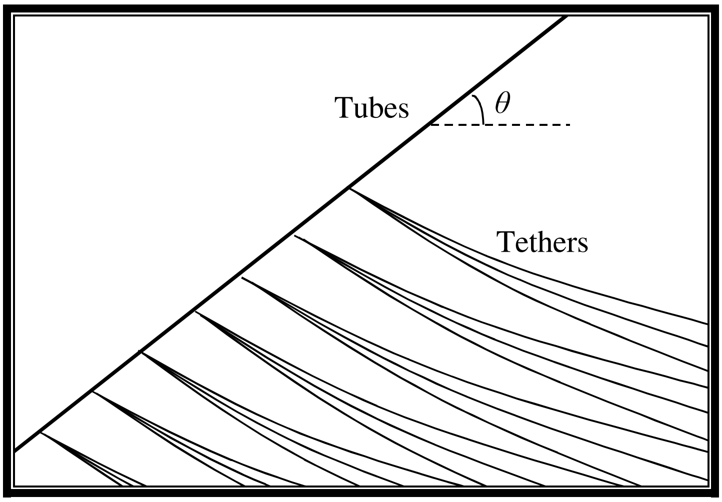

Figure 12 Side view of triples of tethers along the tubes

Using active curvature control removes the need for most of the tethers, but they are still required up to a height of 3 km in order to draw the tubes back from their maximum deflection so that they line up with the surface stations. Triples of tethers are placed at regular intervals along a tube, as in Figure 12. Each tube is anchored at the surface station and is under tension, so that each triple of tethers complements the tube in a stable four-cornered arrangement. The lateral wind forces that the tubes experience are stronger than those in the vertical plane of the tube by a factor $1/\sin\theta$, where θ is the tube's tilt to the horizontal. Only a factor $1/\sin\theta$ of this is experienced as a force orthogonal to the tube in the vertical plane, and so the angles of the tethers reflect that combined factor of $1/\sin^2\theta$. The following calculations assume there are three tethers per meter of tube, one in the vertical plane of the tube and the other two arranged symmetrically on either side. The actual tethers may be spaced more widely than this, as long as the force density per meter fits the calculations. Figure 13 shows the arrangement viewed from above.

At 3 km height, the tubes will move laterally as much as 150 meters to either side as the cross winds fluctuate. The vertical movement may be as much as 60 meters up or down. The tethers will change their tension by ±300 N. At lower altitude along the tethered tubes, the movement is less but the forces are the same. The tethers form catenaries with tension up to a maximum of 2000 N. The lateral tethers weigh 0.1 N/meter; the central tether weighs 0.35 N/meter. The longest tethers extend horizontally over 3.4 to 3.6 km. The slope at the junction with the tubes is approximately 35°; at the bottom it is approximately 17°. As the tethers need to extend or shorten, a winding mechanism is needed at the surface to maintain tension. No power need be supplied, as the movements are driven by the wind; in principle it is possible to draw some power from wind movements, although it is doubtful whether this would be worthwhile in practice.

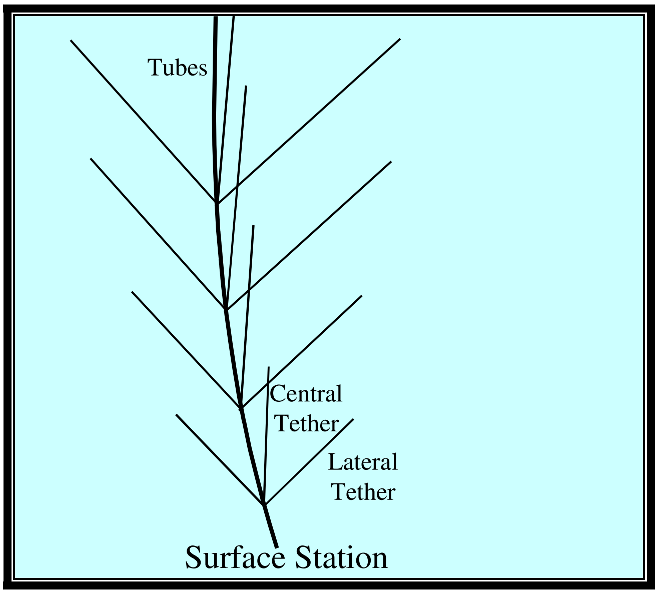

Figure 13 Plan view of triples of tethers along the tubes

The tension in the tethers adds to the force that the rotor and tube must support using magnetic levitation. Each lateral tether imposes a force of 1215 N in the vertical plane in the direction orthogonal to the tubes. The central tether adds 405 N, giving a total of 2835 N. This is a little high for permanent magnets, and electromagnets will be needed in the tubes for the 4 to 5 km where these forces can occur. More details are available elsewhere.[10]

5.3 Initial Erection

Initially, a pair of tubes is laid out flat on the surface of the ocean between the two surface stations. Slowly, the surface stations accelerate the rotor to full speed, which will take several days. The next step is to begin to raise the angle of the ramps. One surface station is at a fixed location, but the other is movable. The movable station is in two widely separated parts, the ramp and the ambit. The ambit is at the farthest point away from the fixed station, but the movable ramp starts close to the fixed station and slowly moves towards the movable ambit as the ramps raise their angle, causing the tubes and rotors to elevate between the two ramps. The movable ambit moves slowly towards the movable ramp to allow for the shortening of the surface distance as the tubes rise.

The magnetic forces required in the ramp are stronger than those needed in the bulk of the tubes, and sufficiently powerful electromagnets must be installed along the entire length of this pair of tubes. These magnets are adjusted while the movement of the floats supports the moving ramp. It can be calculated that the ramp length is about 12 km and it drops to a depth of 1.5 km below the ocean surface. The next (optional) step is to convert the ramp to using superconducting magnets. These must be installed along the 12-km length of tube that serves as the ramp once it has joined with the ambit. The superconductors can then be adjusted to exploit their power by shortening the ramp.

Once the first pair of tubes has been installed, the second pair is raised along it using crawlers. Next, the surface stations accelerate the rotor in the second pair until it can support itself. Further pairs of tubes are erected in the same way. It is possible to take the first pair down if desired in order to salvage the magnets that are no longer required.

Finally, the transfer platform is taken up in sections and assembled at the top.

A method using a helium-filled tube has been described (ref. 9) for use when both surface stations are on land.

5.4 Capturing the Ribbon

Once stage I has been erected, it is necessary to capture the initial threads of the space-elevator ribbon. These will be lowered from geosynchronous orbit. It is possible to think of ingenious methods of capturing the threads at altitude using a lasso or some form of hovering rocket. However, there seems to be no justification for spending significant time or money on such a one-off endeavour. The simple approach is to lower the threads to the ocean, where a team can gather them up using a small boat or launch. The crew can carry the threads to the surface station, where they will attach them to a vehicle to transport them to the transfer platform.

When the threads are secure, further construction of the ribbon can proceed from the transfer platform by means of the small crawlers.

6. Conclusion

A structure 50 km high can constructed using materials and technology available today. It can support a transfer platform that anchors the space-elevator ribbon so that the ribbon does not need to handle winds and storms. The structure, stage I of the space elevator, supports the weight of tethers and other paraphernalia required to deal with strong gusting winds, lightning and other phenomena. Climbers on the ribbon may carry fragile, lightweight solar panels, and they can be kept above 50 km height, protecting them from wind damage.

Stage I can support the required facilities, including a capability to move the ribbon to avoid space debris. If needed, one or more laser power transmitters can be installed at the suggested altitude of 20 km. It is recommended that the surface stations float on the Pacific Ocean south west of the Galapagos Islands.

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[1] Lofstrom, K., "The Launch Loop," AIAA Paper 85-1368, July 1985

[2] Knapman, J., "The Space Cable: Capability and Stability," *Journal of the British Interplanetary Society*, Vol. 62, No. 6, 2009, pp. 202-210

[3] Pearson, J., "The Real History of the Space Elevator," *57th International Astronautical Congress*, Valencia, Spain, October 2-6, 2006

[4] Knapman, J., "Diverse Configurations of the Space Cable," *61st International Astronautical Congress*, Prague, Czech Republic, September 27-October 1, 2010

[5] Shelef, B., *A Solar-Based Space Elevator Architecture*, The Spaceward Foundation, 2008

[6] Barry, R.G., Chorley, R.J., *Atmosphere, Weather & Climate, (Seventh Edition),* Routledge, London, 1998, Section 6-3

[7] Jiang, J.H. et al., "Geographical distribution and interseasonal variability of tropical deep convection: UARS MLS observations and analyses," *Journal of Geophysical Research,* Vol. 109, D03111, 2004

[8] Swan, C.W., Swan, P.A., Penny, R., *Space Elevator Survivability: Space Debris Mitigation,* published by Lulu.com, 2011

[9] Knapman, J., "Dynamically Supported Launcher," *Journal of the British Interplanetary Society*, Vol. 58, No. 3/4, pp.90-102, 2005

[10] Knapman, J., "Space Elevator Stage I," *62nd International Astronautical Congress*, Cape Town, South Africa, October 3-7, 2011