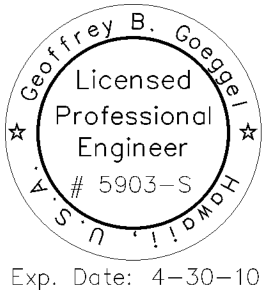


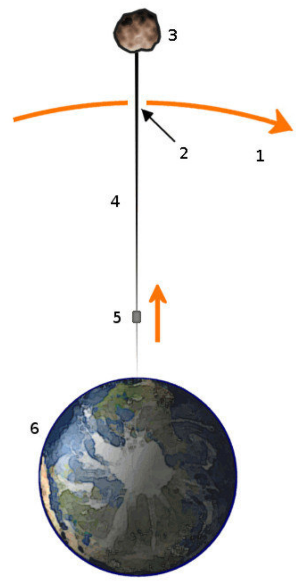
Engineering Study

for the proposed

HCG Space Elevator

September 9, 2009

A. Background

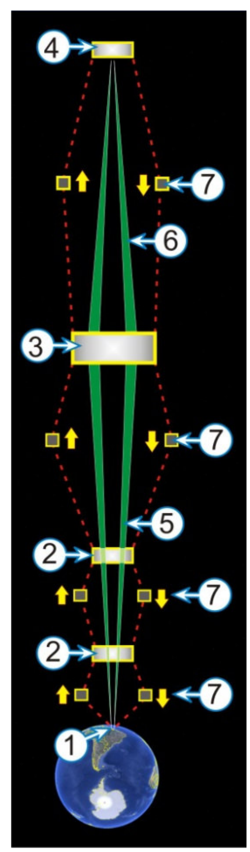


We are not alone. There are other life forms and civilizations out there. We need to go out and meet ***them there*** before ***they*** meet us ***here***. And there are many other doomsday scenarios: asteroids, gamma ray bursts, black holes, super-novas, killer viruses and bacteria, nuclear war, Sky-Net and mad scientists. As long as we all live here on this one planet, we as a species are at risk of extinction. ***We must colonize other worlds to ensure our survival.***

> "A **space elevator** is a method for lifting objects into Earth orbit much less expensively than chemical rockets. It has a lower cable (4) anchored to the Earth's surface (6) extending into space. It uses a counterweight (3) 60,000 miles up to keep the cable stretched tightly (like a yo-yo). An elevator cab (5) rides up the cable to reach geostationary orbit (2) at 22,000 miles. (From Wikipedia….*Diagram not to scale*.)"

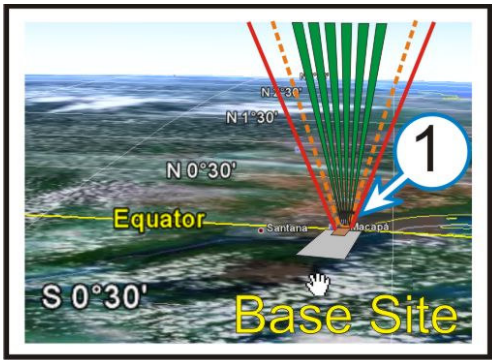
The construction of a space elevator is beyond our current technology. The cables required to build it can't be made yet. The weight of a 60,000 mile cable will snap any known existing material. But there are promising materials (i.e. carbon nanotubes) that might work.

This study examines the engineering aspects of a possible space elevator, including the materials, forces, cable stresses, maintenance issues, safety concerns, costs, and the future technology required to build one. The proposed *HCG Space Elevator* is shown at right.



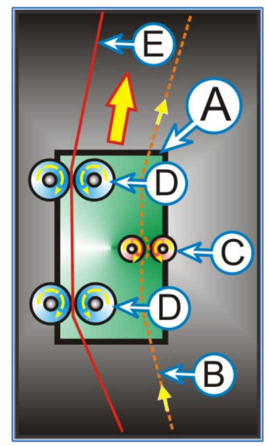
1) It has a **Base Station**;
2) Two **Transfer Stations:** at 2,000 & 5,000 miles;
3) A **GS Platform** in Geostationary Orbit;
4) A **Counterweight;**
5) **Tapered Support Cables** connecting the Base, Transfer Stations, and GS Platform;
6) **Tapered Support Cables** connecting the Platform to the Counterweight;
7) Four sets of **elevator cabs.**

B. Major Components



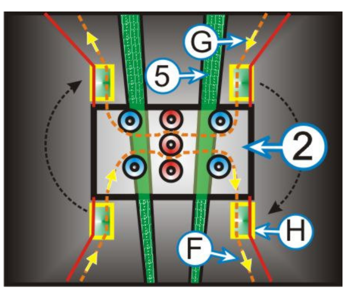
The **Base Station** (1) is in the town of Makapa, Brazil: 2009 Population 330,000. It lies on Brazil's east coast, on the equator, and on the Amazon River. This provides excellent transportation and infrastructure support.

All system power is generated down here and transmitted to the elevator cabs and platforms thru Drive Ribbons. Local energy sources include river and ocean currents (using *HCG's HeliTubes* of course), wind energy (*HeliWinds*), *BioMass*, and solar (*CSC 1's*).

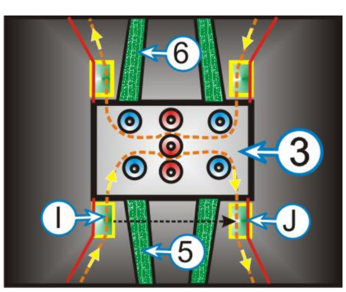


The 20,000 pound **Elevator Cabs** (A) carry 20,000 pounds of cargo and passengers up to the platforms. The **Drive Ribbon** (B) is powered from the Base Station at 10 mph, turning the **Genset** (C), which energizes the **Drive Wheels** (D). This moves the cab up (or down) the **Climbing Ribbon** (E). For safety, there are four drive and four climbing ribbons for each cab.

The torque between the Drive and Climbing Ribbons delivers 55,000 pounds of thrust to the Genset (C). 85% of this power is sent on to the drive wheels, and the remaining 15% powers the cab, provides a 0.2 g cab acceleration, or is lost to friction and heat. The kinetic energy is converted into potential energy as the cab rises. The cabs move at 50 mph in atmosphere but once in space, the cab weight progressively decreases (i.e. it's zero pounds at the GS Platform) and a top speed of 2,000 mph is possible. Bends in the ribbons are due to coriolis forces as the cabs accelerate and decelerate horizontally going into and leaving orbit.



Transfer Station # 1 (2) is at 2,000 miles. The **Lower Support Cables** (5) attach the Station to the GS Platform above. This is a good place for inserting payloads into low earth orbit. The Lower Drive Ribbon (F) cycles through the Station, providing Station power and also powering the Upper Drive Ribbon (G). During the layover, the Cabs (H) are switched between the upper and lower elevator ribbons. **Transfer Station # 2** is at 5,000 miles.

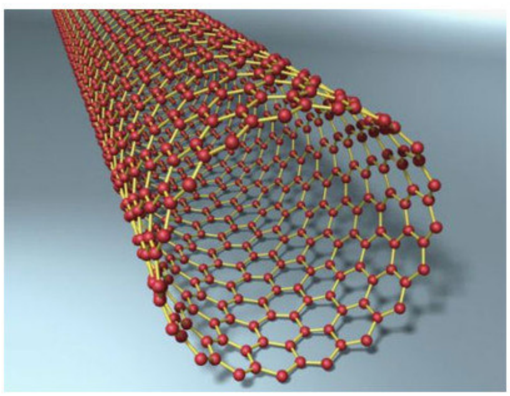


The **GS Platform** (3) is in Geostationary Orbit (22,240 miles), held there by the **Upper Support Cables** (6). The Cabs (H) dock here to transfer crew and cargo. In general, the down cab weighs less than the up cab. The drive ribbon powers the upper cabs and a Genset to power the Platform. The Upper Support Cables attaches to the **Counterweight** (4) at 60,000 miles. After docking, the cabs are moved from the up to the down tethers for the return trip (I ==> J). For safety, the Support Cables are divided into sixteen separated groups.

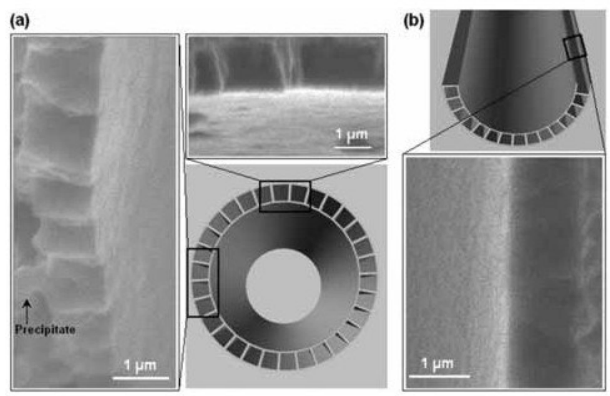
C. Tether

The materials we currently have are not strong enough to build the tethers. Pull the strongest steel cable off the surface of the earth and it will snap just 16 miles up. Kevlar can be pulled 160 miles up before it snaps. The highest strength-to-weight ratio materials we have now are just too weak to work. But one promising material may eventually work: the **carbon nanotube (CNT)**. It is pure carbon, formed by rolling up a flat sheet of graphite into a cylinder. The hexagonal crystal lattice employs the strongest chemical bond we know of: the sp^2 carbon bond. Its diameter is usually 1.5 microns. Theoretically, a carbon nanotube can stretch hundreds of thousands of miles into space without breaking. But not yet. So far, we can't make it in lengths longer than 0.001", and we can't role it into threads much stronger than Kevlar.

A new form of CNT, the **colossal carbon nanotube (CCNT),** is even more promising. Although it is not stronger than CNTs, its lower density provides a higher strength to weight ratio. It is the only potential material we have, so far, that could work. Maybe. It is usually 84 microns across, with the cell columns (basically single wall CNTs) 1.4 microns across.

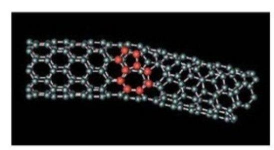


Carbon Nanotube

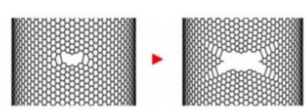


Colossal Carbon Nanotube

Theoretically, filaments of carbon nanotubes can resist tensile stresses of 43.5 Million psi (300 GPa) before they break. In comparison, our strongest steels fail at 0.40 M psi. But in practice, so far, CNTs can only reach 1 million psi due to lattice defects. These include the *Stone Walls* defect, where the regular hexagonal crystal structure is replaced by pentagonal and heptagonal arrangements. *Lattice ripping* also restricts ultimate loading of CNT Filaments. The CCNT appears to be much tougher than a single wall CNT and is expected to significantly reduce the weakening caused by these defects.



Stone Walls



Lattice Ripping

CNT's are highly corrosive. They oxidize in the atmosphere, breaking down the crystalline structure. In space, they're exposed to intense ultraviolet light from the sun and high energy cosmic rays. They will be impacted by micrometeorites and space debris. The useful life of a CCNT tether needs to be assessed. A test panel of carbon nanotubes needs to be installed on the *International Space Station* to learn the effects of long-term space exposure on CCNT's. A realistic budget for the Space Elevator depends on knowing how often to replace the tethers.

An individual CCNT filament is about the width of a human hair and, so far, can only be produced in lengths of a few millimeters. When rolled into threads, the filaments bond poorly, and 98% of the inherent strength of the CCNT is lost. Eventually, a method for the continuous extrusion of CCNTs must be found. Then the filaments can be wound into threads, the threads wound into tendons, and the tendons woven into cables and ribbons.

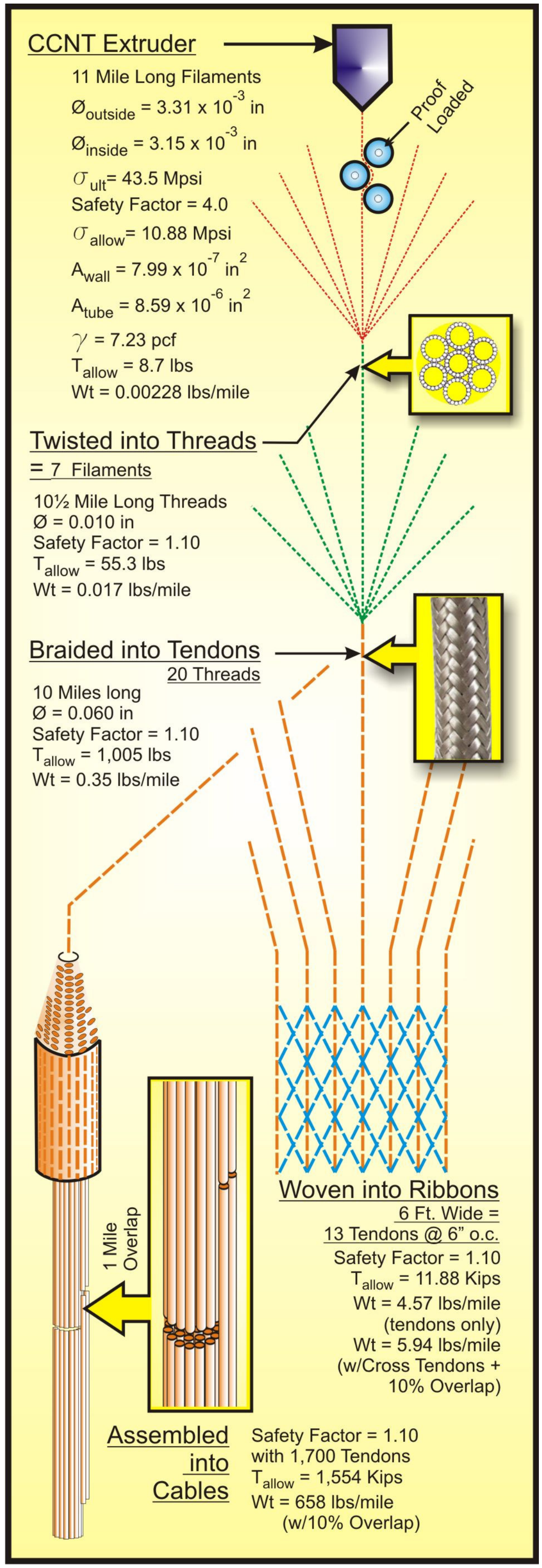
The properties of the CCNT filament presented in this report are based on the '08 work by Huisheng Peng:

> Ultimate Stress = 300 GPa = 43.5 M psi
> Safety Factor = 4.0
> Design Stress = 10.88 M psi
> Density = 0.116 gm/cm^3 = 7.23 pcf

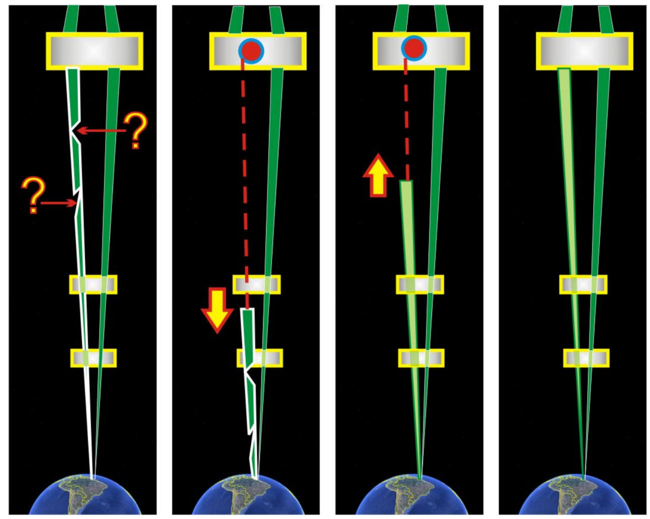
A ***Continuos CCNT Extruder*** is shown at right (hopefully developed by H. Peng by 2015, with a stress capacity of 25% of the theoretical ultimate stress?). An 11 mile long filament could be produced in four years at an extrusion rate of 1.66 ft/hour or 0.0055"/second. A single ***Peng CCNT Filament*** is expected to safely support 8.7 pounds. A proof-load roller must test filament strength before further fabrication.

Ten and a half mile long **Threads** are made by twisting seven 11 mile long Filaments together. Estimated allowable thread capacity is 55.3 pounds. Similarly, 10 mile long **Tendons** are made by braiding twenty 10 mile long Threads together. Braiding should reduce damages from space stuff. Tendon diameter is 0.060" and allowable loading is estimated at 1,005 pounds.

The Tendons are woven into **Elevator Drive Ribbons.** With tendons 6" on center, a six foot wide Ribbon has 13 tendons and can support a 11,880 pound load. To make a continuous Ribbon Loop, 10 mile long Ribbon segments are overlapped 1 mile to allow *Van der Waals* force to develop the full tendon capacity.

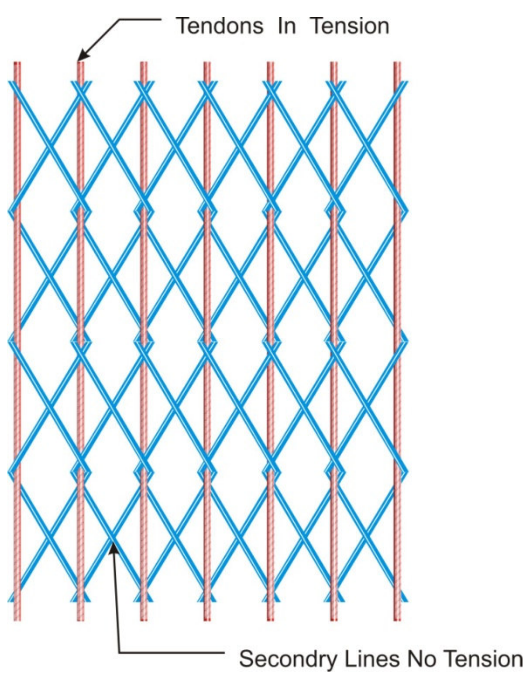


The Support Cables are tapered since even a uniform CNNT cable or ribbon cannot be lifted from the ground into GS orbit without snapping. By tapering the section, the net weight is reduced and the Elevator is structurally possible.

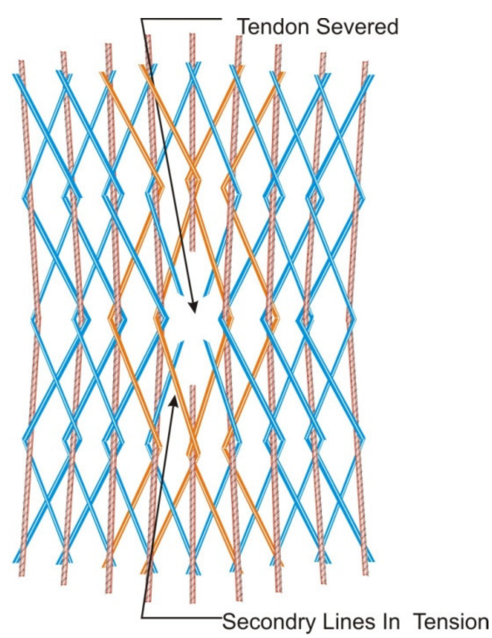


The support cables are made from thousands of tendons layered together with one mile overlaps. These support tethers are separated into 16 groups so that an impact with a space object will hopefully only sever one cable group. This study allows one of the Support Cables to be severed and a second to be out of service for repair. To repair a damaged Support Cable, the bad cable is detached, lowered to the ground, a new cable hoisted back up to the Platform, reattached, and put back into service (see at right).

A Drive Ribbon is woven from tendons spaced 6” apart. Spacing the tendons at 6” reduces the damage effects caused by impacts from small space debris and micro-metreriotes. Even so, every ribbon will degrade in the space environment and a safety factor of 1.1 is assigned for the ribbon’s design capacity. Ribbons are necessary to provide traction for the elevator drive wheels. (Gripping a round CCNT cable is nearly impossible.) Severing of a drive ribbon tendon is inevitable. To reduce the effect of this failure, a ***Hoytfabric Ribbon*** is proposed:



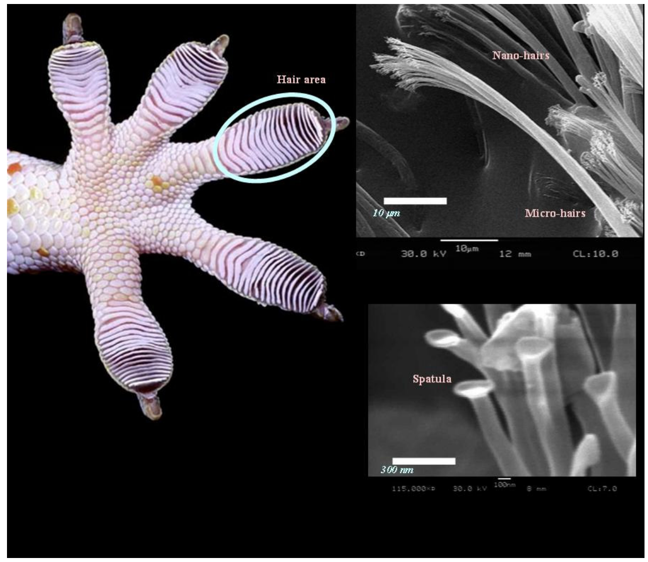
Hoytfabric Ribbon



Ruptured Hoytfabric

Primary tendons (shown in red) are 0.060" diameter and spaced 6" apart. When first installed, they carry all the tension loads. Secondary lines (shown in blue) are 0.020" in diameter and to keep the ribbon flat, initially slack (no tension). When (not if) a tendon is severed, the secondary lines pick up the load and go into tension. This arrangement increases the net ribbon weight 20%, but greatly increases structural reliability of the ribbon. Multiple tendon breaks can be tolerated and the ribbon maintains its full strength. After a tendon failure, the fabric is locally distorted and the damage recorded by a passing cab. Every badly damaged section of ribbon must be replaced immediately.

Running the ribbons through conventional drive wheels will cause excessive wear. And the cab speeds involved (2,000+ mph) cannot work with any known materials. A noncontact solution, such as a linear induction motor drive, must be developed. Another approach is to employ very thin fibers found on the toes of geckos. These *setae* fibers bond to most materials using the *Van de Walls* effect. Attached to the perimeter of a 10 foot diameter wheel spinning at 5,600 rpm, this could drive the cabs at 2,000 mph.



The ribbons will be constructed in 10 mile long strips, overlapping 1 mile at the joints. This overlap should allow the *Van de Walls Force* effect to develop the full design load of the ribbons across the splice area (See Step 1 next page). In general, this force is 1/1000th the normal ionic bonding force of the molecule.

For ribbon repair, the elevator stops at the damaged section and:

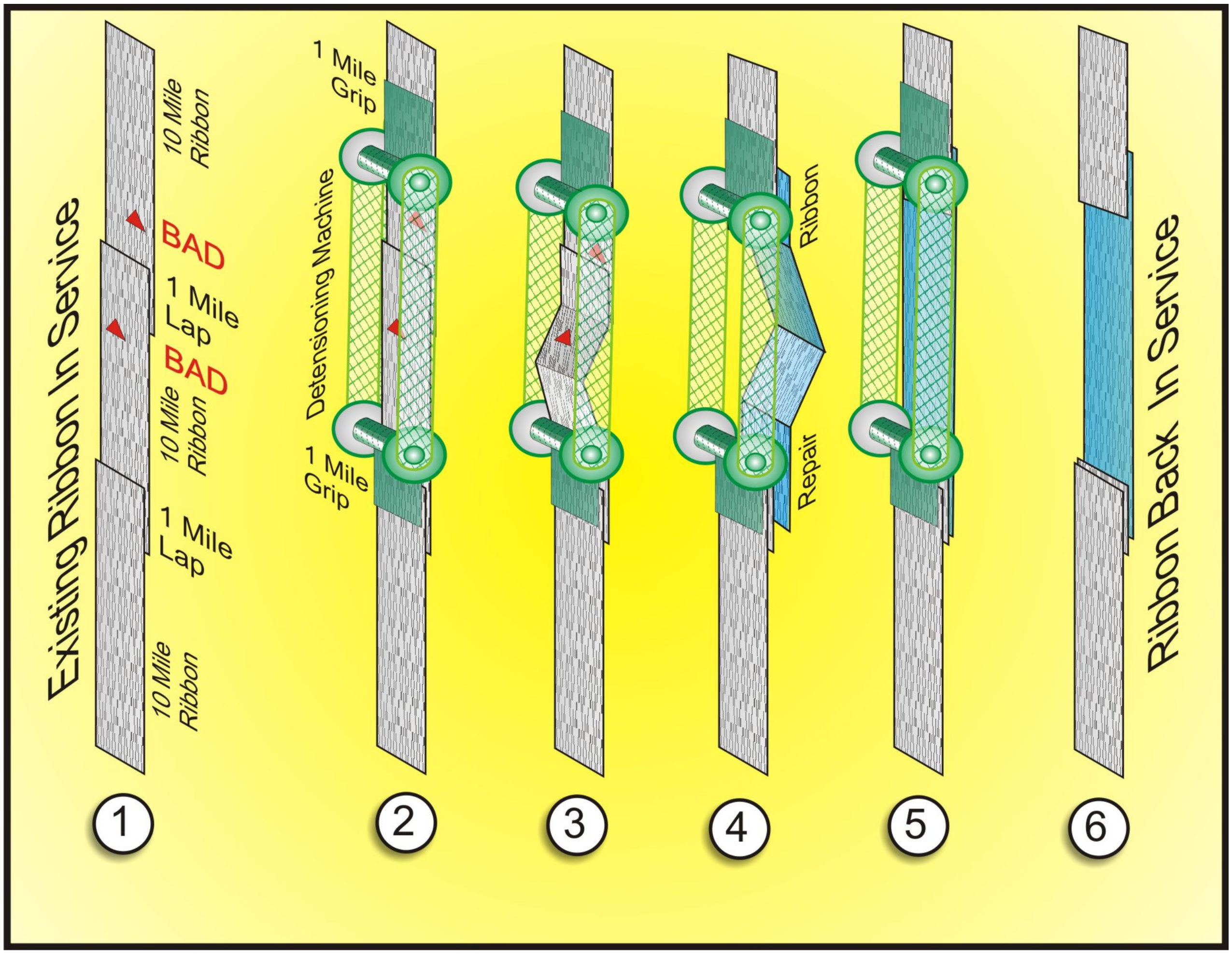
Step 2: A ***Detensioning Machine*** ***(Green)*** straddles the repair area, attaching temporary 1 mile grip ribbons to the existing ribbon;

Step 3: The ***Detensioning Machine*** contracts, relieving the tension in the existing ribbon;

Step 4: The damaged section of ribbon is removed. The replacement ribbon (blue) is attached over the splice joint, overlapping 1 mile on each side;

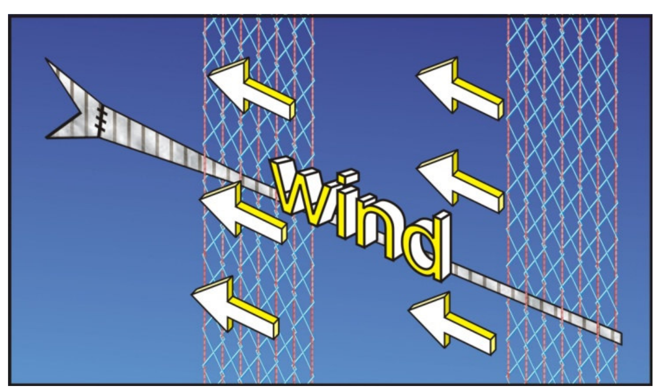
Step 5: The ***Detensioning Machine*** expands, putting the new ribbon section into tension;

Step 6: The ***Detensioning Machine*** is removed, and the ribbon is back in service.



The Elevator configuration must keep the drive and climbing ribbons apart or they will tangle and/or stick to each other. The coriolis force will push the moving drive ribbon outward, but not the climbing ribbon, creating some separation. It might be necessary to positively charge the Ribbons and Cables to create a repulsive force. But this cannot interfere with the electrostatic bonding across the tether joints.

The thin ribbons will flutter in the wind, creating a vortex shedding phenomenon (remember Tacoma Narrow Bridge), and leading to premature ribbon failure. Rigid carbon fiber vanes reduce this problem, at least in moderate winds. They are computer controlled to maintain ribbon alignment and avoid twisting more than 90 degrees.

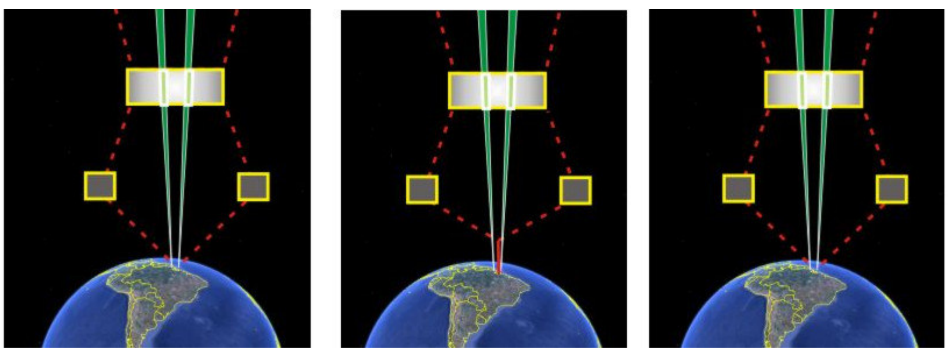


D. Accidents and Safety

CCNTs appear to be highly toxic. Contact with CCNT fibers causes problems similar to asbestos fibers. Cell damage has been reported. Jury's still out, but this remains a problem to be resolved.

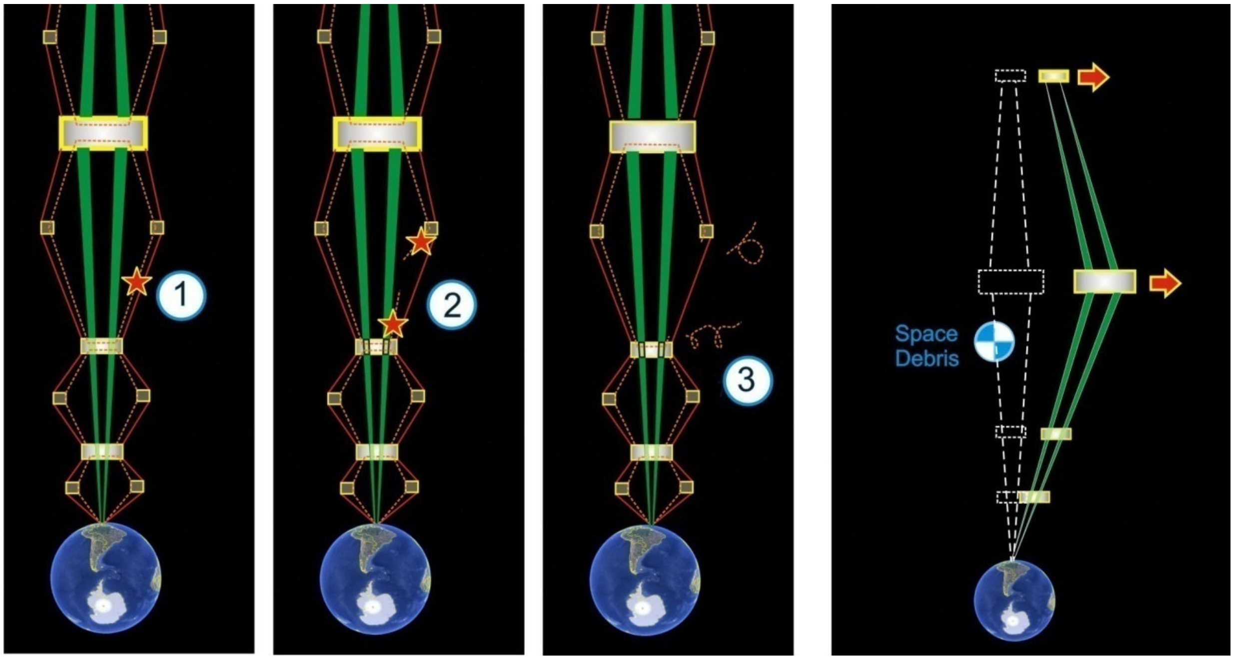
Cabs must be **Fail-Safe:** they must return to Earth safely regardless of how or where the failure occurs. When something terrible happens (and it will), the crew capsule is jettisoned, and a heat shield, parachutes, wings, and inflatable impact bags get the crew back to Earth in one piece.

Even at the best of base sites, bad weather is inevitable. For this Elevator, the lower Elevator Ribbons are held by sixteen circular tethers. These can rise up 50 miles past the stratosphere to move the ribbons out of the high winds and bad weather. Circular tethers resist dynamic wind forces better than the flat ribbons. When the bad weather passes, the ribbon supports are winched back to the ground. The Support Cable Groups, also with a circular cross-section, must also survive the high winds.



This proposed Space Elevator has four levels of elevator cabs, in sets of four at each level, and with each cab attached to eight ribbons. Eight ribbons per cab greatly reduce the risk of catastrophic failure. When a cab fails in transit, the adjacent cab is used to recover and repair the broken unit. Similarly, the Tapered Support Cables are in 16 separate bundles and spaced 500 feet apart near the ground, and 20 feet apart in space, to reduce the risk of catastrophic failure.

This Space Elevator is maneuverable. When incoming space debris or near earth objects threaten its components, the Platform and Counterweight are torqued with the drive ribbons to move the components out of harm's way. Even so, tether breakage is inevitable. The tethers are under very high tension and will immediately start contracting when broken, reaching velocities of 1,000's of miles per hour and temperatures of 1,000's °F in seconds. The ends of the snapped tethers must be immediately separated from the nearest components, allowing the pieces to contract into a ball without damaging the adjacent components. The remaining tethers are designed to take up the extra load. It would be prudent to use the Elevator for space debris control. Using simple orbital thrusters, collection spacecraft can be sent out from the Platforms to capture space debris and return it for disposal.



E. Force Analysis

The structural analysis of the tether forces is modeled in an interactive spreadsheet. Cab movements are based on the travel times tabulated at the right. Two cabs start up the elevator at 50 miles/hour until they clear the atmosphere. At the same time two cabs start down from the Platform, accelerating at 0.20 g's to reach 2,000 mph. At 50 miles, the up cabs accelerate at 0.20 g's until they also reach 2,000 mph. At 1,800 miles, they slow down and dock at Transfer Station # 1. After a 2 hour layover, the cabs start the second leg of the trip, arriving at Transfer Station # 2 eight hours after leaving home base.

The third leg of the trip takes six hours and the cabs dock at the GS Platform 16 hours after leaving Earth.

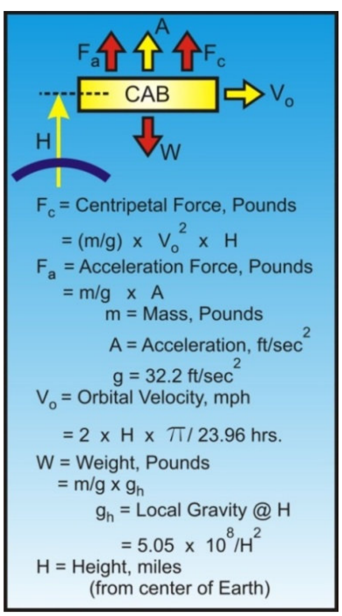
Height Miles	Accel g	Velocity mph	Duration Hours	Ellapsed Time
Leave Base Station				
0.00		0.00	0.00	0:00:00
	0.20			
0.12		50.89	0.0047	0:00:17
50		50.9	0.98	0:59:05
	0.20			
235		2,000.0	0.18	1:09:56
1,000		2,000.0	0.38	1:32:52
1,814		2,000.0	0.41	1:57:18
	(0.20)			
2,000		39.1	0.18	2:08:13
	(0.05)			
2,000		0.1	0.01	2:09:05
Arrive Transfer Station # 1			2.00	Layover
2,000				6:09:05
	0.20			
2,186		2,000.0	0.19	6:20:13
3,000		2,000.0	0.41	6:44:39
4,000		2,000.0	0.50	7:14:39
4,814		2,000.0	0.41	7:39:05
	(0.20)			
5,000		39.1	0.18	7:50:00
	(0.05)			
5,000		0.1	0.01	7:50:52
Arrive Transfer Station # 2			2.00	Layover
5,000				9:50:52
	0.20			
5,185		2,000.0	0.19	10:02:00
6,000		2,000.0	0.41	7:39:06
7,000		2,000.0	0.50	8:09:06
19,000		2,000.0	0.50	14:09:06
20,000		2,000.0	0.50	14:39:06
21,000		2,000.0	0.50	15:09:06
22,054		2,000.0	0.53	15:40:43
	(0.20)			
22,239		54.0	0.18	15:51:33
	(0.05)			
22,240		3.1	0.02	15:52:41
Arrive GS Platform			2.00	Layover

This structural analysis is a **load capacity** study of the support cables and elevator ribbons. First, tendon and ribbon forces are calculated and then compared with the allowable loads. The table at right shows the allowable loads for the various tether components.

Safety factors are applied to account for loss of strength during tether fabrication. For this study, the threads, tendons, cables and ribbons are assigned a 1.10 Safety.

Each cable tendon can support 914 pounds at a weight of 0.39 pounds per mile. A six foot wide elevator ribbon has 13 tendons and can carry 11,880 pounds at a net mass of 5.941 pounds/mile.

Filament		**4.00**	**Safety Factor**						
	extruded as pure CCNT 11 miles long								
	Ultimate Stress =	**300**	**GPa**			43,516	**ksi**	Ultimate Stress =	
						10.9	**M psi**	**= DESIGN STRESS**	
	A36 Steel =	0.25	GPa			**36.26**	**ksi**	A36 Steel =	
	Outer Diameter =	84	microns	8.40E-05	m	0.00331	inches	Outer Diameter =	
	Inner Diameter =	80	microns	8.00E-05	m	0.00315	inches	Inner Diameter =	
	Density =	0.116	gm/cm^3			7.23	lb/CF	Density =	
	Outer Area =	5,542	microns^2	5.54E-09	m^2	8.59E-06	in^2	Outer Area =	
	Inner Tube Area =	5,027	microns^2	5.03E-09	m^2	7.79E-06		Inner Tube Area =	
	Net Wall Area =	515	microns^2	5.15E-10	m^2	7.99E-07	in^2	Net Wall Area =	
	Water =	1	gm/cm^3			62.33	lb/CF	OK	
	Allowable load =	**Wall Area * Allowable Stress**				**8.7**	**lb-f**	**Allowable load =**	
	Unit Weight =	**6.43E-04**	**g/m**	**0.00228**	**lb/mile**	**0.00228**	**lb/mile**	**Unit Weight =**	
	Extrude 11 miles in 4 years			production rate =	1.66	ft/hours		0.0055	in/sec
							Out. Diam. inches	**Allow. Load Pounds**	**Weight per Mile**
Thread			**1.10**	**Safety Factor**			**0.010**	**55.3**	**0.017**
	twisted as 7 part cable		**7**	**filaments**					
	10½ miles long made from 11 mile long filaments								
Tendon			**1.10**	**Safety Factor**			**0.060**	**1,005**	**0.352**
	braided		**20**	**threads**					
	10 mile long, made from 10¼ mile long threads								
								Allow. Load Kips	**Weight per Mile**
Elevator Ribbon # 4			**1.10**	**Safety Factor**					
	3	**feet wide, tendons 6" oc**		**7**	**tendons**			**6.40**	2.461
			+20% weight for HoytRibbon + 10% overlap						**3.199**
Elevator Ribbon # 3			**1.10**	**Safety Factor**					
	3	**feet wide, tendons 6" oc**		**7**	**tendons**			**6.40**	2.461
			+20% weight for HoytRibbon + 10% overlap						**3.199**
Elevator Ribbon # 2			**1.10**	**Safety Factor**					
	6	**feet wide, tendons 6" oc**		**13**	**tendons**			**11.88**	4.570
			+20% weight for HoytRibbon + 10% overlap						**5.941**
Elevator Ribbon # 1			**1.10**	**Safety Factor**					
	18	**feet wide, tendons 6" oc**		**37**	**tendons**			**33.81**	13.006
			+20% weight for HoytRibbon + 10% overlap						**16.908**
								Kips/mile	**Kips/mile**
Cable Tendon			**1.10**	**Safety Factor**		**add 10% wt overlap**		**0.914**	**0.39**



A free body diagram for the elevator cab forces is shown at left. There are three forces:

Centripetal … F_c ... = f (V_o, H)

Acceleration …. F_a …. = f (cab movement)

Weight … W … = f (mass, height)

The support cables, elevator ribbons, and the four platforms are also subject to centripetal and weight forces. For this structural model, the tethers are divided into 1,000 mile increments below the GS Platform, and 10,000 mile increments for tethers above the Platform.

The first set of calculations compute the orbital data and its gravity effect, as tabulated below. From here, component weight and centripetal forces are calculated. The 125,000,000 pound Counterweight weighs only 480 kips at 60,000 miles (1 kip = 1,000 pounds). Centripetal force is 6,984 Kips. The net uplift from the Counterweight is 6,504 Kips. The GS Platform is neutral since it is in geostationary orbit. Forces for each of the two Transfer Stations and the 16 elevator cabs, including cab acceleration, are also shown. The cabs are placed to maximize ribbon forces.

Gravity Calculations

Altitude Miles	C of E Height Miles	Local g ft/sec^2	Local g % g	Orbital Velocity mph
60,000	63,963	0.12	0.4%	16,794
55,000	58,963	0.15	0.5%	15,482
45,000	48,963	0.21	0.7%	12,856
35,000	38,963	0.33	1.0%	10,230
25,000	28,963	0.60	1.9%	7,605
22,240	26,203	0.74	2.3%	6,880
22,160	26,123	0.74	2.3%	6,859
22,000	25,963	0.75	2.3%	6,817
21,000	24,963	0.81	2.5%	6,554
20,000	23,963	0.88	2.7%	6,292
19,000	22,963	0.96	3.0%	6,029
18,000	21,963	1.05	3.3%	5,767
17,000	20,963	1.15	3.6%	5,504
16,000	19,963	1.27	3.9%	5,242
15,000	18,963	1.40	4.4%	4,979
14,000	17,963	1.57	4.9%	4,716
13,000	16,963	1.76	5.5%	4,454
12,000	15,963	1.98	6.2%	4,191
11,000	14,963	2.26	7.0%	3,929
10,000	13,963	2.59	8.1%	3,666
9,000	12,963	3.01	9.3%	3,404
8,000	11,963	3.53	11.0%	3,141
7,000	10,963	4.20	13.1%	2,879
6,000	9,963	5.09	15.8%	2,616
5,000	8,963	6.29	19.5%	2,353
4,000	7,963	7.96	24.8%	2,091
3,000	6,963	10.42	32.4%	1,828
2,000	5,963	14.20	44.2%	1,566
1,000	4,963	20.50	63.8%	1,303
100	4,063	30.59	95.1%	1,067
0	3,963	**32.15**	100.0%	1,041

COMPONENTS

Altitude Miles	Mass Kips	Wt. Kips.	F_c Kips.	Accel % g	Accel Force Kips.	Net Force Kips.
Counterwight						
60,000	125,000	479.8	6,983.9			6,504
GS Platform						
22,240	500	11.44	11.44			0.0
Decending Cabs - in sets of two each side						
60,000	60	0.23	1.56	(0.20)	(12.00)	(13.3)
22,000	60	1.40	1.36	(0.20)	(12.00)	(12.0)
2,000	60	26.50	0.00	(0.20)	(12.00)	14.5
1,000	60	38.26	0.00	(0.20)	(12.00)	26.3
Transfer Platform # 2						
5,000	100	19.55	2.19			17.4
Transfer Platform # 1						
2,000	100	44.17	1.22			42.9
Asecending Cabs - in sets of two each side						
22,240	80	1.83	1.92	0.20	16.00	15.9
5,000	80	15.64	0.63	0.20	16.00	31.0
2,000	80	35.34	0.42	0.20	16.00	50.9
100	80	76.11	0.28	0.20	16.00	91.8

Data Input on Design Diagram ONLY!

(2) Distribute Counterweight Uplift Forces		
Upper Support Cables =	6,484	Kips
10 K each to elev. Ribbon =	10.0	Kips

TOTAL Weight of Tethers =	**146,844**	**Tons**

Equations

Orbital Velocity = **Orbital Circumference**/(23 Hours - 56 Miutes) = 2 * **CoE Height** * pi /23.93 hours

Local g = 5.05E8/**Height**^2)

Weight = **Mass** * **Local g**

Centripital Force = Cf = m * v^2/r = **Mass**/G * **Velocity**^2/**Height** ... where Mass in pounds, Velocity in ft/sec, Height in feet

Tether Tension = Cummulative Centripital Forces - Cummulative Weight + Cab Acceleration

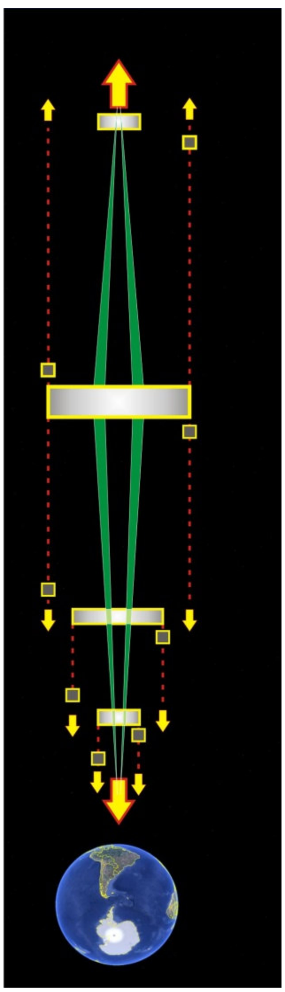
Sign Convention : Tension and Forces that INCREASE tension are positive

Cable Mass = Segment Length in miles x Number of Tendons x Unit Weight per mile

Cable Weight = Cable Mass x % Local Gravity

The forces above the GS Platform are calculated first, generating a net uplift. Forces below the GS Platform are calculated next, generating a net downward force. For stability, the up forces must be larger than the down forces.

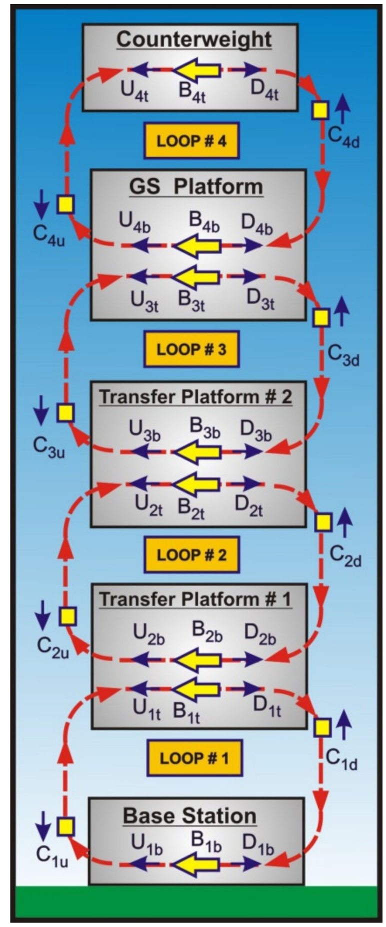
Calculations for the Elevators are shown at right. The elevator ribbon tensions for each set of cabs is first calculated hanging from the Platform and Transfer Stations as shown below.



Tether Lengths		Elevator Ribbons - 16 Up, 16 Down 10 Kps/Ribbon P/T			Ascending		Decending	
Altitude Miles	Length Miles	Mass Kips	Wt. Kips	F_c Kips	Tension Kips	+ CW T, K	Tension Kips	+ CW T, K
60,000	2,500	128.0	0.5	7.1	6.7	16.66	(6.7) (3)	3.33
55,000	7,500	383.9	1.7	19.8	24.7	34.7	11.4	21.4
45,000	10,000	511.8	3.4	21.9	43.2	53.2	29.9	39.9
35,000	10,000	511.8	5.3	17.4	55.4	65.4	42.0	52.0
25,000	6,380	326.5	6.1	8.3	57.5	67.5	44.2	54.2
22,240	1,380	70.6	1.6	1.6	73.4 (3)	83.4	44.2	54.2
		Total M =	1,933	Tons	Allow T =	6.4	Kips	
		W # 4, Ft. =	3		Ribbon # 4 Weight =		3.2	#/Mile
		Allow Ribbon #4 Load =			6.4	Kips		
22,240	40	4.98	0.11	0.11	141.8	151.8	98.9	108.9
22,160	120	14.92	0.34	0.34	141.8	151.8	98.9 (3)	108.9
22,000	580	72.09	1.68	1.63	141.8	151.8	110.8	120.8
21,000	1,000	124.30	3.13	2.71	141.8	151.8	110.8	120.8
20,000	1,000	124.30	3.40	2.60	141.4	151.4	110.3	120.3
19,000	1,000	124.30	3.70	2.49	140.6	150.6	109.6	119.6
18,000	1,000	124.30	4.05	2.38	139.4	149.4	108.3	118.3
17,000	1,000	124.30	4.44	2.28	137.7	147.7	106.7	116.7
16,000	1,000	124.30	4.90	2.17	135.5	145.5	104.5	114.5
15,000	1,000	124.30	5.43	2.06	132.8	142.8	101.8	111.8
14,000	1,000	124.30	6.05	1.95	129.4	139.4	98.4	108.4
13,000	1,000	124.30	6.78	1.84	125.3	135.3	94.3	104.3
12,000	1,000	124.30	7.66	1.73	120.4	130.4	89.4	99.4
11,000	1,000	124.30	8.72	1.62	114.5	124.5	83.4	93.4
10,000	1,000	124.30	10.01	1.52	107.4	117.4	76.3	86.3
9,000	1,000	124.30	11.62	1.41	98.9	108.9	67.9	77.9
8,000	1,000	124.30	13.64	1.30	88.7	98.7	57.6	67.6
7,000	1,000	124.30	16.24	1.19	76.3	86.3	45.3	55.3
6,000	1,000	124.30	19.67	1.08	61.3	71.3	30.2	40.2
5,000	500	62.15	12.15	0.49	42.7 (3)	52.7	11.7	21.7
5,000	500	91.39	17.87	0.72	210.1	220.1	159.1 (3)	169.1
4,000	1,000	182.79	45.27	1.27	192.9	202.9	142.0	152.0
3,000	1,000	182.79	59.21	1.11	148.9	158.9	98.0	108.0
2,000	500	91.39	40.37	0.48	90.8 (3)	100.8	39.9	49.9
2,000	500	266.87	117.88	1.39	809.0	819.0	731.6 (3)	741.6
1,000	950	507.06	323.31	2.20	692.5	702.5	600.7	610.7
100	500	266.87	253.90	0.95	371.4 (3)	381.4	279.5	289.5
0	50	26.69	26.69	0.09	26.6	36.6	26.6	36.6
		Total M =	1,879	Tons				
		# 3 W ft=	8	Ribbon # 3 #/mi=		7.8	All. Load K =	15.5
		# 2 W ft=	12	Ribbon # 2 #/mi=		11.4	All. Load K =	22.8
		# 1 W Ft =	36	Ribbon # 1 #/mi=		33.4	All. Load K =	66.7
3) Add Cab Forces to Ribbon Tension								

Stability Check before Post Tensioning (P/T)			
Total Weight below GS Platform =	11,178	Total Weight above GS Platform =	2,492
Acceleration =	12.00	Net Acceleration =	4.00
Total Cent. Force below GS Platform =	1,462	otal Cent. Force avove GS Platform =	14,465
NET =	9,728	NET =	11,977
Cable + Ribbon Tensions =	9,842	Cable + Ribbon Tensions =	11,975

There are 4 drive and 4 climbing ribbons for each of two cabs. They are combined and analyzed as a single force (i.e. 16 ribbons are treated as one tether for each set of two cabs). The up and down ribbons are computed separately. Next, the ribbons are attached to a lower structure and a tension of 10 kips added to each set of ribbons to stabilize it.



The next step is to normalize the belt forces so they sum to zero around each drive loop. The diagram at right lays out the process. At the Counterweight, the upper Loop Ribbon # 4 passes through a Genset to produce station power. With a 5 kip ribbon load moving at 10 mph:

Power = 5 Kips x 14.67 ft/sec
= 73,350 ft-lbs/second
= 133 HP = 75 KW (75% efficiency)

This 5 Kip load across the genset is designated Load B_{4t}. The upper left ribbon tension U_{4t} plus B_{4t} must equal the upper right tension D_{4t}. From the initial ribbon calcs:

$$U_{4t} + B_{4t} = D_{4t}$$

16.66 K + 5.0 K = 3.33 . Delta = 18.33 Kips

Half this tension imbalance is added to the right ribbon, and half released from the left ribbon:

(16.66 K - 9.17 K) + 5.0 K = (3.33 + 9.17 K)
7.49 K + 5.0 K = 12.49 K …. and Delta = 0 Kips

The lower end of Loop #4 passes through the GS Platform. The belt force here, B_{4b}, must drive the upper genset, Load B_{4t}, and also move the two cabs. Cab C_{4u} must be pulled up by the ribbons, while Cab C_{4d} acts like a typical elevator counterweight, helping to pull the other Cab up. Belt force B_{4b} is computed as 7.58 Kips as tabulated at right. The imbalance here is 36.81 Kips and again normalized 50/50.

This causes the drive ribbon to become too slack, and an additional 10 Kips is added to both sides to stabilize the ribbons. Loop # 1 requires 50 Kips extra tension to stabilize it.

The remaining belt calcs are also shown in this table. A 500 KW genset is provided at the GS Platform, and 75 KW gensets power the Transfer Stations. At the Base Station, the winches that power the loop drive ribbons deliver 123 Kips (B_{1b}) of thrust to power the entire Elevator.

Force			Initial Delta	Adjust Tension
B4u =	**5**	**Kips**	18.33	
5	= 75 KW genset			**10**
B4d =	**7.58**	**Kips**	36.81	
5	= B4u			
2.6	= C4u-C4d			
B3u =	**57.58**	**Kips**	100.55	
7.58	= B4d			**20**
50	= 500 KW genset			
B3d =	**76.63**	**Kips**	107.64	
57.58	= B3u			
19.1	= C3u-C3d			
B2u =	**81.63**	**Kips**	132.55	
76.63	= B3d			
5	75 KW genset			**0**
B2d =	**118.05**	**Kips**	168.96	
81.63	B2u			
36.4	= C2u-C2d			
B1u =	**123.05**	**Kips**	200.37	
118.05	= B2d			
5	75 KW genset			**50**
B1d =	**123.05**	**Kips**	123.05	
123.05	B1u			
65.6	= C1u-C1d			

The normalized Drive Ribbon tensions are shown at right. Peak tension is 892 Kips just below Transfer Platform # 1 on the down side of Loop # 1. Drive loop # 4 has the lowest tension at 17 Kips.

These disproportionate ribbon forces are not sound engineering, and a more balanced load between the three lower drive loops is clearly preferable. This would allow a single width ribbon for these three drive loops, simplifying construction and maintenance.

Several alternative configurations were examined:

1) Add a third Transfer Station @ 750 miles;

2) Lower the two Transfer Stations to 4,000 and 750 miles.

Both of these schemes are preferable to the one studied here, and a combination of the two is probably the best solution. However, this study is not intended to produce an optimized Elevator design. Its primary purpose is to demonstrate that a looped drive belt can power the Elevator. The next engineering study (assuming there is one?) should begin with a detailed assessment of the operational parameters of the Elevator. This could establish where the best platform locations should be for completing space missions.

(***But*** *the HCG Space Elevator is intended as the second step in a broader vision of the conquest of space. The major lift required for this elevator is for proposed Step # 3: launching the 25,000,000 pound* ***HCG Space Ship 1:***

http://www.hicon.us/gpage28.html

And mankind will be able to travel between the stars!)

Normalize Loop Tension

Altitude Miles	Normalize Ascending Cable Tension	Normalize Descending Cable Tension	Final Delta Tension	Check
60,000	17.49	22.49	5.00	B4u
55,000	34.31	41.75		
45,000	50.40	62.74		
35,000	60.07	77.31		
25,000	59.77	81.90		
22,240	75.00	82.58	7.58	B4d
22,240	121.56	179.13	57.58	B3u
22,160	121.54	179.15		
22,000	121.50	191.14		
21,000	121.25	191.30		
20,000	120.63	191.09		
19,000	119.62	190.49		
18,000	118.21	189.49		
17,000	116.34	188.03		
16,000	113.97	186.07		
15,000	111.03	183.55		
14,000	107.46	180.38		
13,000	103.15	176.49		
12,000	98.00	171.75		
11,000	91.87	166.03		
10,000	84.57	159.14		
9,000	75.87	150.85		
8,000	65.45	140.85		
7,000	52.90	128.71		
6,000	37.65	113.86		
5,000	18.86	95.48	76.63	B3d
5,000	153.79	235.42	81.63	B2u
4,000	130.57	224.34		
3,000	80.50	186.40		
2,000	16.33	134.37	118.05	B2d
2,000	768.78	891.83	123.05	B1u
1,000	671.63	741.51		
100	367.92	403.00		
0	25.07	148.12	123.05	B1d

1) All forces in Kips (= 1,000 pounds)

With the normalized loads for the ribbon loops computed, their safety is next evaluated (see below). The tensions in normalization table are increased 5% for the right side (the pulling side) and 2½% on the left side to allow for friction losses. To determine the actual force for each ribbon, these tensions are divided by 16. One of the cab ribbons is severed and the safety for of the remaining 7 ribbons computed. This provides an additional safety factor when (not if) one of the elevator ribbons is severed. By adjusting the ribbon width, a stable elevator system is designed. Loop # 1 is 36 feet wide, Loop # 2 is 12 ft., # 3 8 ft., and # 4 is 3 feet wide.

Design Elevator Ribbon

Altitude Miles	Up Cabs - 16 Ribbons: Total Tension Kips	Ribbon Tension	Safety Factor	OK?	Up Cab	Platform / Down Cab	Down Cabs - 16 Ribbons: Total Tension Kips	Ribbon Tension Each-K	Safety Factor	OK?
60,000						Counterweight				
60,000	17.93	1.12	5.02			Cab #4 Dn (1)	23.62	1.48	3.81	
55,000	35.16	2.20	2.56				43.84	2.74	2.05	
45,000	51.66	3.23	1.74				65.87	4.12	1.37	
35,000	61.57	3.85	1.46				81.17	5.07	1.11	
25,000	61.27	3.83	1.47				86.00	5.37	1.05	
22,240	76.88	4.80	1.17		Cab #4 Up (2)		86.71	5.42	1.04	
22,240	**Up Cabs - 16 Ribbons**					**GS Platform**	**Down Cabs - 16 Ribbons**			
22,240	124.6	7.8	1.8				188.1	11.8	1.2	
22,160	124.6	7.8	1.8			Cab #3 Dn (1)	188.1	11.8	1.2	
22,000	124.5	7.8	1.8				200.7	12.5	1.1	
21,000	124.3	7.8	1.8				200.9	12.6	1.1	
20,000	123.6	7.7	1.8				200.6	12.5	1.1	
19,000	122.6	7.7	1.8				200.0	12.5	1.1	
18,000	121.2	7.6	1.8				199.0	12.4	1.1	
17,000	119.2	7.5	1.8				197.4	12.3	1.1	
16,000	116.8	7.3	1.9				195.4	12.2	1.1	
15,000	113.8	7.1	1.9				192.7	12.0	1.1	
14,000	110.1	6.9	2.0				189.4	11.8	1.2	
13,000	105.7	6.6	2.1				185.3	11.6	1.2	
12,000	100.5	6.3	2.2				180.3	11.3	1.2	
11,000	94.2	5.9	2.3				174.3	10.9	1.3	
10,000	86.7	5.4	2.5				167.1	10.4	1.3	
9,000	77.8	4.9	2.8				158.4	9.9	1.4	
8,000	67.1	4.2	3.3				147.9	9.2	1.5	
7,000	54.2	3.4	4.0				135.1	8.4	1.6	
6,000	38.6	2.4	5.7				119.6	7.5	1.8	
5,000	19.3	1.2	11.3		Cab #3 Up (2)		100.3	6.3	2.2	
5,000		-				Trans. Station # 2				
5,000	157.6	9.9	2.0			Cab #2 Dn (1)	247.2	15.4	1.1	
4,000	133.8	8.4	2.4				235.6	14.7	1.2	
3,000	82.5	5.2	3.9				195.7	12.2	1.4	
2,000	16.7	1.0	19.2		Cab #2 Up (2)		141.1	8.8	1.9	
2,000		-				Trans. Station # 1		-		
2,000	788.0	49.3	1.2			Cab #1 Dn (1)	936.4	58.5	1.0	
1,000	688.4	43.0	1.4				778.6	48.7	1.2	
100	377.1	23.6	2.5		Cab # 1 Up (2)		423.2	26.4	2.2	
0	25.7	1.6	36.5				155.5	9.7	6.0	

Earth

Notes: For loop friction losses, 2½% tension added to all Up ribbons and 5% added to all Down ribbons

Elevator Safety Factor Based on 7 of 8 Cab Ribbons still OK (1 broken each cab) SF = 0.88 * T_{Allow}/T_{calced}

1. Two 30,000 # Cabs Accel. Down @ 0.2 g's

2. Two 40,000 # Cabs Accel. Up @ 0.2 g's

Ribbon #4 Width, Ft. =	**3**	**Allow. Load/Ribbon, Kips =**	**6.40**
Ribbon #3 Width, Ft. =	**8**	**Allow. Load/Ribbon, Kips =**	**15.54**
Ribbon #2 Width, Ft. =	**12**	**Allow. Load/Ribbon, Kips =**	**22.85**
Ribbon # 1 Width, Ft. =	**36**	**Allow. Load/Ribbon, Kips =**	**66.71**

The tension loads on the Tapered Support Cables are designed next (see table at right). Loads are summed from the Counterweight down to the GS Platform. The Upper Cable has a tension of 11,857 Kips at the GS Platform, decreasing to 6,957 Kips at the Counterweight. The Upper Cable tapers from 15,500 tendons at the Counterweight to 9,000 at the GS Platform.

The Support Cable tension below the GS Platform is summed from the ground up. The loads from the Transfer Stations and the attached elevator ribbons # 1 and # 2 are added at 2,000 and 5,000 miles. The 1,064 Kip uplift from the Upper Support cable is then added as a post-tensioning load. The Lower Support Cable carries 1,736 Kips at the ground and 10,644 Kips at the GS Platform. The number of tendons taper from 1,900 at the Base Station to 13,700 at the GS Platform. Uplift at the ground and at the GS Platform are both over 1,000 Kips, providing a reasonable tension to keep the Elevator stable.

The table on the next page evaluates the safety of the support cables. This is a five step iterative process:

1) Size the CW;
2) Size the Upper Cable;
3) Size the Lower Cable;
4) Check Uplift;
5) Go back to Step # 1 until stable.

Tether Lengths		Support Cables - Tapered Tendons Carries Counterweight Uplift Load - Elevator P/T							
Altitude Miles	Length Miles	# Tendons	Mass Kips	Wt. Kips	F_c Kips	T Kips			T-Allow Kips
60,000	2,500	9,000	8,700	33.4	486.1	6,957	(2)		8,224
55,000	7,500	11,000	31,900	144.1	1,643.0	8,456			10,052
45,000	10,000	13,000	50,267	329.3	2,149.9	10,276			11,880
35,000	10,000	14,600	56,454	584.0	1,921.3	11,614			13,342
25,000	6,380	15,000	37,004	692.8	936.2	11,857			13,707
22,240	1,380	15,500	8,271	189.2	189.3	11,857			14,164
		# Tendons	Mass Kips	Wt. Kips	F_c Kips	T Kips		T + Uplift Kips	T-Allow Kips
22,240	40	13,700	212	4.9	4.86	9,601		10,644	12,519
22,160	120	13,700	636	14.6	14.5	9,601		10,644	12,519
22,000	580	13,633	3,058	71.2	69.3	9,601		10,644	12,459
21,000	1,000	13,567	5,246	132.2	114.4	9,599		10,642	12,398
20,000	1,000	13,500	5,220	142.8	109.3	9,581		10,625	12,337
19,000	1,000	13,460	5,205	155.0	104.4	9,548		10,591	12,300
18,000	1,000	13,420	5,189	168.9	99.6	9,497		10,540	12,264
17,000	1,000	13,380	5,174	184.9	94.7	9,427		10,471	12,227
16,000	1,000	13,340	5,158	203.3	89.9	9,337		10,381	12,191
15,000	1,000	13,300	5,143	224.6	85.2	9,224		10,267	12,154
14,000	1,000	13,040	5,042	245.4	79.1	9,085		10,128	11,916
13,000	1,000	12,780	4,942	269.7	73.2	8,918		9,962	11,679
12,000	1,000	12,520	4,841	298.4	67.5	8,722		9,765	11,441
11,000	1,000	12,260	4,741	332.5	62.0	8,491		9,534	11,204
10,000	1,000	12,000	4,640	373.8	56.6	8,220		9,264	10,966
9,000	1,000	12,120	4,686	438.0	53.1	7,903		8,947	11,076
8,000	1,000	11,360	4,393	482.0	45.9	7,518		8,562	10,381
7,000	1,000	10,600	4,099	535.6	39.2	7,082		8,126	9,687
6,000	1,000	9,840	3,805	602.0	33.1	6,586		7,629	8,992
5,000	500	9,300	1,798	351.5	14.1	**6,017**	(1)	7,060	8,499
5,000	500	8,200	1,585	309.9	12.4	5,273		6,316	7,493
4,000	1,000	8,100	3,132	775.7	21.79	4,975		6,019	7,402
3,000	1,000	6,840	2,645	856.7	16.09	4,221		5,265	6,251
2,000	500	3,700	715	316.0	3.73	**3,381**	(1)	4,424	3,381
2,000	500	3,700	715	316.0	3.73	1,365		2,408	3,381
1,000	950	2,800	1,029	655.8	4.46	1,053		2,096	2,559
100	500	1,990	384.7	366.0	1.37	401		1,445	1,819
0	50	1,900	36.7	36.73	0.13	37		1,080	1,736

Total M = 143,032 Tons

Weight per Tendon = 0.39 Pounds/Mile

Allowable Tendon Load = 0.914 Kips/Tendon

1) Add Transfer Station + Normalized Lower Elevator Ribbon Forces here

NET UPLIFT @ GS PLATFORM = 1,064 Kips

Distribute Net Uplift Forces @ GS Platform to Lower Tethers

Apply to Lower Support Cable = 1,043.5 Kips

10 Kips to each lower & middle elev. Ribbon = 10.0 Kips

The tendon safety factor is based on fourteen of sixteen cable groups in service: one is assumed severed and a second one is under repair.

Design Support Cables

Altitude Miles				Total Tension Kips	Tension per ea. Tendon Kips	Safety Factor	OK?
60,000	Wt, Kips =	125,000	Counterweight				
60,000	# Upper Loop Tendons =	9,000		6,957	0.77	1.03	
55,000	# Upper Loop Tendons =	11,000		8,456	0.77	1.04	
45,000	# Upper Loop Tendons =	13,000		10,276	0.79	1.01	
35,000	# Upper Loop Tendons =	14,600		11,614	0.80	1.01	
25,000	# Upper Loop Tendons =	15,000		11,857	0.79	1.01	
22,240	# Upper Loop Tendons =	15,500		11,857	0.76	1.05	
22,240	Uplift Kips	OK	GS Platform				
22,240		13,700		10,644	0.78	1.03	
22,160	# Support Tendons =	13,700		10,644	0.78	1.03	
22,000		13,633		10,644	0.78	1.02	
21,000		13,567		10,642	0.78	1.02	
20,000	# Support Tendons =	13,500		10,625	0.79	1.02	
19,000		13,460		10,591	0.79	1.02	
18,000		13,420		10,540	0.79	1.02	
17,000		13,380		10,471	0.78	1.02	
16,000		13,340		10,381	0.78	1.03	
15,000	# Support Tendons =	13,300		10,267	0.77	1.04	
14,000		13,040		10,128	0.78	1.03	
13,000		12,780		9,962	0.78	1.03	
12,000		12,520		9,765	0.78	1.03	
11,000		12,260		9,534	0.78	1.03	
10,000	# Support Tendons =	12,000		9,264	0.77	1.04	
9,000		12,120		8,947	0.74	1.08	
8,000		11,360		8,562	0.75	1.06	
7,000		10,600		8,126	0.77	1.04	
6,000		9,840		7,629	0.78	1.03	
5,000	# Support Tendons =	9,300		7,060	0.76	1.05	
5,000			Trans. Station # 2				
5,000	# Support Tendons =	8,200		6,316	0.77	1.04	
4,000		8,100		6,019	0.74	1.08	
3,000		6,840		5,265	0.77	1.04	
2,000	# Support Tendons =	6,500		4,424	0.68	1.17	
2,000			Trans. Station # 1				
2,000	# Support Tendons =	3,700		2,408	0.65	1.23	
1,000		2,800		2,096	0.75	1.07	
100		1,990		1,445	0.73	1.10	
0	# Support Tendons =	1,900		1,080	0.57	1.41	

Earth

		Calced	**NOTE :** Tendon Safety Factor Based on 2 of 16 cable bundles out of service
Above Platform, Kips =	12,020.6	UPLIFT	SF = (14/16) *(T_{Allow}) / (T_{calced})
NET UPLIFT, KIPS =	1,063.5	1,063.5	
Below Platform, Kips =	10,957.05	Circular Reference Problem	Adjustable Cells =
At Ground, Kips =	1,261.33	Must manually INPUT Uplift	Allow. Tendon Tension, Kips = 0.91

F. Costs

The bottom line is **MONEY**: the cost to send one pound of payload into GS orbit. Chemical rockets generally run $ 20,000/pound and are notoriously unreliable. There are many other launch proposals on the drawing boards, but only the proposed *HCG ICC-1 Launch Vehicle* (http://www.hicon.us/gpage26.html) can launch a GS payload for less than $ 3,000 a pound with a 99+% reliability.

The first step is to build a Base Station on a 100 acre site, with a 100,000 square foot Operations Building and a 10 MW power plant. Next step is to build a 1/100th size *Construction Elevator*. Hopefully, it can be done for 1/4th the cost of the final unit. Estimated weight is 1,300,000 pounds. Gradually, this small elevator will be expanded into the big one.

The major cost item for the *HCG Space Elevator* is the lift costs: $ 3.8 B for the temporary elevator and $ 22 B for the final. The next most expensive item is the CCNT tethers: $ 3.7 B. Hopefully they will cost only $ 100/pound to manufacture in 2020. The 2009 price of carbon fiber is $ 10/pound.

The budget for the proposed *HCG Space Elevator* is on the next page. Construction cost is estimated at $ 41 B, with annual operating costs estimated at $ 4.5 B/year. The eight cabs can lift 142,000 pounds a day and 52,000,000 pounds per year into Orbit at an estimated cost of around $ 100 per pound. That's a lot of satellites and at least one Star Ship every year!

G. Conclusions

We can build this by 2025. We must build this, or something similar, for the very survival of our species. With this *HCG Space Elevator*, we will have the ability to orbit 52 Million pounds/year for only $ 100 per pound. And *Homo Sapiens* will be on the way to the conquest of space. *"The final frontier."*

The *Proposed HCG Space Elevator* presented in this report will not resemble the first **Space Elevator** actually built. It is intended to show feasibility, establish realistic budget costs, and to encourage the World to immediately fund the research needed to get things started.

References: *(**Note**: Data in this report came off these web sites and the links provided)*

http://en.wikipedia.org/wiki/Space_elevator ….. A good starting point.

http://en.wikipedia.org/wiki/Carbon_nanotube ….. Background on CNT's.

http://en.wikipedia.org/wiki/Colossal_carbon_tube ….. Background on CCNT's.

http://www.mse.ncsu.edu/research/zhu/papers/CNT/PRL-CCTs.pdf ….. Peng's Paper

http://www.spaceelevatorblog.com/ ….. up-to-date web blog

HCG's Space Elevator Budget

Item	Quantity	Units	Unit Cost	Total Cost	Comments
Base Site					
Land + Sitework	100	Acres	$ 250,000	**$ 25,000,000**	
Building	100,000	SF	$ 400	**$ 40,000,000**	
Power Plant	10	MegaWatts	$ 2,500,000	**$ 25,000,000**	*HeliTubes, HeliWinds*
Drive Winches	4	each	$ 500,000	**$ 2,000,000**	*2,500 HP*
Equip., Spare Parts		LS		**$ 10,000,000**	
			Subtotal =	**$ 102,000,000**	
Space Elevator		**Build out from Temporary Elevator**			
Tethers	146,844	Tons	$ 20,000	**$ 2,936,884,284**	$ 100/lb
Transfer Station	200,000	lbs	$ 750	**$ 150,000,000**	Two
GS Platform	500,000	lbs	$ 750	**$ 375,000,000**	
Counterweight	125,000,000	lbs	$ 25	**$ 3,125,000,000**	
Lift into Space	125,846,844		$ 175	**$ 22,023,197,737**	Using Tempory Elevator
Elevator Cabs	20	each	$ 2,500,000	**$ 50,000,000**	4 spares
Emergency Lift Cables	16	each	$ 1,000,000	**$ 16,000,000**	to avoid bad weather
Detension Machine	2	each	$ 10,000,000	**$ 20,000,000**	
Spare Tethers	36,711	Tons	$ 20,000	**$ 734,221,071**	Replace 1/4 per year
			Subtotal =	**$ 29,430,303,093**	
Temporary Elevator		**1/100 the capacity of the final**			i.e. 200# cab capacity to start
Build	1,258,468	lbs		**$ 7,383,075,773**	**1/4 the cost of the final**
Lauch into Orbit	1,258,468	lbs	$ 3,000	**$ 3,775,405,326**	**Use ICC-1 Launch Vehicle**
				$ 11,158,481,100	
			TOTAL =	**$ 40,690,784,192**	

Item	Quantity	Units	Unit Cost	Total Cost	Comments
Annual Costs					
Staff	500	people	$ 200,000	**$ 100,000,000**	
O&M		LS		**$ 100,000,000**	
Replace Tethers & Cables		LS		**$ 734,221,071**	25% each year
Cap Loan				**$4,144,000,000**	8%, 20 years
			TOTAL =	**$ 5,078,221,071**	per year

Payload Orbit Costs

18 Hours/trip x 8 cabs x 20,000#/trip * 67% up time =

142,933 #/day 52,206,400 #/year

COST = $ 97.00 per pound