The Multi-stage space Elevator
ISEC 2018 Report

John M. Knapman, Ph.D., FBIS
Director of Research
ISEC
Purpose

• To be able to use tether materials that are available now or likely to be available soon
  – Carbon fiber yarn
  – Improved graphene or CNTs
    • Beyond the small samples produced today
• To deal with Earth’s turbulent atmosphere
  – Wind, ice, electric storms
Topics

• Principles
• First Stage
• Upper Stages
• Resilience
• Prototype Work
• Mini Workshop Questions
How to use a weaker tether

Apex Anchor

Keep tether masses similar

Taper Ratio 6:1

Tether Supports

38 MYuri (27)

11 MYuri (7.8)

Torayca Yarn

3.9 MYuri (2.8)

(7GPa/1.79g•cm⁻³)

Geosynchronous Altitude

Earth’s Atmosphere
Two stages

Material 11 MYuri (7.8)

Apex Anchor

88,000 km

Self supporting tether with mass 4200 tons

Taper ratio 13:1

35,786 km

GEO

Second stage ambits support tether mass 2400 tons

Taper ratio 47:1

6000 km

First stage ambits support tubes in atmosphere

Taper ratio 13:1

100 km
Streams of bolts in space

Tether supported by second-stage ambit

First stage above atmosphere

Pairs of tubes for second stage

Tubes and ambit for first stage

Ambits for second stage

Lower Ambit

Earth
First Stage
Design Choices

• Tube climbers in the atmosphere (up to 100 km)
  – Winch up to first stage
  – Climbing up the tubes
  – Narrow tether or rope
  – OR meter-wide tether

• Tube climber design
  – Carrying payload capsule to transfer to tether climber
  – Carrying tether climber in a protective box
  – OR same as tether climber
A group of bolt streams

Tether

A group of bolt streams
Streams of bolts and the tether
First Stage Automation

• Automate transfer of climbers to tether
  – First stage should not be manned continuously
  – Humans should only inspect and maintain

• At the first stage, tether climbers...
  – ...grip the tether
  – ...open their solar panels or laser receivers
  – ...commence their ascent under their own power
Upper Stages
Passing through Upper Stages

• Second and higher stages support the tether

• Jump-over mechanism
  – Either transfer climber from one section of tether to the next
    • Climber must renew its grip on the tether
  – Or have the second or higher stage support the tether in two places
    • Remove supports in turn to allow the climber to pass
  – Process is fully automated
Transferring Climber
Transferring Climber

Streams of bolts

Tether climber

Streams of bolts

Ambits
Support tether in two places

Streams of bolts

Parked tether climber

Tether supports

Streams of bolts
Resilience

• Power failure
  – Use the stored energy until power is restored
  – Ensure standby power always available
• Multiple tubes provide backup if one tube needs repairs
• Space debris
  – Structures in space need shielding
  – Bolts travel in vacuum of space without tubes
Space Debris

• Nylon is good for bolt construction
  – It vaporizes on collision
• Large incoming object smashes through
  – Carries vapor, dust and ejecta with it
• Small incoming object forms a crater on a bolt
• Bolt-size incoming object
  – Both objects vaporize or shatter
  – Resultant debris travels at 8 km/s
• Risk of cascade effect in unlucky cases
  – More work needed
Space Debris

Debris before impact $\mathbf{v}_d$

Bolt before impact $\mathbf{v}_b$

Next bolt $\mathbf{v}_b$

Resultant cloud of fragments and vapor $\mathbf{v}_r$

Point of impact
Stability

• In the atmosphere, measure the wind force near each control point along the tube
  – Algorithm called “active curvature control”
  – The tubes bend so that the centrifugal force as the bolts pass the bend equals the wind force

• In space, measure the gap between ascending and descending bolts
  – Controls in the bolts ensure that they arrive at theambits in the right positions
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- Mini Workshop Questions
Prototypes

1. Circular loop 80 cm diameter
   - In vacuum chamber
   - Bolt speed 18-25 m/s

2. Circular loop 50 meters diameter
   - Evacuated tubes
   - Bolt speed 300 m/s

3. Raise the upper part of the loop
   - It becomes the upper ambit
   - Insert additional tubes
Technology Convergence

Altitude km

15,000
12,000
9000
6000
3000
0

Reach of stronger materials

Height of multi-stage ambits
Mini Workshop Questions

• What prototype phases should we plan?
  – How big does a prototype need to be to be convincing?

• What should the funding balance be between strong materials and multi-stage technology?
  – Suppose we had $1 million, $10 million or $100 million.

• What are good methods of descent?
  – Falling, gliding, retro rockets?
  – Coming down the tether?
    • What about jumping or crossing over ascending climbers?

• Propose good operating procedures
  – Use automation and remote control as much as possible