Discussion Topics

- HASTOL Concept Overview
- Hypersonic Vehicle Description
- Trajectory Analysis Results
- Tether Design Considerations
Hypersonic Airplane – Space Tether Orbital Launch System
CardioRotovator Concept
Tillotson Two-Tier Tether (T4) Concept

- Two-Stage Rotovator

- Reduces Ratio Of Tether System Mass To Payload Mass
### Rotovator Tether Mass Ratios

<table>
<thead>
<tr>
<th>Tether Length (km)</th>
<th>Orbital Radius ( R_O ) (km)</th>
<th>Orbital Velocity ( V_O ) (m/s)</th>
<th>Tip Velocity ( V_T ) (m/s)</th>
<th>Hypersonic Airplane Velocity ( V_H = V_O - V_T - 470 \text{ m/s} )</th>
<th>Tether to Payload Mass Ratio ( M_{T/M_P} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>6878</td>
<td>7614</td>
<td>2494</td>
<td>4650 (Mach 15.0)</td>
<td>Spectra™ 2x 10x</td>
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<tr>
<td>500</td>
<td>6978</td>
<td>7559</td>
<td>2749</td>
<td>4340 (Mach 14.0)</td>
<td>16.7 4.2 0.56</td>
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<tr>
<td>600</td>
<td>7078</td>
<td>7506</td>
<td>3006</td>
<td>4030 (Mach 13.0)</td>
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<td>700</td>
<td>7178</td>
<td>7453</td>
<td>3263</td>
<td>3720 (Mach 12.0)</td>
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<tr>
<td>800</td>
<td>7278</td>
<td>7402</td>
<td>3522</td>
<td>3410 (Mach 11.0)</td>
<td>71.8 11.6 0.90</td>
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<tr>
<td>900</td>
<td>7378</td>
<td>7352</td>
<td>3782</td>
<td>3100 (Mach 10.0)</td>
<td>117.6 16.3 1.07</td>
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</table>
## CardioRotovator Tether Mass Ratios

<table>
<thead>
<tr>
<th>Tether Length (km)</th>
<th>Orbital Radius R₀ (km)</th>
<th>Orbital Velocity V₀ (m/s)</th>
<th>Tip Velocity Vₜ (m/s)</th>
<th>Tip Accel. a (m/s²)</th>
<th>Hypersonic Airplane Velocity Vₜ= V₀-Vₜ-470 m/s</th>
<th>Tether to Payload Mass Ratio Mₜ/Mₚ</th>
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<tbody>
<tr>
<td>1000</td>
<td>7478</td>
<td>7147</td>
<td>2076</td>
<td>0.43</td>
<td>4601</td>
<td>Spectra 2x 0.39</td>
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<td>1200</td>
<td>7678</td>
<td>7004</td>
<td>2440</td>
<td>0.50</td>
<td>4094</td>
<td>10.8 3.1 0.55</td>
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<td>1400</td>
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<td>8078</td>
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<td>3143</td>
<td>44.7 8.4 0.97</td>
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<td>1800</td>
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<td>6611</td>
<td>3445</td>
<td>0.66</td>
<td>2695</td>
<td>87.8 13.4 1.24</td>
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High-strength Electrodynamic Force Tether (HEFT) Facility

- Plasma Contactors
- Tether Rotation
- Magnetic Field
- Current
- Electrodyncmic Force
- HEFT Facility
- High Strength Tapered Survivable Hoytether
- Solar Array Power Supply
Dual-Fuel DF-9 Dual Role Vehicle

- JP-7 Tanks
- Crew Station
- Linear Rocket Payload
- Air Core Enhanced Turboramjets (AceTR)
- Ramjet/Scramjet AceTRs
- Looking Aft
- SH2 Tanks
- 208.5 ft
Dual-Fuel DF-9 Dual Role Vehicle
Dual-Fuel DF-9 Performance

- Space Launch Mission
- Cruise Mission
- TSTO Takeoff
- Cruise Subsonic Cruise
- Mach 10 Cruise
- Decel Refueling Inflight
- Upper Stage to Orbit
- Staging Altitude 280,000 ft
- Flight Path Angle 5.5°
- Speed 11,120 ft/sec

Radius: 7,390 NM

TOGW: 531,987 lb

TOGW: 620,762 lb
Matrix Of Payload Transfer Points Analyzed

![Graph showing achievable and unachievable points in altitude versus velocity.]

- **Achievable Points**
- **Unachievable Points**

**Altitude**
- 80 km
- 90 km
- 100 km
- 110 km
- 120 km
- 130 km
- 140 km
- 150 km
- 160 km
- 170 km
- 180 km
- 190 km
- 200 km
- 210 km
- 220 km
- 230 km
- 240 km
- 250 km
- 260 km
- 270 km
- 280 km
- 290 km
- 300 km
- 310 km
- 320 km
- 330 km
- 340 km
- 350 km
- 360 km
- 370 km
- 380 km
- 390 km
- 400 km

**Velocity**
- 8,000 m/s (26,246 ft/s)
- 9,000 m/s (29,535 ft/s)
- 10,000 m/s (32,808 ft/s)
- 11,000 m/s (36,081 ft/s)
- 12,000 m/s (39,354 ft/s)
Normal Load Factor Along Descent Trajectory

- 81 km, 3700 m/s
- 120 km, 2400 m/s
Dynamic Pressure Along Descent Trajectory

- 81 km, 3700 m/s
- 120 km, 2400 m/s

Dynamic Pressure (psf)

Time Since Apogee (s)
Hoytether™ Failsafe Tether Design

Primary Lines

Secondary Lines (initially unstressed)

0.2 to 10’s of meters

0.1 - 1 meter

Severed Primary Line

First Level of Secondary Lines Redistributes Load to Adjacent Nodes

Effects of Damage Localized

Second Level of Secondary Lines Redistributes Load Back to Undamaged Portion of Primary Line

a.

b.

c.

PHANTOM WORKS

BOEING®
# High Temperature Tether Materials

## Tensile Strength (GPa) vs. Temperature

<table>
<thead>
<tr>
<th>Material</th>
<th>$V_C$ (km/s)</th>
<th>Density $d$ (g/cc)</th>
<th>20 C</th>
<th>300 C</th>
<th>600 C</th>
<th>800 C</th>
<th>1000 C</th>
<th>1200 C</th>
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<tr>
<td>Spectra 2000</td>
<td>2.87</td>
<td>0.97</td>
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<tr>
<td>Zylon (PBO)</td>
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<td>1.56</td>
<td>5.8</td>
<td>3.7</td>
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<tr>
<td>Quartz Glass (SiO$_2$)</td>
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<td>Carbon</td>
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<td>Tyranno (SiTiCO)</td>
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<td>3.5</td>
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<tr>
<td>Textron β-SiC</td>
<td>2.19</td>
<td>2.93</td>
<td>7.0</td>
<td>6.6</td>
<td>6.0</td>
<td>5.6</td>
<td>5.2</td>
<td>4.5</td>
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<tr>
<td>0.72 β-SiC/Ti-coated</td>
<td>1.72</td>
<td>3.37</td>
<td>5.0</td>
<td>4.8</td>
<td>4.3</td>
<td>4.0</td>
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<td>3.2</td>
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<tr>
<td>Altex (Al$_2$O$_3$/SiO$_2$)</td>
<td>1.21</td>
<td>3.30</td>
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<tr>
<td>Nextel (α-Al$_2$O$_3$)</td>
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<td>?</td>
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<tr>
<td>0.65 Nextel/Al-coated</td>
<td>0.97</td>
<td>3.40</td>
<td>1.6</td>
<td>1.4</td>
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<td>Tungsten Wire</td>
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<td>19.35</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
</tr>
</tbody>
</table>
HASTOL GRAPPLE ASSEMBLY

- Tether Deployer and Retrieval Mechanism
- Mounting Structure for Reaction Control System
- High Temperature Tether With Embedded Conductor For Electrodynamic Tether Electric Power Generation
- Housing for Tether Reel, Avionics, RCS Fuel, Batteries, and Electrodynamic Tether Battery Recharging Circuits
- Mounting Structure for Reaction Control System
- RCS Nozzles Flush with Surface to Minimize Drag and Heating

PHANTOM WORKS

BOEING
Grapple to Payload Attachment Option

1. Grapple/End mass comes down on Payload
2. Grapple stops on Payload, levers on payload are in “in-close” position
3. Attach Levers then move radially outward toward ring; sliding on rails. Once contact with ring is made, they latch to the ring securing the payload to the grapple.

Payload Surface

Grapple Ring
Conclusions

- The HASTOL System provides a system to deliver payloads to space with minimal reliance on rocket propulsion
- Tether designs using existing materials can provide required strength at required thermal loads
- The Hoytether™ design provides a survivable tether concept for long duration operation
- Issues to be addressed in future work include Grapple design refinement and payload transfer logistics