Hypersonic Airplane Space Tether Orbital Launch (HASTOL) Study

NASA Institute for Advanced Concepts
Second Annual Meeting
Goddard Space Flight Center
Greenbelt, Maryland
June 7, 2000

John E.Grant
The Boeing Company
5301 Bolsa Ave., Huntington Beach, CA 92647-2099
+1-714-372-5391
john.e.grant@boeing.com   www.boeing.com

Presentation Outline

- **Team Acknowledgments**
- **HASTOL Concept of Operation**
- **Phase I Results**
  - Hypersonic Airplane
  - Tether Boost Facility
  - Tether
  - Payload Capture
- **Phase II Plan**
- **Follow-On Efforts**

HASTOL Phase II Study Team

The Boeing Company

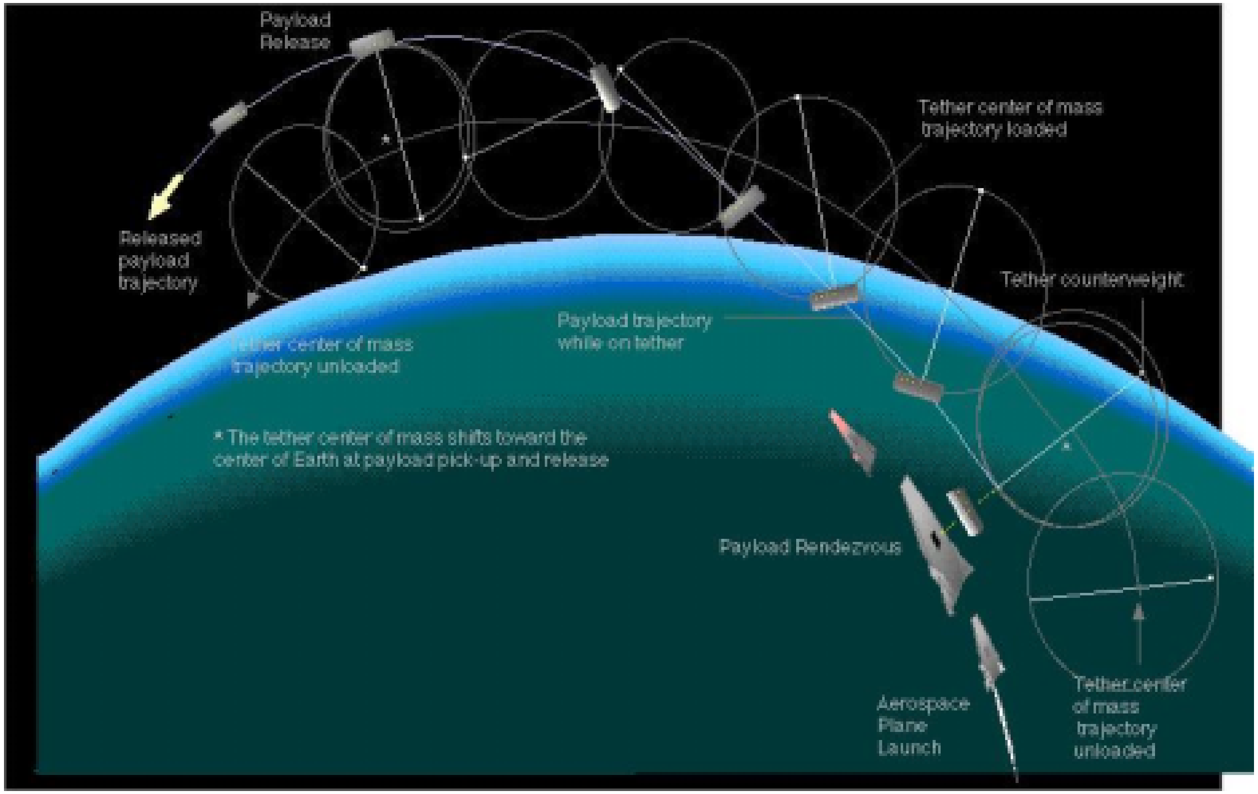
- John Grant, Reusable Space Systems, Huntington Beach, CA
- Jim Martin, Reusable Space Systems, Huntington Beach, CA
- Tom Bogar, Phantom Works, St. Louis, MO
- Don Johnson, Phantom Works, St. Louis, MO
- Joe Stemler, Phantom Works, St. Louis, MO
- Mike Bangham, Space and Communications, Huntsville, AL
- Ben Donahue, Space and Communications, Huntsville, AL
- Beth Fleming, Space and Communications, Huntsville, AL
- Brian Tillotson, Space and Communications, Seattle, WA

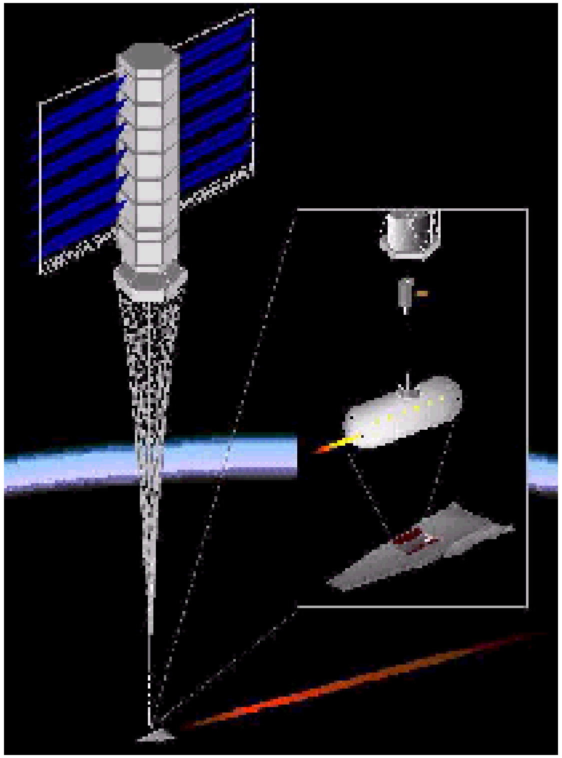
Tethers Unlimited, Inc.

- Rob Hoyt, Seattle, WA
- Bob Forward, Seattle, WA

The HASTOL System Concept of Operation Features a Reusable Launch Architecture

- **Hypersonic Airplane Carries Payload up to 100 km, Mach 12**
- **Rendezvous with Tip of Rotating Tether in Orbit**
- **Tether Lifts and Tosses Payload into Orbit or Escape**

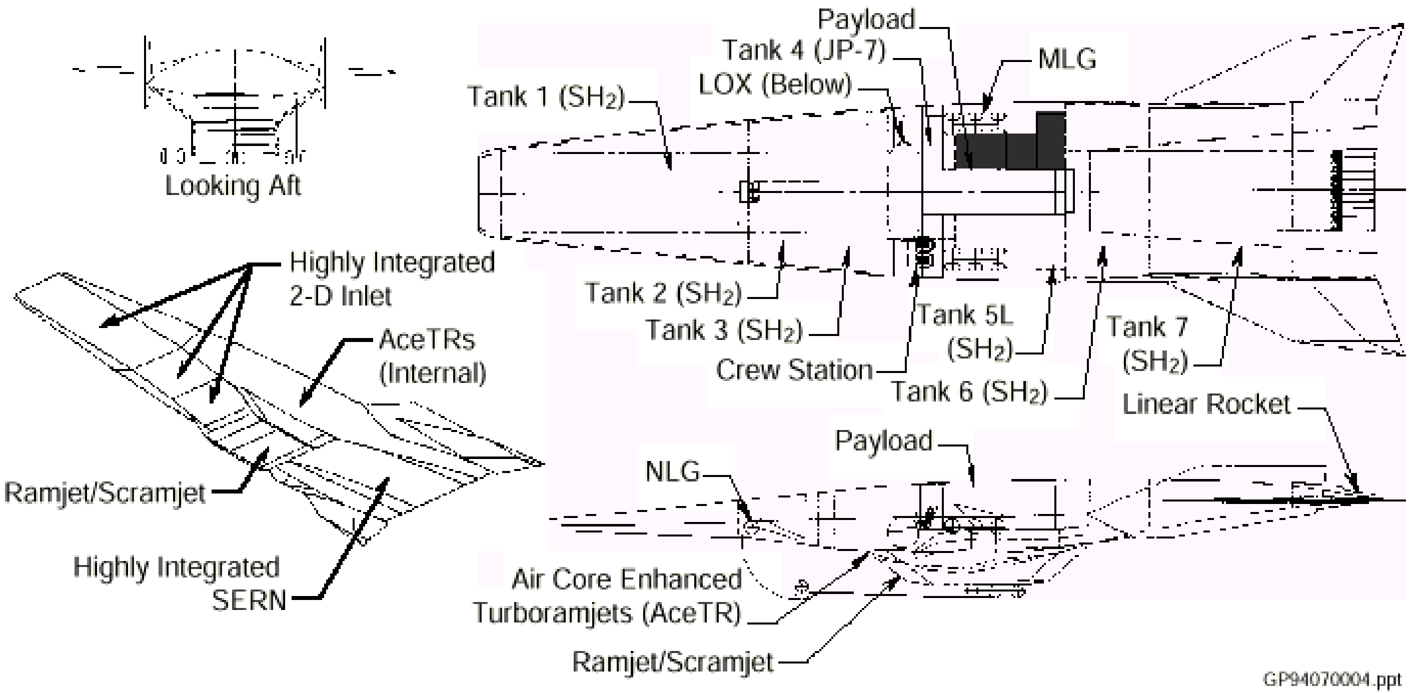




HASTOL Phase I Results Showed Concept Feasibility

- **Top -Level Requirements Developed; Top-Level Trades Conducted to Define Basic Design Approaches**
- **Selected Hypersonic Aircraft Concept (DF-9)**
- **Validated Overlap of Tether Tip and Hypersonic Aircraft Velocity and Geometry Envelopes for Capture**
  - **Defined Aircraft Apogee Altitude/Velocity Envelope**
  - **Tether Tip Can Withstand Thermal Loads as it Dips into the Atmosphere**
- **Tether Boost Facility Concept Defined**
- **Rotovator Tether Concept Selected**
- **Simplified Grapple Concept Identified**

HASTOL Baseline Hypersonic Aircraft Concept: Boeing-NASA/LaRC DF-9 Dual-Fuel Aerospaceplane

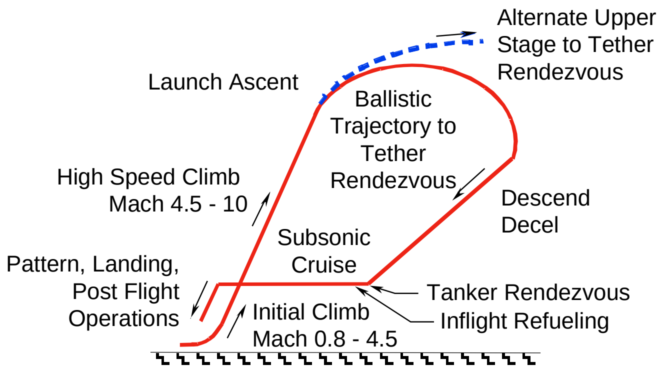


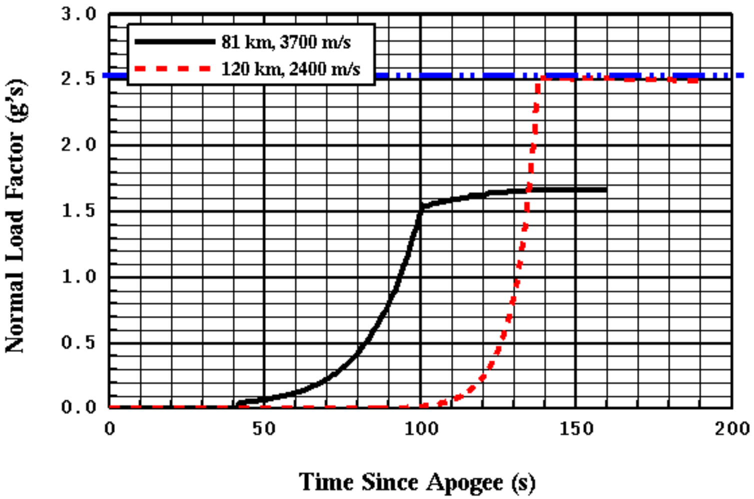
Takeoff Wt: 270 MT (590,000 lb)
Payload: 14 MT (30,000 lb)
Length: 64 m (209 ft)
Apogee: 100 km

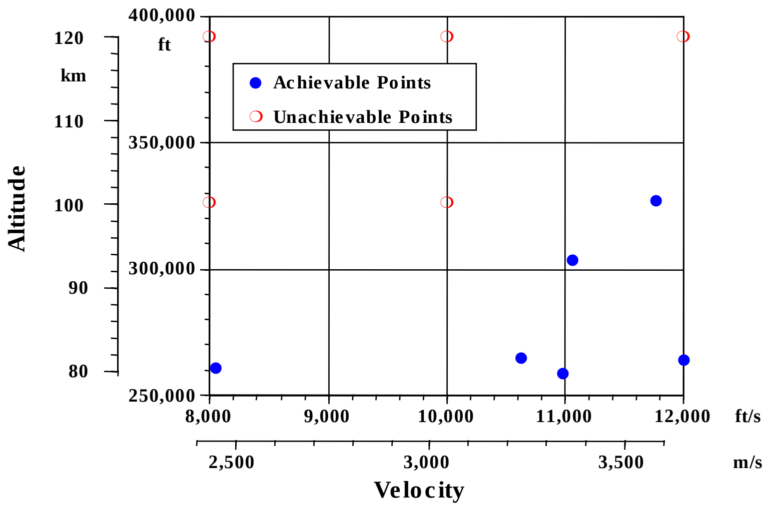
Speed at Apogee: 3.6 km/sec (approx. Mach 12)
4.1 km/sec (inertial)

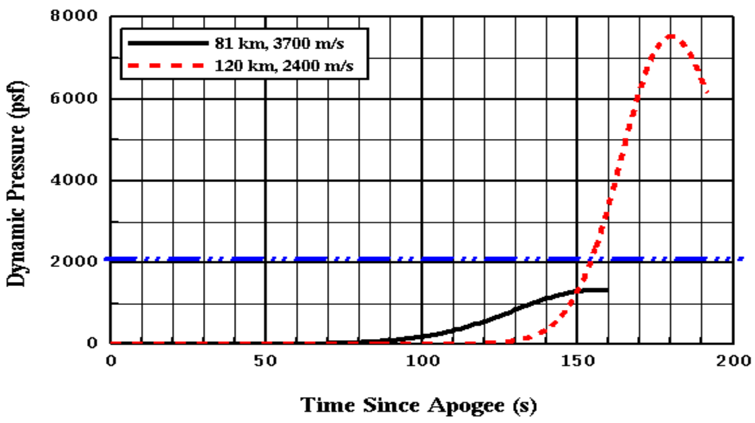
Turboramjets up to Mach 4.5
Ram-, Scramjets above Mach 4.5
Linear Rocket for Pop-Up Maneuver

Aircraft “Pop-Up” Mission Profile Analysis Shows Required Speed and Altitude are Attained





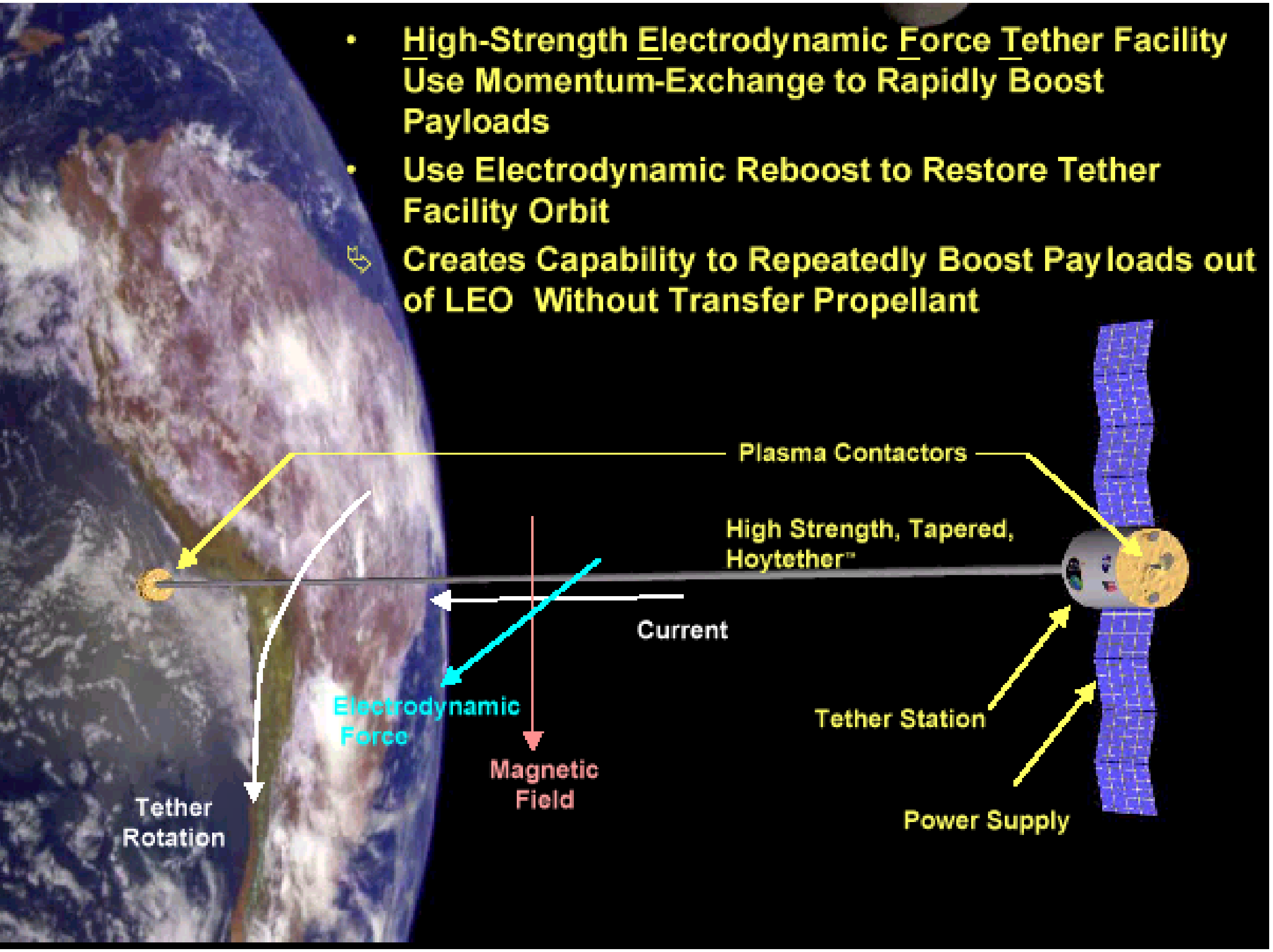




Ongoing Hypersonic Aircraft Development Programs Will Benefit HASTOL Concept Maturity

- DF-9 - Horizontal takeoff, horizontal land concept
  - Developed by Boeing for NASA LaRC
  - Derivative of DF-7 hypersonic cruise airplane concept
- Hyper-X (X-43) - Scramjet flight test vehicle from Pegasus booster
  - Microcraft prime contractor; Boeing subcontractor
  - First flight test vehicle delivered; flight to Mach 7 in Sept 2000
  - Second flight test vehicle to be delivered to NASA in August 2000
  - Third flight test vehicle in design/fab; will fly to Mach 10 in Oct 2001
- X-34 - Rocket boosted hypersonic flight demo
  - Being developed by Orbital Sciences
  - Captive flight tests completed
  - Phase 1 flights to Mach 3.8; Phase 2 flights to Mach 8
- X-33 lifting body, aerospike engine
  - Being developed by Lockheed-Martin
  - Flight vehicle being assembled; testing to Mach 10+ envisioned
- X-37 (Future-X) Hypersonic research test bed vehicle
  - Boeing/NASA MSFC Cooperative Effort
  - First flight planned for 2003 (Shuttle payload); re-entry to powerless horizontal landing

HEFT Tether Boost Facility is Adaptable to the HASTOL Mission

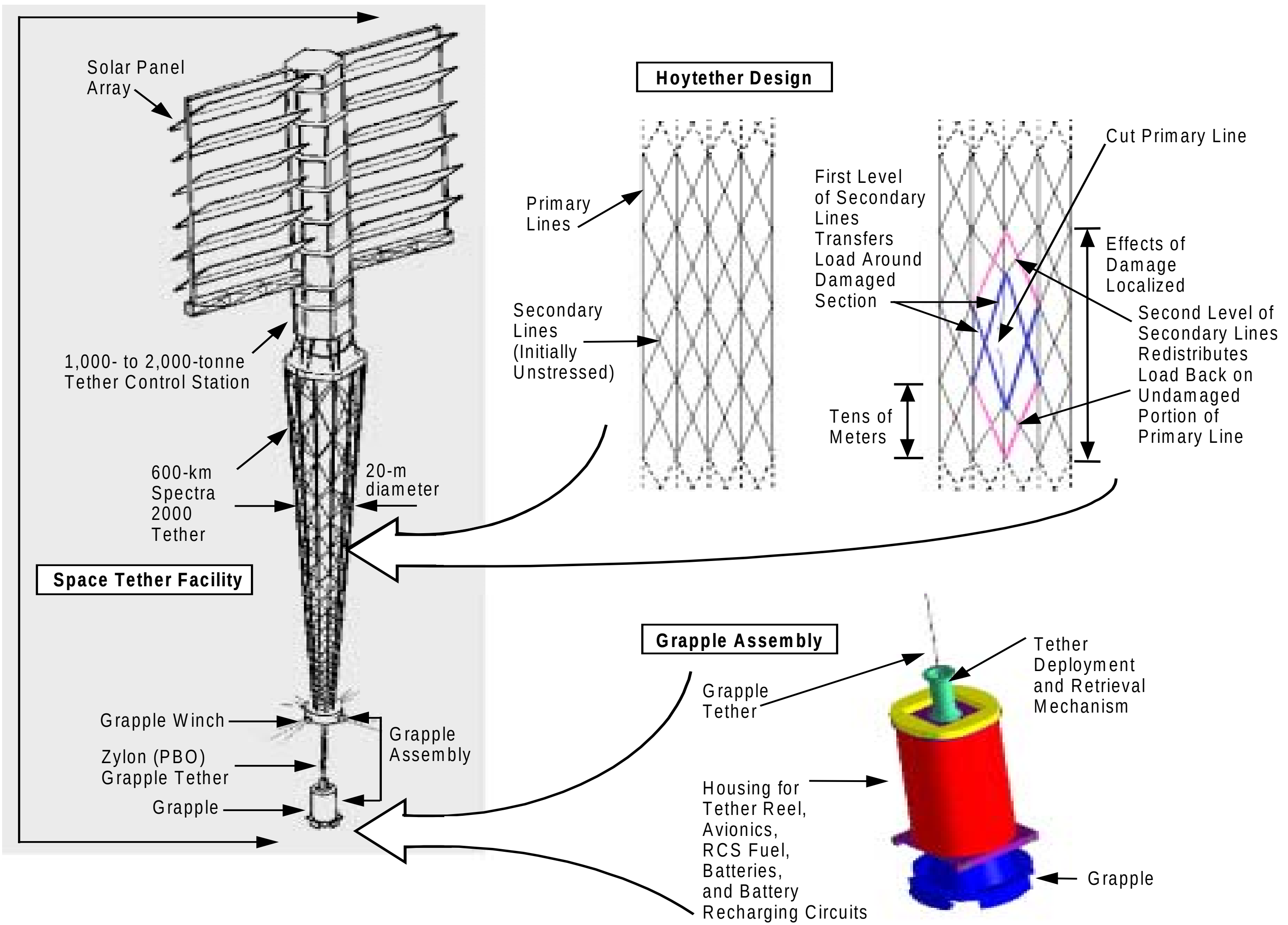


Facility center of mass in slightly elliptical orbit:
- 700 km apogee
- 610 km perigee
- 90 km from tether station
- 7.6 km/sec perigee velocity

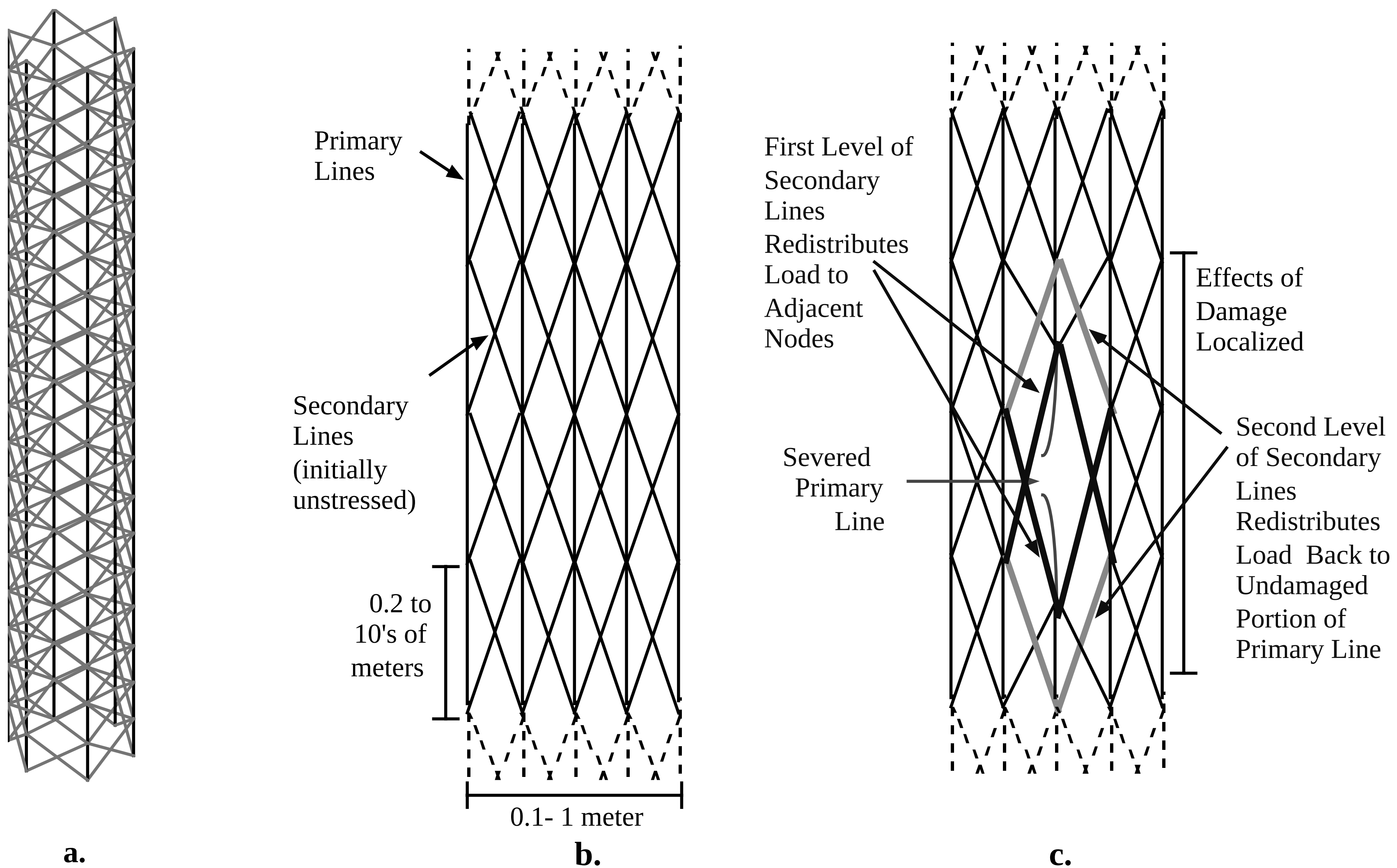
Tether:
- Length: 600 km
- Tip velocity: 3.5 km/sec
- When facility center of mass is at perigee, tether tip is at100 km altitude

Station Mass:	**1,650 MT**
Tether Mass:	**1,360 MT**
Grapple Mass	**650 MT**

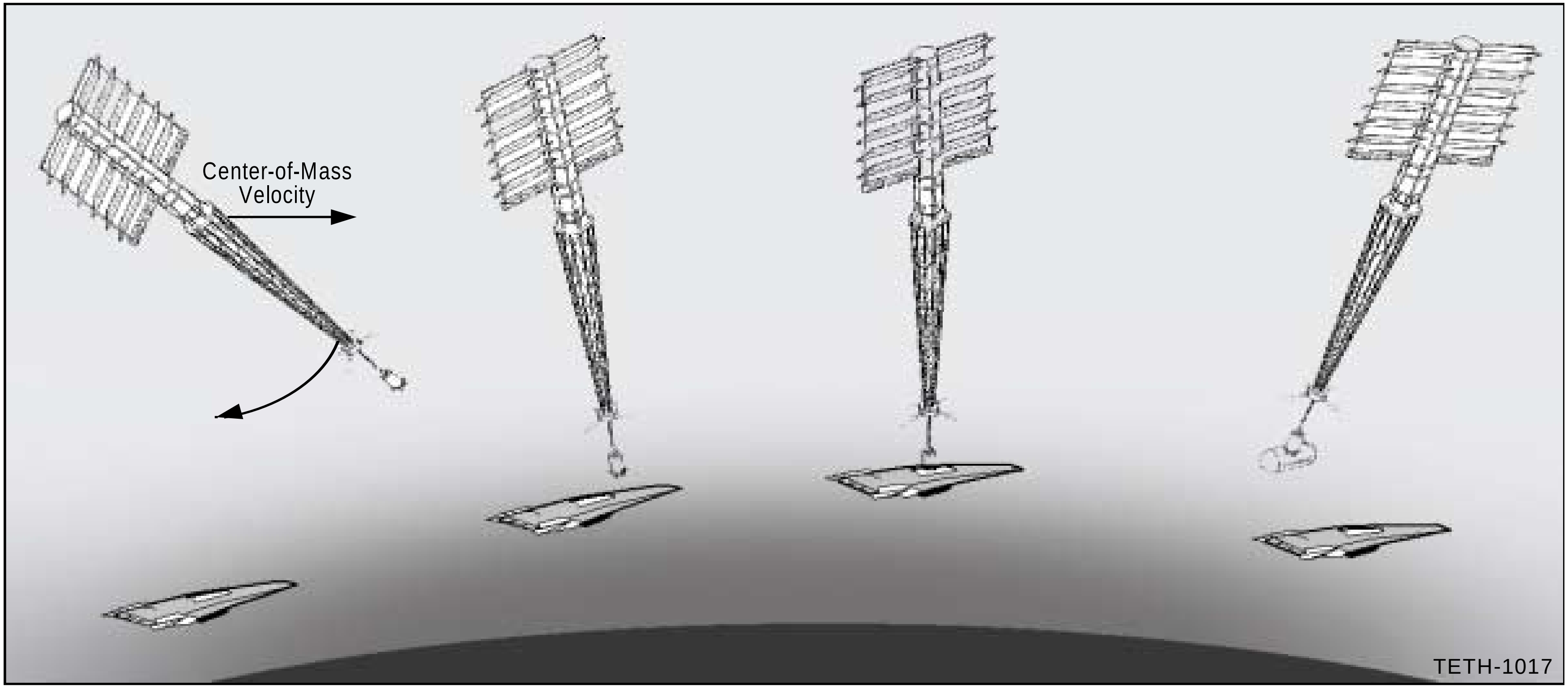
HEFT Tether Boost Facility is Adaptable to the HASTOL Mission

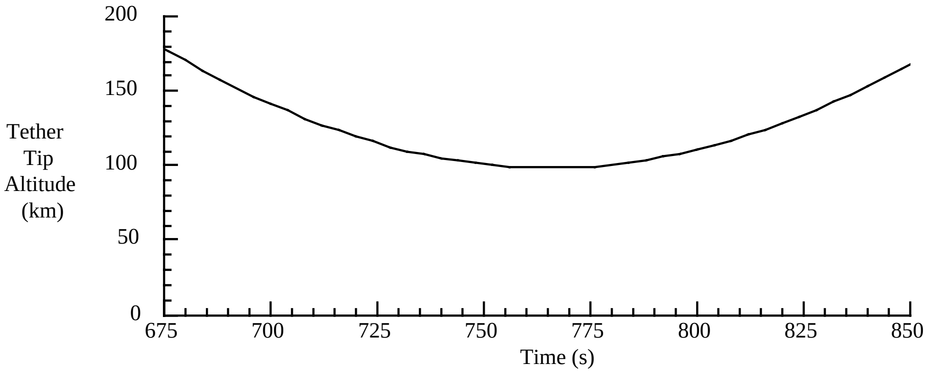


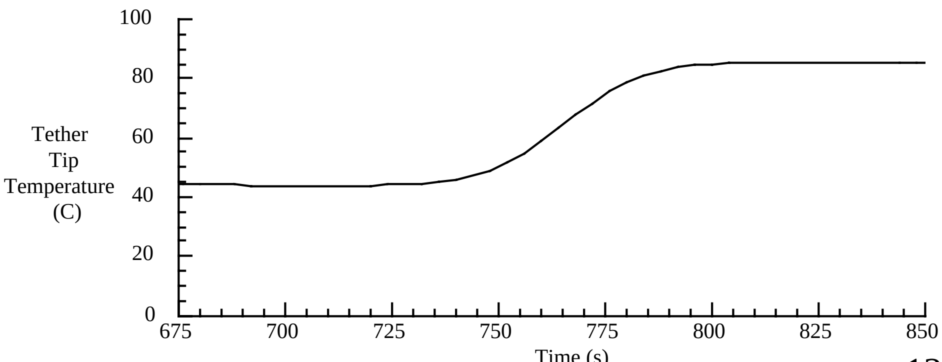
The Hoytether™ Design will survive meteorite strike cuts or material failure of primary lines



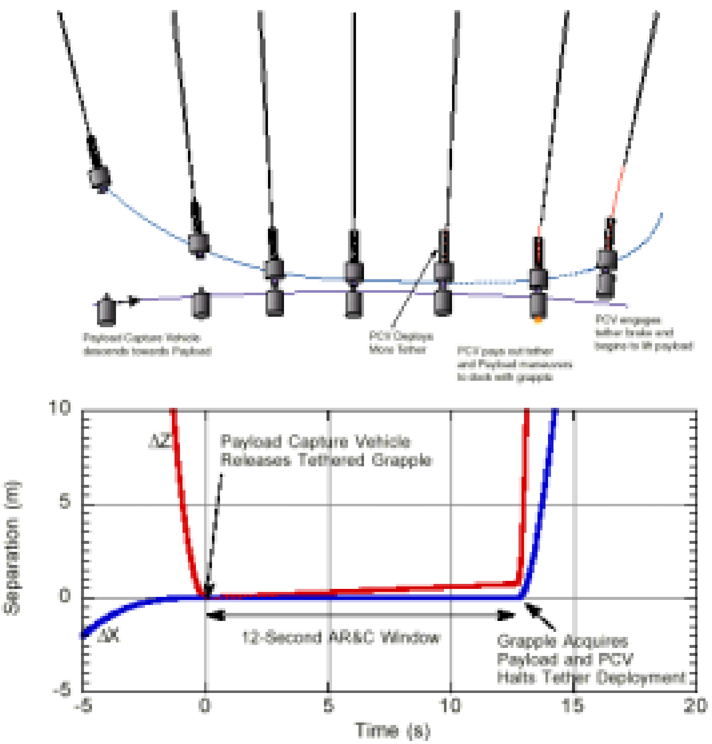
Rotovator™ Tether and Hypersonic Airplane Rendezvous occurs at 100 km, 4.1 km/sec





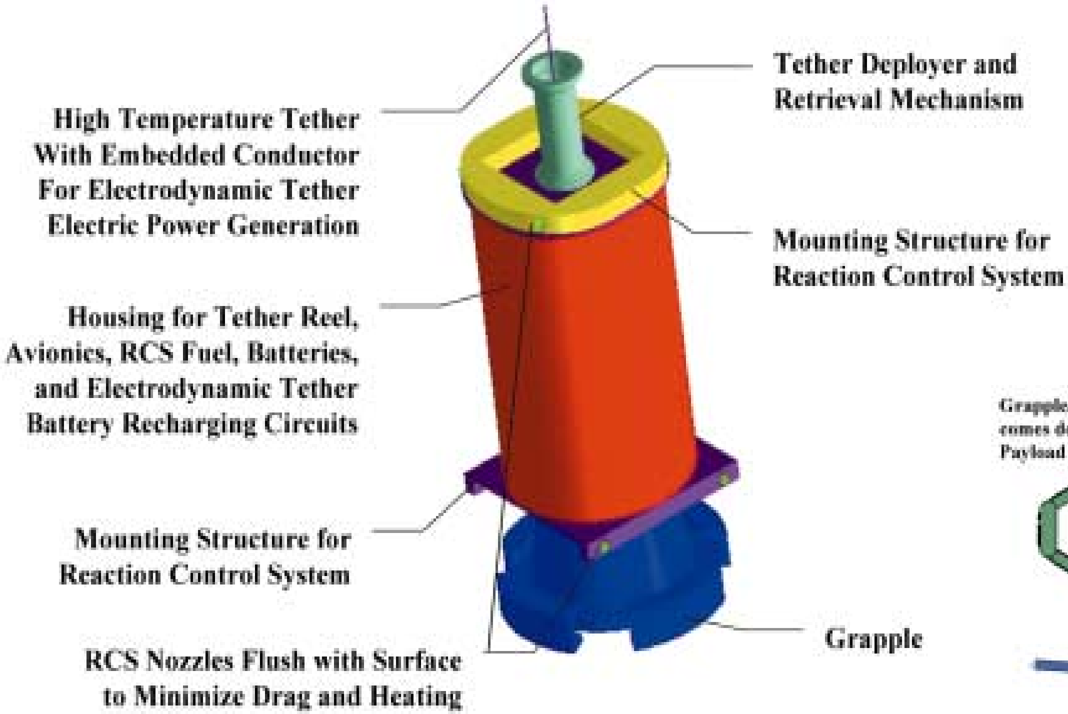


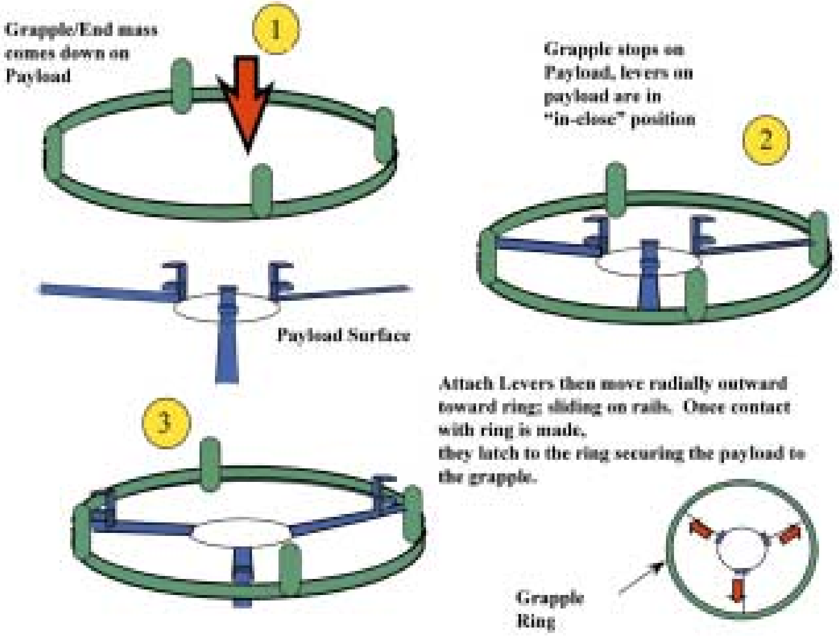
Phase I Results Show Feasibility of Payload Capture



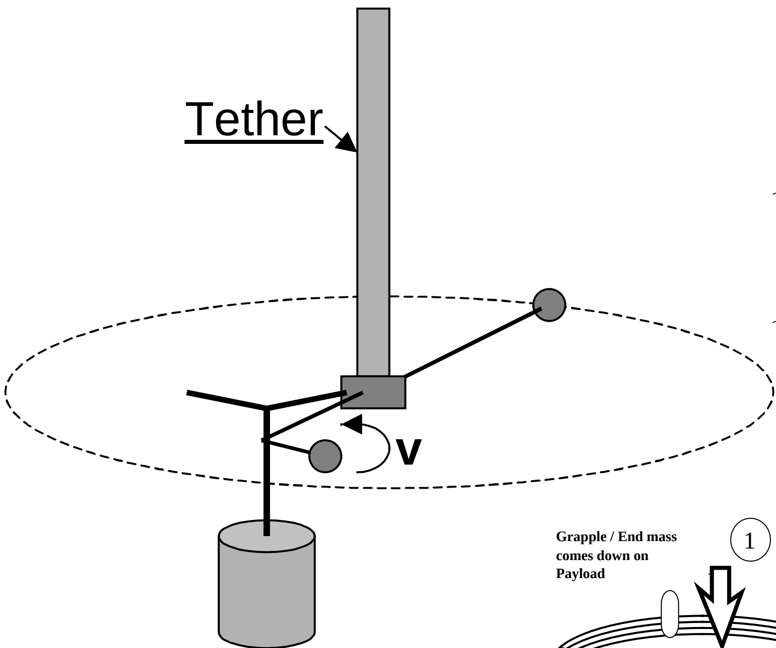
- **Tether-Payload Rendezvous Capability is a Key Enabling Technology**
- **TUI Has Developed Methods for Extending Rendezvous Window**
  - **Works in Simulation**
  - **Validation Experiments Needed**

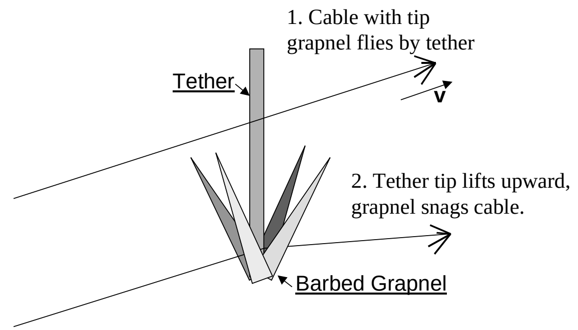
Simplified Grapple Approach Selected for Phase I

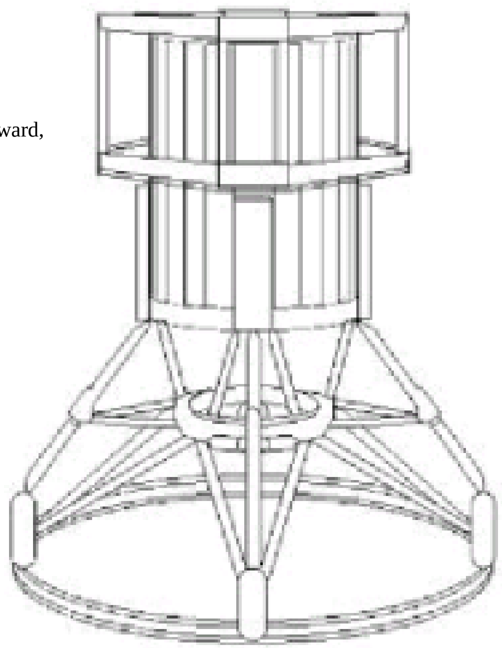


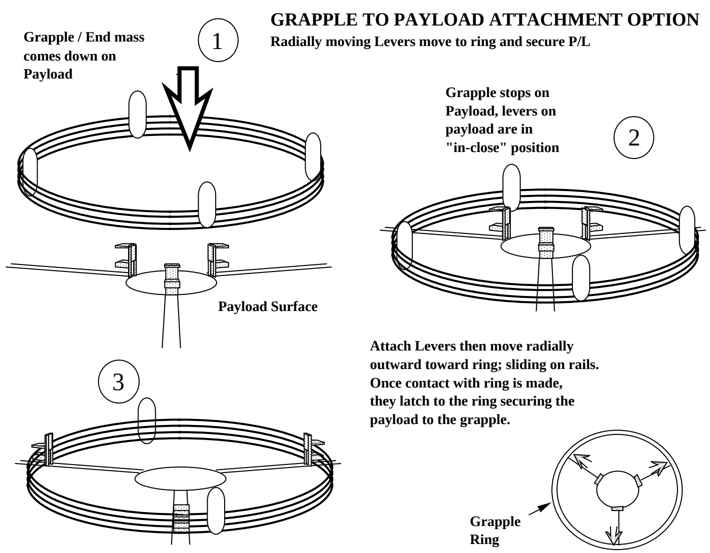


Other Grapple Concepts Have Been Investigated; Baseline Approach Will Be Revisited in Phase II









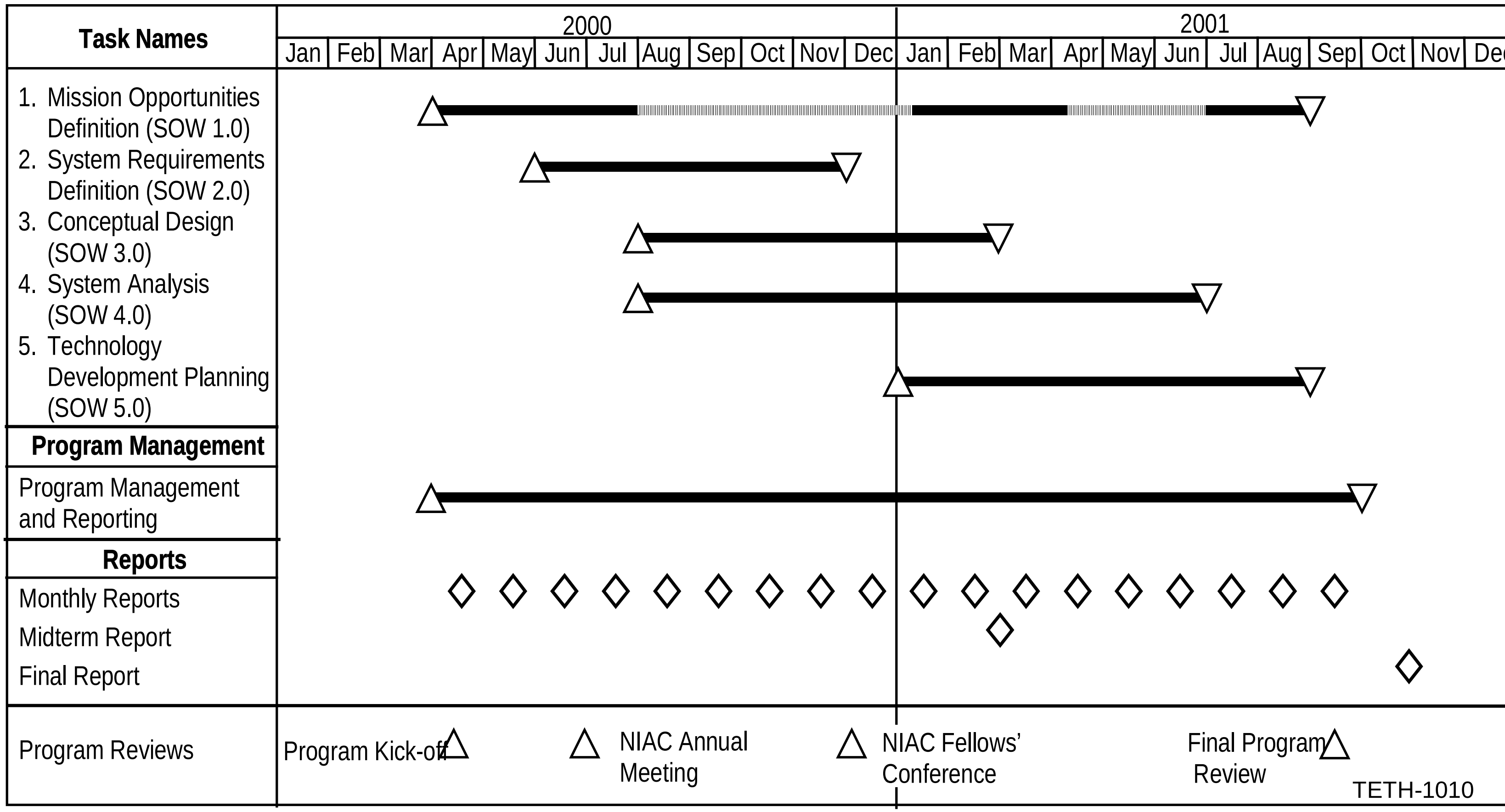
HASTOL Phase II Study Tasks

- Mission Requirements and Mission Opportunity Definition
- System Requirements
- System Concept Definition
- System Analysis
- Technology Development Roadmap

  (near term demos)

- Contract Schedule/Key Milestones:
  - First 12 of 18 month program funded
  - Concept Definition and System Analyses will be nearly complete by end of 12th month

HASTOL Phase II Study Schedule



HASTOL Phase II Study Approach

Phase I Results

- Rotovator concept
- Technology Readiness Level 2 systems (hypersonic airplane, tether control station, tether, grapple assembly, payload accommodation assembly)
- Trade study results: discovery that rendezvous point can be achieved by existing airplane (X-43) without overheating tether tip
- Selected concepts
  - DF-9 hypersonic vehicle
  - Rendezvous point at Mach 10, 100-km altitude
  - HoytetherTM with Spectra2000TM material and PBO tip material

Hypersonic Airplane Space Tether Orbital Launch (HASTOL) Study Program, Phase II

Task 1 Mission Opportunities Definition

- Develop contact plan
- Conduct kick-off with potential customers and NIAC
- Meet with customers to assess potential missions and near-term applications
- Identify opportunities to integrate into NASA programs

Candidate list of mission needs

Task 2 System Requirements Definition

- Derive preliminary system requirements for each of the HASTOL systems
- Determine payload characteristics, traffic rate, guidance and control, g-force limitations, initial and life cycle costs, and system interface requirements
- Identify, define, allocate, and trade major system requirements

Task 3 Conceptual Design

- Integrate into system architecture
- Conduct trade studies
- Develop ROM cost estimate

Task 4 System Analysis

- Conduct modeling and simulations
- Conduct preliminary technical assessment
  - Identify high-risk areas
  - Develop mitigation plans

Task 5 Technology Development Planning

- Identify technology needs
- Develop technology development roadmap
  - Flight test plan
  - Laboratory tests

Phase II Deliverables

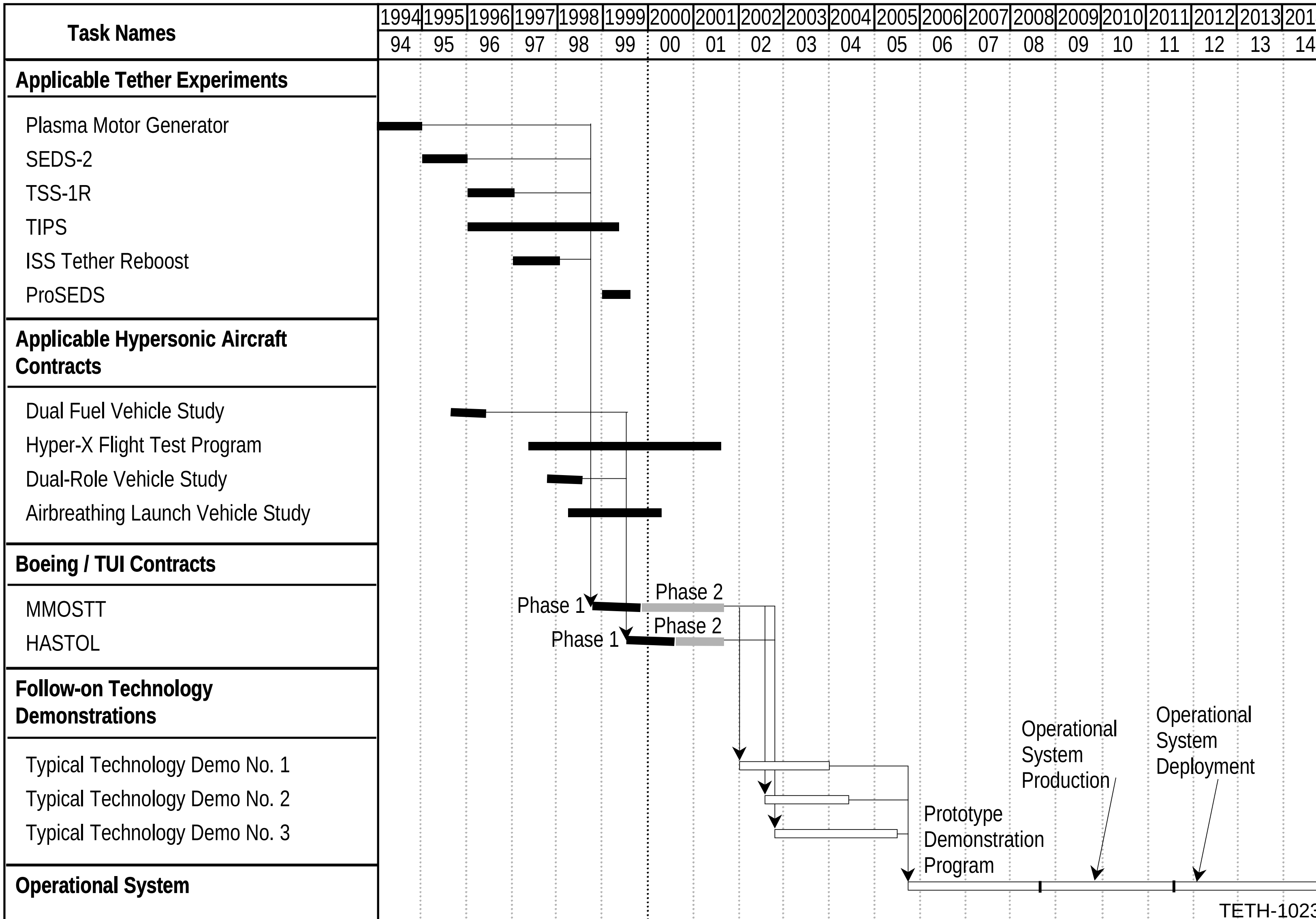
- Final Phase II program review
- Phase II final report
  - System requirements
  - Complete system design concept to TRL 3
  - Areas of development work needed
  - Technology roadmap
  - Cost models
  - Analyze key technical issues
    - ✔ GN&C
    - ✔ Payload transfer operations
    - ✔ Tether design and dynamics
    - ✔ Material selection
    - ✔ Simulation results
- Phase III customer funding commitment

System Analysis Tasks Address Areas of Concern

- Detailed rendezvous and payload capture simulation will identify payload grapple requirements
- Abort modes will be investigated -- what if payload is not captured?
- Payload release orbits
- Cost modeling -- compare HASTOL to other launch system architectures
- Tether dynamics and associated interaction with grapple assembly
- Tether material survivability in space environment
- Electrodynamic thrust control for reboost and orbit transfer
- Collision avoidance of known orbiting assets

Technology Development Roadmap will identify near term demonstrations needed for low risk flight demonstration.

Roadmap Identifies Stepwise Technology Demonstration and System Development, Production and Deployment



Additional Near-Term Studies Can Assess Feasibility and Identify Key Flight Demos

- **Automated Rendezvous & Capture**
  - Time Window for Capture < 10 Seconds
  - High Accuracy Requirements
- **Electrodynamic Tether Operation**
  - High Power & Voltage Issues
  - Control of Tether Dynamics
- **Traffic Control/Collision Avoidance**
- **Economic Analysis/Business Plan**
  - Technology Risk Reduction
  - Incremental Commercial Development Path
  - Customer Acceptance

Near-Term Flight Experiments will Validate Feasibility for Prototype System Development

- **Spinning Tether Orbital Transfer System - STOTS**
  - Deploy Small Payload on a Tether
  - Demonstrate Spin-Up of Tether System Using Reeling
  - Demonstrate Controlled Toss of Payload
  - Build on SEDS Heritage
  - Piggyback on Delta II Launch

- **Tether Orbit Raising Qualification Experiment - TORQUE**
  - Deploy Hanging Tether Below Small Facility
  - Demonstrate Payload Rendezvous & Docking with Hanging Tether
  - Demonstrate Electrodynamic Spin-up of Tether
  - Demonstrate Controlled Toss of Payload
  - Demonstrate Electrodynamic Reboost of Facility
  - Perform Repeated Boosting of Commercial/Scientific Payloads

Tether Systems Have the Potential to Enable Low Cost Access to Space

- **Concept feasibility study already completed.**
- **Key targets for technical risk reduction have been identified.**
- **Tether experiments have already flown in space.**
- **Planned near term experiments further reduce potential system risks.**
- **Phase II analyses will reveal near term demonstrations and flight experiments required for full scale system development.**
- **Modest near term government investment is encouraged to fund demos and experiments.**