Advanced ETO Space Transportation

Dr. Dana G. Andrews

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Agenda

- **What are requirements for Advanced Space Transportation?**
- **Solutions for ETO Transportation?**
- **Solutions beyond LEO?**

What are Future Space Transportation Requirements?

- **Affordable, Safe Access to LEO for people and freight**

- **Affordable Exploration of Mars system (Phobos, Deimos, & Mars)**
  - **SEP or NEP can satisfy requirements**

- **Industrialization of the Asteroid belt (2-3.5 AU)**
  - **SEP or NEP can satisfy requirements**
    - **SEP requires high concentration/tracking**
    - **NEP has affordability & non-proliferation issues**
  - **Mass drivers allow in situ propellants**

- **Outer planet human exploration?**
  - **Torch Ships (continuous acceleration at fraction on one gee)**
  - **Human hibernation /stasis**

ETO Technology summary

System-Level Technologies	Description	Strengths/Benefits	Weaknesses/Risks	Supporting Techno	Information Sourc
Advanced Chemical Rocket systems (e.g., Pulse Detonation Wave Engines, Metallized/Slush/Gelled Propellants, High-Energy Density Propellants)	Metal Hydride Propellants	Improved propellant density -Isp	Expensive Developments & expensive propellants	Current SBIR	DGA has papers
Advanced Airbreathing Combined-Cycle Systems	Air Collection & Enrichment System (ACES) RLVs	Infinite Isp on 1st Stage, Safest RLV ever analyzed (intact recovery if 2nd stage doesn't start)	Expensive 1st stage development	1965 and 2006 rotating fractional distillation unit testing	DGA has papers
Nuclear-Based Systems (e.g., Fission, Fusion, LENR)	Mini-Mag-Orion (40 gm Pu_{239} Bomblet)	15,000 sec Isp, 500,000 lbf Thrust	No proof of concept test results	Phase II SBIR in 2002/03	DGA has papers
Magneto-Hydrodynamic Systems	Crossed Field Rocket Exhaust Augmentation	Increases exhaust Velocity & Isp	Requires large power source	MHD Generator Work	
Beamed Power Systems (e.g., Laser-Based, Microwave-Based)	Coil gun firing Smart Particles	Magentic interaction with exploding particles	Serious damage with particle impact	Project Orion 1958-65 and Coil gun studies back in 1980s	
Advanced Field Propulsion Systems					
Space Elevator Systems	Skyhook Tether System	Can bootstrap growth, Allows affordable RLVs	Potential for LEO Debris impact	Tether climber competitions	DGA has papers
Ground-Based Launch Assist Systems	Cable Catapult	No new technologies, Low Cost, Civil Engineering Project, Allows Affordable RLVs	Limited redundancy	Sailing & kite industries	DGA has papers

Other Key ETO Technologies

Other Key Technologies					
Ultra-High Strength/Temperature-to-Weight Materials	M5 fibers, Carbon NanoTube Fibers	3X Spectra, 10X Spectra	No consistent product, short fiber lengths	Dupont, various producers	
Ultra-High-Density Power Storage	?				
Ultra-Low-Cost Manufacturing	Universal Automated Manufacturing Facility	Zero tooling expenses	Aircraft Industry is logical precedent - nothing apparent there	3-D printers	
Artificial-Intelligence-Based Automated Ground/Mission Operations	SOA in Aircraft				
Artificial-Intelligence-Based IVHM	SOA in Aircraft				

Reducing the Cost of ETO

- **Our Philosophy**
  - **If you're not cheating, you're not trying hard enough**
  - **Good enough is the enemy of best**

- **Our Approach**
  - **Look for new advances and synergies that reduce cost and enhance safety**

- **Recommendations:**
  - **Near Term ETO – HTHL TSTO with Skyhook**
  - **Mid Term ETO – Catapult-Launched SSTO with Skyhook**
  - **Far Term ETO – Beamed Power and/or MMO**

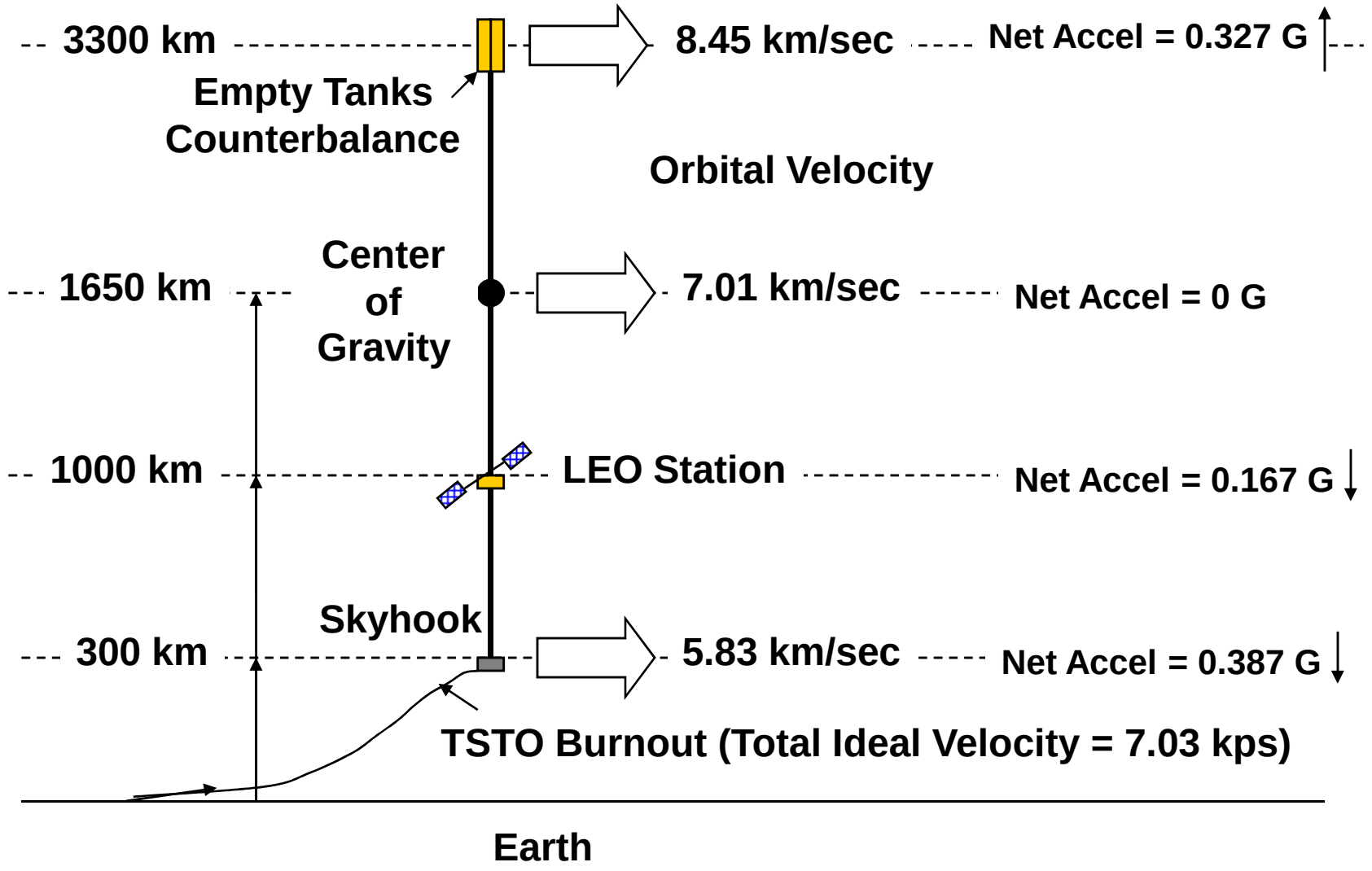
Near-Term Methods to make ETO Affordable

1. **Reduce the total Ideal ΔV for Earth-to-Orbit (ETO) trip**
   - **Use orbiting tether to go from 9.8 km/sec to 7.0 km/sec total Ideal ΔV**
   - **Add catapult launch to go from 7.0 km/sec to 5.0 km/sec**

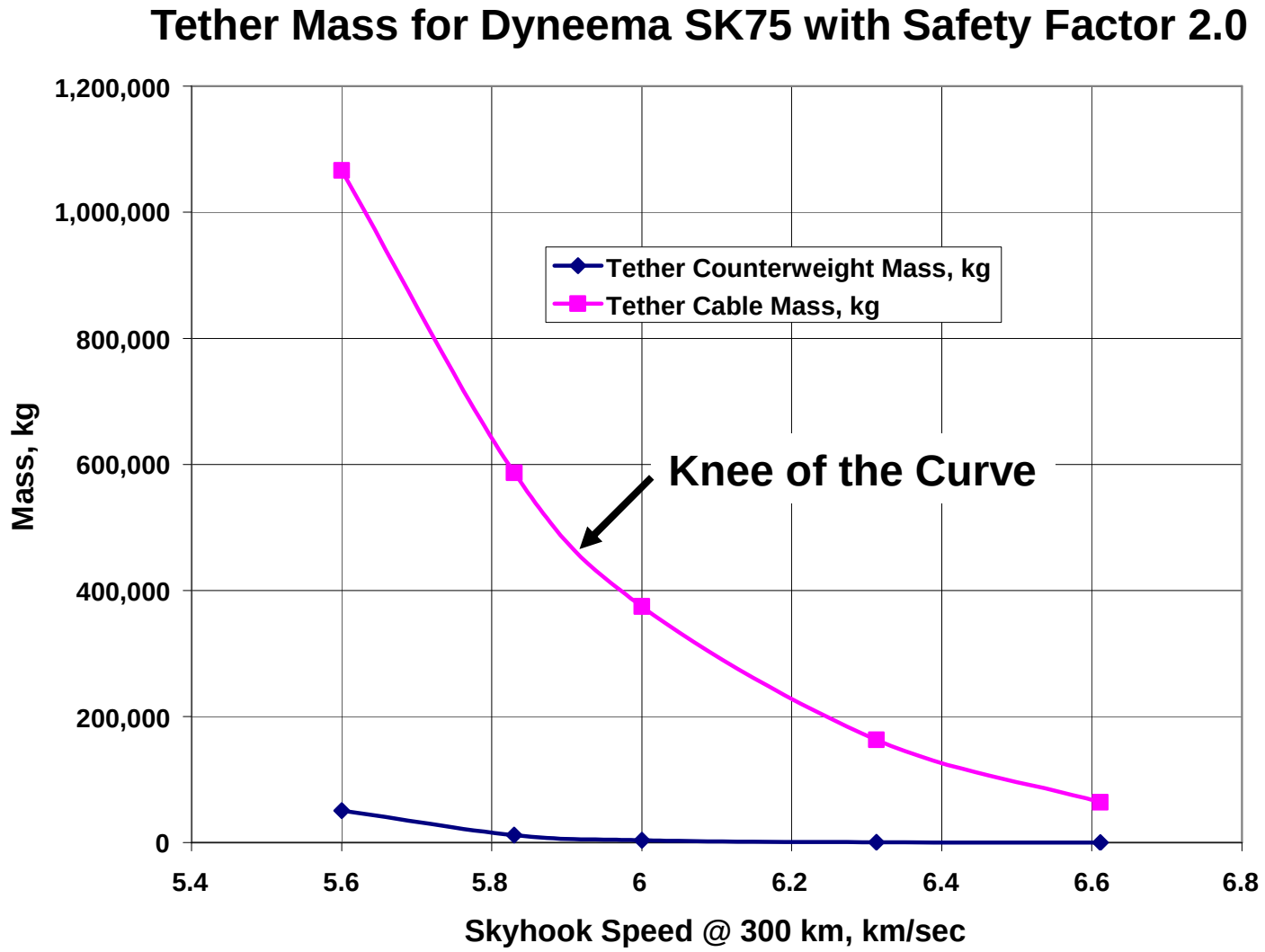
2. **Use portion of mass fraction savings to add margin and safety features**
   - **Go-around landing engines for "Orbiter"**
   - **Ejection reentry capsule for Crewed Stages**
   - **De-rated rocket engines for longer life w/o overhaul**

3. **Invest in airplane-like operations features**
   - **Adaptive GN&C**
   - **IVHM**
   - **Fail-operational Subsystems**

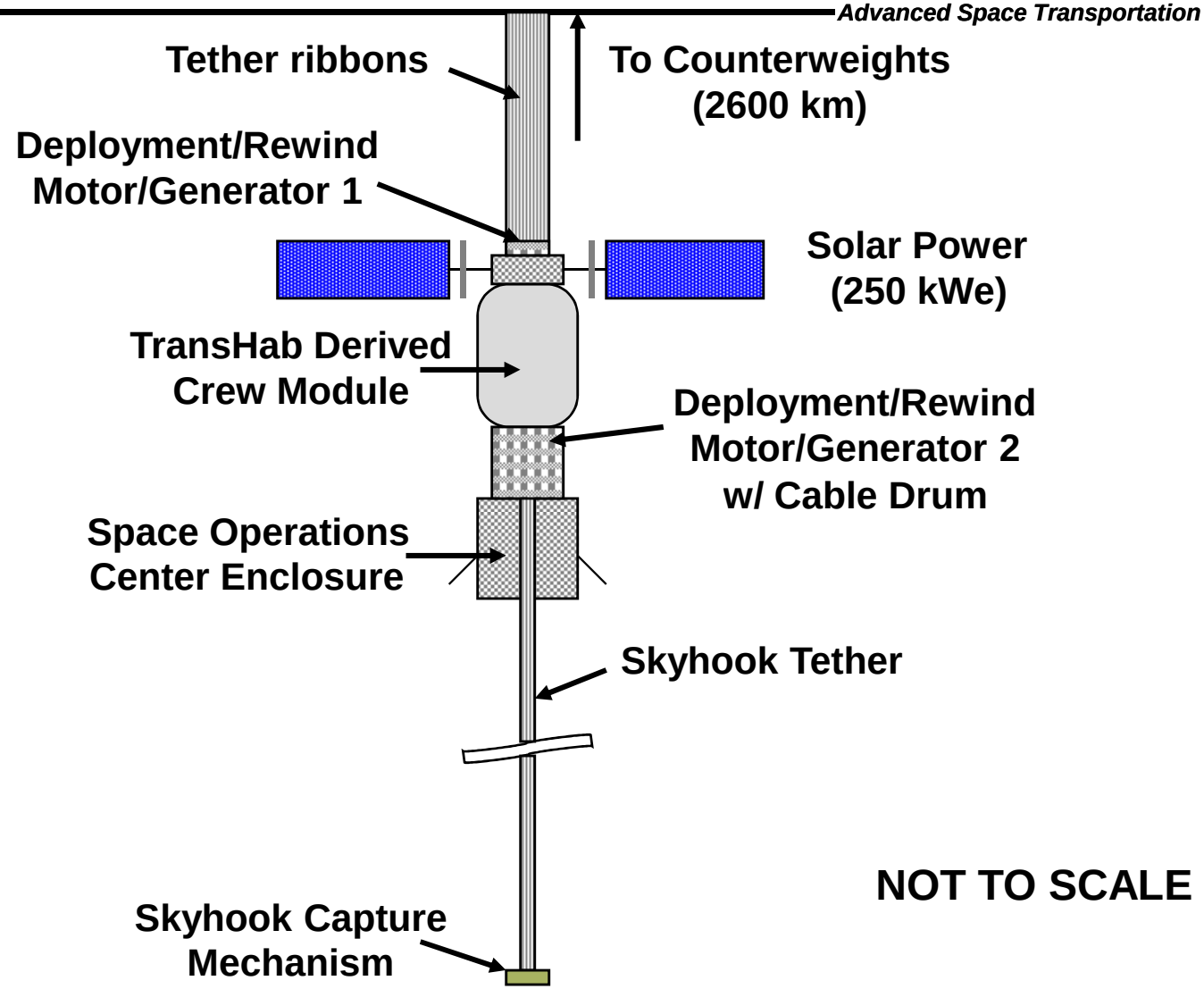
Proposed Operational Skyhook Schematic



Reduced Orbital Velocity requires more Tether Mass



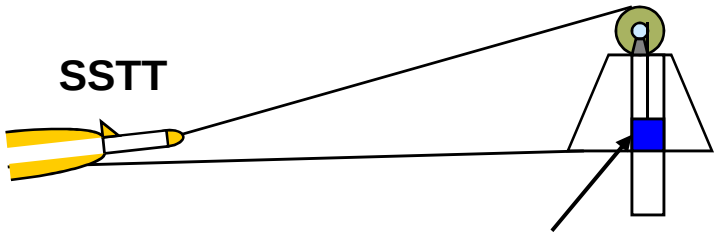
Initial SkySOC Configuration (Notional)



Cable Catapult to reduce Gravity and Aerodynamic ΔV Losses

- **Use high strength, abrasive-resistant fibers to best effect**
- **Design with low cost pumped water energy storage**
- **Mechanical advantage can be selected to provide ΔV savings as desired**
- **Advantage is low DDT&E and operating costs**

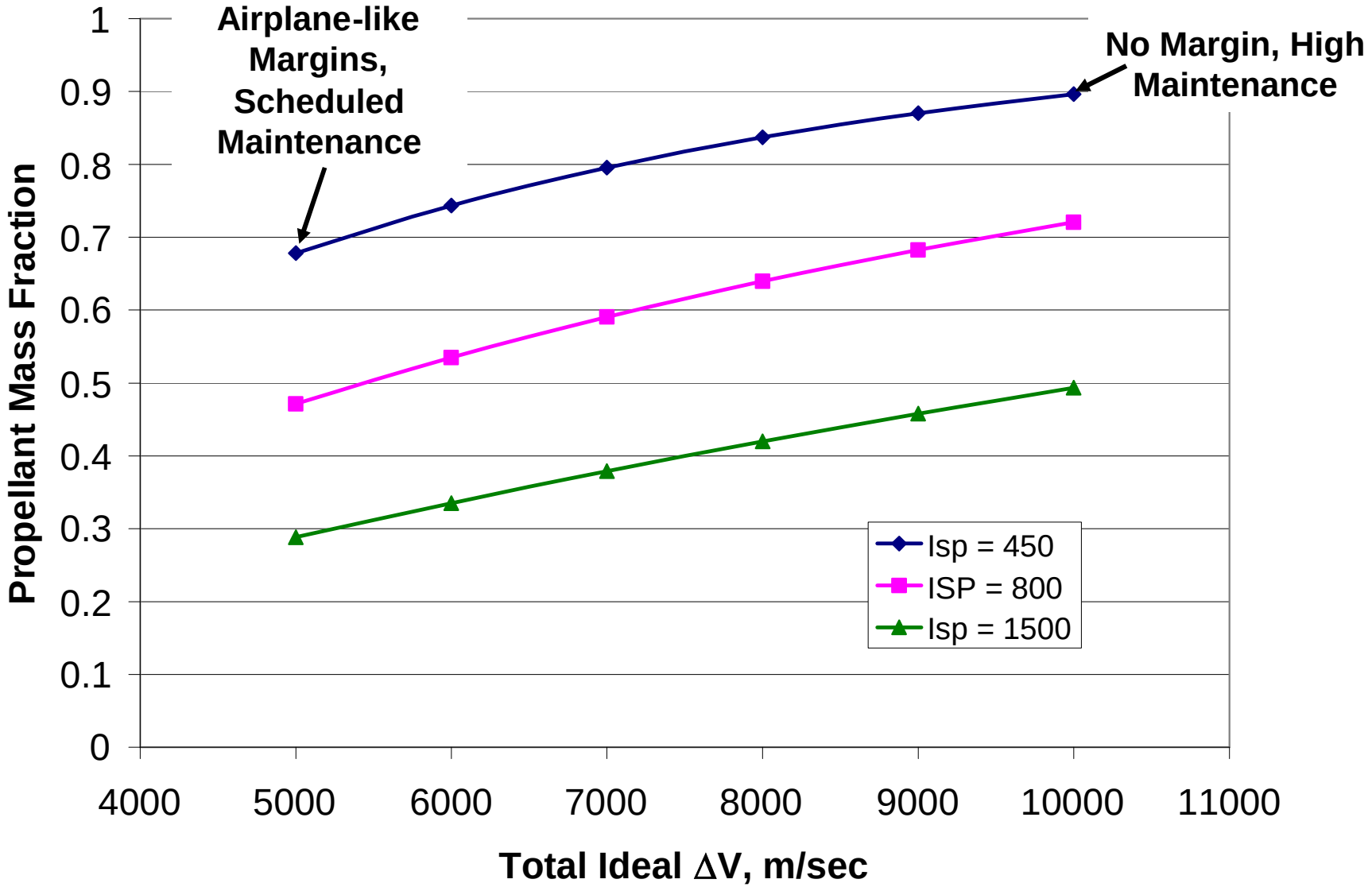
Cable Catapult
NOT TO SCALE



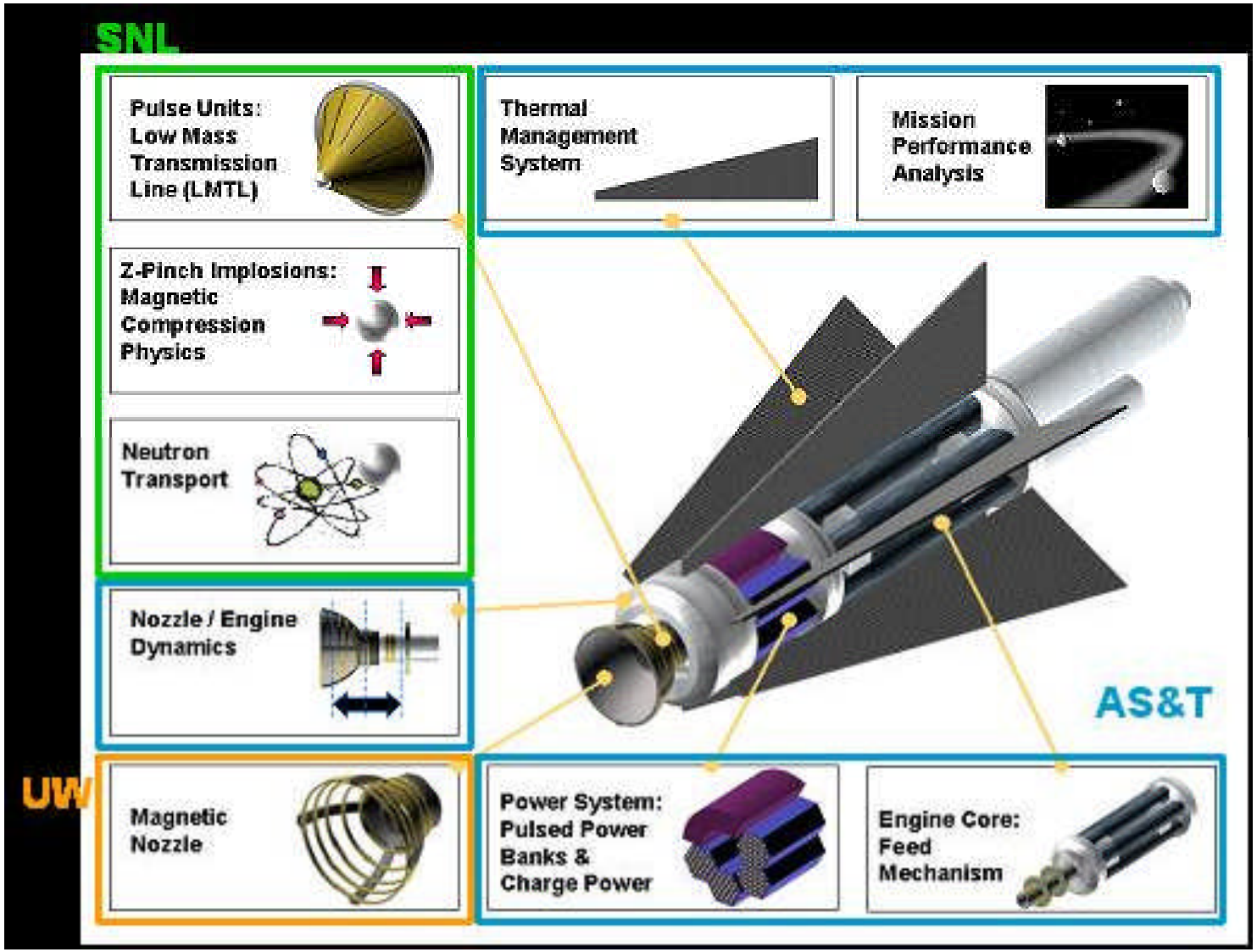
Pumped Water Energy Storage Bucket

SSTT = Single Stage to Tether

Impact of ΔV and Isp on Mass Fraction



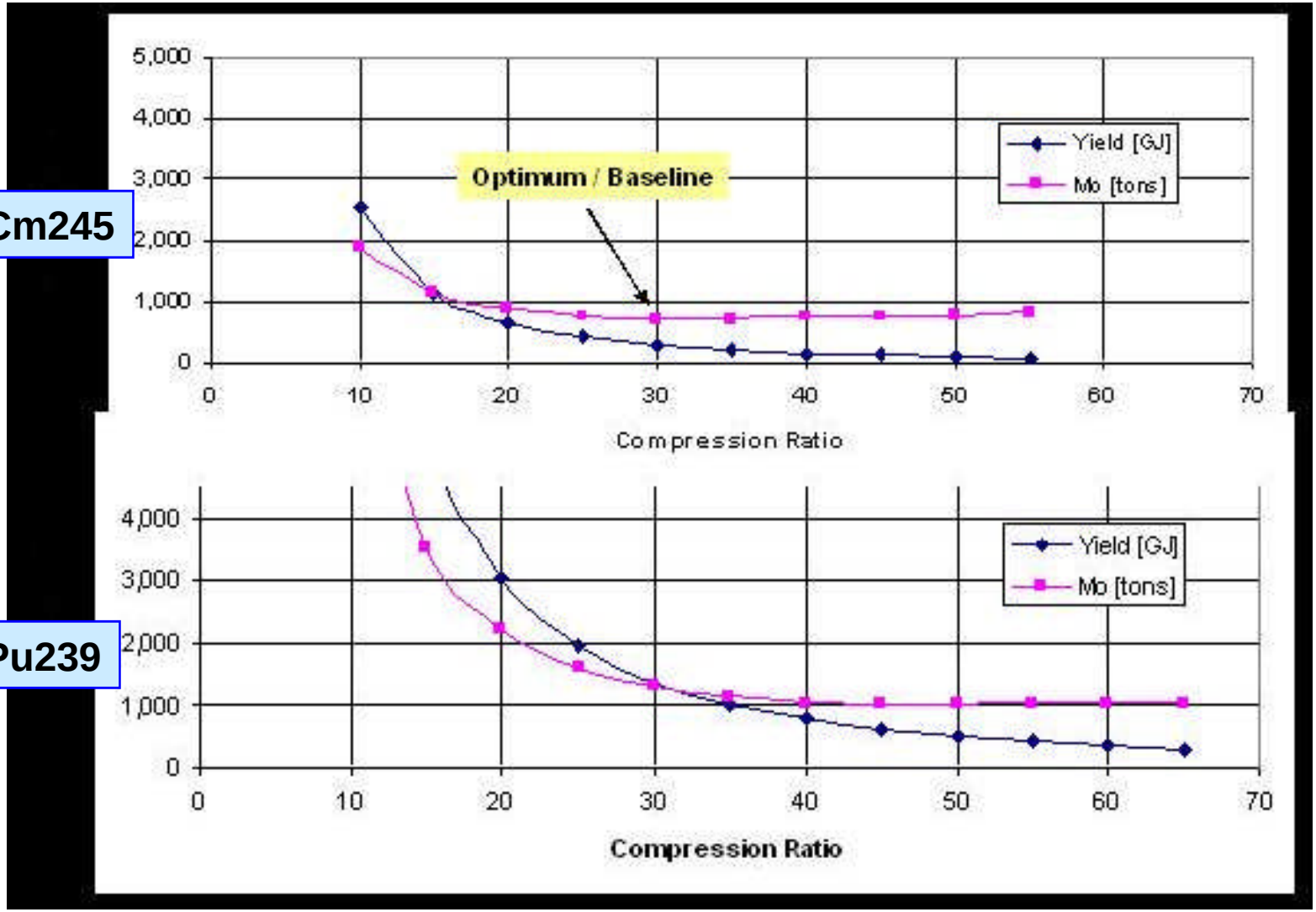
Mini-MagOrion (MMO)



Mini-MagOrion Spaceship Sizing

Sized for 100 ton payloads and 100 km/sec ΔV

Cm245



Pu239

Reducing Space Transportation Costs beyond LEO

- **ETO is only halfway to anywhere (R. A. Heinlein left that part out)**

- **Tremendous progress in electric propulsion options since 1980s**
  - **4-grid Ion Thrusters (4000 to 300,000 sec w/ various Props)**
  - **HiPEP Thruster (4000 to 6000 sec w/ long life and high η)**
  - **2-Stage Hall Thrusters (2000 to 8000 sec w/ bismuth)**
  - **VASIMR (4000 to 5000 sec w/ argon)**
  - **Various Lorentz MPD Thrusters (direct-drive & high thrust density)**

- **Powerplants have fallen behind**
  - **Best Solar PV Powerplants ~ 5-8 kg/kWe @ 200 kW**
  - **Best Solar Dynamic Powerplants ~ 2-4 kg/kWe @ 200 kW**
  - **Best NEP Powerplants ~ 8-10 kg/kWe @ 200 kWe**

New Upper Stage concepts should be examined, e.g. MMO

Future Technologies to Consider

- **Advanced Nuclear Propulsion Options – High Thrust**
  - **Orion ~ 5000 secs**
  - **Mini-Mag-Orion ~ 15,000 secs**
  - **Gas Core Nuclear Rocket ~ 6000 secs**
  - **Nuclear Light Bulb ~ 1800 secs**
  - **Fusion ~ TBD secs**

- **Interplanetary Cargo**
  - **Light Sail**
  - **MagSail**
  - **Electric Solar Wind Sail**

- **Interstellar Precursor Propulsion**
  - **Laser Light Sail**
  - **Beamed Power EP**
  - **Quench Gun Launched Smart Particles**
  - **Fusion Rocket**