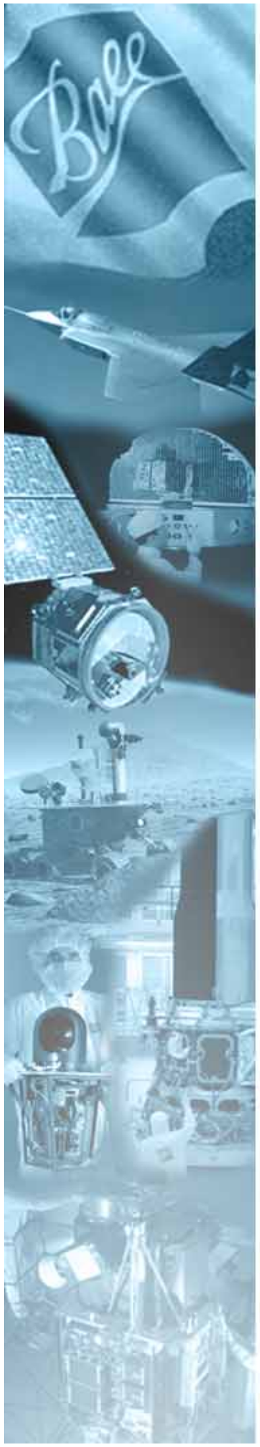


Ball Aerospace & Technologies Corp.
&
L'Garde Inc.

Rapid De-Orbit of LEO Space Vehicles Using Towed Rigidizable Inflatable Structure (TRIS) Technology: Concept and Feasibility Assessment

Dave Beckett, Bryce Carpenter

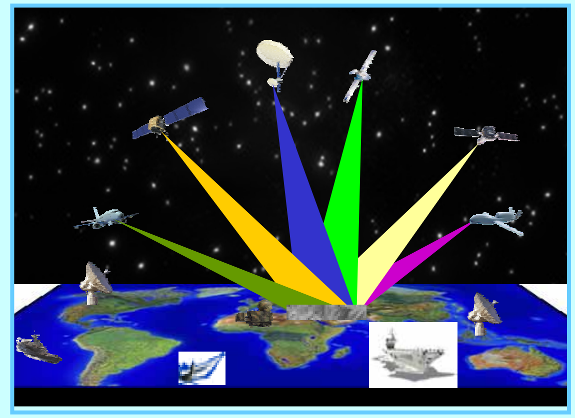
Dr. Costas Cassapakis

August 10, 2004

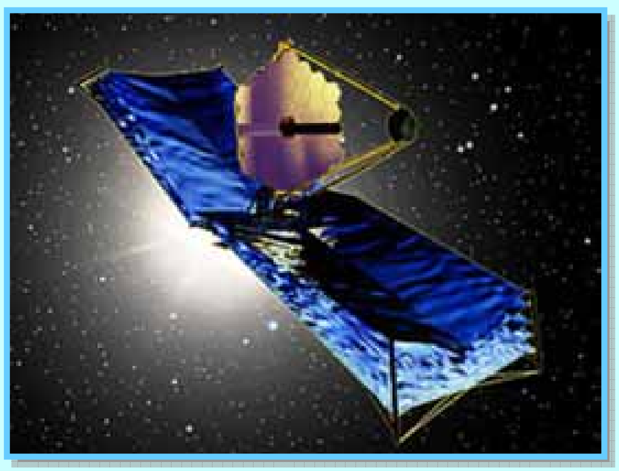
Ball Aerospace Mission Areas

Earth Science & Meteorology

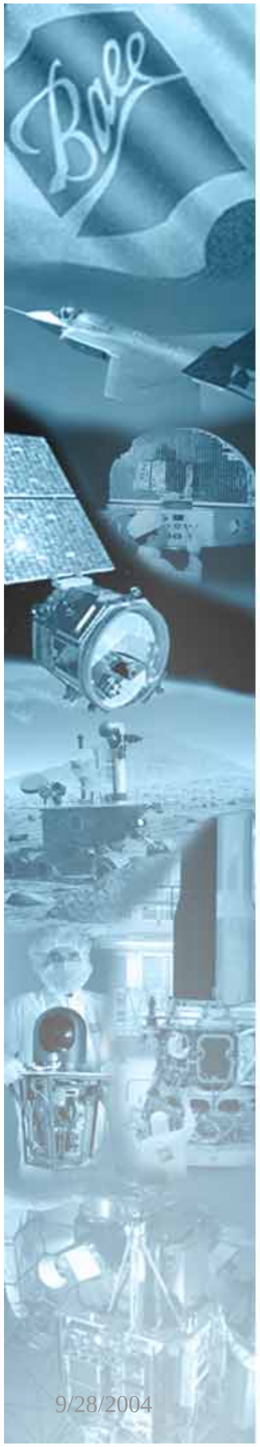
NASA and Commercial Missions



Intelligence, Surveillance, & Reconnaissance - DOD



Space Science & Exploration - NASA



Key Technical Domains

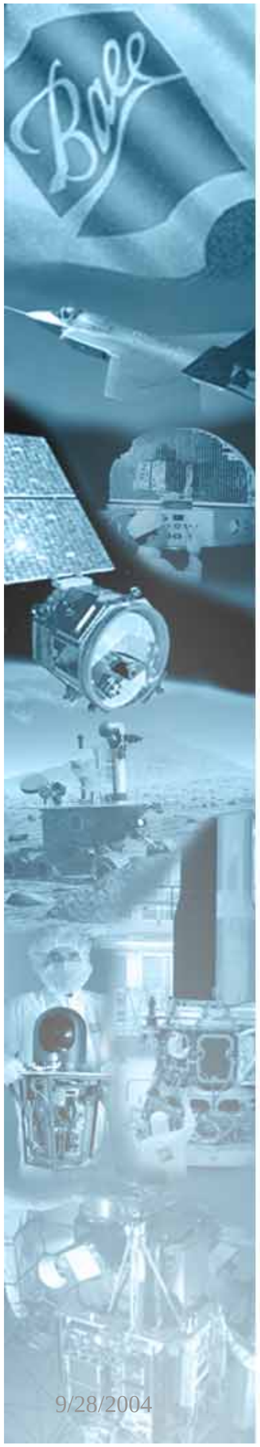
Electro-Optical Hardware and Data Exploitation Solutions

Laser and Pointing & Tracking Solutions

Microwave Payloads and Radio Frequency Technologies

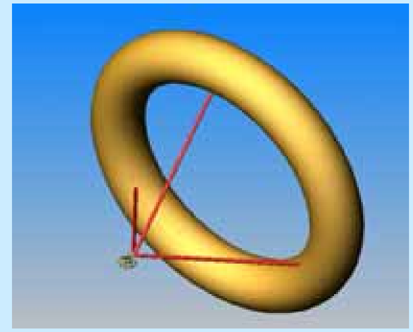
Precision, Low-cost, Spacecraft (Small to Medium Size)

Advanced Technology Solutions



History of Inflatable Structures Development

Ball and L’Garde Have a Culture that Encourages Innovation



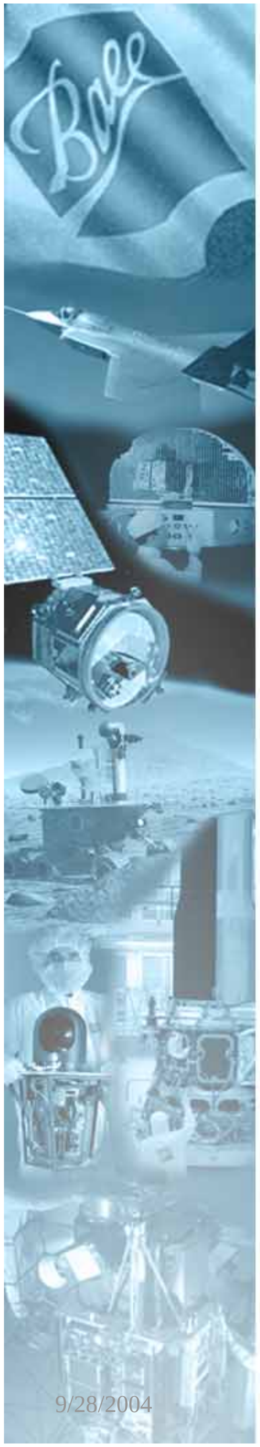
Conceptual Aerobreaking Toroid

Decoy Experiment

14 Meter NASA STS-77 Inflatable Mirror Experiment

10 Meter^2 NASA ISP Solar Sail

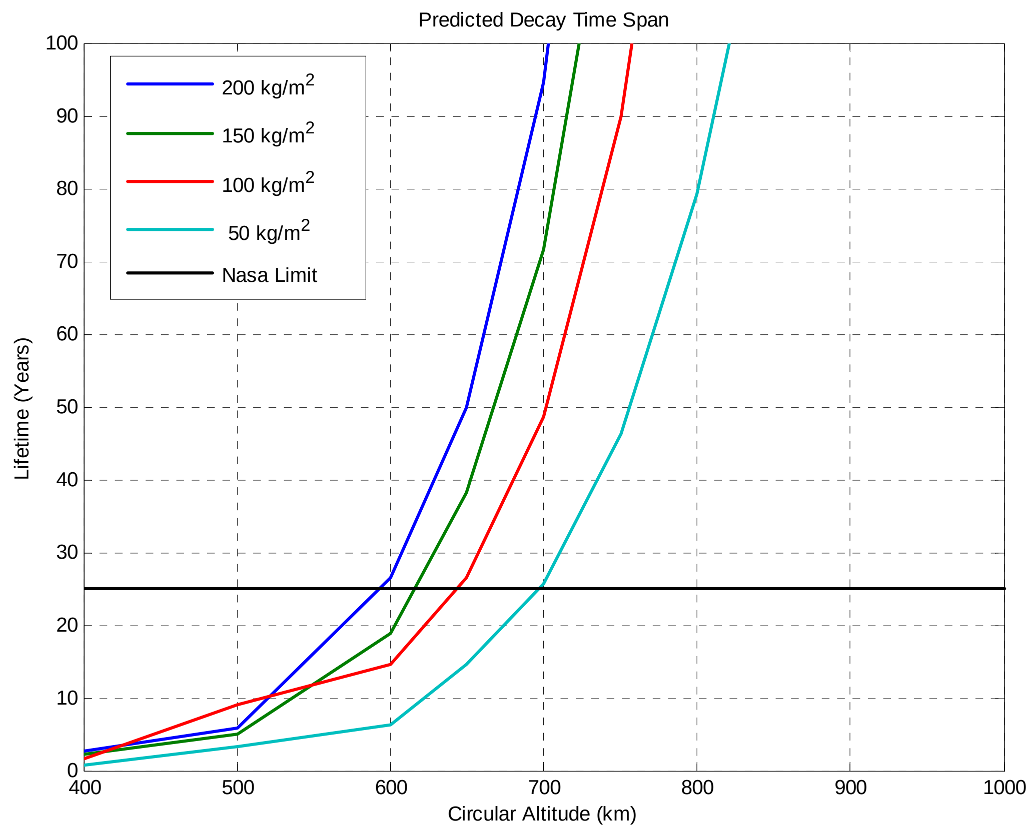
Turning Innovative Concepts into Highly Successful Scientific/Technology Missions



Motivation

- **Rapid Increase in the Amount of Orbital Debris**
- **NASA Safety Standard 1740, “Guidelines and Assessment Procedures for Limiting Orbital Debris” Disposal methods identified in guideline 6-1:**
  - **<u>Atmospheric Reentry Option:</u>**
    - **Limit the lifetime to no longer that 25 years after EOL.**
    - **The size of debris must be minimized or a controlled de-orbited must be performed in an unpopulated area**
    - **Small spacecraft will meet the debris size requirement due to their limited mass (less than ~1000 kg)**
    - **Spacecraft can use only small quantities of high melting point materials (titanium ceramics, and beryllium)**
  - **<u>Maneuvering to a storage orbit between LEO and GEO</u>**
  - **<u>Direct retrieval of the spacecraft</u> and remove if from orbit within 10 years after EOL**
- **Recent FCC order requiring geostationary spacecraft disposal plan before a license is issued**

Effect of Ballistic Coefficient on De-Orbit

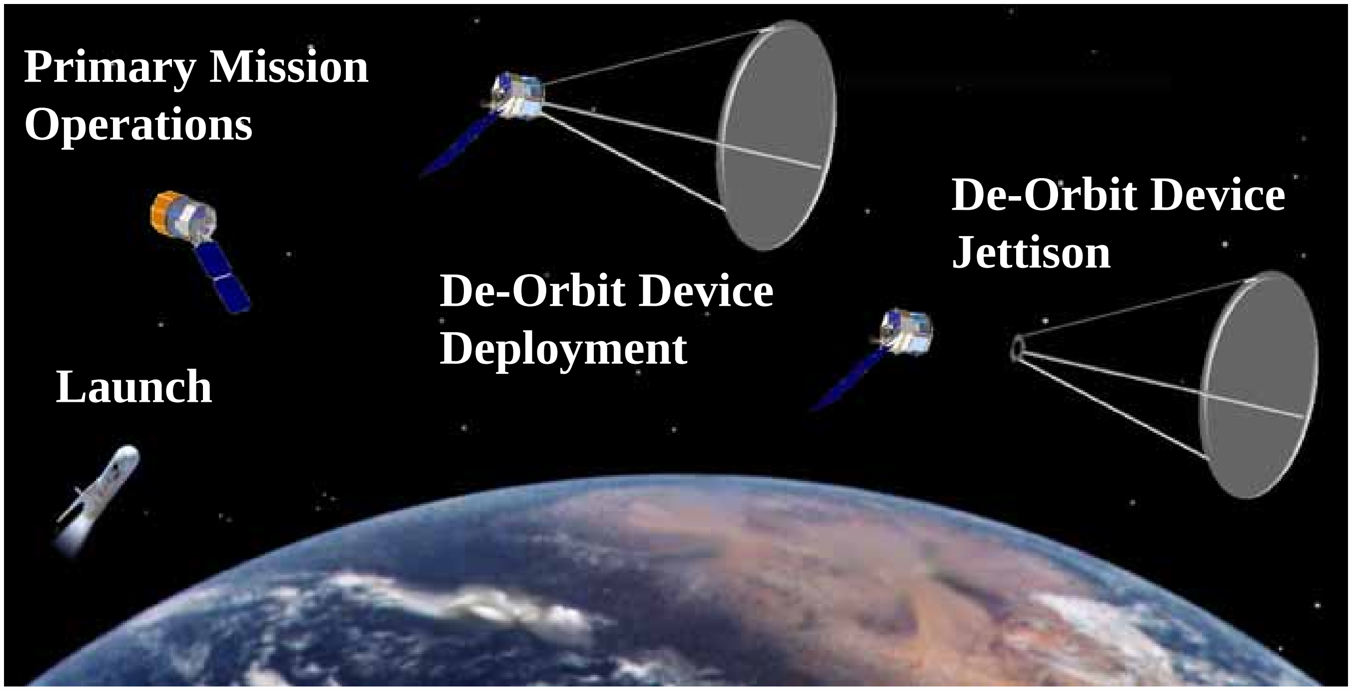


Transition Zone –

Beyond 600 - 700 km Spacecraft Cannot Rely on Natural Decay to Meet the NASA De-Orbit Requirement

Orbital Decay vs. Altitude with Respect to the Ballistic Coefficient

Concept of Operations

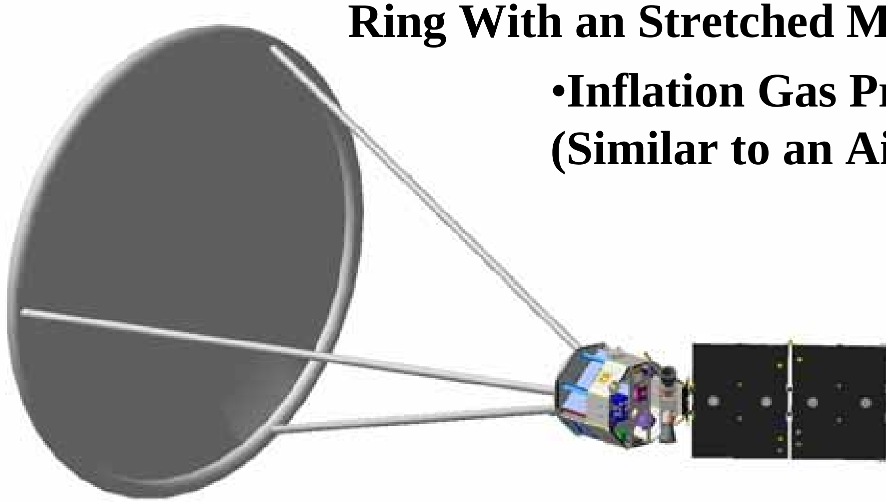


- Secondary Payload (Activated at Primary Mission EOL)
- Low Stowed Volume Until Deployed
- Can be Activated by On-board System or By Ground Command
- Capability of Precision Reentry Profile Using the TRIS Device

De-Orbit Space Vehicles Using Towed Rigidizable Inflatable Structures (TRIS)

• <u>TRIS System:</u> Gas Generator, Rigidizable Structure, Separation System, Storage Box, and Support Electronics

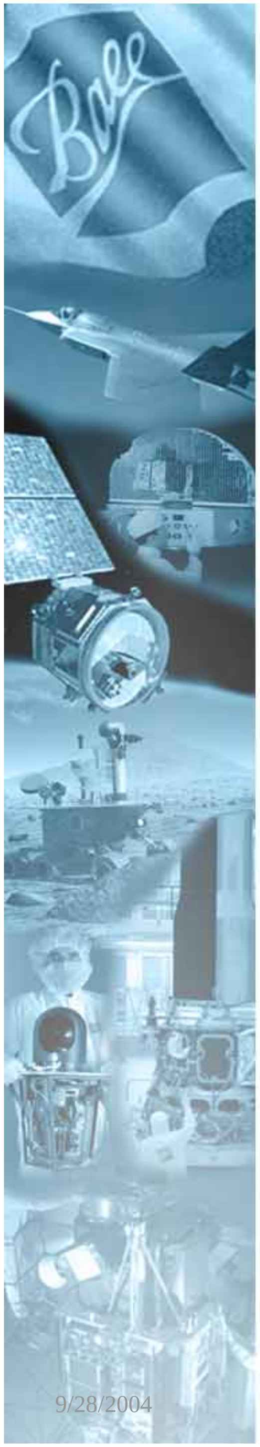
• Construction Consists of Rigidized Struts and Annular Ring With an Stretched Membrane



•Inflation Gas Provided by Solid Propellant (Similar to an Air Bag) or By Stored Gas

• Structure is Rigidized During Deployment (Metallized Polymer or Thermoset Resin)

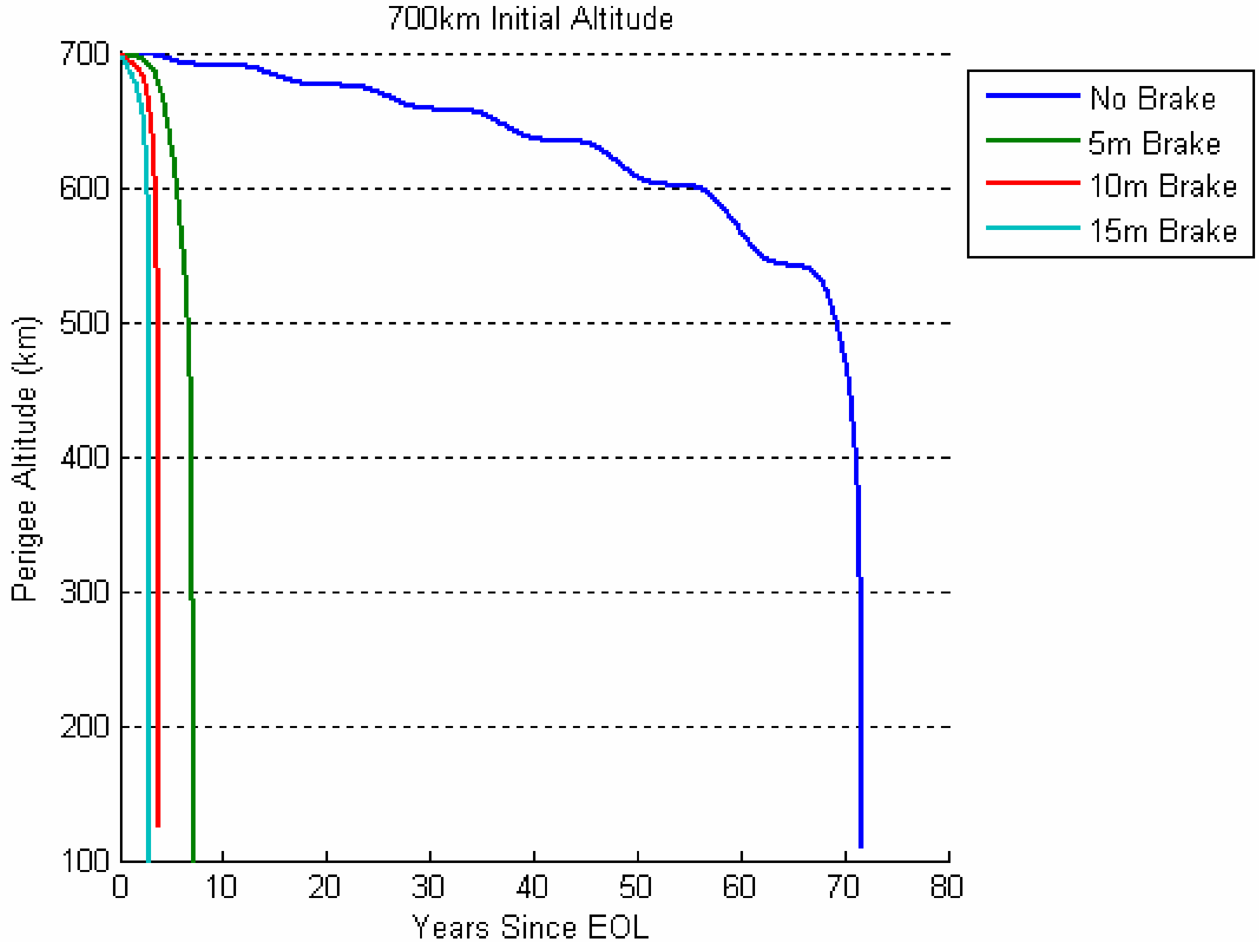
• Structure Does Not Rely on Gas Pressure to Maintain Shape After it is Rigidized (Insensitive to Micrometorites)



TRIS System - Comparison

Mass	
TRIS System	23.9 kg *
Propellant Based De-Orbit System	46 kg ** 15 kg system hardware, 31 kg propellant
	435 kg *** 110 kg system hardware, 325 kg propellant (with 240kg reserved for de-orbit)
Cost	
TRIS System	$105 K *
Propellant Based De-Orbit System	$.5 to 1.5 M**/***
Volume	
TRIS System	.024 m^3 *
Propellant Based De-Orbit System	~.47 m^3***
* 15 Meter TRIS Device	
** Values Calculated for a 300 kg Spacecraft	
*** Values Calculated for a 1200 kg Spacecraft (includes propellant margin)	

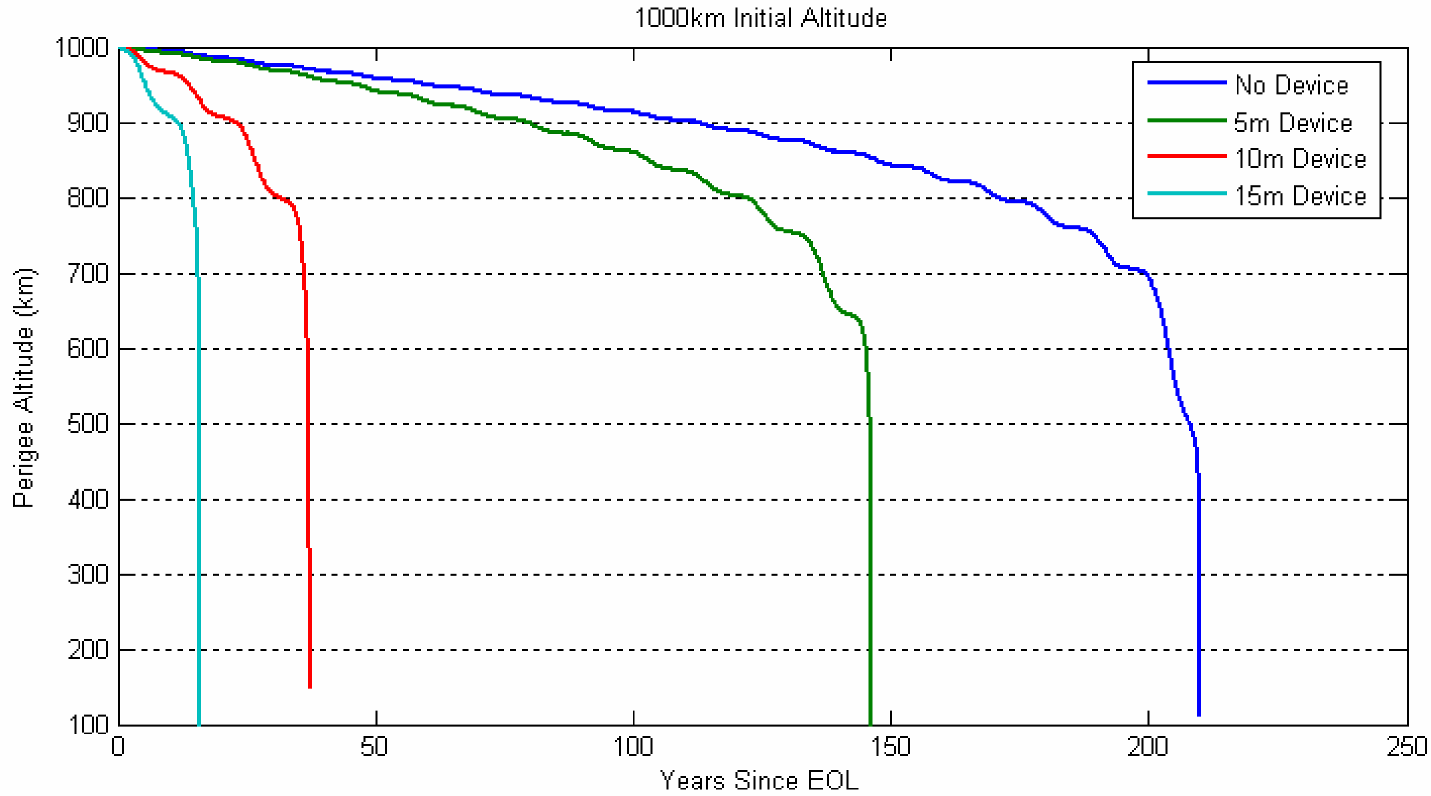
TRIS Performance (700 km)



Orbital Decay of SV With / Without TRIS Payload

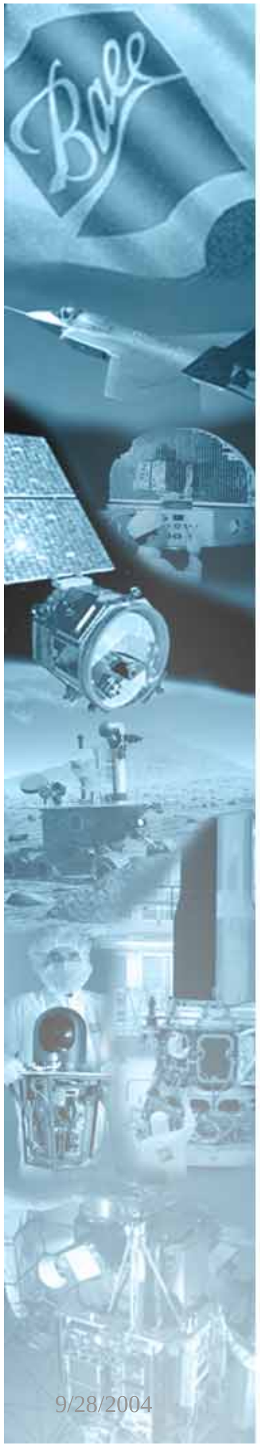
Assumptions: 300 kg SV, Ballistic Coefficient of 150 kg/m2

TRIS Performance (1000 km)



Orbital Decay of SV With / Without TRIS Payload

Assumptions: 300 kg SV, Ballistic Coefficient of 150 kg/m2



STS-77 Experiment

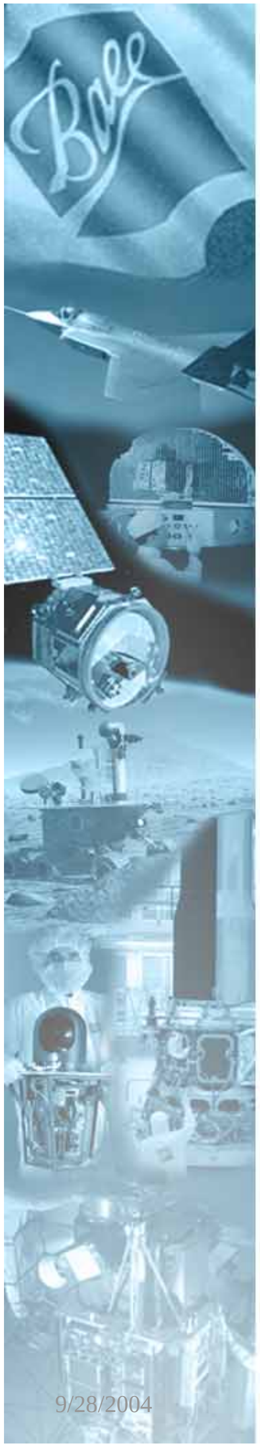
Inflation Movie

On-Orbit Operation

Risks

- Extended On-Orbit Storage Requirements
- Stability of the Spacecraft During Deployment
  - Controlled Inflation
  - Inherent Damping of the Rigidized Structure
- Spacecraft Attitude Control After Deployment

- Aerodynamic Stability in “Near” Vacuum Conditions
  - Hypersonic Wake Generation
  - Gravity Gradient
  - Solar Pressure
  - Stability Dependant Upon Size/Shape of the Device
- Increased Cost Due to Extended Mission Operations



Summary

- A TRIS System Must be Optimized for the Mission
- The TRIS System Provides Another De-orbit Choice for Small and Large Spacecraft at Altitudes Exceeding 650 km
  - Rapid de-orbit of a LEO SV without a propulsion system
  - Meets the NASA 25 year de-orbit requirement for missions between 650 km and 1000 km
- A rigidized TRIS device maintains shape after inflation without maintaining pressure
- Capability of precision reentry profile using the TRIS device
  - Release between 120-150 km
  - The impact zone can be selected to be at any location along the ground track of the last orbit
- Low Mass, Volume and Cost De-Orbit Alternative for Many LEO Missions