National Aeronautics and Space Administration

RS-34 Phoenix In-Space Propulsion System Applied to Active Debris Removal

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MSFC Advanced Concepts

RS-34 and MSFC Timeline

Early 2000's

RS-34 Assets in Storage

2009

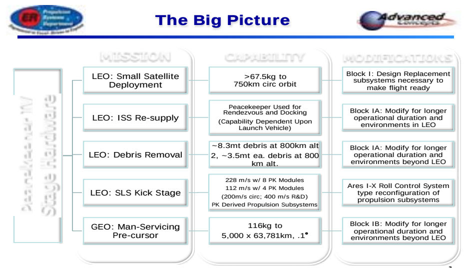
Components Re-configured for Ares I-X RoCS Control

2011

Spare hardware transferred to MSFC

2012

ACO Utilization Study & Cost Study



2013

Attitude Control Engine hot fire

Seed Funding Acquired Concept Study ACE Hot-fire

RS-34 Orbital Debris Removal Application Concept Study Objectives

- Purpose
  - Investigate the mission applications for the Peacekeeper RS-34 stage to deorbit orbital debris and non-functioning spacecraft

- Objectives
  - Identify and evaluate candidate missions
  - Perform subsystem concept design analysis and trade studies
  - Develop integrated RS-34 design concepts for the candidate missions

RS-34 Concept Study Philosophy

- This study sought to define a flight ready design of RS-34 stage for a Orbital Debris Removal Design Reference Mission
- Multiple configurations and payloads were considered for Orbital Debris Mission Capture.
  - Capture Mechanisms were selected to bound a payload envelope and are not intended to be a recommendation
- Key Trades and Analyses
  - Prop Load
  - Heritage structure vs. New Structure
  - Heritage RCS vs. New RCS
- A Flight Ready RS-34 was designed to utilize heritage hardware to the extent possible and add new, low-cost subsystems where necessary

Study Tasks

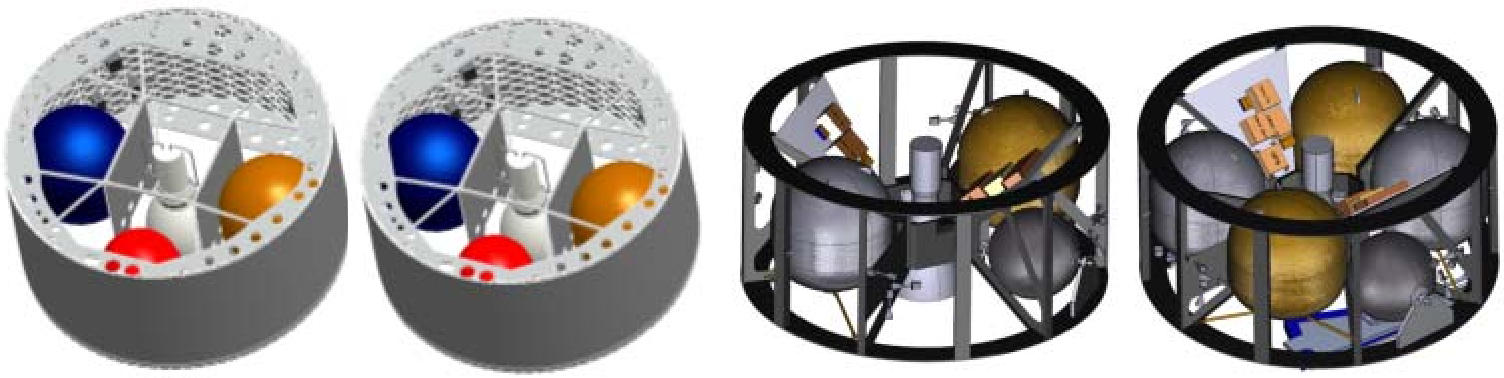
- Stage Configuration Definition
- Mission Payload Definition
- Subsystem Design Analysis and Mass Estimation
  - Structures
  - Propulsion
  - Avionics
  - Power
  - Thermal
- Subsystem Integration and Mass Summaries
- Target Definition
- Stage Mission & Performance Analysis

Study Participants

Role	Name	Organization
Study Lead	Mulqueen, Jack	MSFC / ED04
Systems Analysis	Esther, Elizabeth	MSFC / ED04
Systems Analysis	Wiegmann, Bruce	MSFC / ED04
Mission Analysis	Kos, Larry	MSFC / ED04
Mission Analysis and Propulsion	Thomas, Dan	MSFC / ED04
Mission Analysis	Russell, Tiffany	MSFC / ED04
GR&A and Mass Summary	Maples, Dauphne	MSFC / ED04
Design & Configuration	Fincher, Sharon	MSFC / ED04
Design & Configuration	Baysinger, Mike	MSFC / ED04
Structures	Purlee, Eric	MSFC / ES22
Structures	Garcia, Jay	MSFC / ED04
Propulsion	Burnside, Christopher	MSFC / ER23
Power	Fabisinski, Leo	MSFC / ED04
Avionics	Capizzo, Pete	MSFC / ED04
Avionics	Flowers, Tammy	MSFC / ES42
Thermal	Hornsby, Linda	MSFC / ED04
Thermal	Schnell, Andrew	MSFC / ER24
Cost Analysis	McCaulley, Stanley	MSFC / CS50
Cost Analysis	Hill, Spencer	MSFC / CS50

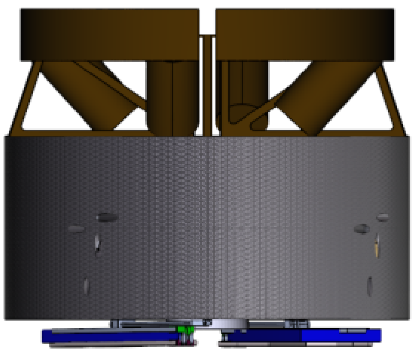
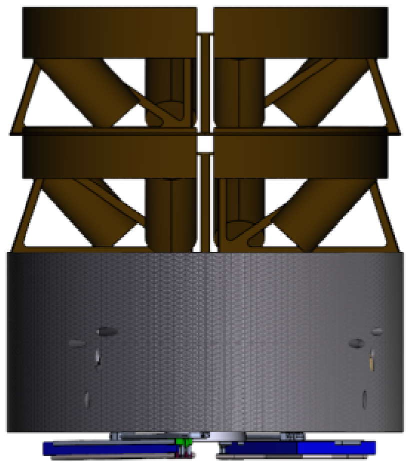
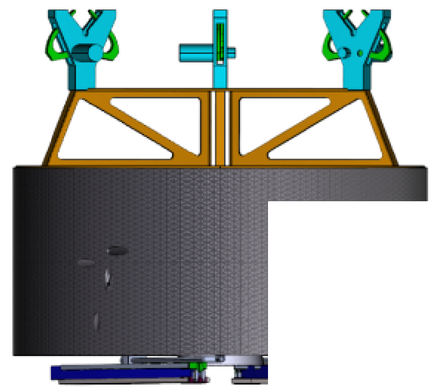
Configuration Definiton

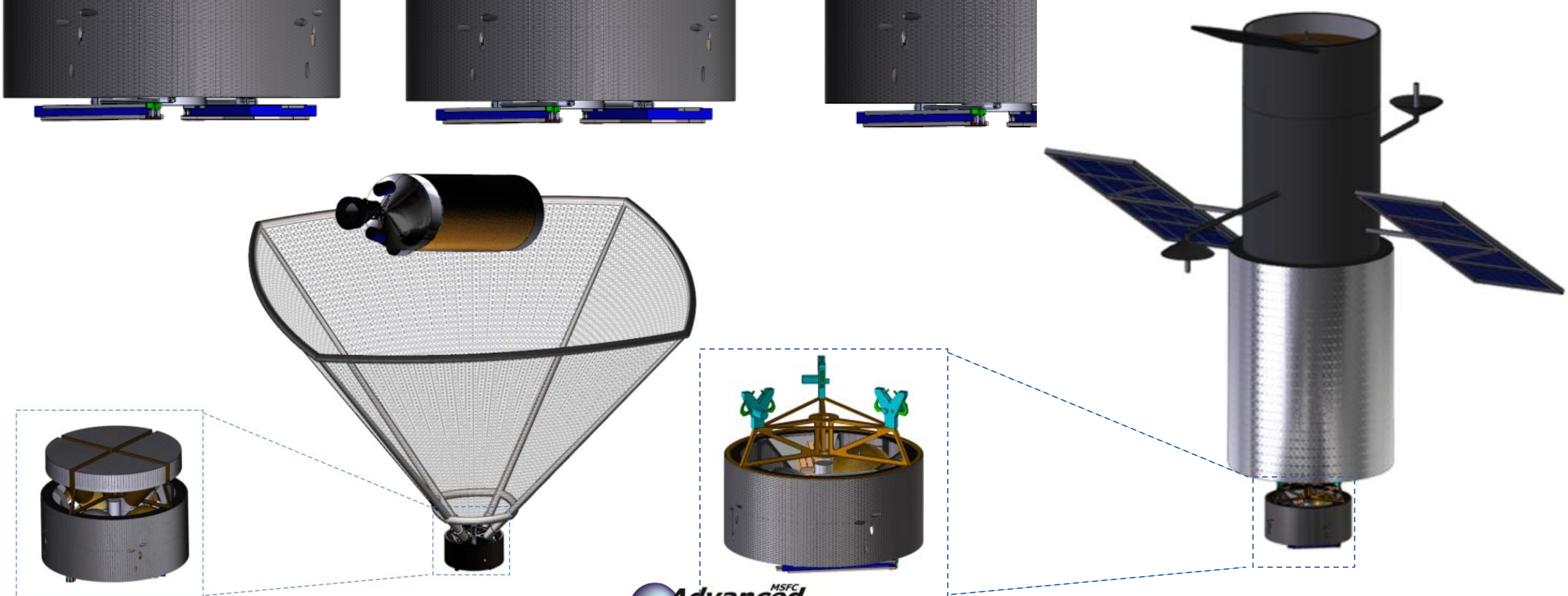
- Upon Decommissioning of the Peacekeeper ICBM, the guidance package was removed as part of an activity to remove all mission specific hardware.
- A Flight Ready RS-34 was designed to utilize heritage hardware to the extent possible and add new, low-cost subsystems where necessary



System	Stock Tanks	Extended Tanks	Derived 1 Tank Sets	Derived 2 Tank Sets
Main Propulsion	Heritage	Heritage	Modified	Modified
RCS	New	New	New	New
Structures	Heritage	Heritage	New	New
Avionics	Replace	Replace	Replace	Replace
Power	Replace	Replace	Replace	Replace
Prop Storage Assy	Heritage	Modified	Heritage	Heritage

Payloads Definition

One Object Capture Mechanism	Two Object Capture Mechanisms	Hubble Space Telescope Docking Mechanism
		



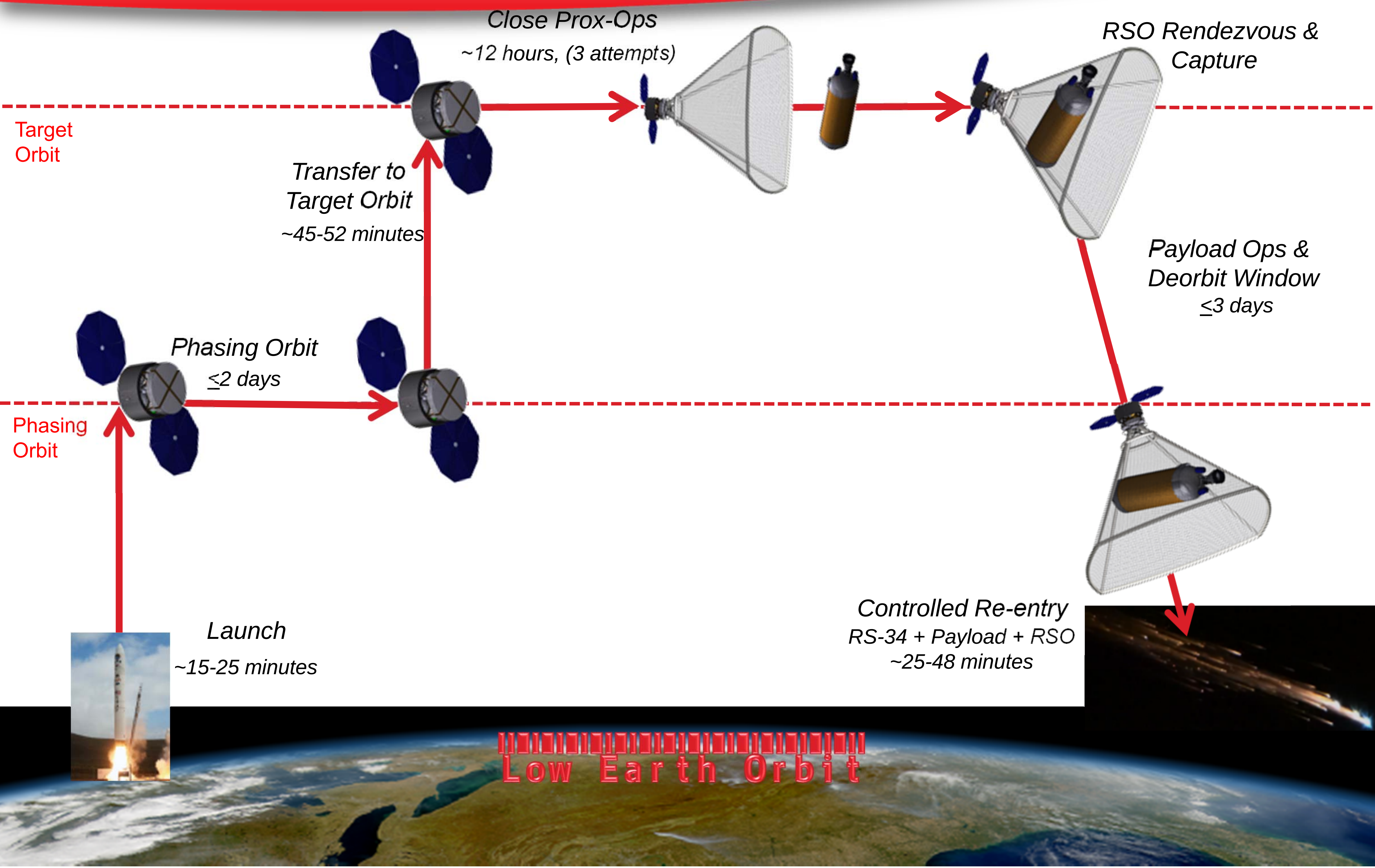
MSFC Advanced Concepts

Potential Targets

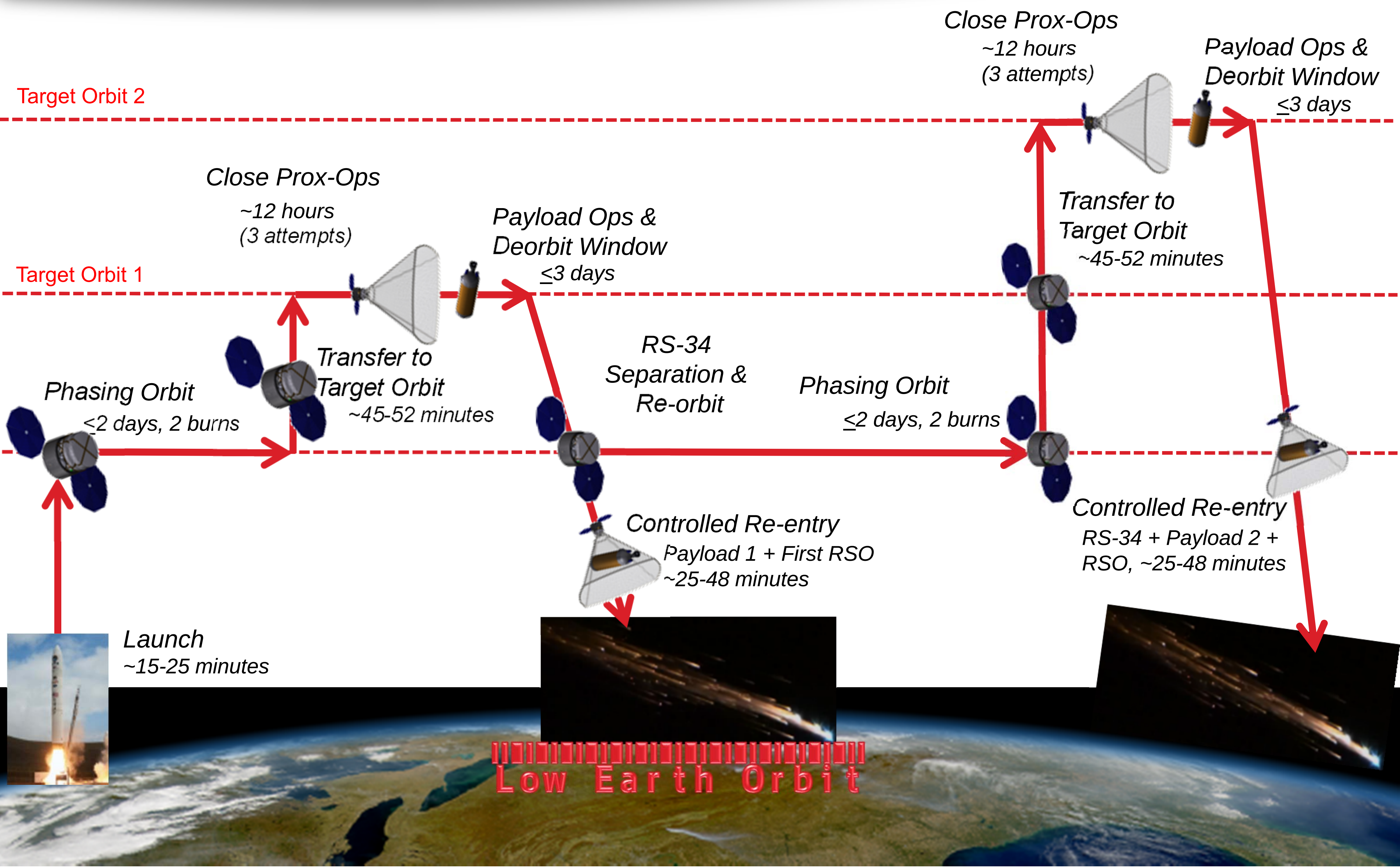
- Potential Resident Space Object (RSO) targets were identified for preliminary analysis

RSO Targets	NORAD ID	Owner	Inclination (deg)	Perigee Altitude (km)	Apogee Altitude (km)	Estimated Mass (kg)
Atlas V Centaur R/B	3598	U.S.	35	681	753	2631
Atlas V Centaur R/B	6155	U.S.	35	638	694	2631
OAO-1	2142	U.S.	35	775	785	1769
OAO-2	3597	U.S.	35	738	746	2150
HST	20580	U.S.	28.5	586	610	11,600
EnviSat	27386	ESA	98.6	785	791	8000

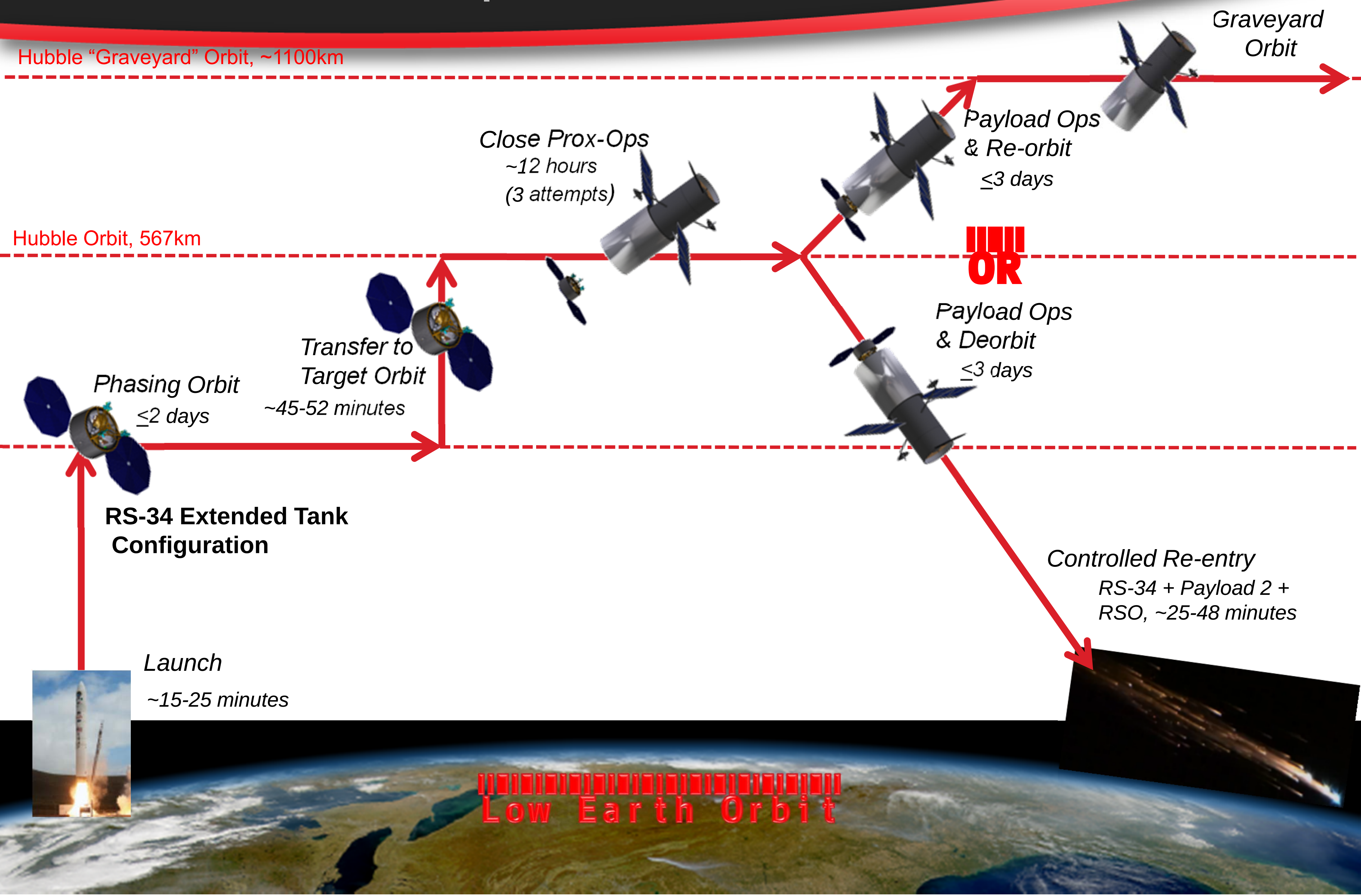
Mission Profile
Single RSO De-orbit



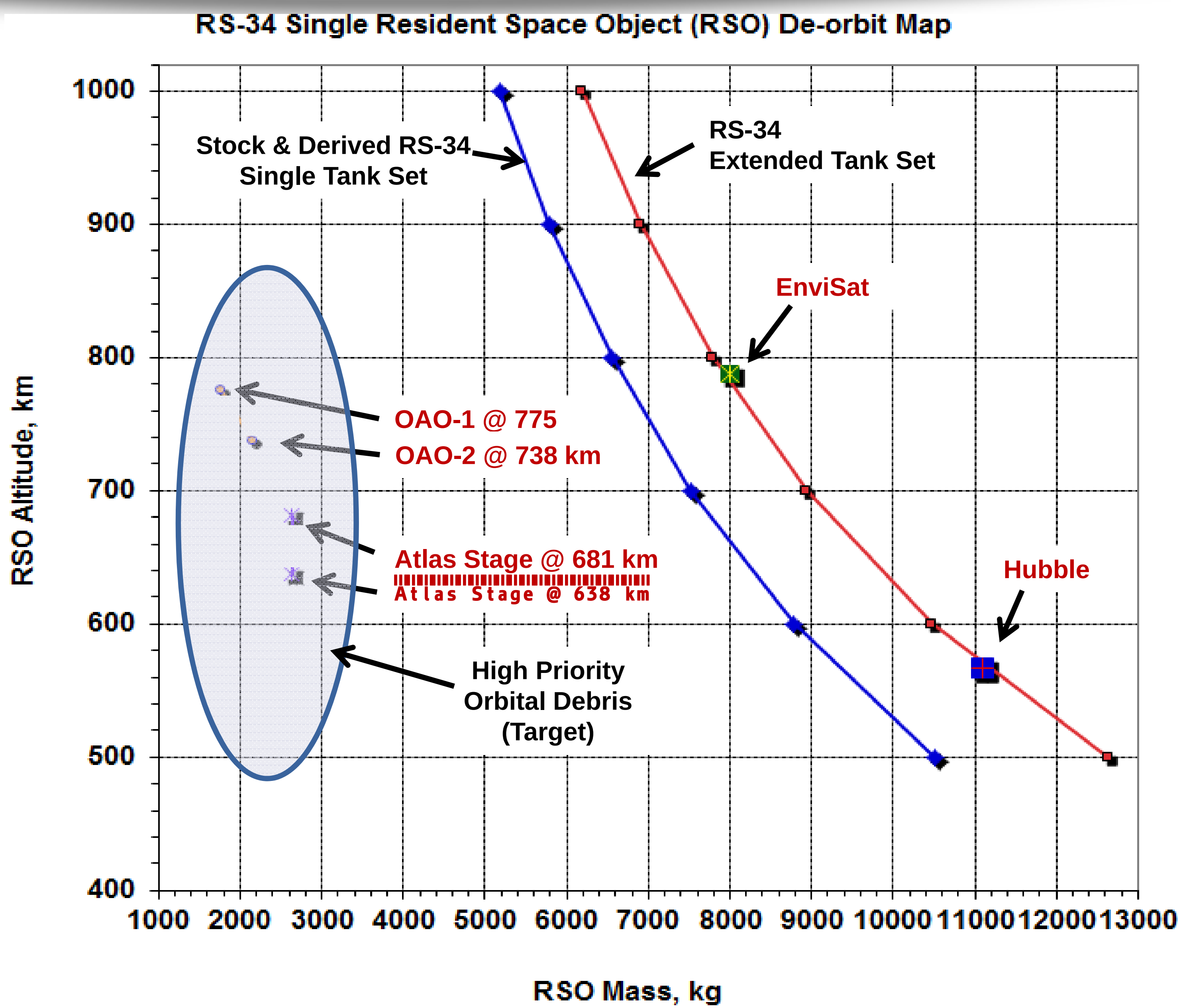
Mission Profile
Double RSO De-orbit



Mission Profile Hubble Disposal

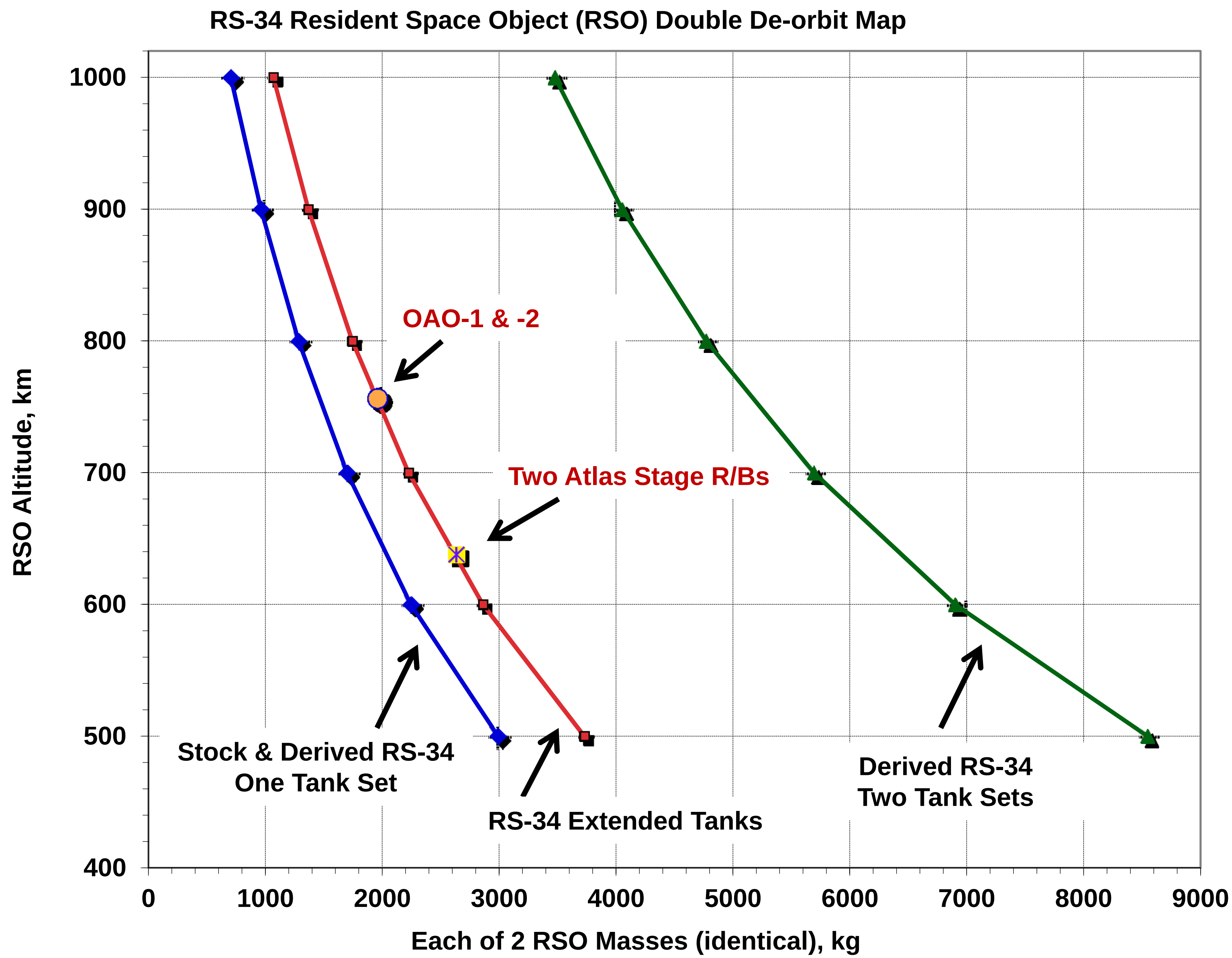


Performance
Single RSO De-orbit



RSO	RSO Circ. Alt., km	RSO Mass, kg
Atlas R/B	681	2631
Atlas R/B	638	2631
OAO-1	775	1769
OAO-2	738	2150
Hubble	567	11,100
Envisat	788	8000

Performance
Double RSO De-orbit



RSO	RSO Circ. Alt., km	RSO Mass, kg
Two Atlas R/Bs	638 and 681	Both @ 2631
OAO-1 & OAO-2	775 and 738	1769 and 2150

Conclusion

- This study sought to define a flight ready design of RS-34 stage for a Orbital Debris Removal Design Reference Mission
- Multiple configurations and payloads were considered for Orbital Debris Mission Capture.
  - Capture Mechanisms were selected to bound a payload envelope and are not intended to be a recommendation
- Objectives Met
  - concept design analysis and trade studies complete for key trades
    - Prop Load
    - Heritage structure vs. New Structure
    - Heritage RCS vs. New RCS
  - Capture of Active Debris Removal for large RSO's including Envisat and Hubble

BACK UP

Avionics
Key Assumptions

C&DH

- A new C&DH system will be integrated into existing systems
- All proximity and capture operations will be performed by the payload
- The payload will perform its own data collection, storage, and processing

Communication

- A minimum NEN downlink capability will be provided by the RS34 bus
  - assume160 kbps for a DART like mission
- For higher data rates, like video, a payload comm. system will be required

GN&C

- All attitude control will be accomplished using the RS34 RCS system
- The RS34 bus will provide navigation to within 1 km of the target
  - The payload will take over control for AR&C operations
- 500 arcsec (0.14 deg) pointing accuracy assumed for AR&C operations:
  - was expected to accommodate AR&C operations in Deploytech study

Power
Key Assumptions and Methodology

- Power supplied to spacecraft bus in addition to a single, 28V 20A circuit to the spacecraft payload. Payload is responsible for secondary distribution
- Single power system designed for all 12 configurations.
- UltraFlex Solar Arrays selected - may be stowed beside engine bell. Arrays capable of withstanding 2.5 g propulsive acceleration while deployed. Li-Ion secondary batteries used for energy storage
- Power electronics are integrated into the avionics package – 3 power boards added to Integrated Avionics Unit enclosure

Avionics Payload

Assumptions and Approach

- The payload will perform all its own data processing, storage, and control.
  - If downlink requirements exceed RS34, a dedicated comm system will be used
- The payload will command all proximity and capture navigation to the target
- Pyrotechnic systems are used for releasing RSO and capture mechanism and are located on the RS34 bus, but payloads must account for separation mechanisms mass.
  - HST uses an electromagnetic capture and release mechanism
- All payload de-orbit systems contain an independent GNC/Payload controller, data recorder, and an X-band communication system.
  - For 2 RSO disposals, a second set of capture mechanisms is included (Booms, nets, hinges, reels lidar, and cameras)
  - For HST disposal, the NASA standard 3-point docking mechanism is used
- Data storage is provided for only one RSO disposal operation.
  - Its expected that a 2nd RSO disposal operation will over write data if required
- The payload controller is assumed to include required load switching and power distribution for the AR&C mechanisms.

Thermal
Approach and Tools

- Thermal Desktop® model of spacecraft bus developed to assess bus structure interface temperatures
- Environments analyzed for a representative altitude, orientation, and beta angle
- Structure modeled as aluminum, heat dissipated via radiation & conduction, no aero-thermal heating considered
- White paint assumed for outer surfaces
- An MLI e* = 0.004 was assumed
- Subsystems equipment heat loads are imposed directly on avionics shelf
- Propellant tank thermal control is achieved with MLI and heaters
- Payload components, cameras, RCS thrusters, antennas, solar arrays & mechanisms are not part of Pre-Phase A analysis

Structures Assumptions

<u>General</u>

- The stock RS-34 stage primary structure with standard or extended tank sets is assumed to meet all structural requirements without modification
- The RS-34 derived configuration with 2 tank sets was selected as the analysis configuration
- Aluminum 2219 was selected for fabrication of all primary structure parts

<u>Analysis Assumptions</u>

- Factors-of-Safety are based on NASA-STD-5001A
  - Ultimate Factor of Safety: 1.4
  - Yield Factor of Safety: 1.25
- Minimum natural frequency is 35Hz
- The design load condition is assumed to be Athena II launch load
  - Launch loads are +5g axial and +/-2g lateral
  - A flight load factor of 1.25 was applied to the launch loads to account for aerodynamic and dynamic loads during ascent.

Mission Analysis Key Assumptions

Mission Event	Description	Other Comments
Launch and Phasing Orbit	Launch Vehicle delivers stage and capture mechanism(s) to intermediate phasing orbit with lower altitude than the target. The maximum allowed phasing covers 360° in 2 days.	Error of +/- 8 hours to catch up with target
Transfer to Target Orbit	Two-maneuver Hohmann transfer between phasing orbit and target orbit.	First maneuver: "orbit targeting maneuver" Second maneuver: "orbit rendezvous maneuver"
Close Proximity Operations	Stage will close distance to and dock with (or capture) target. Total ΔV = 25 m/s (up to 3 attempts) will be performed by ACS.	
Pre-capture Spin-up	Prior to docking (or capture), ACS will be used to match target rotation.	
Post-capture Spin-down	After docking (or capture), ACS will remove the rotation of the combined stage and target.	
Controlled Deorbit	The stage RS-34 engine will perform a controlled re-entry burn. The maneuver targets a flight path angle of -1.2° at an altitude of 60 km.	Hubble may be moved to a "graveyard" orbit

For the case of 2 targets, immediately following first deorbit maneuver, RS-34 stage will perform a single re-orbit burn that places the stage into the phasing orbit for the next target. Then, the process repeats.