SPACE GENERATION ADVISORY COUNCIL

IN SUPPORT OF THE UNITED NATIONS PROGRAMME ON SPACE APPLICATIONS

DESIGN AND EVALUATION OF AN ACTIVE SPACE DEBRIS REMOVAL MISSION USING CHEMICAL PROPULSION AND ELECTRODYNAMIC TETHERS

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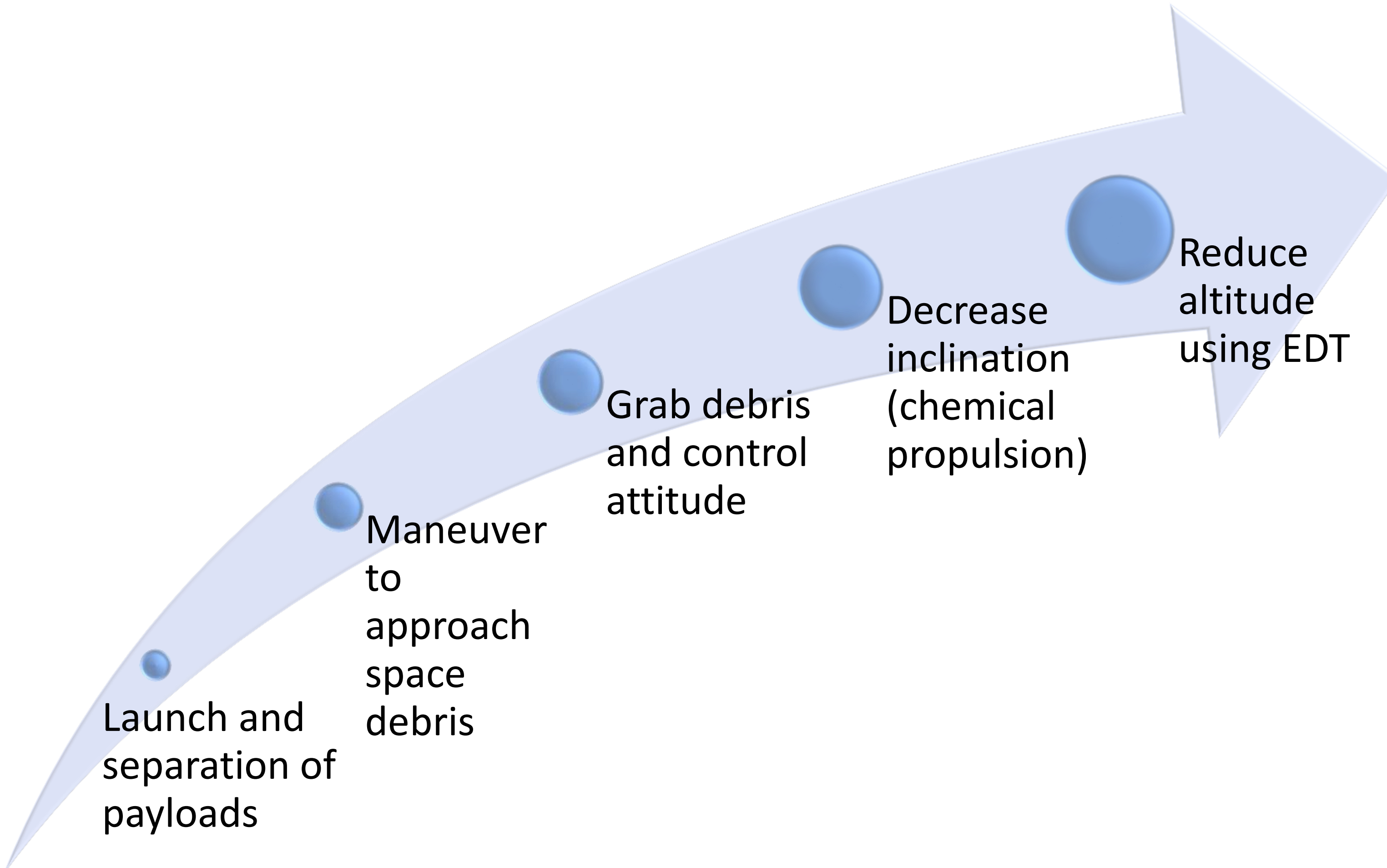
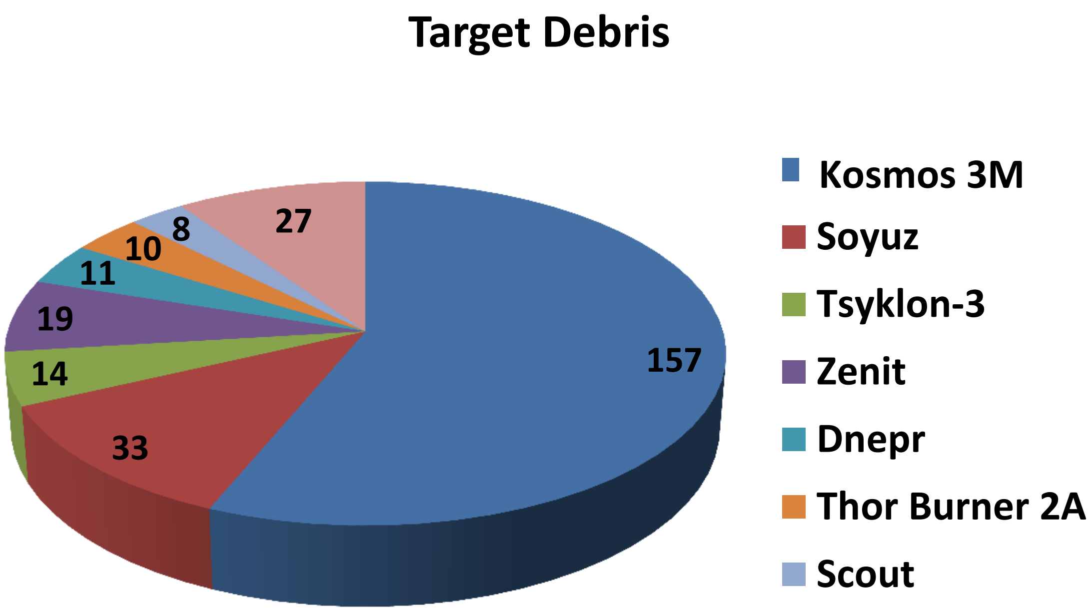
Introduction

- Space Debris: Critical Level LEO
- Kessler Effect
- Idea: Integrate de-orbiting system with an upper stage
- Each upper stage will de-orbit itself and space debris
- We can use upper stage subsystems during the mission, reducing mission costs.

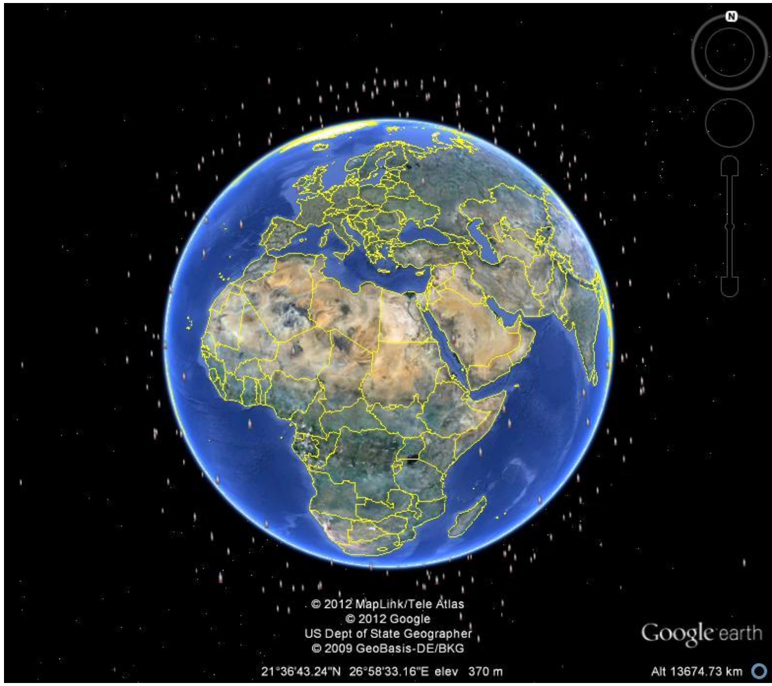
Introduction: Flight Phases



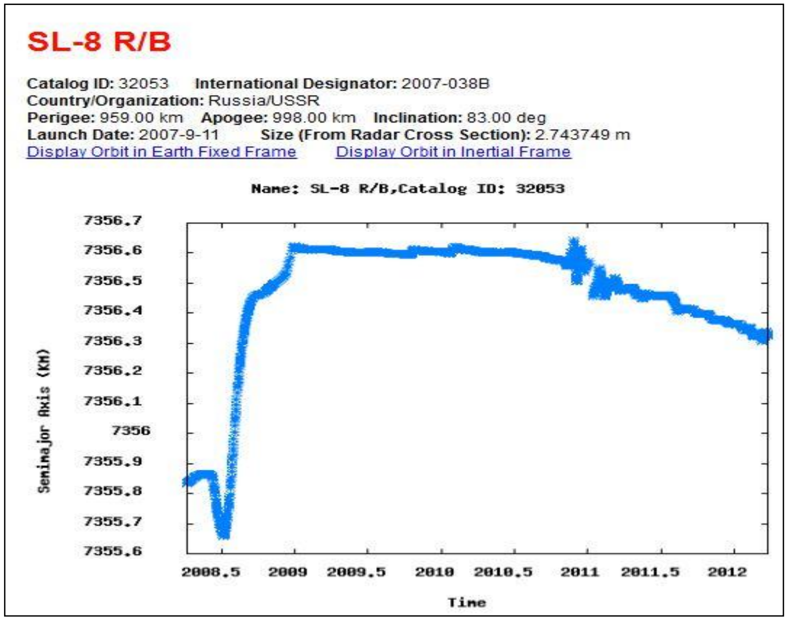
Target Debris Identification



- Low earth orbit.
- Selected body: Kosmos 3M



Target Debris Identification



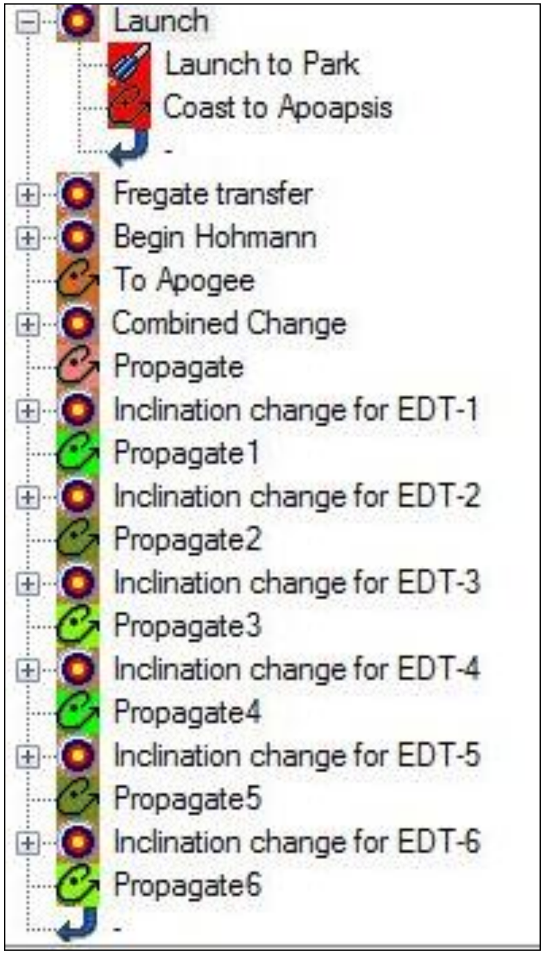
Mean Motion (deg/s)	0.0573292
Eccentricity	0.002639
Inclination (deg)	82.976
Argument of Perigee (deg)	151.655
RAAN (deg)	233.421
Mean Anomaly (deg)	208.605

Launch Vehicle and Launch Site

- Analyzed all launch vehicles with
  - Upper stage restartability
  - Large payload mass for SSO
  - High propellant capacity
- Chosen Launch Vehicles:
  - Soyuz 2 with Fregat upper stage
  - Proton-M with Breeze-M upper stage
- Chosen Launch site:
  - Plesetsk (Russian Federation - 62°57′35″N, 40°41′2″E)

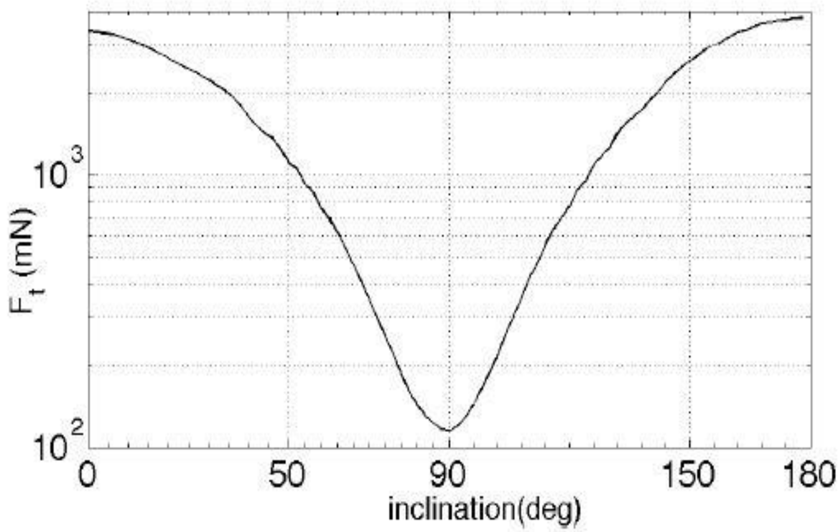
Mission Simulation in STK

Maneuver	Velocity Increment (km/s)	Provided by
Launch to Park Orbit	-	Launch Vehicle
Altitude increase	0.105	Upperstage
Hohman transfer	0.056	Upperstage
Combined change	0.849	Upperstage
Inclination change 1 (83 to 74 deg)	1.71	Upperstage
Inclination change 2 (74 to 66 deg)	1.101	Upperstage
Inclination change 3 (66 to 53 deg)	1.809	Upperstage
Inclination change 4 (53 to 43 deg)	1.402	Upperstage
Inclination change 5 (43 to 29 deg)	1.576	Upperstage
Inclination change 6 (29 to 18 deg)	2.808	Upperstage
Altitude Decrease (900 to 500 km)	Depends	EDT



EDT Model

- EDT mass
  80 kg



Orbit-Average tangential thrust for a 20km EDT on a 1000-km altitude orbits of different inclinations

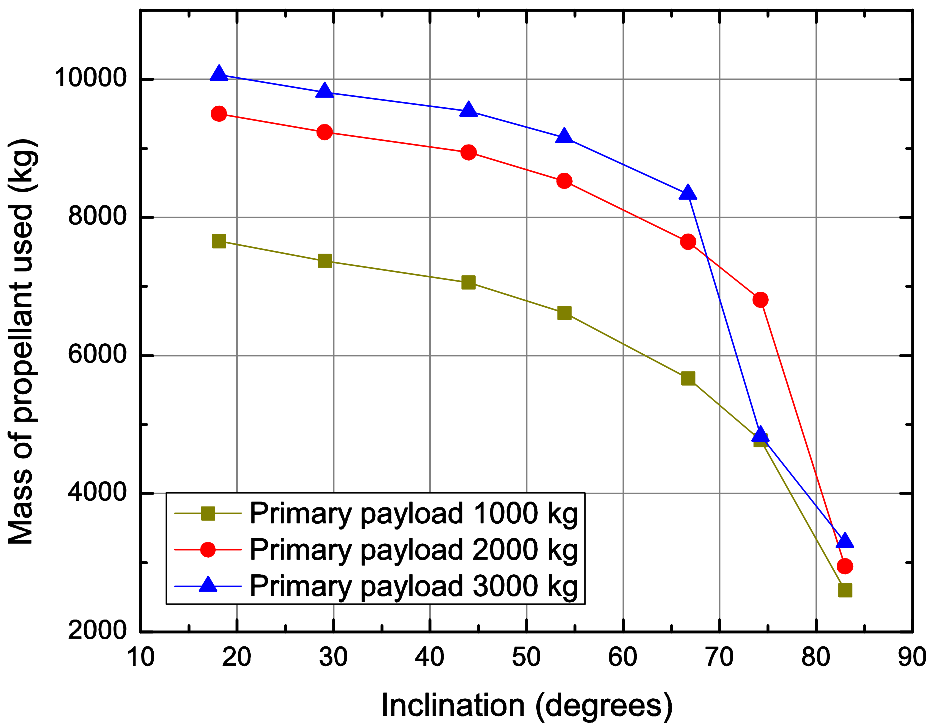
$$T(mN) = 0.0077 * i^3 - 0.8542 * i^2 - 21.315 * i + 3391.5 \; (i < 90^\circ)$$

$$T(mN) = -0.0001 * i^4 + 0.0604 * i^3 - 9.5709 * i^2 + 646 * i - 15987 \; (i > 90^\circ)$$

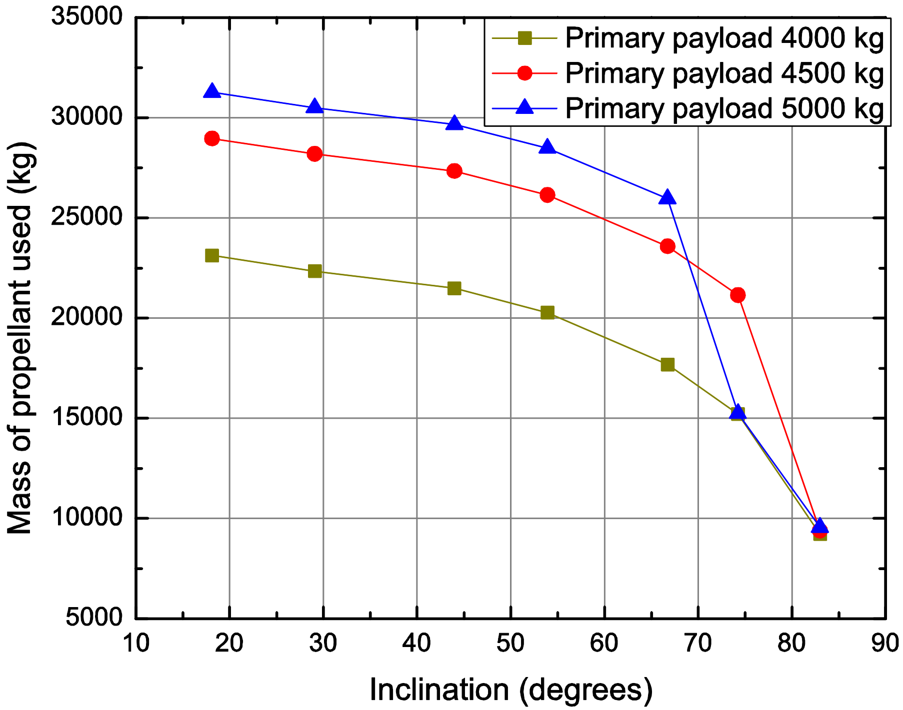
Mass and Altitude Properties

	Soyuz upper stage (Fregat)	Proton upper stage (Breeze-M)
Primary payload mass (ton)	1-3	4-5
Vacuum specific impulse (s)	327	325.5
Propellant mass (ton)	5.35	19.8
Structural mass (ton)	1	2.37
EDT mass (kg)	80	
Debris altitude (km)	900	
Debris inclination (deg)	83	
Kosmos 3M mass (kg)	1435	
Target orbit (km)	500	

Results: Propellant use

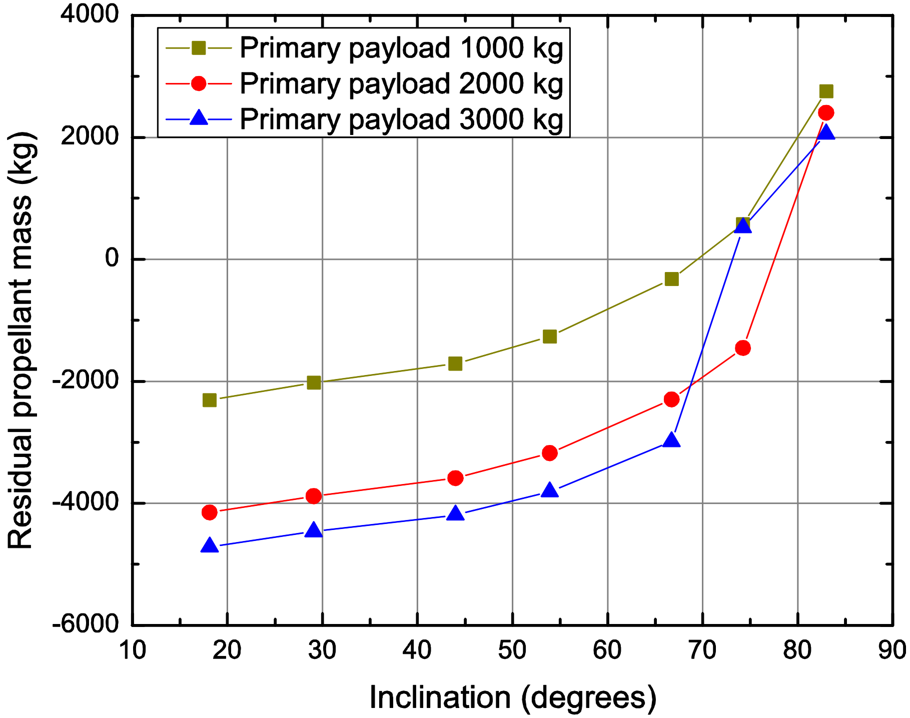


(a) Propellant used versus inclination at which EDT is turned on for the Soyuz upper stage

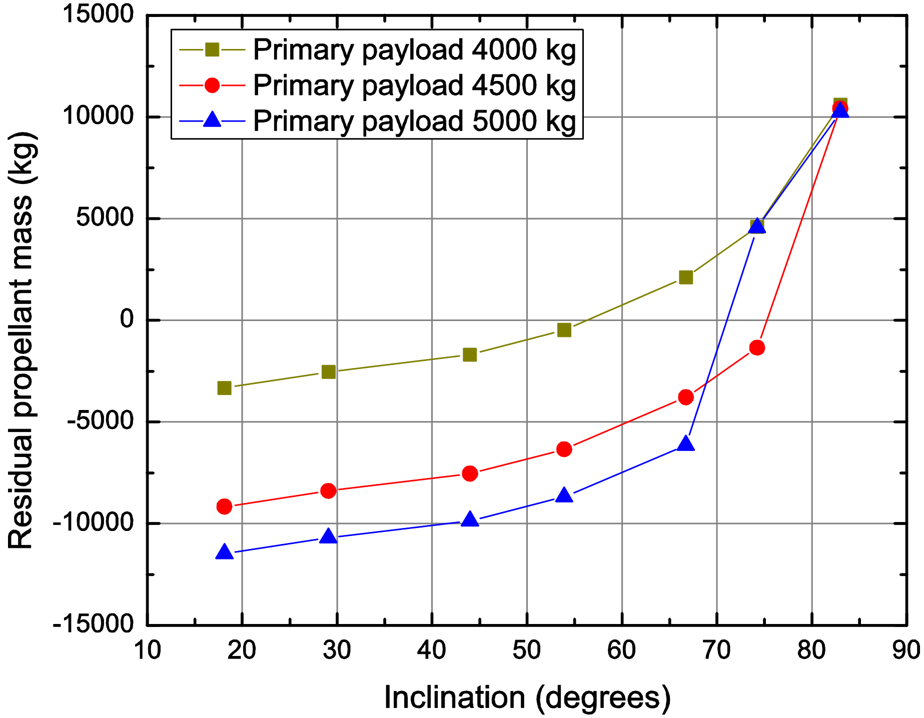


(b) Propellant used versus inclination at which EDT is turned on for the Proton upper stage

Results: Residual Propellant

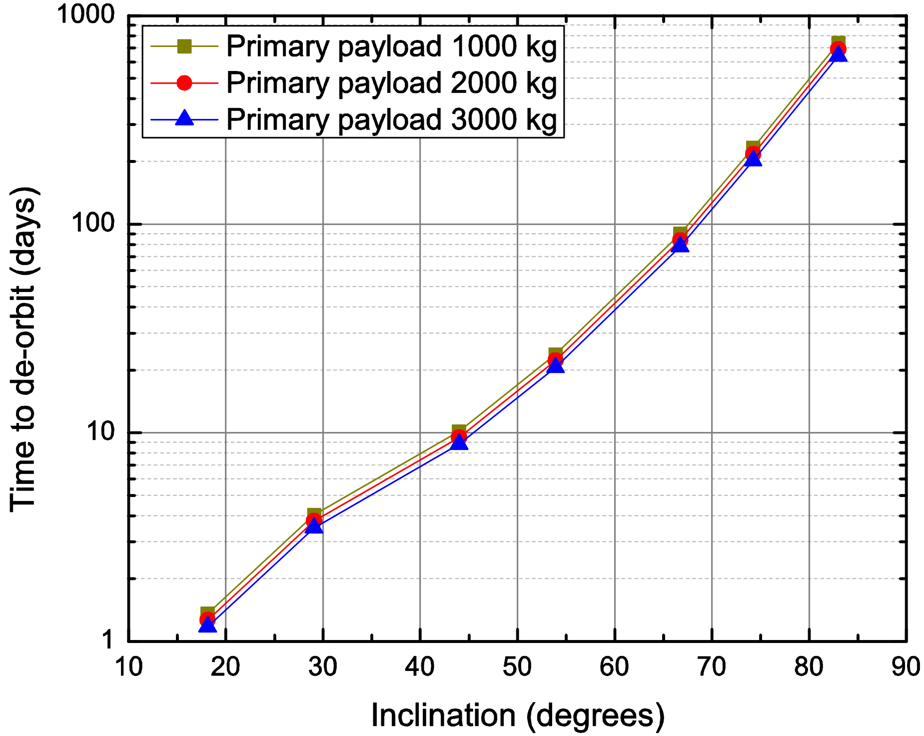


(c) Residual propellant versus inclination at which EDT is turned on for the Soyuz upper stage

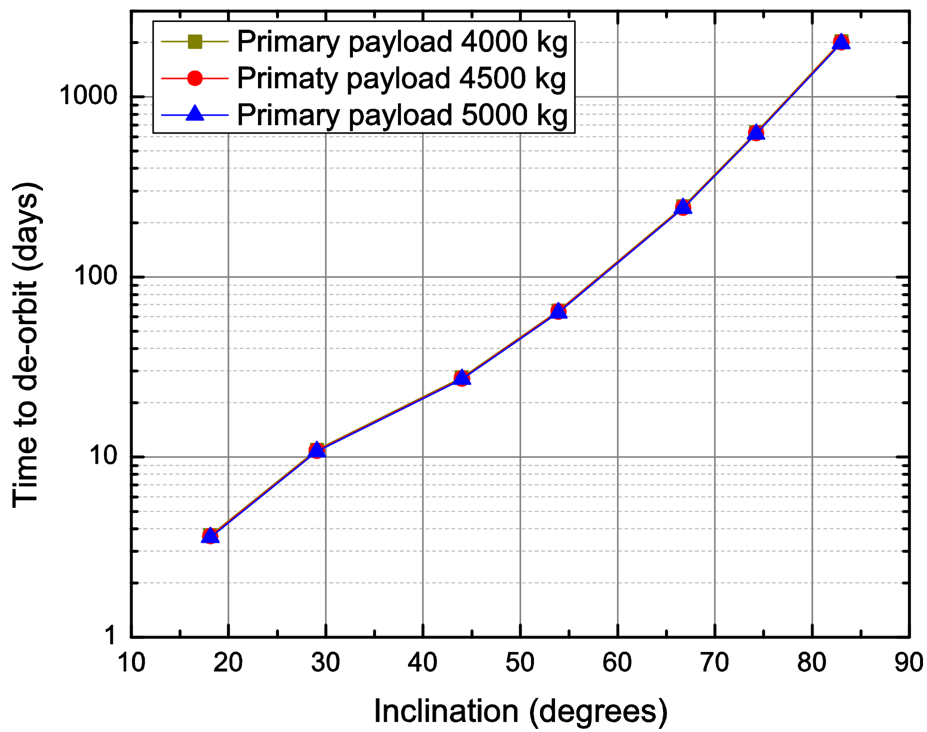


(d) Residual propellant versus inclination at which EDT is turned on for the Proton upper stage

Results: De-orbiting Time



(e) Time to de-orbit versus inclination at which EDT is turned on for the Soyuz upper stage



(f) Time to de-orbit versus inclination at which EDT is turned on for the Proton upper stage

Conclusions

- Modified Soyuz or Proton upper stage equipped with a tether system, can deliver a primary payload to a 900 km polar orbit and connect to a Kosmos 3M 2nd stage to de-orbit it.
- It is clear that a hybrid solution using a chemical-EDT system is the best choice for this particular mission because of the short quantity of propellant left from previous stages of the mission.

Future Work

- Further simulation to refine the preliminary result
- Modelling the close approach, grabbing and stabilization of the space debris
- Simulating the EDT system using MATLAB

Acknowledgement

1. Analytical Graphics, Inc. (AGI)

2. Secure World Foundation

Thank you!

Space Safety and Sustainability Group

Sustaining space activities for future generations

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