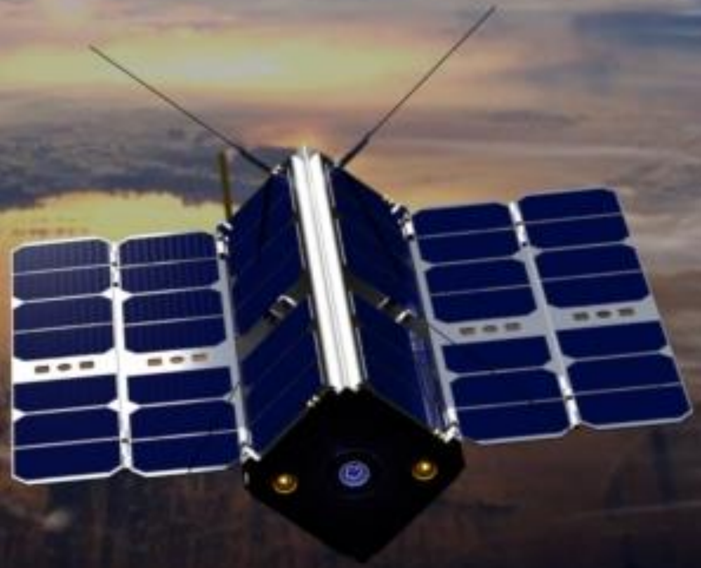
Collision avoidance assessment for CubeSats with propulsive capabilities



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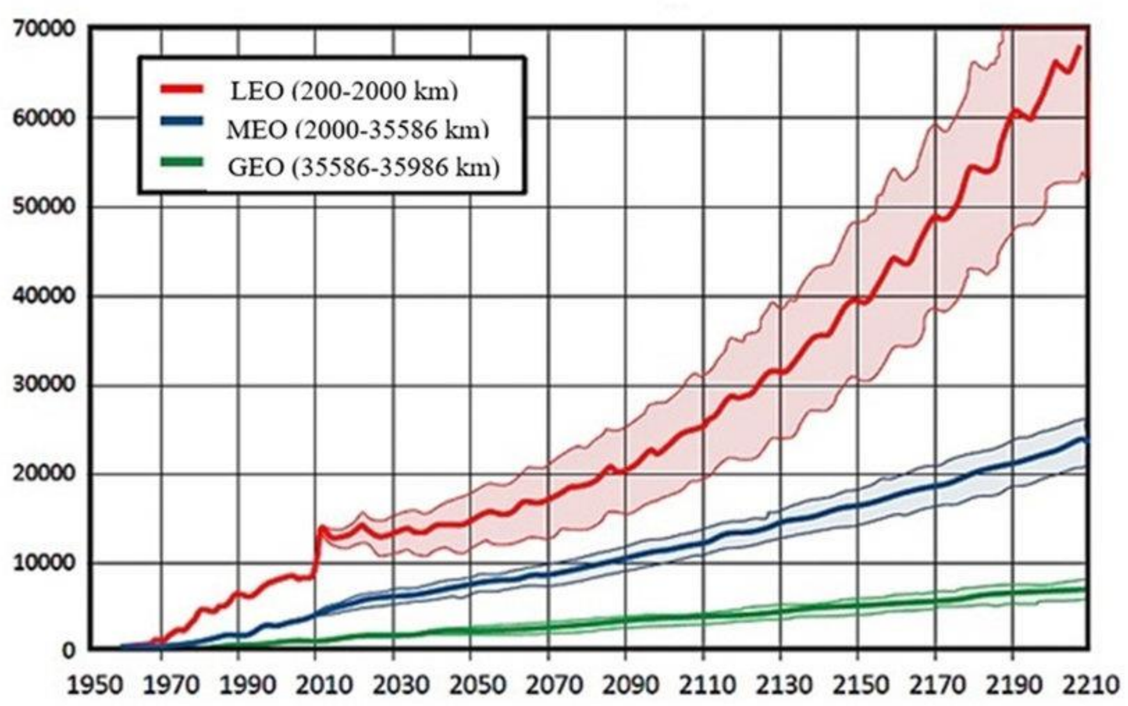
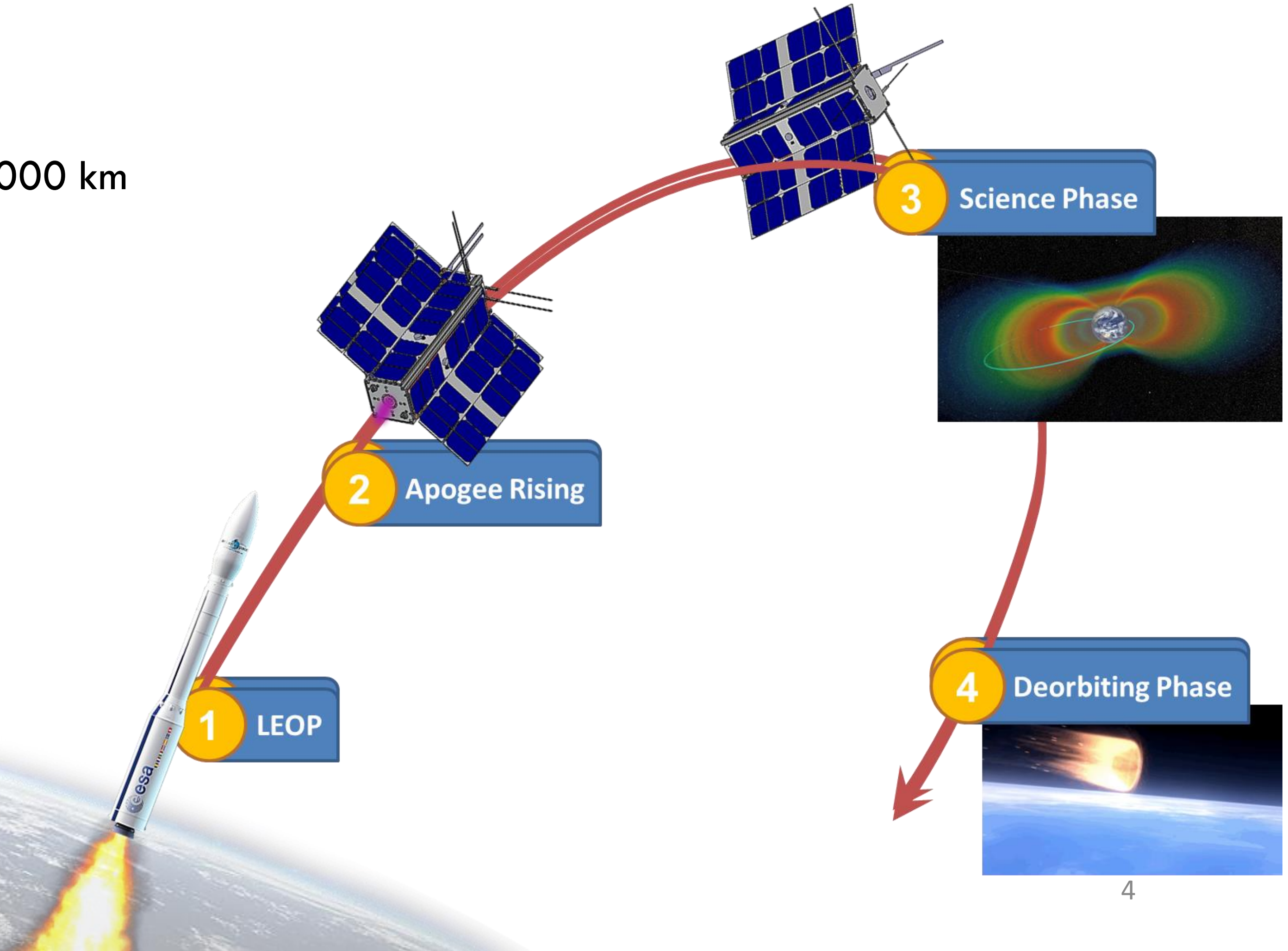
Necessity of collision avoidance

- The number of debris has exponentially increased in past decades and is always increasing.
- The development of highly efficient electric propulsion systems provides higher options for propulsive capabilities for CubeSats.
- Thus, a need for development of collision avoidance strategies using electric propulsion for CubeSats.



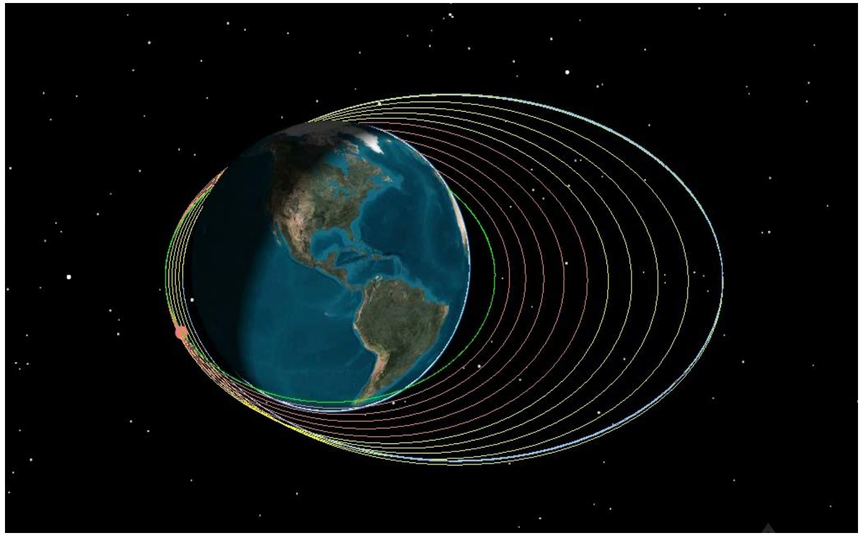
CLIMB Mission Scenario

- Mission Objective: To investigate the impact of space radiation on commercial-off the shelf elements.
- Total mission time: ~ 2.5 – 3 years
  - Phase 1: Launch into orbit and commissioning
  - Phase 2: Lifting the apogee from 500 km to 1000 km
  - Phase 3: Radiation measurement in the VAB
  - Phase 4: Deorbiting

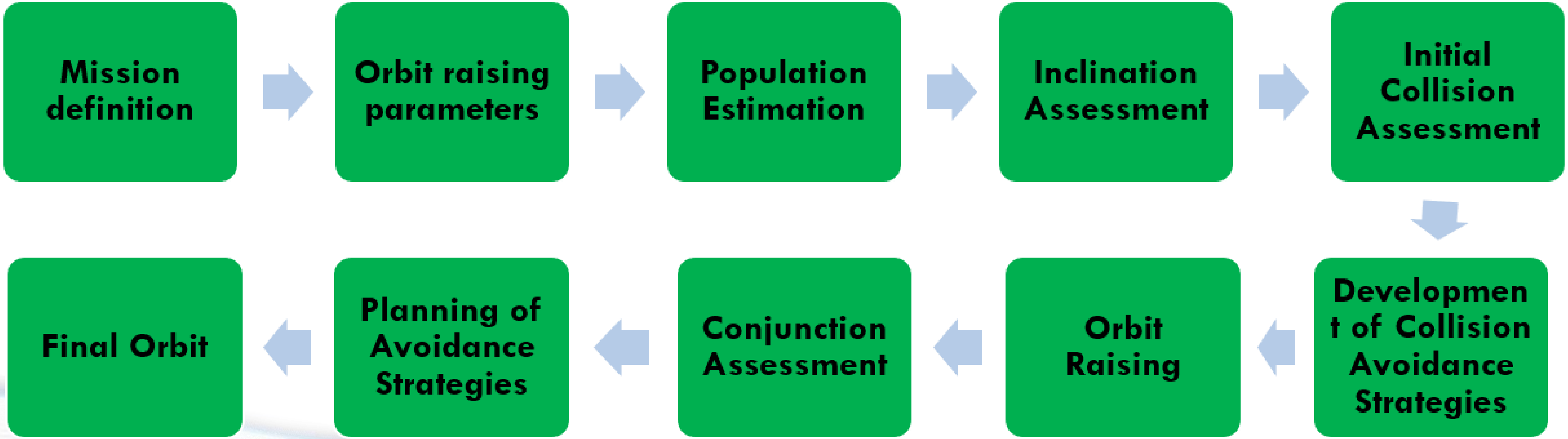


Mission Profile

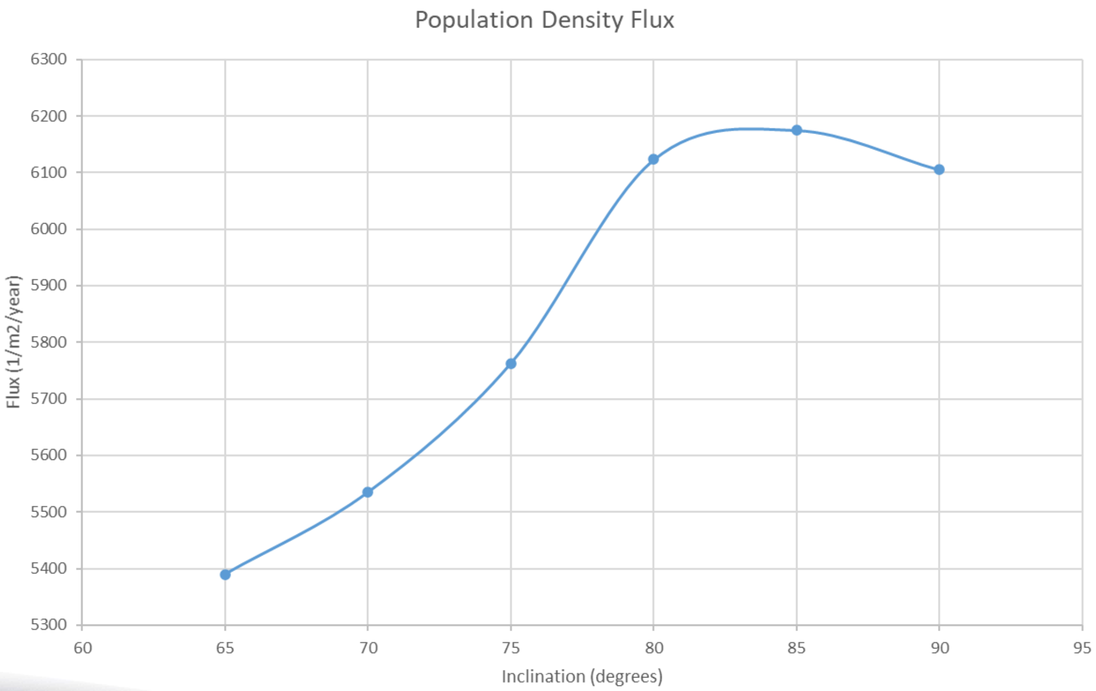
- Orbit Scenario:
  - Initial orbit: 500 km (circular orbit)
  - Final orbit: 500 km x 1000 km.
  - Orbit raising: Thrust manoeuvre at every perigee.
- Orbit Drivers:
  - Available power
  - Data collection by payload.
  - Collision avoidance



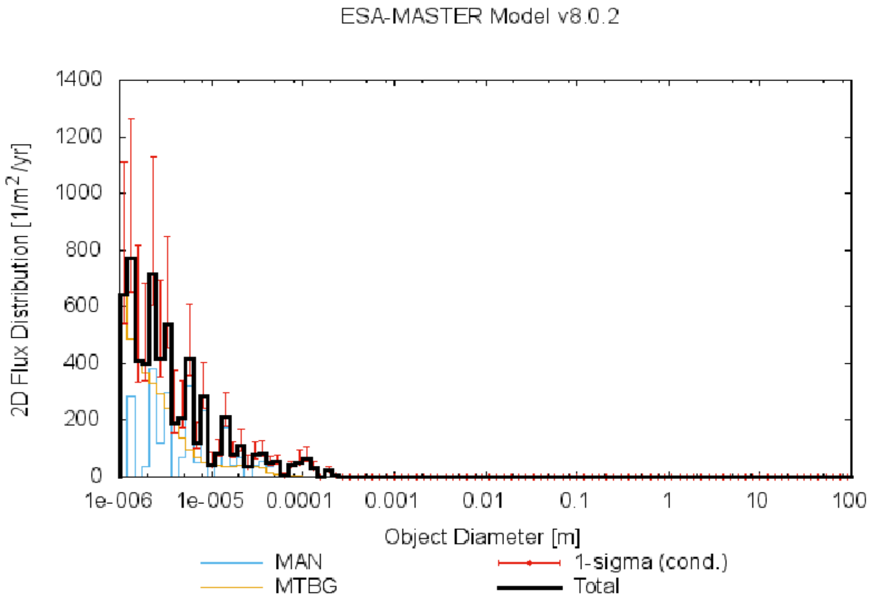
Workflow


Mission definition
Orbit raising parameters
Population Estimation
Inclination Assessment
Initial Collision Assessment
Development of Collision Avoidance Strategies
Orbit Raising
Conjunction Assessment
Planning of Avoidance Strategies
Final Orbit

Population Estimation

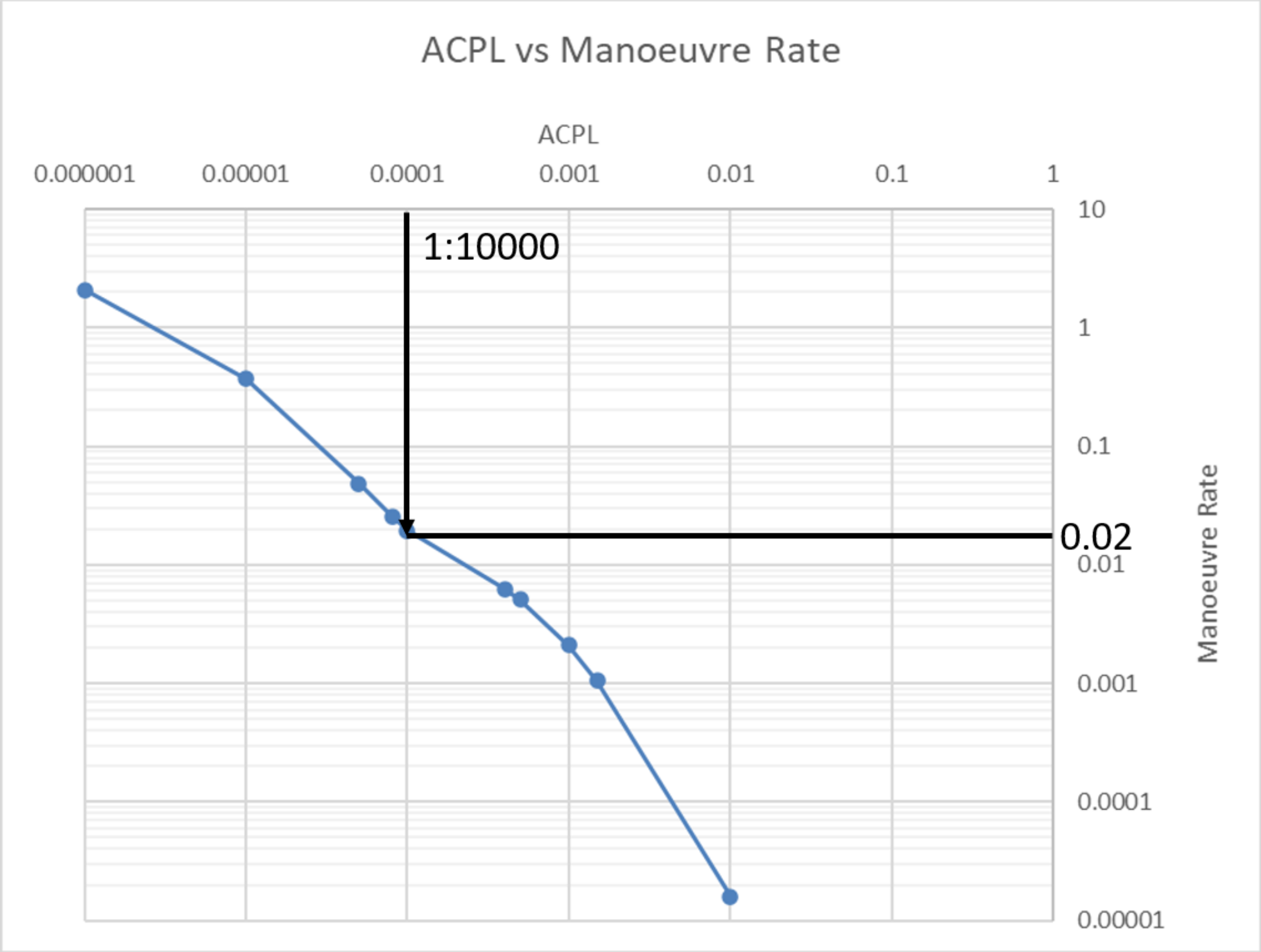


- Orbit was segmented with raising in 3 months.
- Higher population at higher angles as expected.
- Maximum number of object: 6180.



- Most of objects are in size of e-6 m.
- The final orbit can be chosen based on payload and power requirements.

Theoretical ACPL



- Orbit was segemented to raise by 8 km every 10 days in pyDRAMA.
- pyDRAMA runs for one year at each segment and results are taken as weighted average for the whole mission.
- For industrial standard, required ACPL: 10^{-4}; Required number of manoeuvres: 0.02

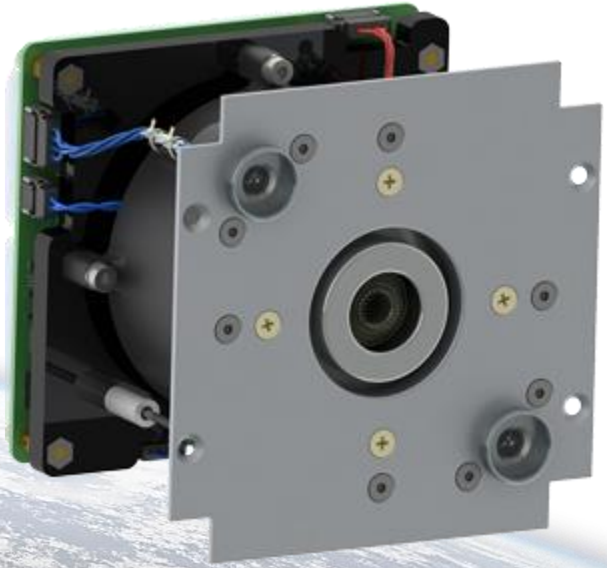
Collision Avoidance Strategies

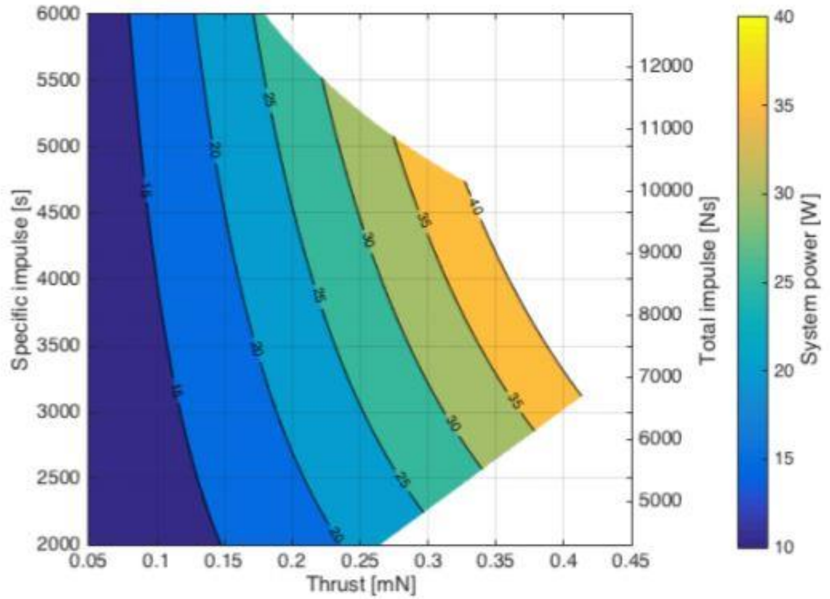
- The study uses Conjunction Data Message received regularly from the FHWN's first satellite PEGASUS.
- The data obtained from CDM exhibits a near miss between PEGASUS and a rocket body with miss distance of 62m at time of closest approach.
- The strategies for collision avoidance are:
  - Using thrust manoeuvres
  - Changing the drag areas
- The strategy involving thrust manoeuvres also includes uncertainties in the thrust vector. The uncertainties considered are:
  - +5% in magnitude of thrust.
  - -5% in magnitude of thrust.
  - 3° variation in direction of thrust.
  - 6° variation in direction of thrust.

IFM FEEP Multiemitter

FOTEC
Forschungsunternehmen
-der FH Wiener Neustadt-

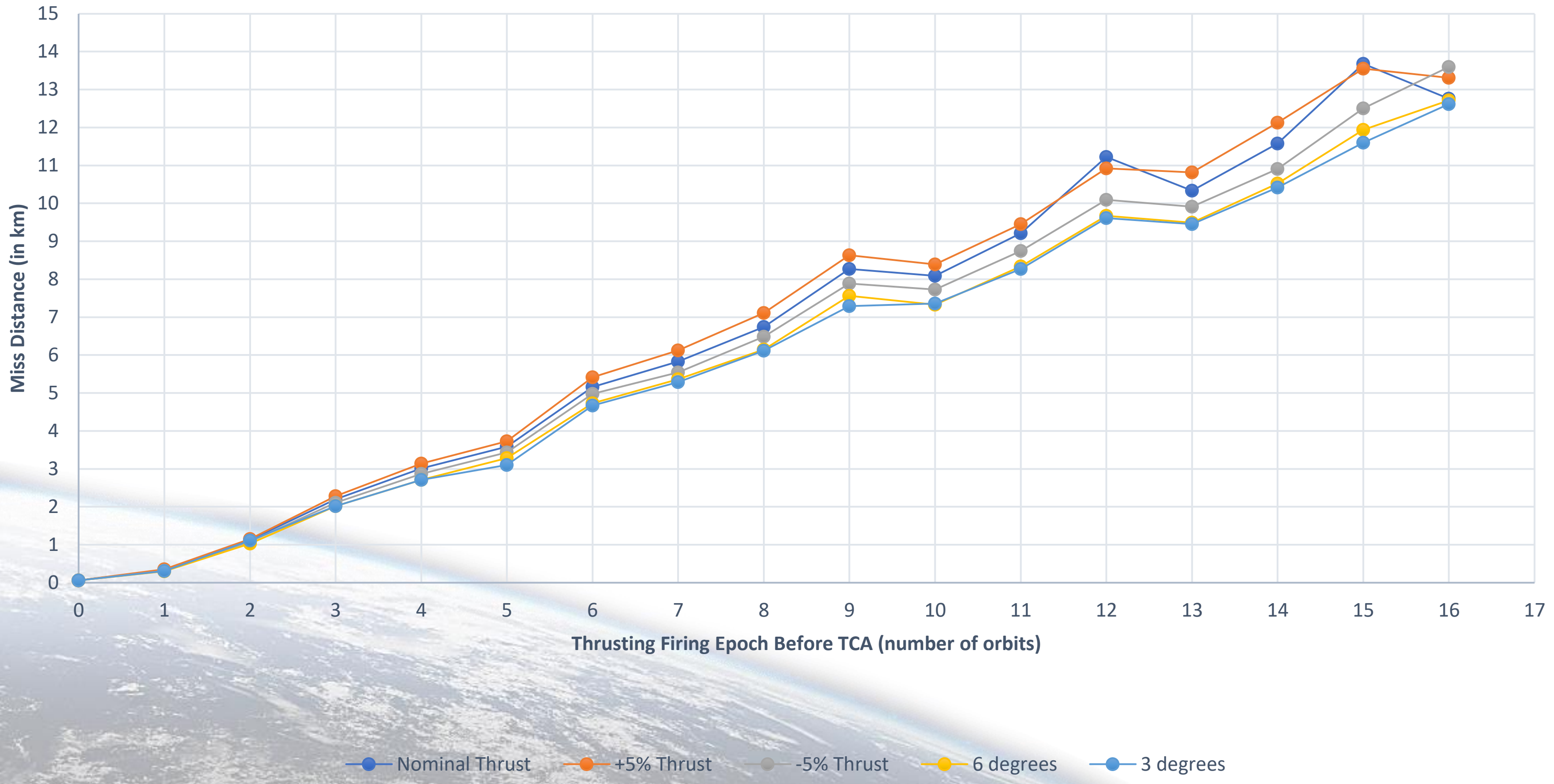
- Wet mass: 900 grams.
- Dimensions: 1U CubeSat unit.
- Propellant mass: 230 grams.
- Thrust: 350 micronewtons
- Specific impulse: 4000 sec
- Power required: 40W





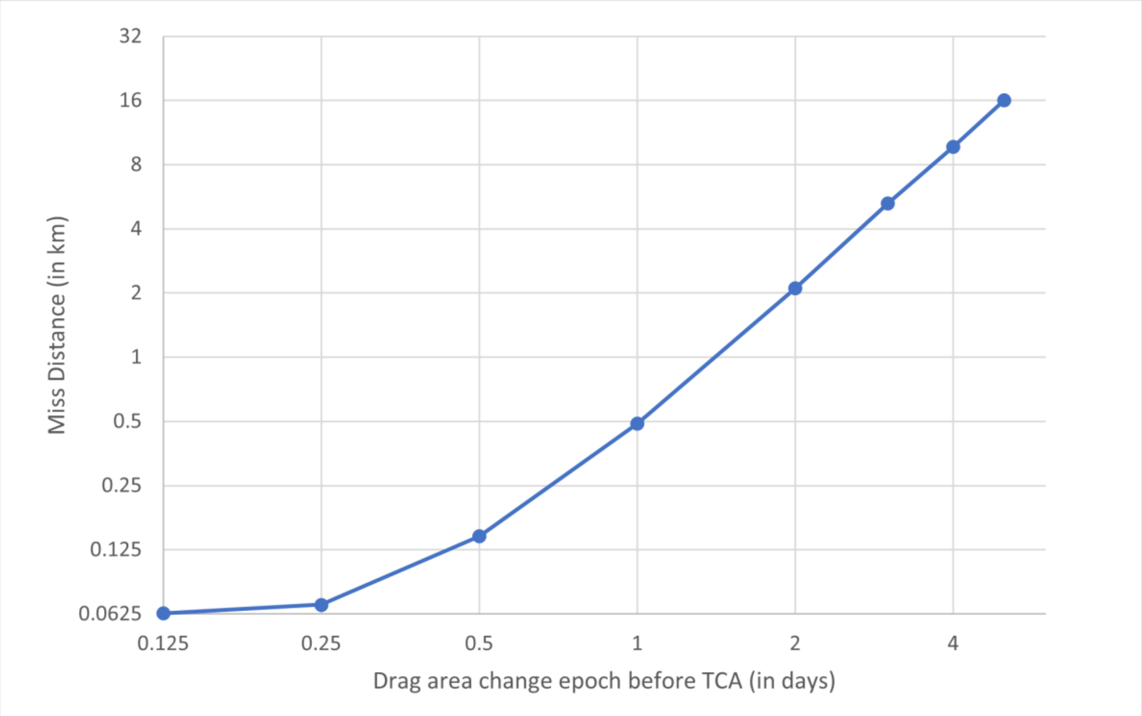
Using IFM FEEP Thruster for collision avoidance

- Maximum change in miss distance varies between 12km to 14km.
- A 2km variation can occur due to uncertainties in the thruster.
- Thrust manoeuvres provide enough separation for avoiding conjunction events.

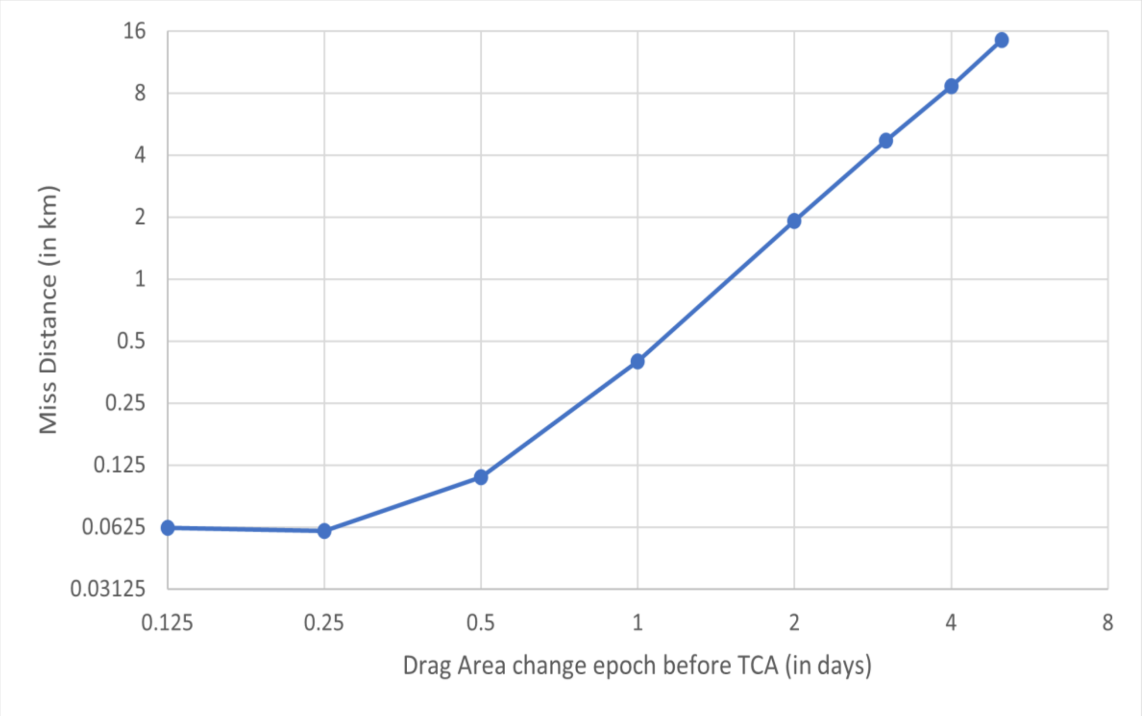


Using Drag Area to avoid Collision

- Drag acts in direction of motion of satellite.
- Increase Drag -> Slower Satellite
- Reduced Drag -> Faster Satellite



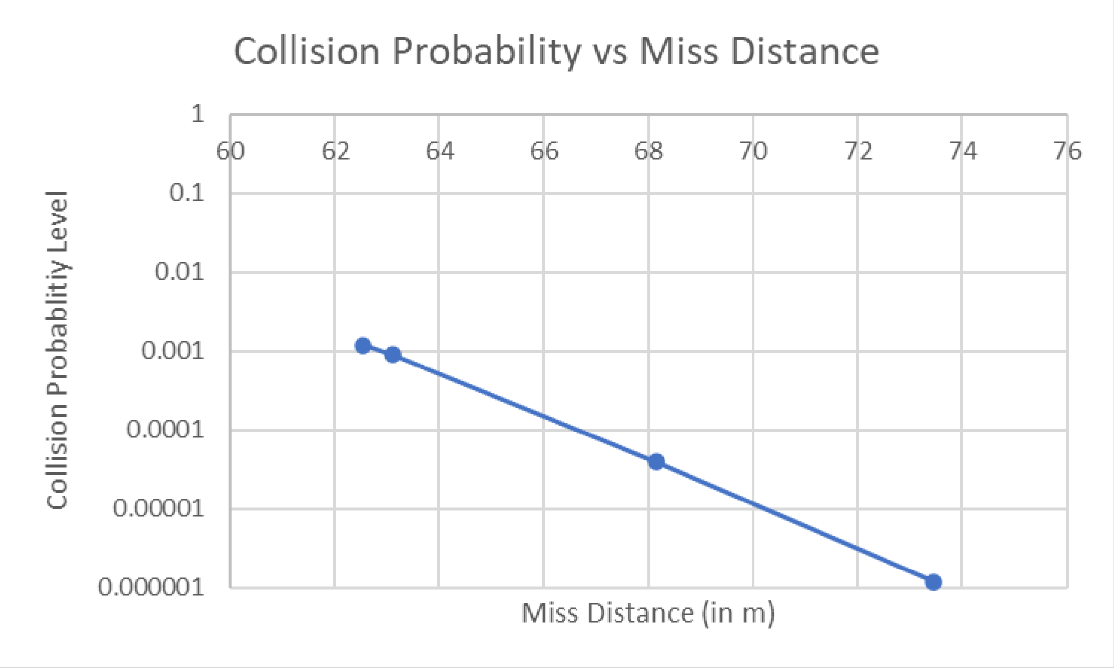
Using minimum drag area

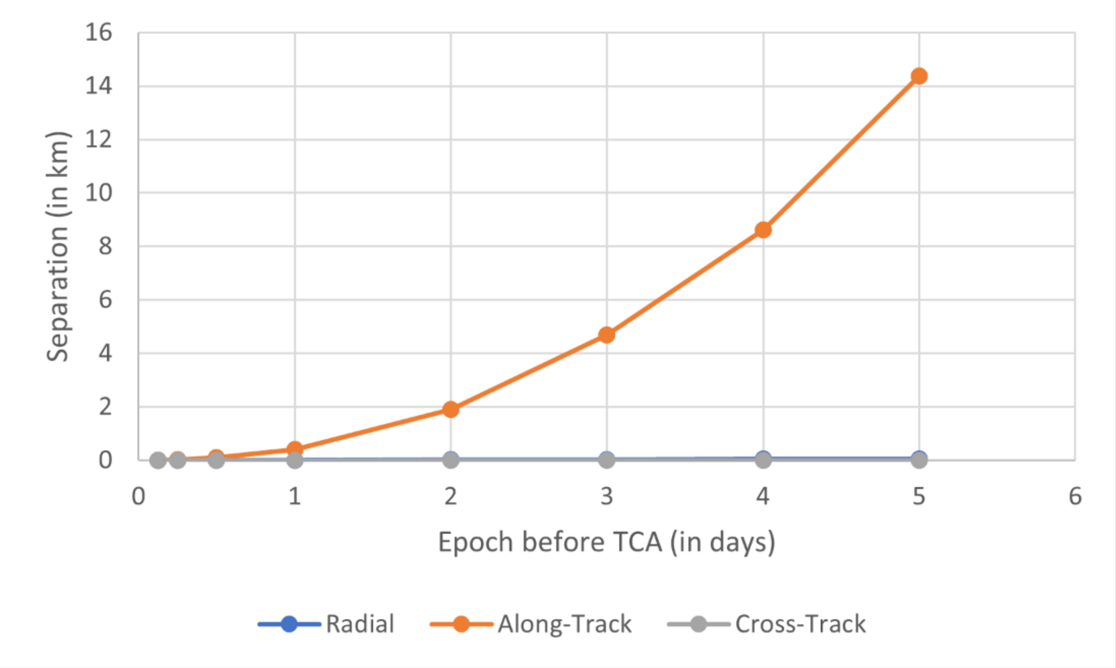


Using maximum drag area

Miss Distance Required

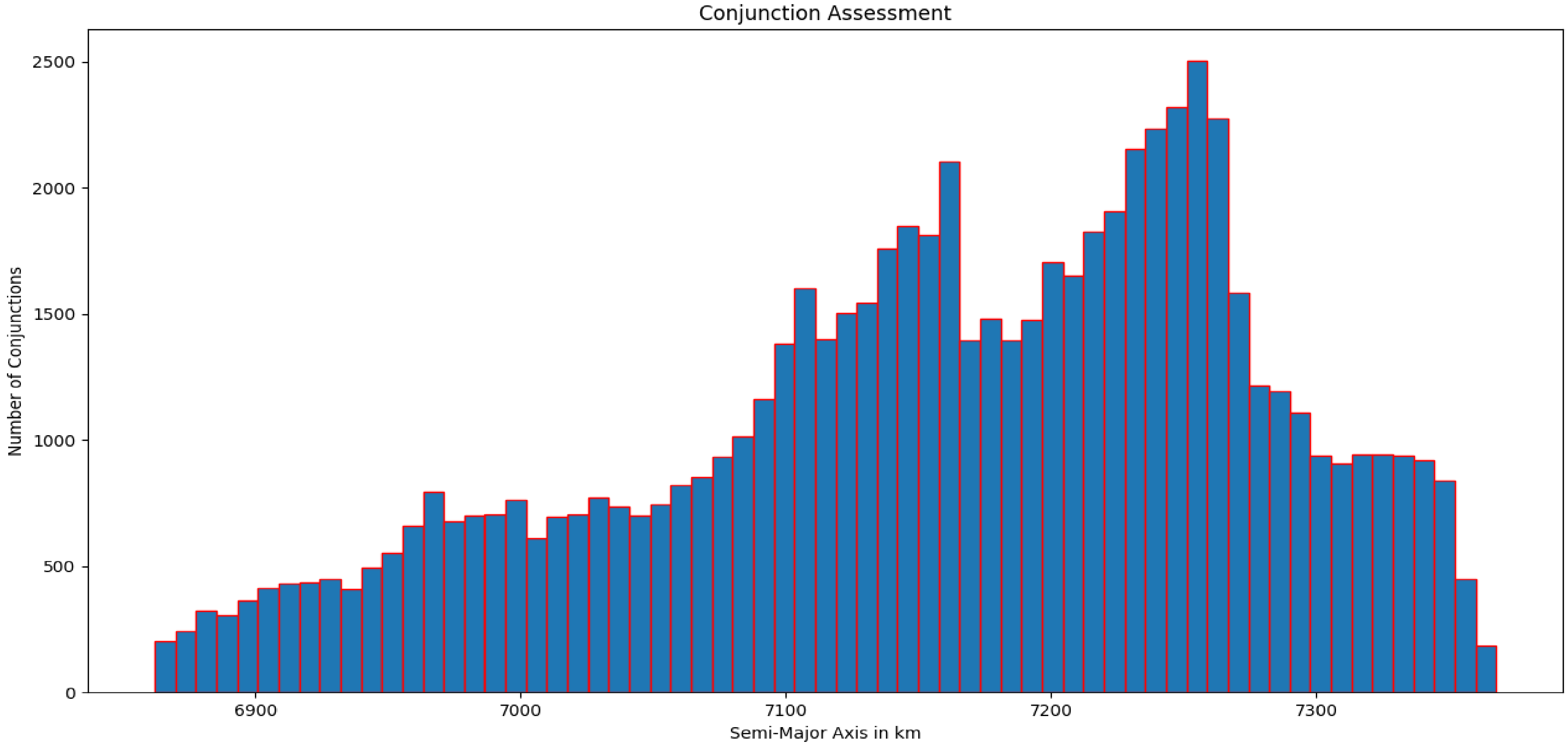
- The required change in miss distance to be considered safe for this conjunction event is about 67m.
- The separation occurs only in along track direction, if the drag area is changed to avoid the conjunction event.
- Collision avoidance using thrust manoeuvre can be used if the required change is in radial or cross-track direction and collision avoidance by changing the drag area can be used if required change is in along track direction.





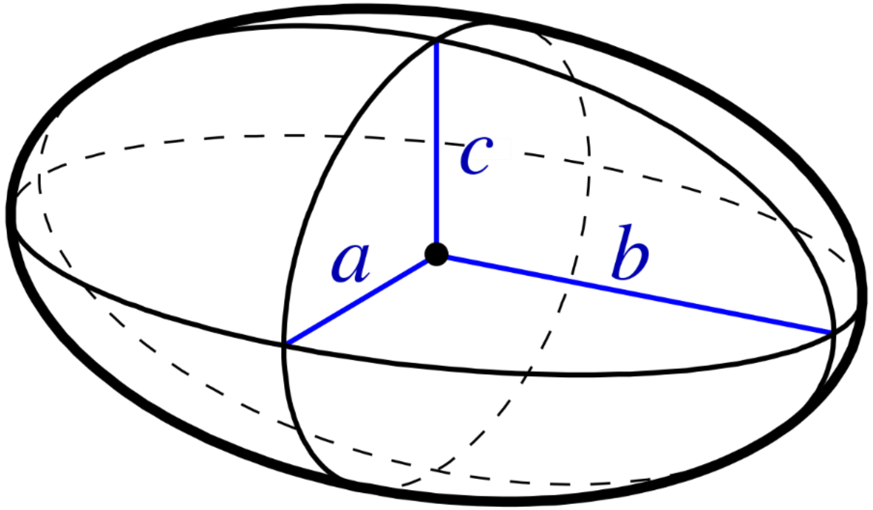
Conjunction Assessment

- Initial Screening Volume: 51 km x 51 km x 51 km.
- Total identified conjunction events: 71,792.



Conjunction Assessment

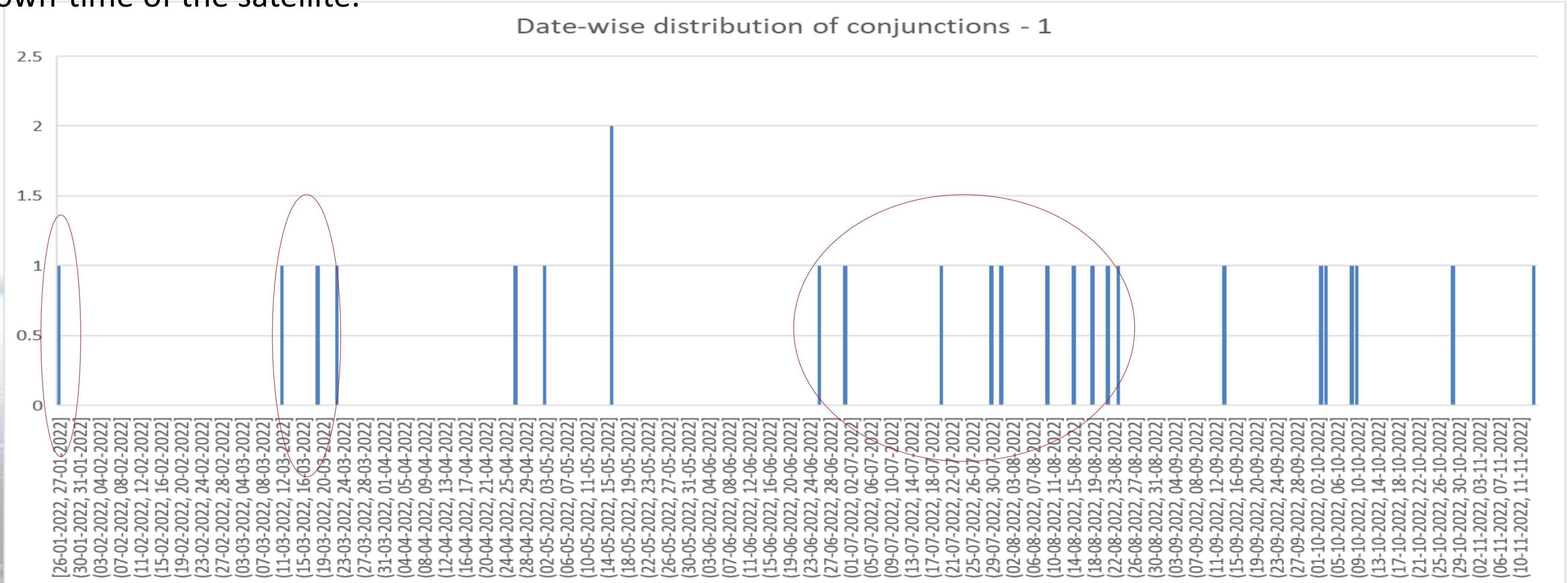
- Screening volumes defined by 18th Space Control Squadron (18 SPCS).
- Screening Volume 1: LEO Basic: 1 km x 1 km x 1km
  - Total number of conjunctions: 50
- Screening Volume 2: LEO Advance: 2 km x 44 km x 51km
  - Total number of conjunctions: 3984



ToC UTC	Miss Distance (in km)	Semi-major axis (in km)
2022-12-11T23:44:11.220Z	0.069	7216.1
2022-09-14T06:49:00.700Z	0.091	7123.4
2022-12-19T08:14:54.743Z	0.132	7222.7
2022-10-04T16:31:37.753Z	0.145	7144.4
2022-05-03T18:09:54.646Z	0.151	6989.1

Conjunction Avoidance Planning

- 1 day plan – to avoid single conjunction event occurring in a single day with no events in near days.
- 2-3 day plan – to avoid multiple conjunctions occurring in small interval, however is thrust manoeuvre is used to avoid the first conjunction event, the orbit changes and conjunction assessments needs to be re-evaluated for the following days.
- 5-7 day plan – to avoid multiple events over a longer time interval and is critical if the conjunction events occur during down-time of the satellite.



Conclusion

- Theoretical ACPL - 3.38×10^{-5} and Number of required manoeuvres to attain required probability level: 0.02, thus CLIMB can be considered 'theoretically safe' during orbit raising.
- No potential dangerous event was identified during conjunction assessment.
- Two strategies for avoiding collisions are developed for CubeSats with propulsive capabilities.
- Changing the drag area strategy can be used to avoid conjunction events from the 'Basic' screening volume and for separations required in along-track directions.
- To avoid conjunction events from 'Advance' screening volume thrust manoeuvres are required and for separations required in cross-track and radial directions.
- Thus, IFM FEEP thruster can be sustainably used for orbit raising as well as collision avoidance for CubeSats.