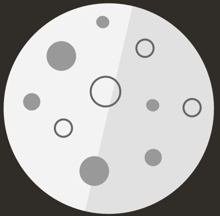
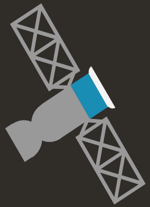
Beyond Fuel

An On-Orbit Refuelling and Debris Mitigation Solution

28th May 2024





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Our Journey

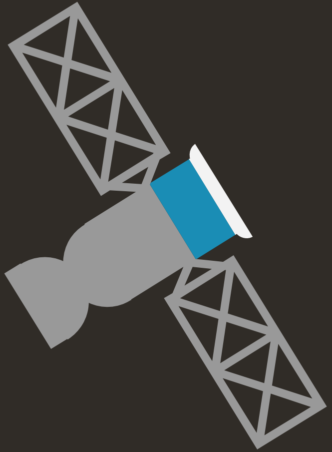
01 The Growing LEO Ecosystem

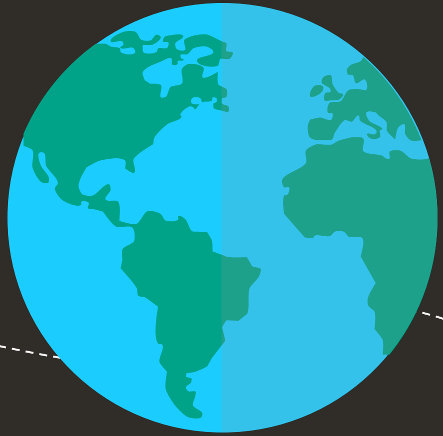
02 The Limitation of Satellite Lifetimes

03 The Beyond Fuel Solution

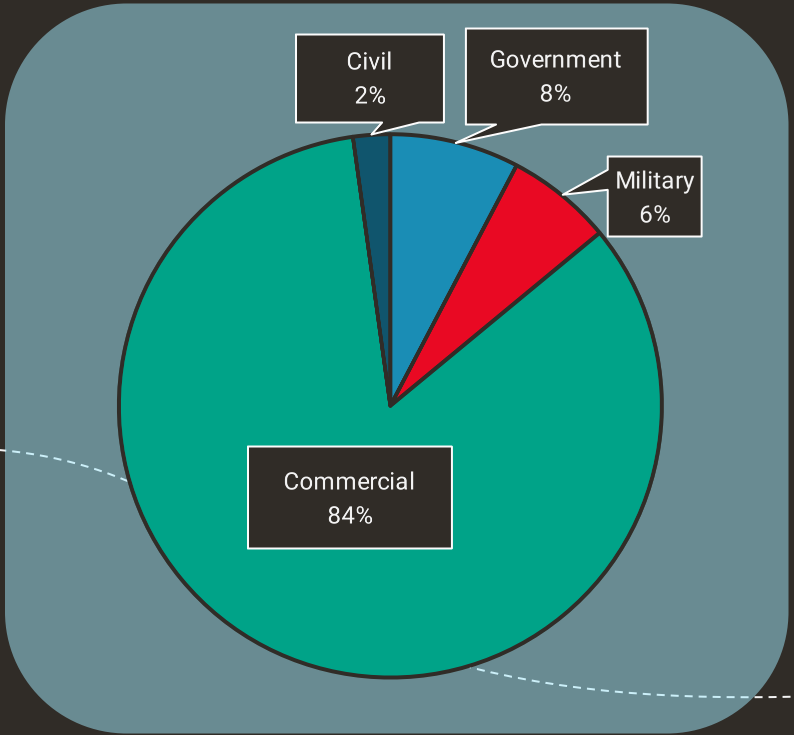
04 Project Overview and Next Steps

01 The Growing LEO Ecosystem

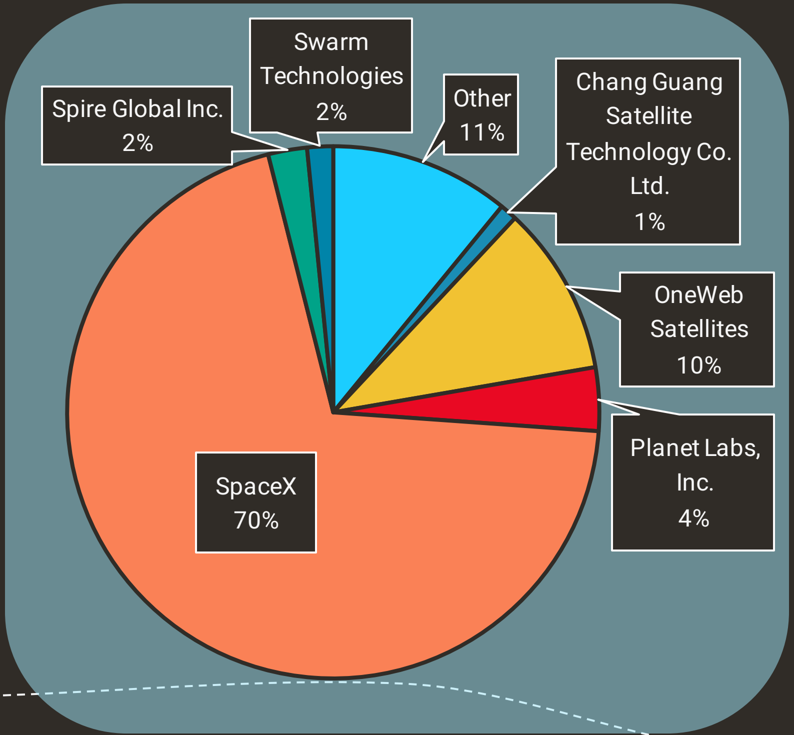




Satellite Surge — The Growing Market of Low Earth Orbit

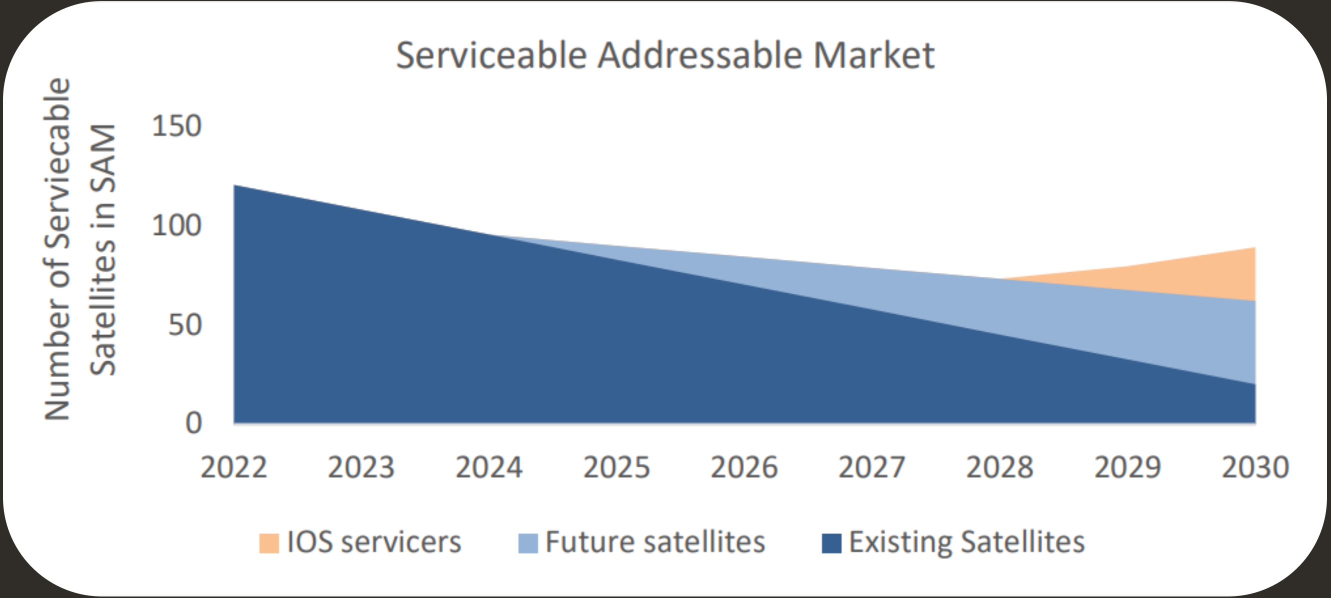


Satellite Sectors By Population



Commercial Sector By Company.

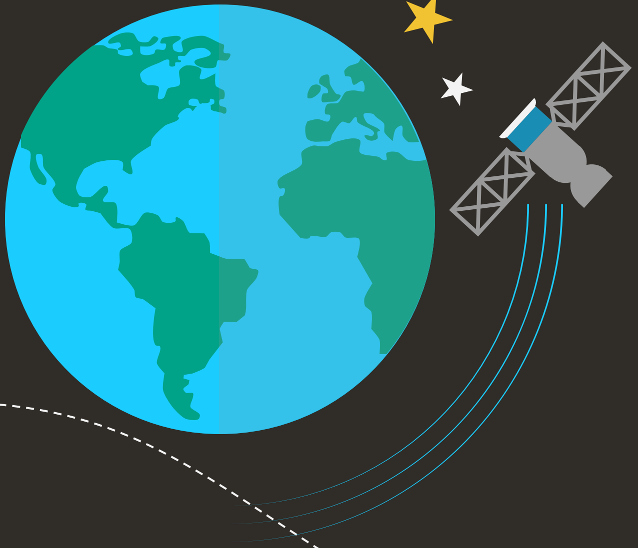
Refueling Satellites? In this Economy?



Service addressable market for existing and future satellites

02 The Limitation of Satellite Lifetimes

The Lifetime Problem

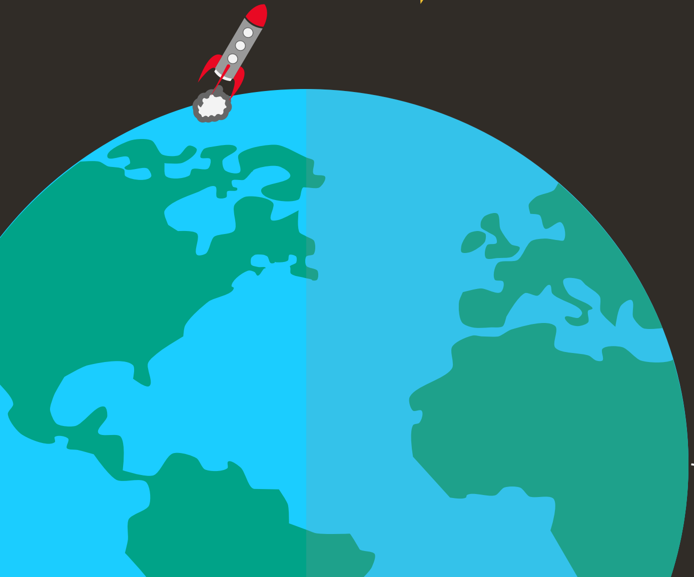


- **82%** of LEO satellites have lifetimes below **4 years**.
- **Limited fuel reserves** are utilised to conduct station keeping.
- **Fuel depletion or debris impact** lead to decommission.

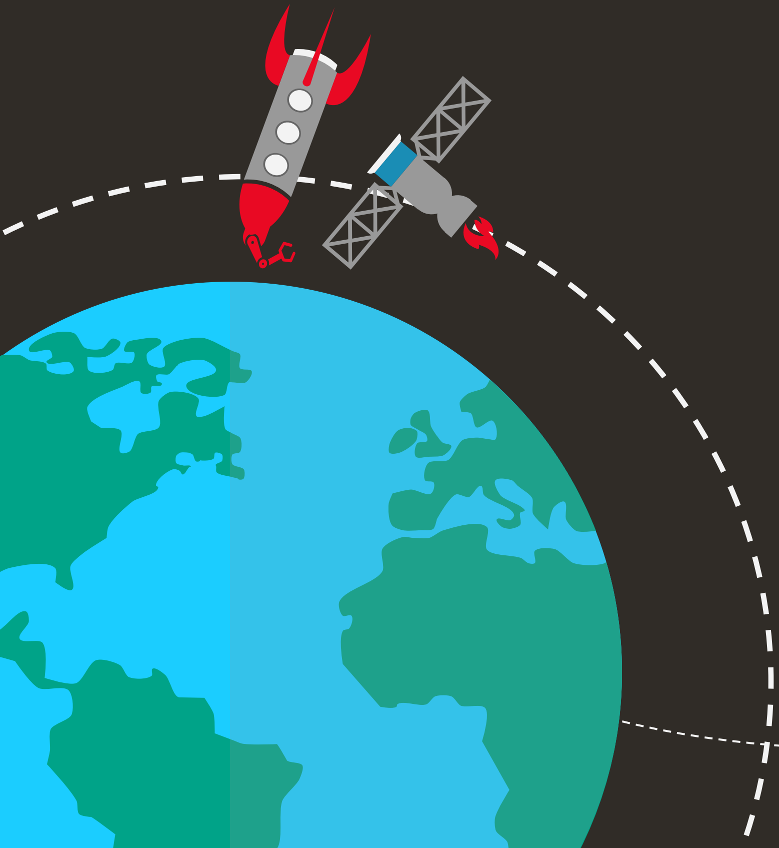
Replacement, Yes — But At What Cost?

- **$400k** per satellite per launch.
- **$500k >** per satellite per unit.
- **~$1 Million** per satellite replacement.

Assuming the satellite to be replace is a 240kg Starlink satellite ridesharing on a on a falcon heavy and estimating manufacturing costs. Values from 240kg Starlink Satellite



A Better Future; On-Orbit Servicing



- NASA, Robotic refuelling missions.
- ESA, ‘Clean Space’ initiative.
- Astroscale, ELSA-d.

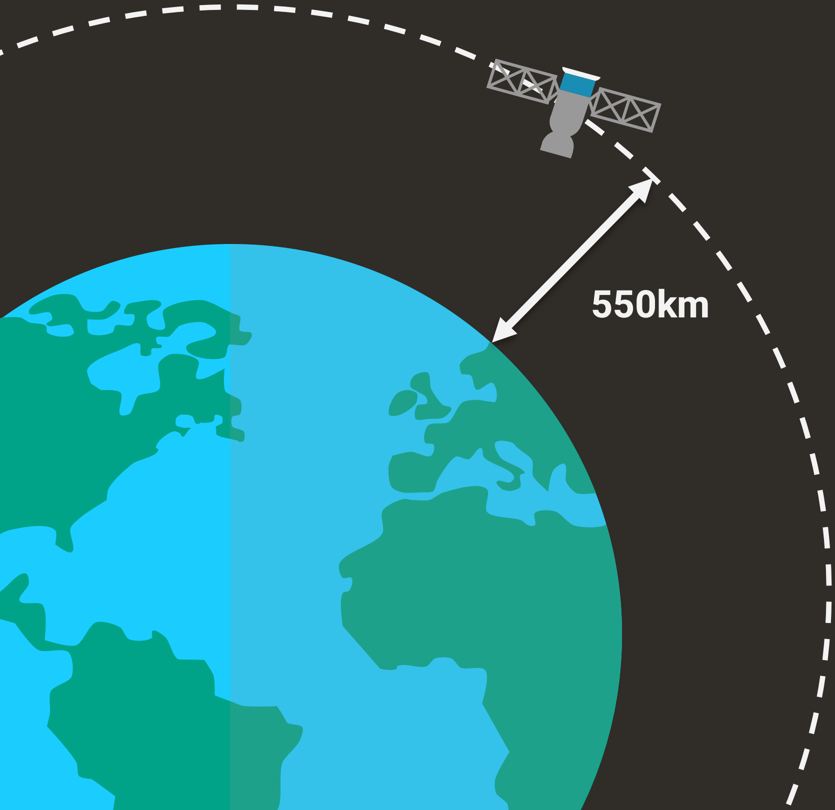
03

The Beyond Fuel Solution

Project Work Streams

1. Orbit Determination, Maintenance and Rendezvous
2. Robotic Arm Control and Material Selection
3. Fuel Pumps in Microgravity
4. Electrodynamic Tethers for Debris Mitigation
5. Structural Integrity and Material Selection

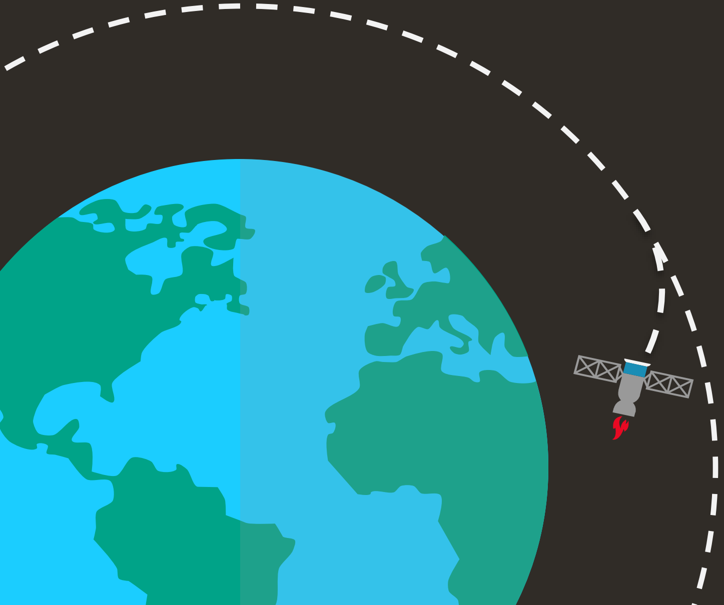
Determining An LEO Parking Space



- Low Earth Orbit
- 550 km from surface
- 53° inclination
- 0 eccentricity

The Cost Of Longevity

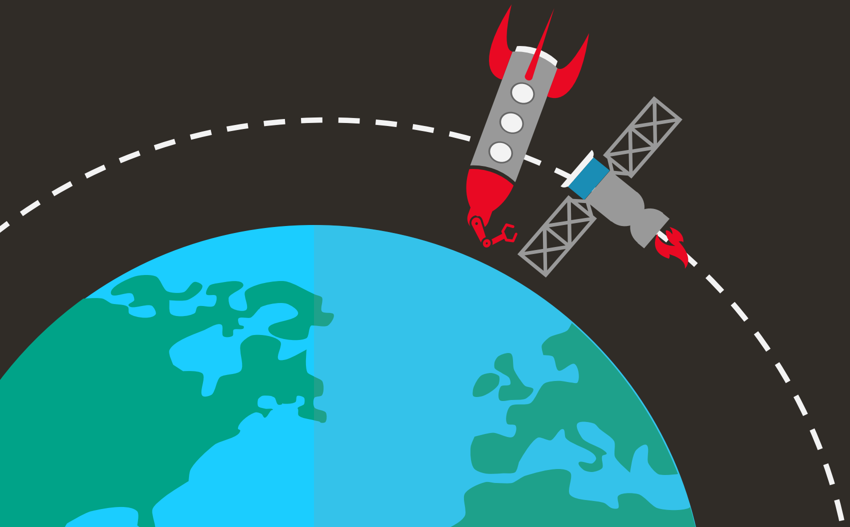
- Across a **20-year period, 104 kg of fuel is required** for station keeping.

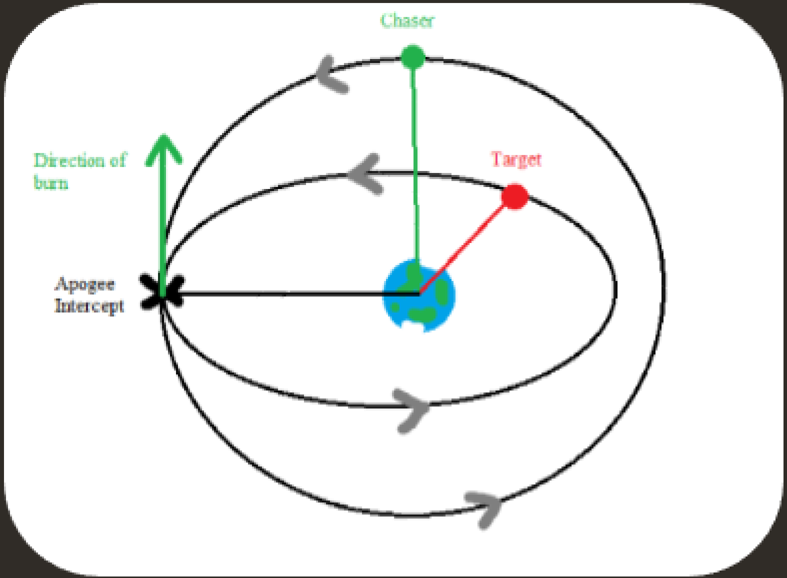


Visualization of an orbit maintenance **Hohmann transfer**.

High-Cost Hookups: Rendezvous

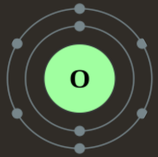
- For an exemplary **rendezvous mission, 182 kg** of fuel is required.



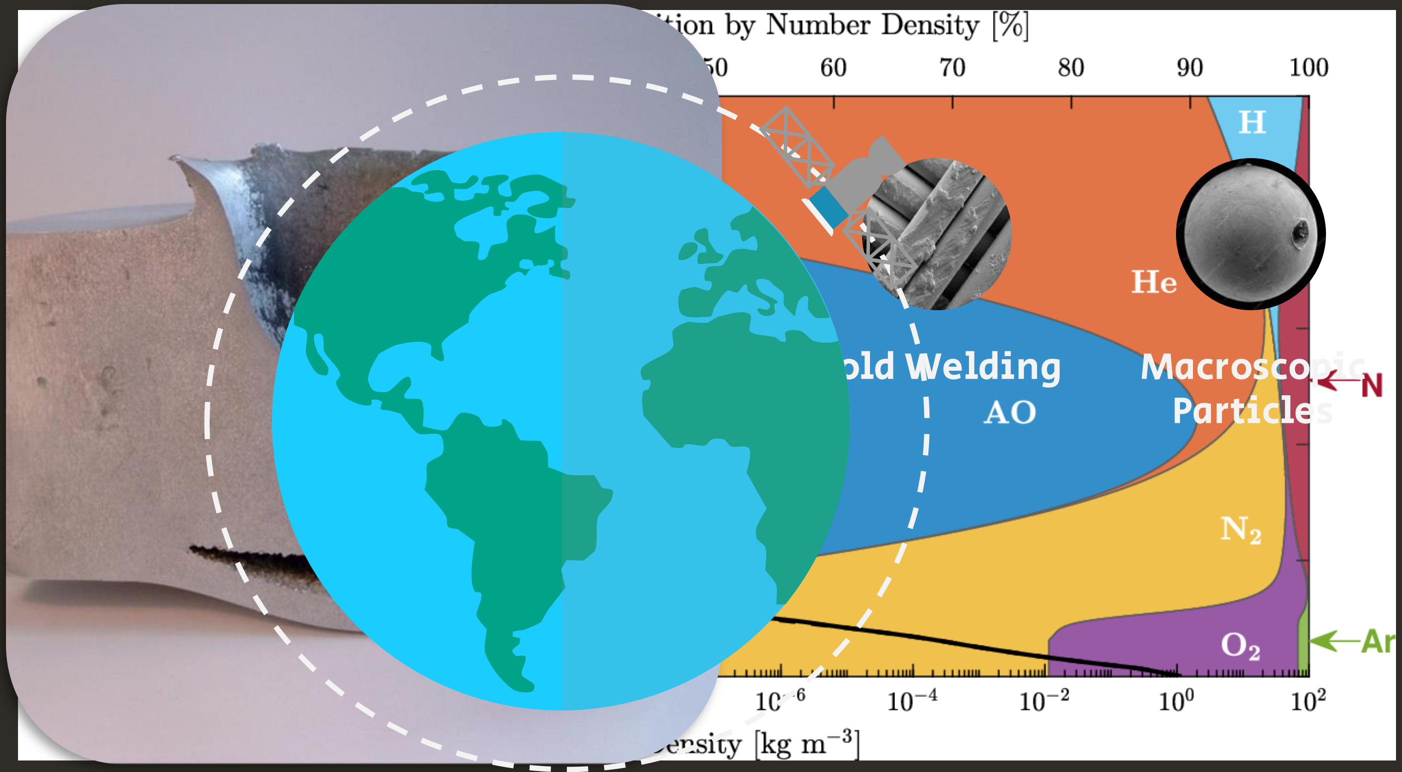


Plan for a **Hohmann Spiral Transfer** for long range rendezvous.

The LEO Environment

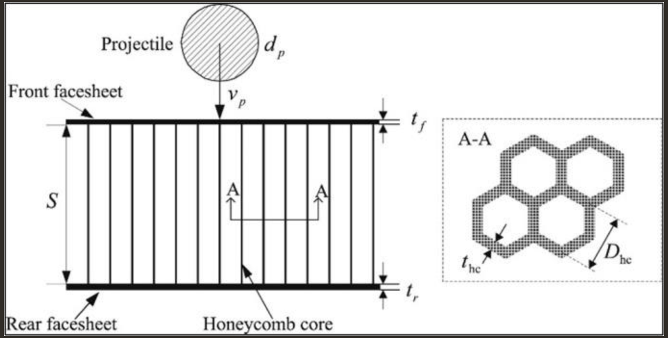


Atomic Oxygen



Robot Arm Materials

Outer Protective Material



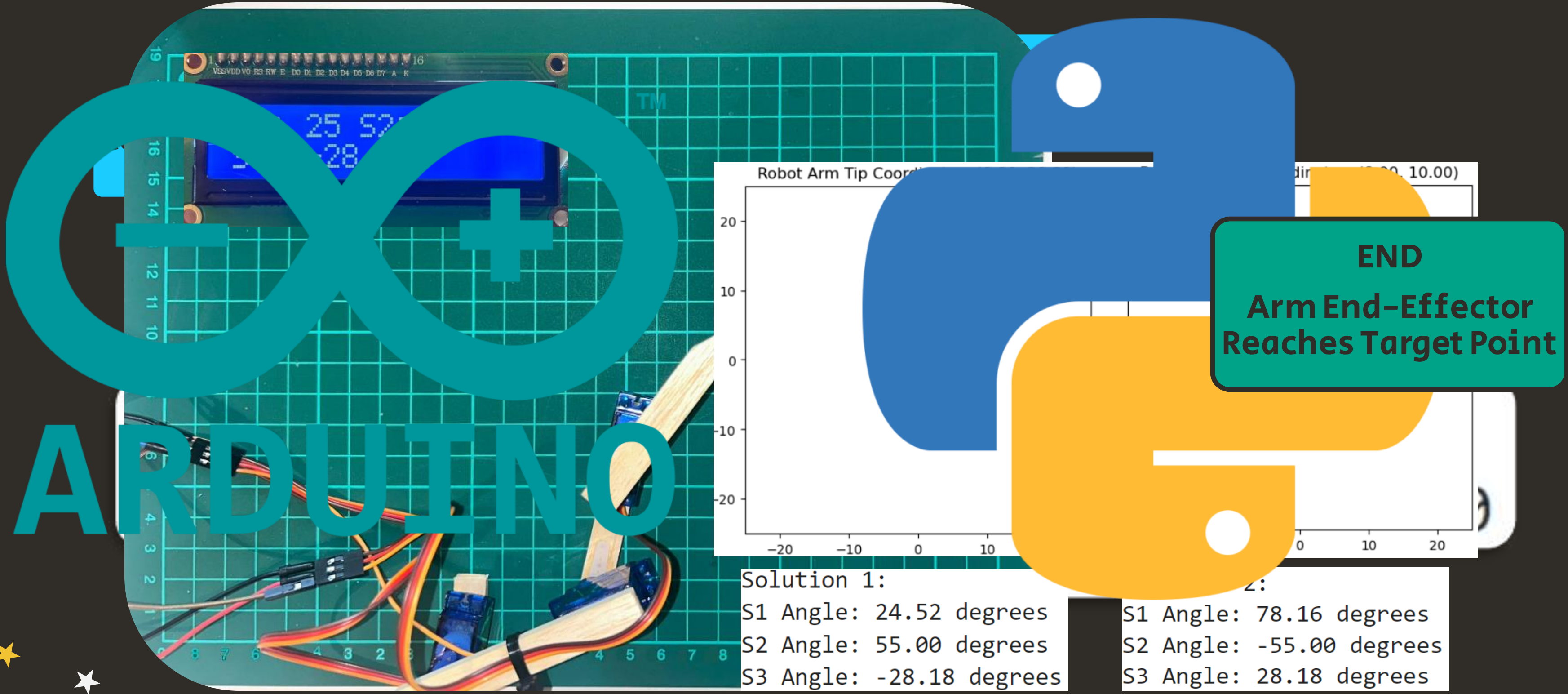
Inner Structural Material

- Specific Strength
- Fatigue Resistance
- Thermal Expansion
- Specific Stiffness
- Specific Price

Nextel + Aramid Fibres

PEEK IM Carbon Fibre

Robot Arm Control



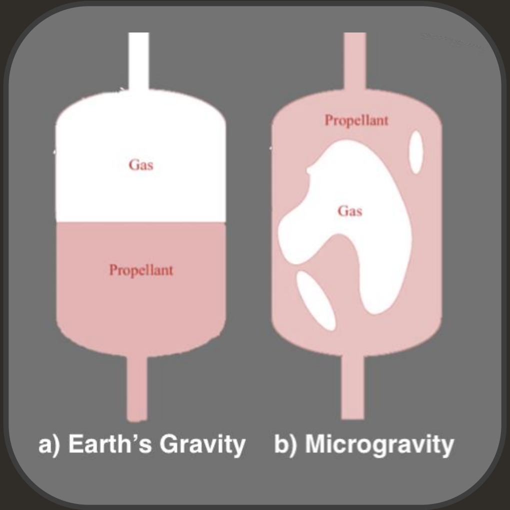
Fuel Pumps in Microgravity

Challenges

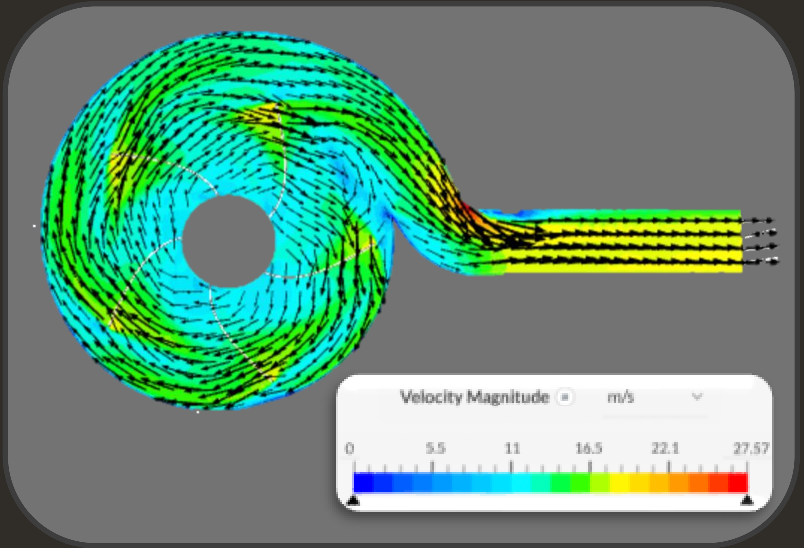
- Microgravity
- Surface tension
- Bubbles forming due to sloshing of fuel in the tank

Solution

- Centrifugal pump



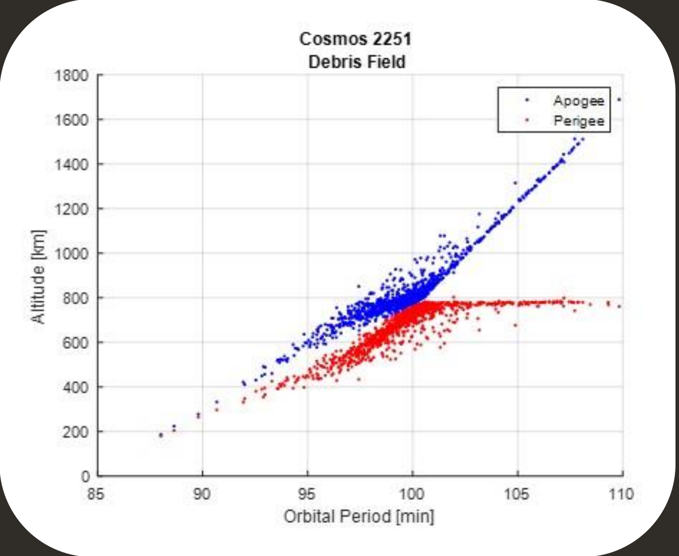
Surface Tension at Different Gravities



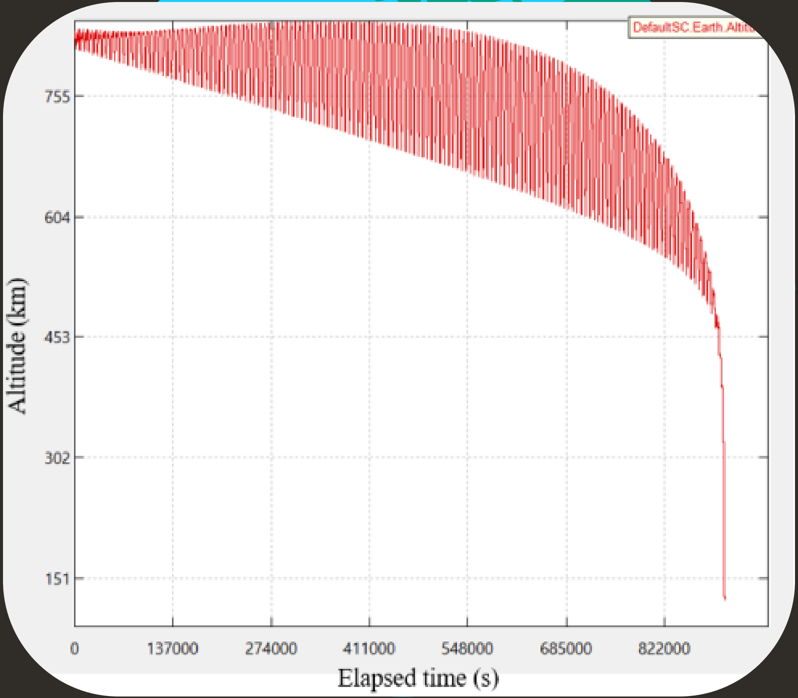
Centrifugal Pump Simulation

Debris Mitigation

- Collision Consequence
- Kessler Syndrome
- Drag Augmentation reduces decay to <10 days



Debris spread from collision



Orbital Decay of CubeSat with EDT

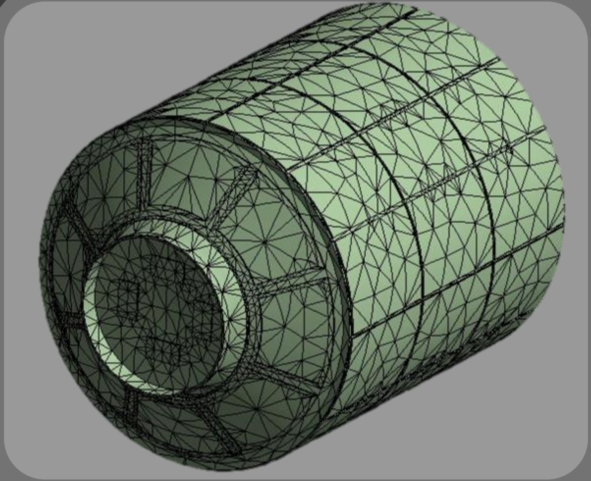
Structural Integrity and Material Selection

Challenges

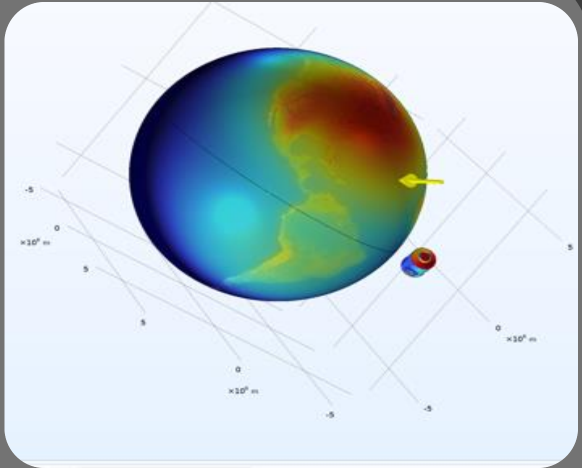
- Structure of our module
- Extreme Thermal conditions
- Micrometeorite impacts

Experiments

- Whipple Shield Impact Simulation (Ansys)
- Thermal Variation Simulation (COMSOL Multi Physics)



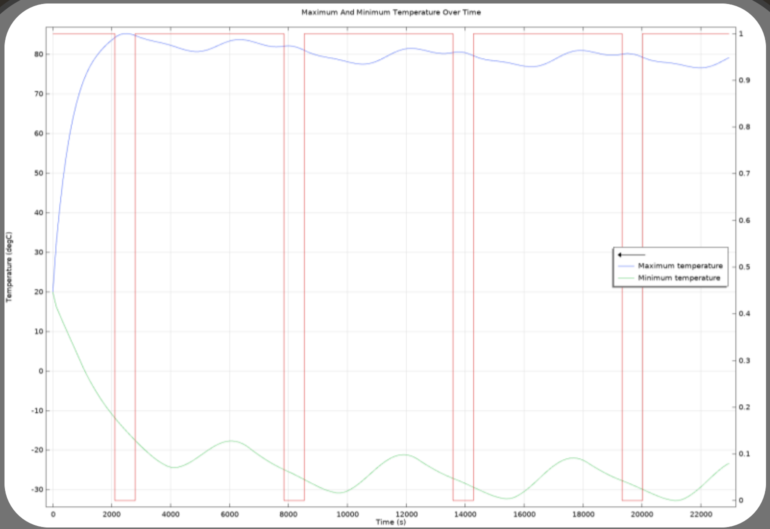
Module CAD Model



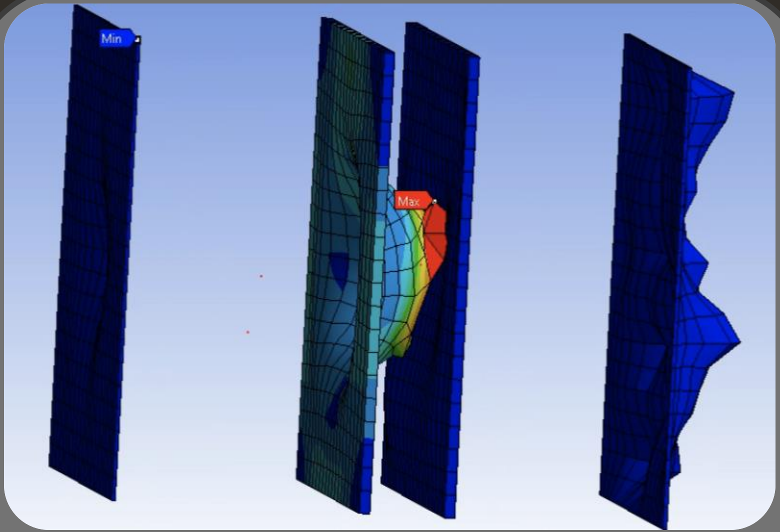
Thermal Variation Simulation

Simulation

Chosen Material:
Al 6061 + Spectra1000 + PI + Al 6061

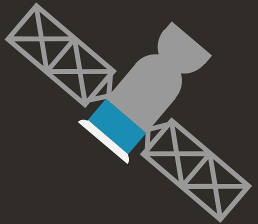


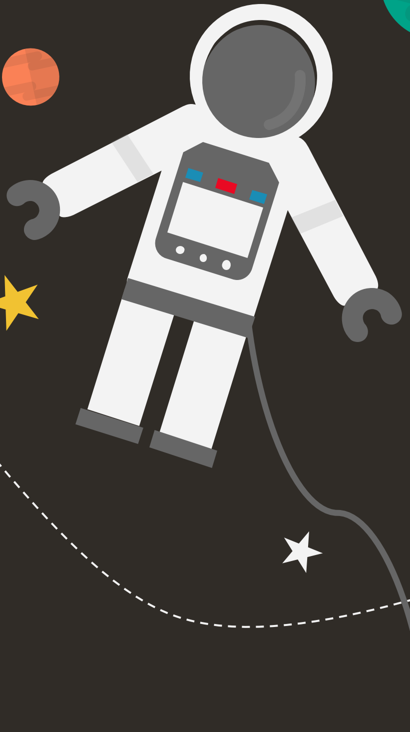
Temperature ($^\circ C$) obtained against Time (s)

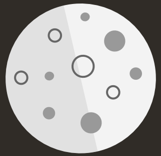


Ansys Impact Simulation

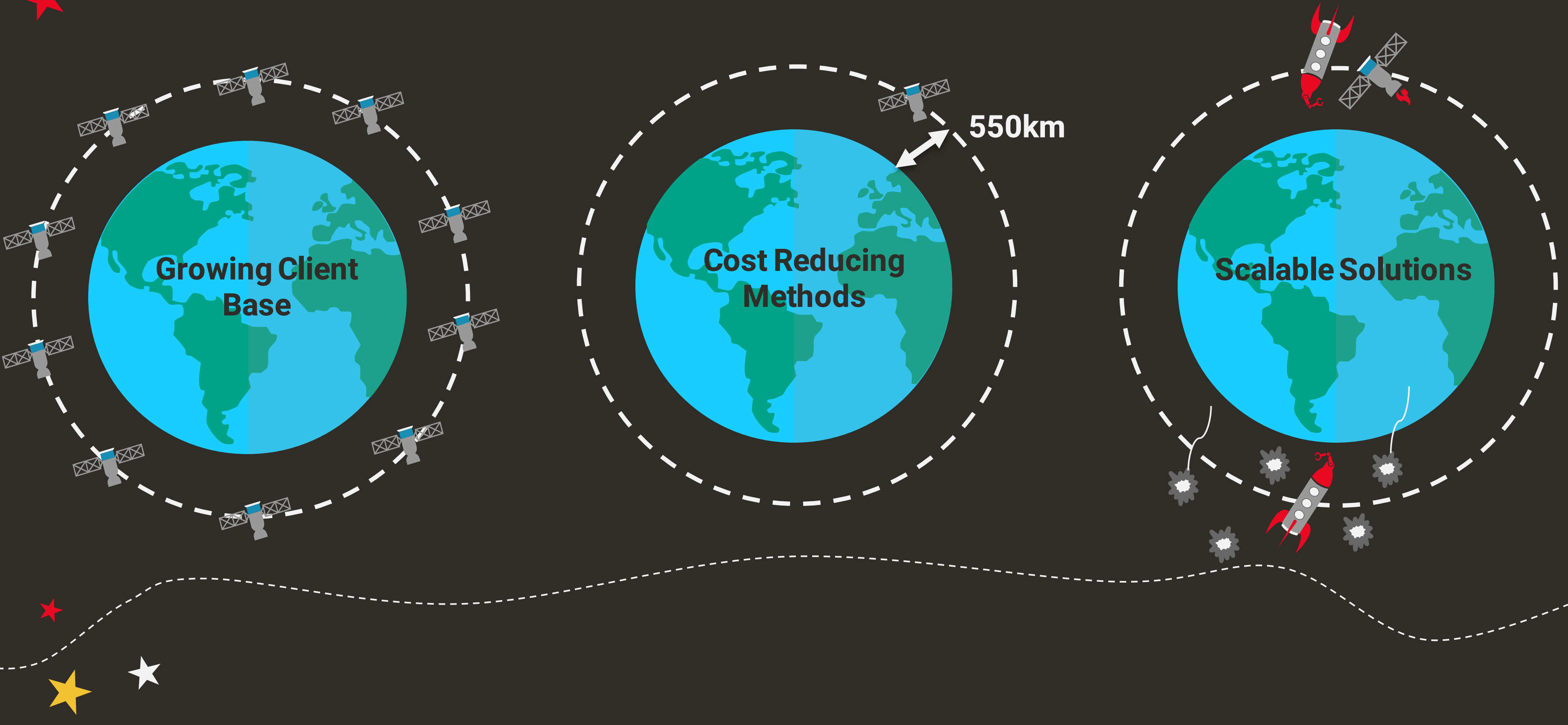
04 Project Overview and Next Steps







What is Beyond Fuel?



Further Improvements

Automated rendezvous and soft capture mechanism

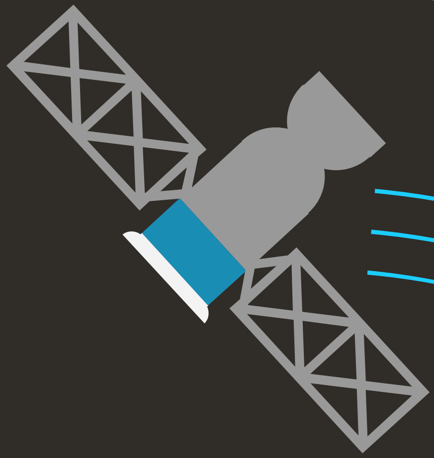
Use of different drag augmentation devices

Further experimentation into fuel storage and pumps

Implementing fatigue, wear and vibrational testing

Integration of AI in robotic arm command and control

Thanks



Do you have any questions?