Mission Overview with Concept of Operations (ConOps)

D3 – Deorbit Drag Mission

Rev 04-16-2025

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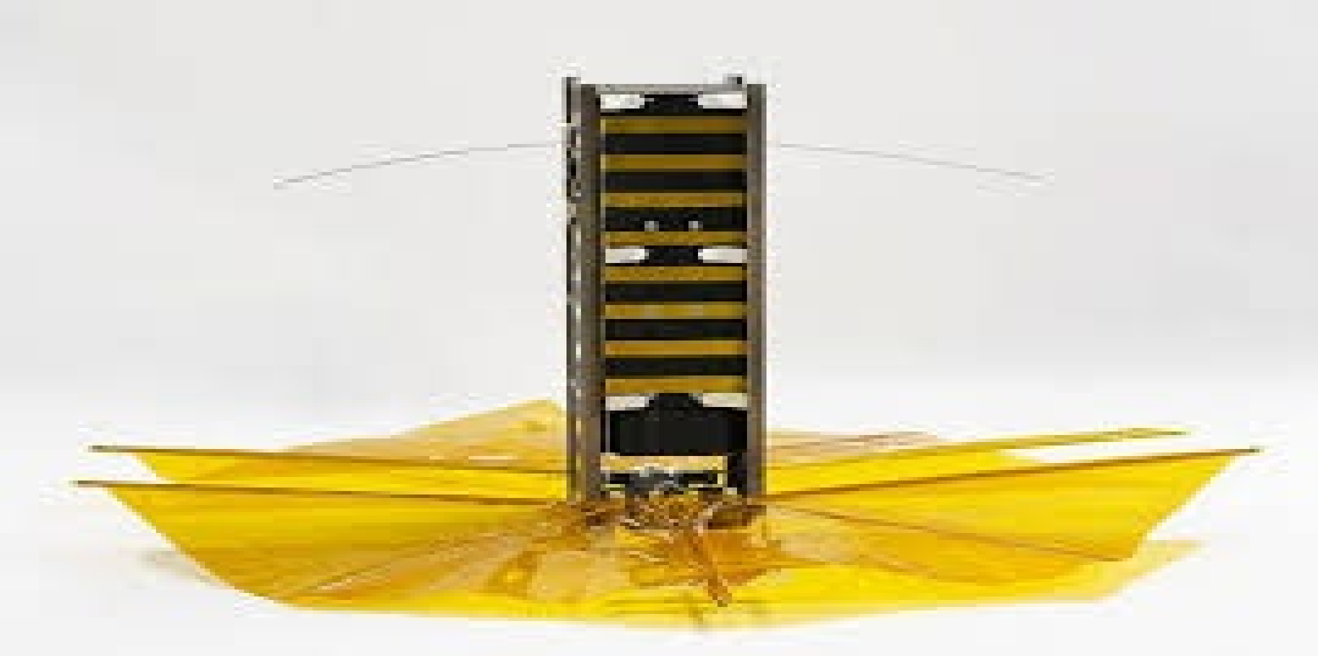
Maneuvering without Thrusters! What a Drag…

Drag devices are designed to deorbit and maneuver spacecraft naturally, by leveraging the molecular density of low Earth Orbit (LEO). The technical details of various designs may differ, but they all typically work the same way.

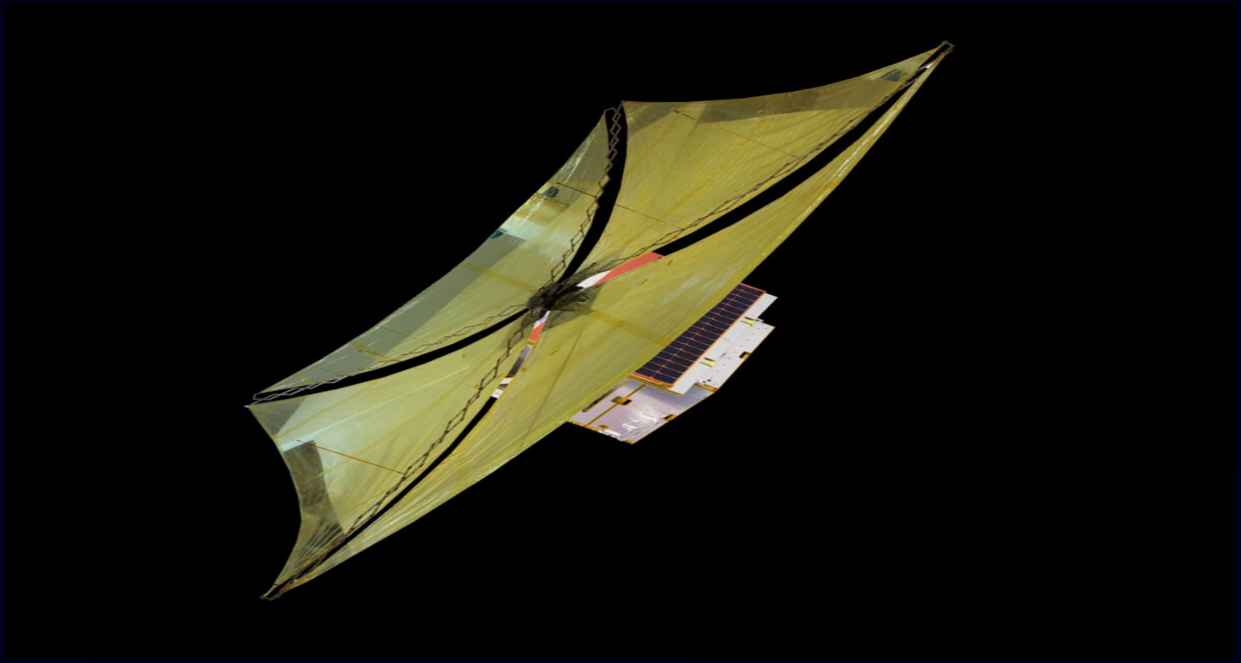
Drag is Nothing New:

Credit: Vestigo Aerospace

Credit: Millennium Space Systems



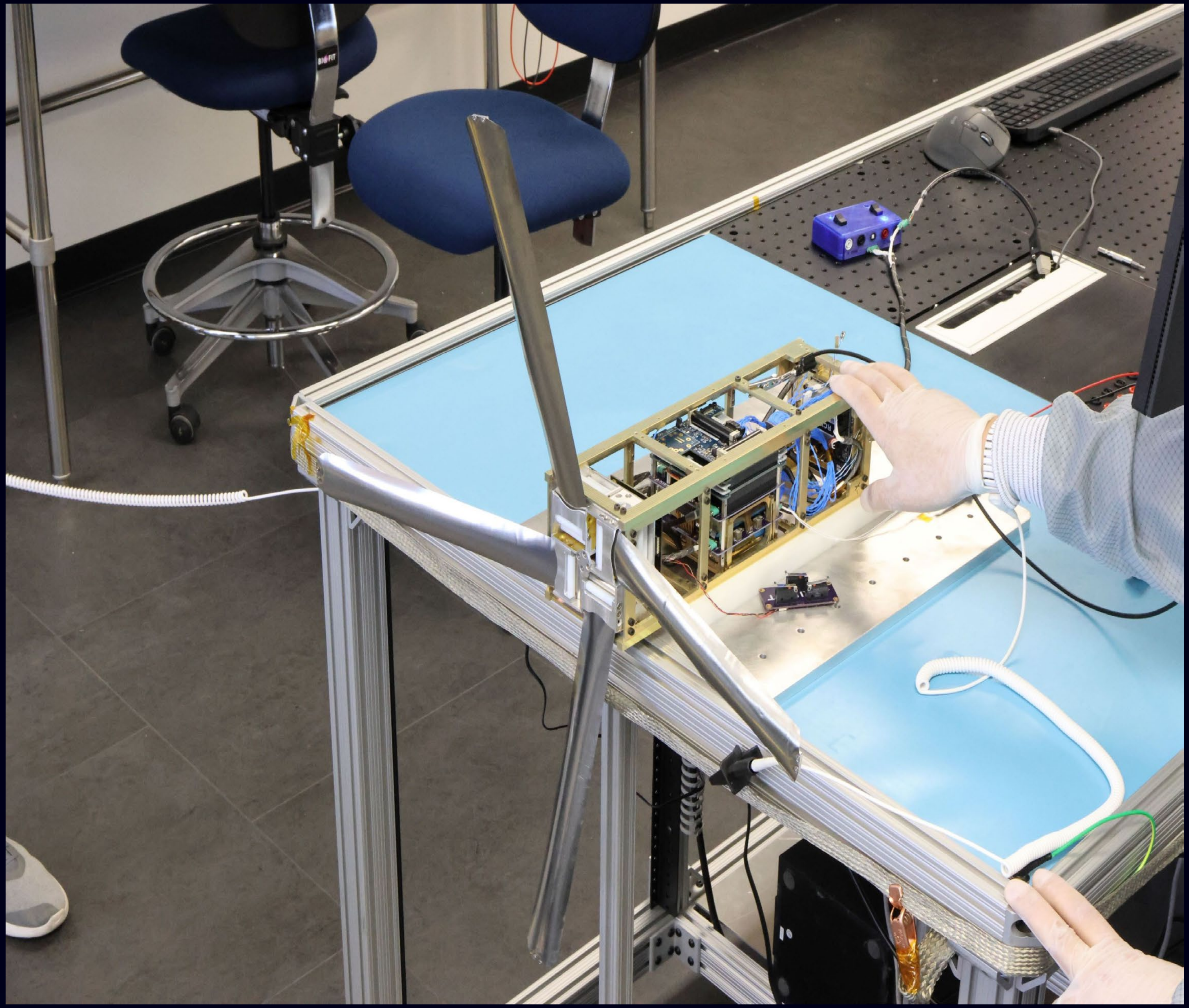
Credit: NASA



Credit: MMA Space

Can you guess my favorite Drag Device? <u>Hint: D3</u>

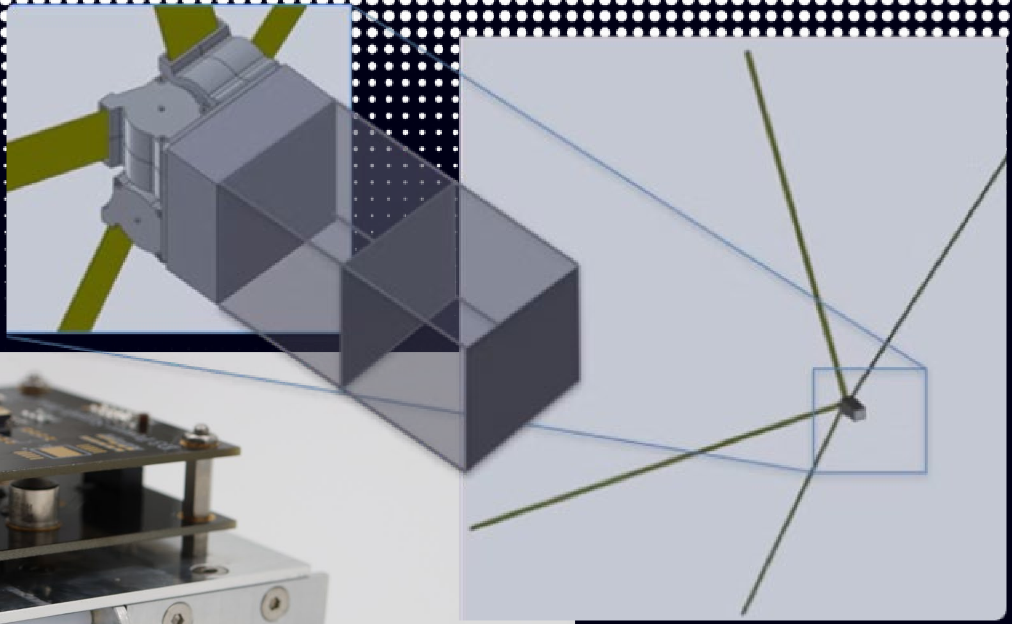
Credit: Orbotic Systems, 2021

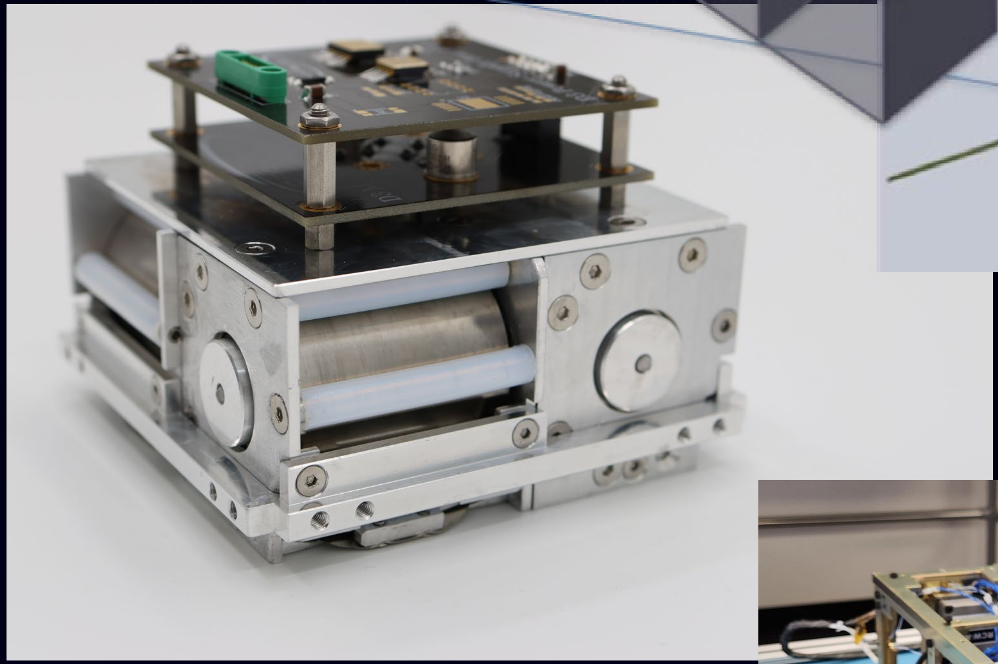


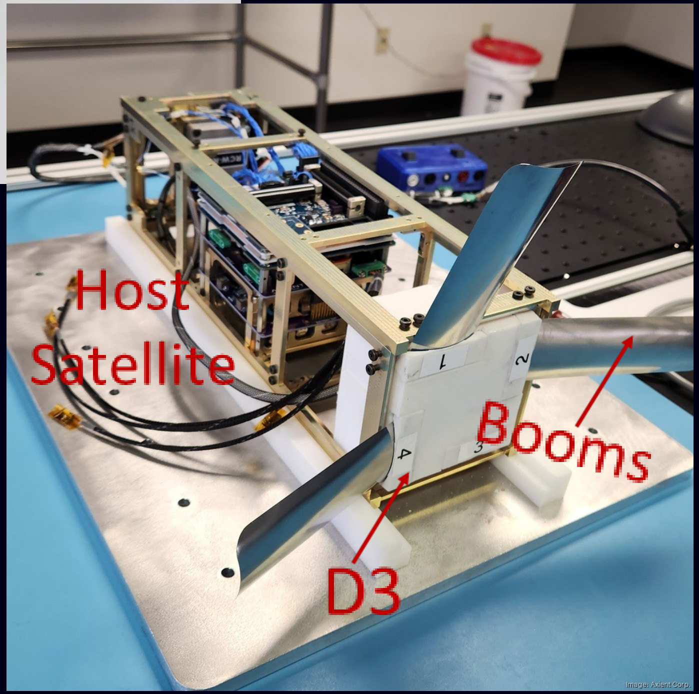
Credit: AXIENT Space, 2024

Solution Benefits

- Complies with FCC ‘Five-Year Deorbit Rule’
- No explosion risks or hazardous materials
- Passive deorbiting at end of mission
- Cost considerably less than thrusters
- Low power use and simple integration
- Deorbit from any altitude up to 700 km
- Can replace expensive ADCS systems
- Quickly produced and replicated (120 days)
- Does not require ITAR
- Allows for late-stage spacecraft integration







FCC Compliance

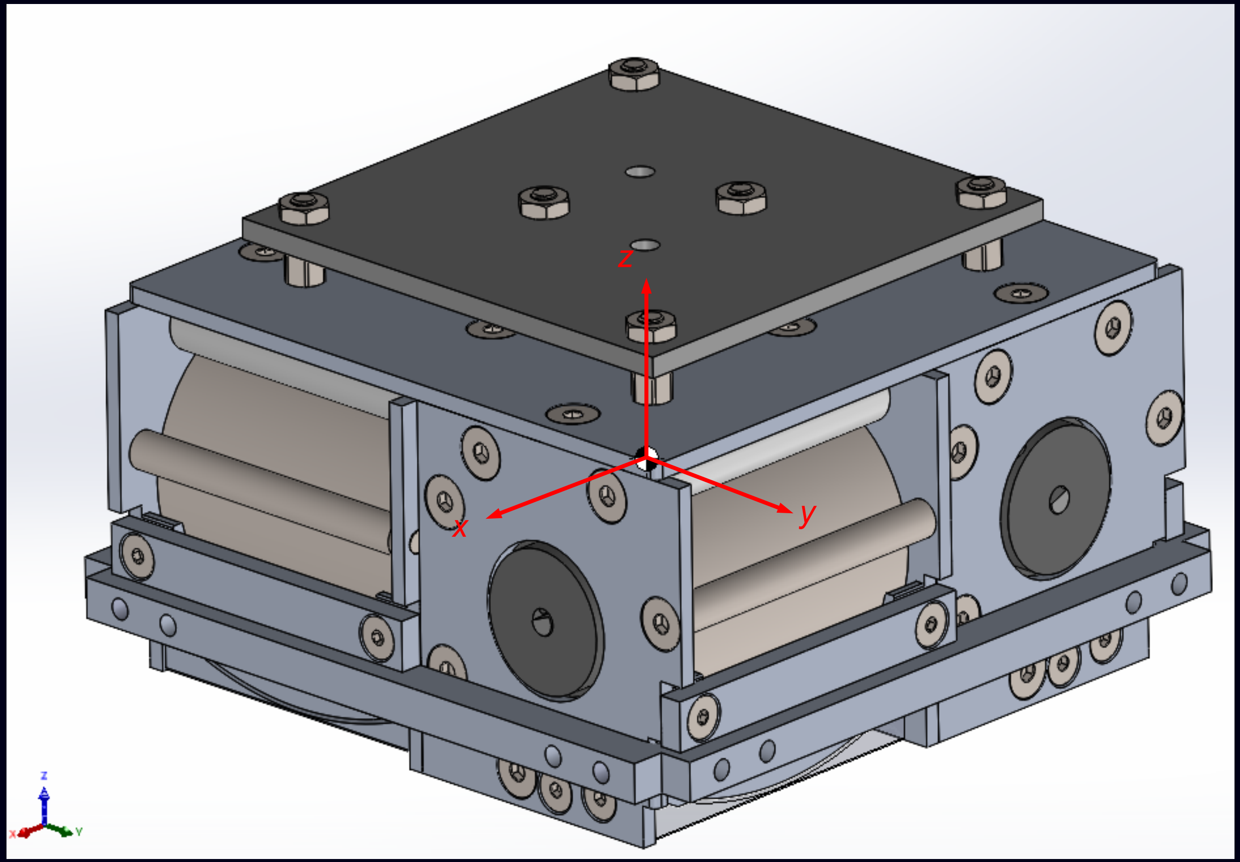
Satisfies the FCC's five-year deorbit rule.

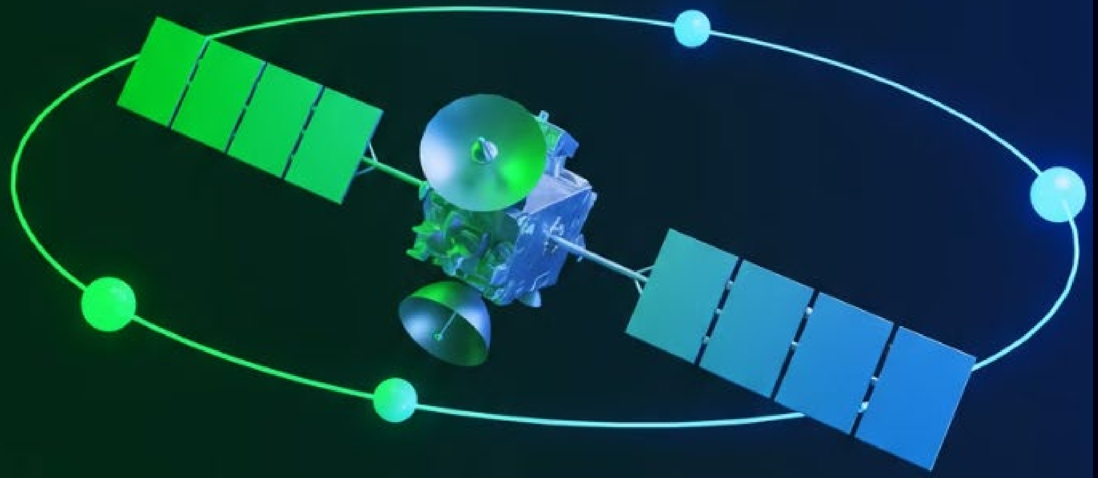
Safety and Reliability

No explosion risks or hazardous materials, ensuring safe and reliable deorbiting.

Mass Properties of D3

Mass	~934 g
Moments of Inertia (g-mm2)	
Ixx	733695.89
Iyy	733695.88
Izz	1153879.37





D3 Physics Overview

1 Orbit Lifetime Factors

Orbit lifetime is influenced by various factors, including ballistic coefficient, atmospheric density, solar activity, and gravitational effects from the Earth and Moon.

2 Ballistic Coefficient

The ballistic coefficient is a key parameter that determines a spacecraft's resistance to atmospheric drag. Increasing the ballistic coefficient extends orbit lifetime.

3 D3's Role

D3 modulates its cross-sectional area by deploying variable booms, effectively altering the ballistic coefficient and atmospheric drag to control its altitude decay profile.

4 Atmospheric Density

Atmospheric density on-orbit can vary significantly from predicted models, posing a challenge for D3's robust design and closed-loop control system to accommodate these variations.

Additional Benefits (Gets Better)

- Allows for maneuvering and attitude control.
- Multiple missions per launch.
- Lower launch payload weight/mass.
- Low complexity (less that can go wrong).
- Stagger spacecraft constellations.
- Improve radar visibility (greater surface area profile).
- Collision Avoidance Maneuver (CAM).
- Target unpopulated re-entry points.
- LOW COST

D3 On-Orbit AXIENT Mission Objectives

Rate of Change (ROC)

Demonstrate that D3 Satellite's increased drag profile with booms deployed at various lengths will result in a controlled rate of change.

Drag Analysis

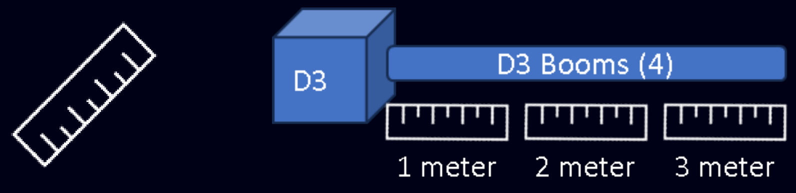
Anchor analyses for drag and orbit lifetime. Compare against 5 year deorbit calendar.

LEO Functionality

Validate D3's mechanical and electrical functionality in a LEO environment under multiple boom adjustments.

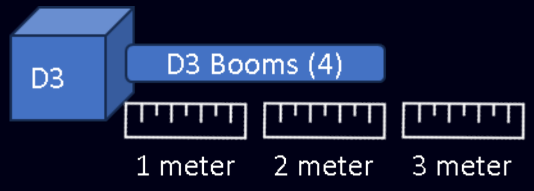
D3 On-Orbit Boom Adjustment (Tests 1-4):

1



2

3



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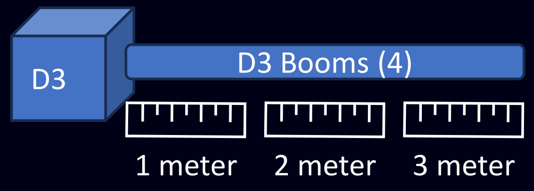


1

D3 Pre-Deployment

Obtain Two Line Element (TLE) values and stabilize orientation. Fully Charge D3 Satellite Battery.

2

D3 Extension/Retraction (Rinse & Repeat)

Extend or retract booms and satellite transmits orientation state, MET of command state changes, and measures current draw during motor operation.

3

Mission Objectives Complete

Obtain Two Line Element (TLE) values.

Calculate new orbital lifetime and compare change to previous state (Extension/Retraction).

D3 On-Orbit Deorbit Test Procedure

1

D3 Pre-Deployment

- Obtain Two Line Element (TLE) values
- Stabilize orientation
- Fully charge D3 battery

2

D3 Extend/Retract Booms (Rinse & Repeat)

- Extend/Retract booms: D3 Satellite issues extend command
- Full deployment takes about 120 seconds MET
- D3 Satellite transmits: orientation state, MET of command state changes, current draw during motor operation

3

D3 Test Procedure Complete

- Forecast D3 Satellite's new orbital lifetime (No TLE).

4

Post-Deployment

- Obtain Two Line Element (TLE) values
- Calculate new orbital lifetime and evaluate/compare change compared to previous D3 state

Final Demise:
D3 On-Orbit Deployment

1 **Satellite Passivation**

The satellite must be passivated except for power. The satellite must be oriented with the Z-axis aligned with the velocity vector. This helps to minimize the satellite's impact on space debris.

2 **Host Satellite End-of-Mission**

The deploy command is sent to the D3. The booms extend to their full length of 3.7 meters. The D3 power supplies are then passivated and the satellite passively aligns with the RAM axis.

3 **Atmosphere Ballistic Entry**

The D3 will enter the atmosphere and burn up. The demise path can be propagated using updated TLEs.

Maximum FCC-Compliant Altitudes with D3 Deorbiting

622

6U

Maximum altitude for FCC compliance with a 6U CubeSat

578

12U

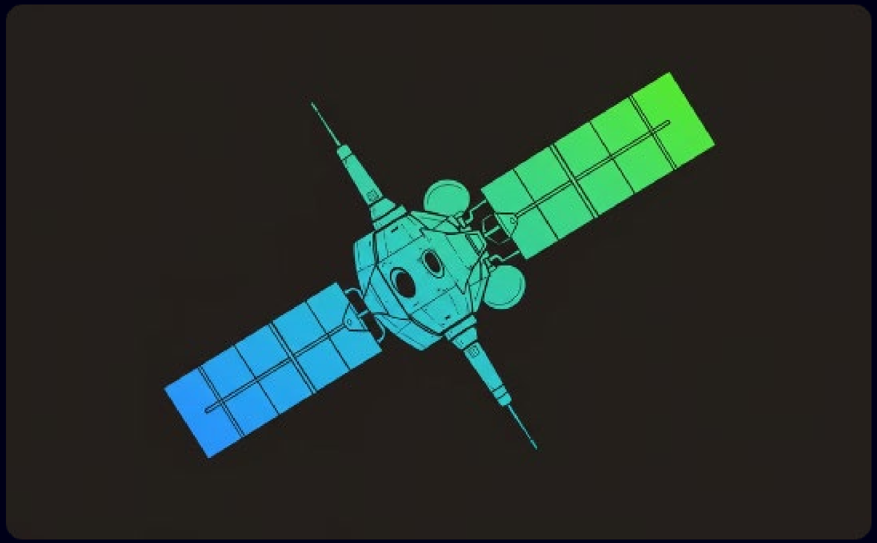
Maximum altitude for FCC compliance with a 12U CubeSat

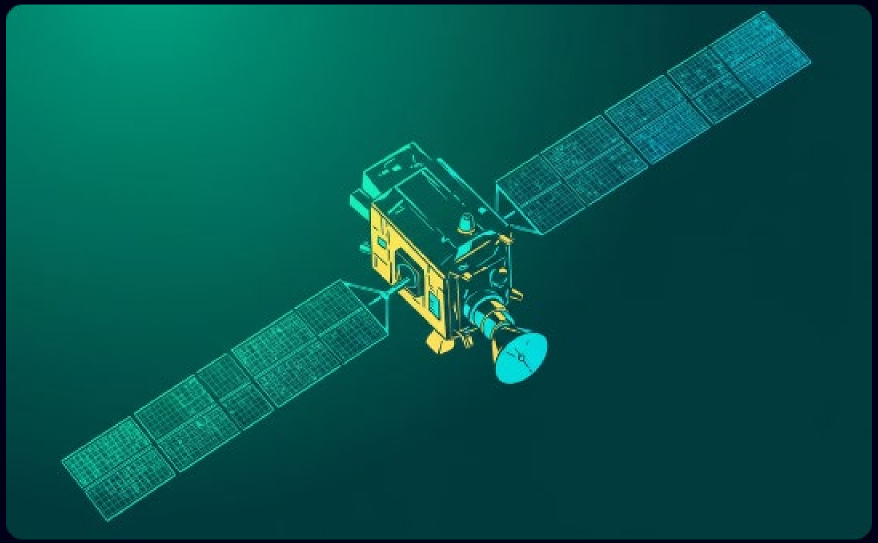
565

180 kg

Maximum altitude for FCC compliance with a 180 kg satellite

Mission Expectations and Future Plans





Drag Based Deorbiting

The primary mission objective is to demonstrate the feasibility of drag-based deorbiting using the D3 device.

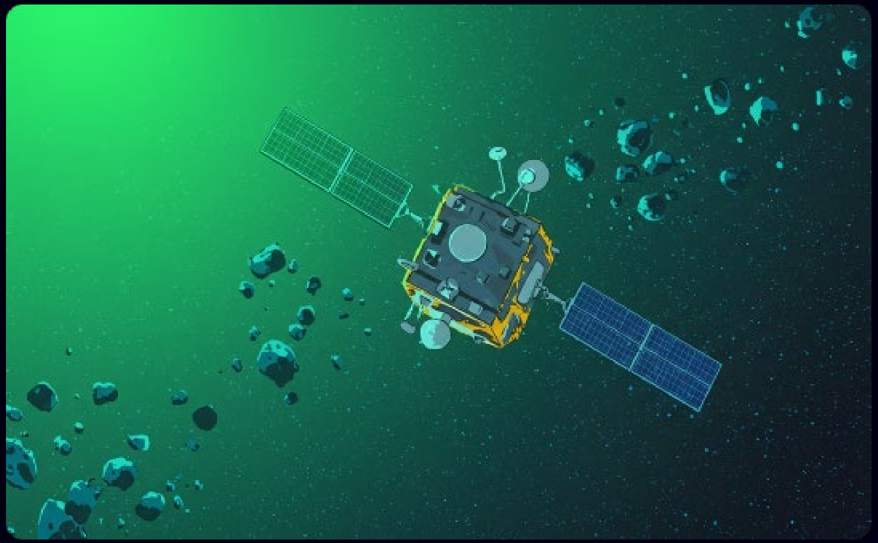
Drag Based Attitude Adjustment

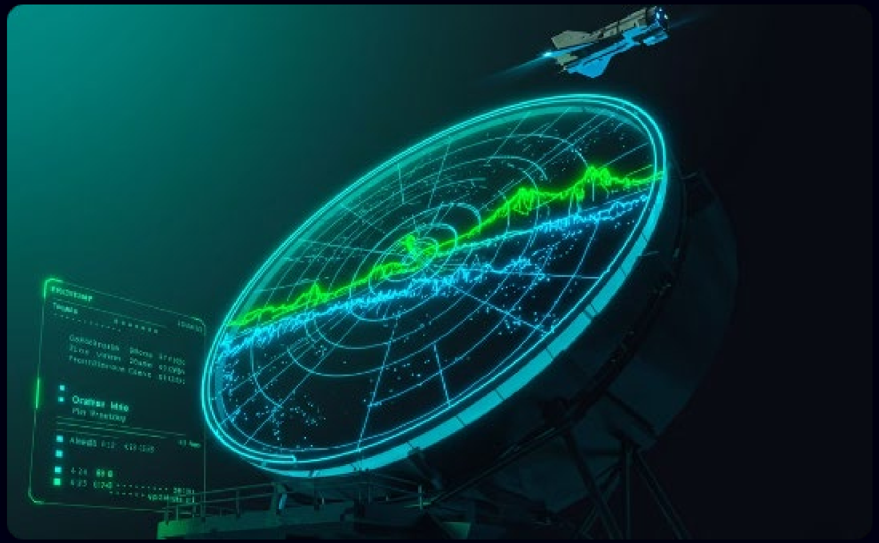
The D3 device will be used to explore the potential for drag-based attitude adjustment maneuvers.

Orbital Change Possibilities

Data collected during the mission will be analyzed to assess the potential for orbital changes using the D3 device.

Key Messages





Space Traffic Management

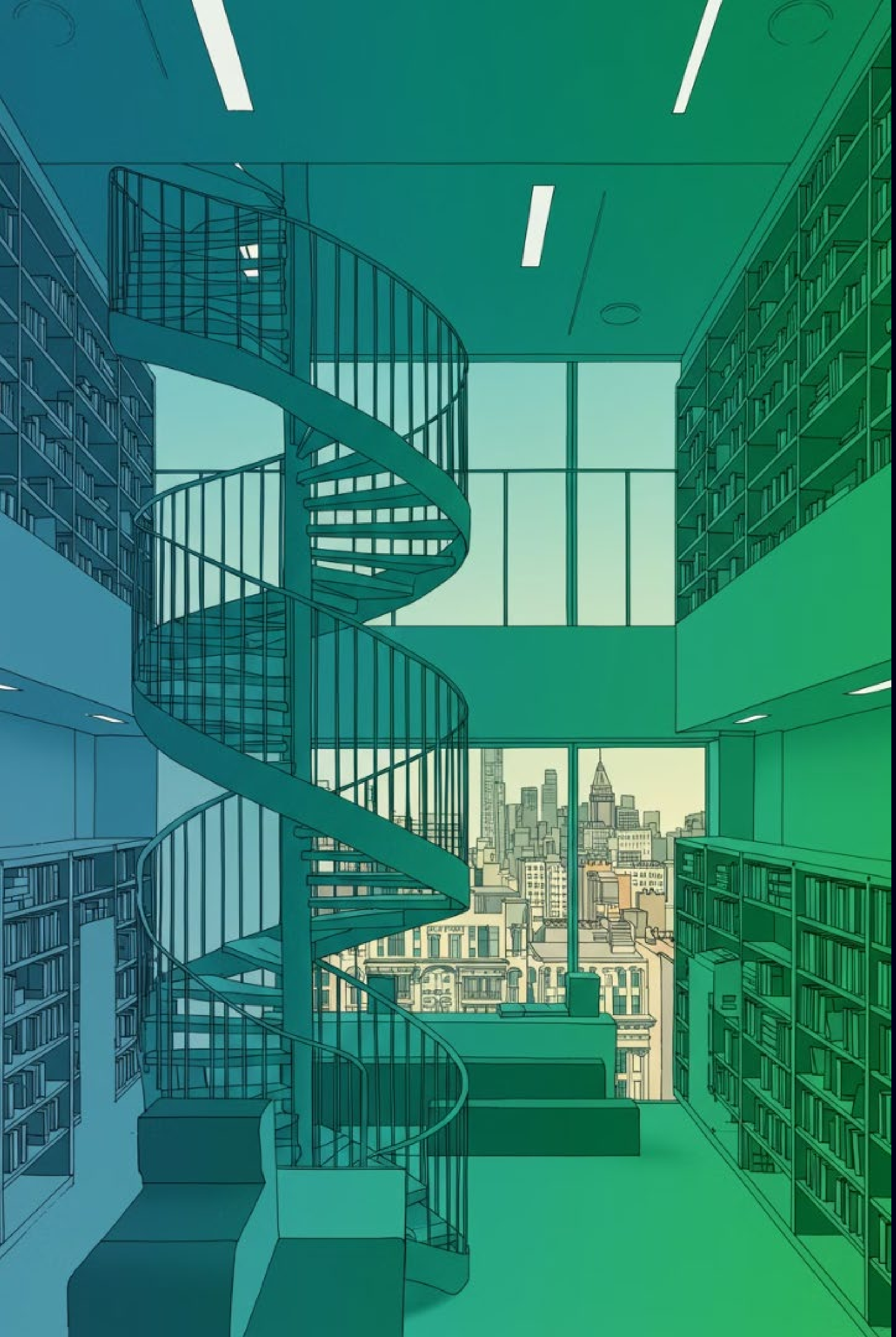
Addresses issues concerning CubeSats, such as orbital debris mitigation.

Staggered Constellations

Enables CubeSat (or other spacecraft) constellations to be staggered via differential drag force.

Improved Visibility

Improves ground radar visibility of spacecraft (greater surface area profile).



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[Large Constellations of Satellites: Mitigating Environmental and Other Effects]

Omar & Bevilacqua

[Hardware and GNC solutions for controlled spacecraft re-entry using aerodynamic drag]

Wertz, Everett, Puschell

Space Mission Engineering: The New SMAD (SME-SMAD)

Guglielmo et al.

Drag Deorbit Device: A New Standard Reentry Actuator for CubeSats

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Additional Reference Slides

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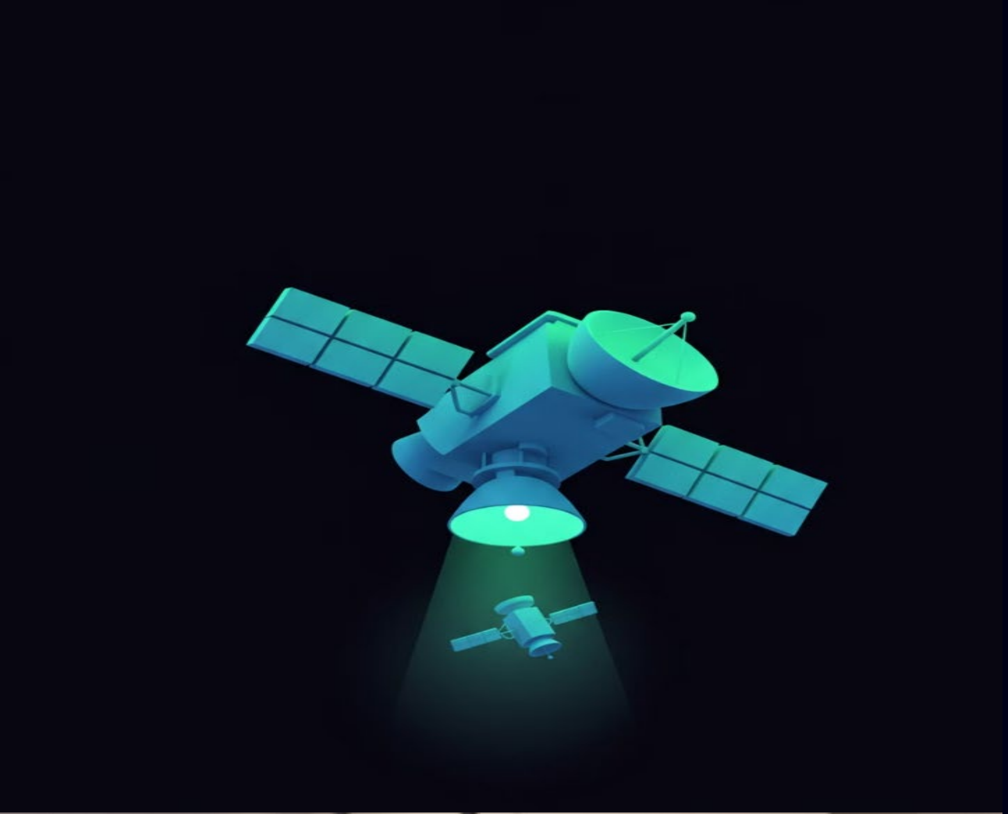

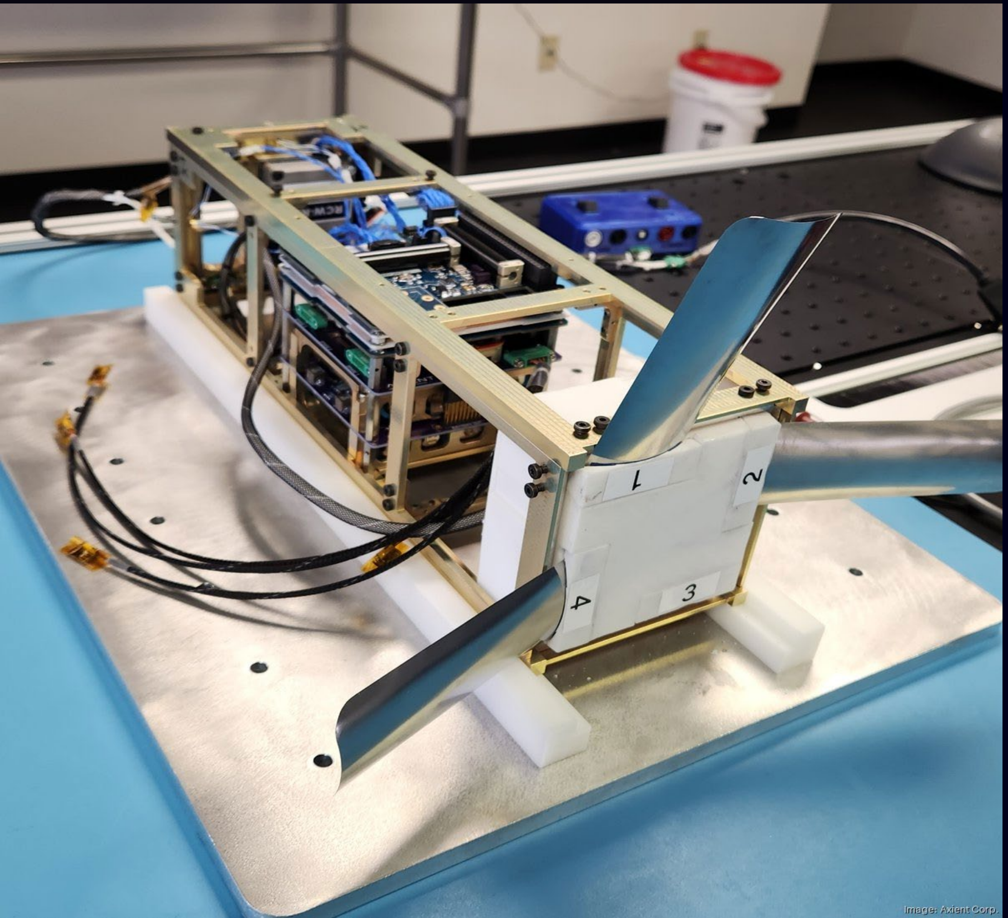

D3 Integration Process

1

D3 Delivered to Host Satellite

D3 is delivered to the host satellite.

2

Integration

The D3 device is integrated into the host satellite, ensuring mechanical and electrical compatibility.

3

Functional Test

A deployment command is sent to the host satellite, triggering a partial deployment of the booms. The host satellite partially deploys booms about 15cm.

4

Power Consumption

The power consumption is approximately 4 Watts for 5 seconds, with 1 Watt per boom. The current is 0.25 amp per motor and the voltage is 5-12 VDC.

D3 Success Criteria

Compatibility

D3 meets CubeSat Form Factor specifications for compatibility with the deployer and LEO environment.

- Deployer ICD verification (pre-flight)
- Orbital Debris Analysis Report (ODAR)
- Fatigue testing: 500 deployment/retraction cycles
- Vibration and thermal-vacuum tested (GEVS)

Deployment

D3 deploys successfully after the Host Satellite primary mission, with verification through tracking and radio contact.

- Track CubeSat with ground radar
- Radio contact with Host Satellite

Boom Operation

D3 boom operation changes the cross-wind area and ballistic coefficient of the CubeSat, altering its orbital behavior.

- Host satellite commands motor position
- Track difference between JSpOC TLE's and CubeSat GPS data
- Track difference between JSpOC TLE and orbit propagation values

Attitude Control

D3 stabilizes the CubeSat's attitude in LEO using its booms, with minimal momentum transfer to the host satellite.

- Booms can be used to stabilize attitude in LEO
- D3 boom momentum transfer to host satellite are negligible

Orbital Lifetime Test Cases: 6U and

Altitude (kilometer)	Host Spacecraft Mass (kilogram)	Reference	Host Drag Area (square meters)	Orbital Life Without D3	Orbital Life WITH D3	Compliant with FCC
400	12	6U	0.02	2.8 years	49 days	YES
	24	12U	0.04	2.8 years	84 days	
	180	SCISAT	2.81	115 days	100 days	
500	12	6U	0.02	28 years	234 days	
	24	12U	0.04	28 years	1.3 years	
	180	SCISAT	2.81	1.9 years	1.6 years	
622	12	6U	0.28	100+ yrs (never)	5 years	
578	24	12U	1.06	100+ yrs (never)		
565	180	SCISAT	14.06	31.8 years		

Notes

- Baseline commercial D3: 1.1kg and RAM area is 0.51 square meters
- CubeSat mass is 2kg per U
- SCISAT is a typical small satellite that weighs a little under 180kg. Launched in 2003 to 650km altitude and is still in orbit
- For 180kg satellites: D3 boom area grows 22-fold for FCC compliance

Assumptions

- 21 gravitational harmonics
- nrlmsise-00 density model
- Moon and sun attractions included
- Cd is the standard 2.0
- Decay altitude set at 120km