**CubeSat report rough**

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**-Physical design**

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- Frame Material choice

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**Introduction**

-Growth of space industry

https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-the-1-point-8-trillion-dollar-opportunity-for-global-economic-growth

-Space Debris problem

-Interest in Demise

-Mission details

-Cubesat intro

-What will be covered in the report

The space industry plays a key role in modern society, driving technological innovation, supporting global communications and addressing challenges such as climate monitoring and disaster management. Satellites in orbit enable GPS navigation, weather forecasting and internet connectivity, all of which are deeply ingrained in daily life. Looking ahead, the industry is expected to grow rapidly, with projections estimating the market to reach nearly $2 trillion USD by 2035. Much of this growth is being fuelled by increasing involvement from the private sector and new markets in areas such as space tourism and asteroid mining. We’ve already seen some of this growth come to fruition, with SpaceX having launched over 4,000 satellites in the past five years for their Starlink Satellite constellation. Furthermore, we’re expecting to see the worlds first Space Hotel in the not-too-distant future – Voyager station is expected to open in 2027. With all this new interest Earth’s Orbit is going to become a much busier place.

However, this comes with its own set of issues. Global space agencies are already tracking over 25,000 objects in low earth orbit, with over half of it being classed as debris or rocket bodies. However not all objects are being tracked, with the European space agency estimating there could be 130 million space debris objects larger than 1mm in diameter. The source of this debris is often collisions or explosions of defunct satellites or rocket bodies left in orbit. Given this level of debris is only from 70 years of the developing space industry, it’s clear that the issue could compound uncontrollably if ignored– as described by the Kessler effect, where a chain reaction of colliding space debris leads to the accumulation of debris, eventually rendering low Earth orbits unusable for space missions due to the high risk of collisions with debris. This has led to an increased interest in re-entry dynamics as de-orbiting spent satellites or using reusable vessels has become more of a priority. Being able to predict how an object will interact with the atmosphere during re-entry is key to designing vessels with efficient demise, or that will survive re-entry for reuse or recovery. In the long term, this understanding could also be crucial to protecting the environment from potentially harmful materials that are released during re-entry.

The current understanding of how any specific material or geometry behaves in the hypersonic environment of re-entry is limited, as ground testing facilities can’t effectively replicate the high enthalpies and high speeds in conjunction with each other. Furthermore, facilities that are capable of high enthalpies are limited to short test times, meaning test models are limited to small sizes. The fixed nature of these tests does not allow for much or any change in orientation, so fails to accurately replicate tumbling that would be present during re-entry of a satellite of certain geometries.

This is the problem this project aims to address, by developing a commercially available CubeSat platform that allows for the standardised testing of heatshield materials in the hypersonic conditions of re-entry. In addition, the environmental impact of the material on the ionosphere will also be examined.

CubeSats are a modern standardised classification of microsatellites that make small space missions more cost effective through the use of standardised commercially available parts and services. Launch providers offer rideshare opportunities for different CubeSat geometries for a reasonable price, allowing many to be deployed in a single launch, often alongside the primary load. A CubeSats geometry is often described by its volume in the “U” unit, which roughly describes a 100mmx100mm cube, these units are then arranged in a variety of geometries, from the simplest 1U to the largest standard configuration, 12U.

For the purposes of this project, an 8U configuration in a 2x2x2 configuration is being proposed, as it provides a sufficient volume for the required hardware and heatshield materials whilst being symmetrical in 3 dimensions. This allows a tumbling condition to be assumed as there’s no equilibrium point, allowing for even exposure of all faces of the CubeSat to the freestream. Even exposure degrades all sides evenly, keeping the internals within their operating region for as long as possible while allowing multiple materials to be tested simultaneously.

Recession sensors placed within the test material will be used to measure the degradation of the ablatives during re-entry alongside a set of thermocouples to track temperatures on the inside faces of the heatshield. The Environmental impact of the materials will be examined by an optical spectrometer which will observe the emission spectra of the demising species within the hypersonic shock layer to quantify the contamination of different species in the ionosphere. This data will be transmitted back to Earth via the Iridium Satellite network, using Constructive interference from multiple antennae to direct a strong signal through the thin plasma layer formed at the back of the CubeSat.

The proposed launch date is December 2026, when space weather is predicted to be ideal for our mission and conforms with RocketLab’s - our chosen launch provider – timeline. The expected mission length is 20 days. The CubeSat will be deployed at around 400km altitude where it will perform a deorbit burn of its cold gas thrusters. At 200km measurements will start to be taken and transmitted via Iridium which will continue until demise or complete power drain. To ensure demise and eliminate the risk of dangerous ground impact, the CubeSat is fitted with a set of carefully placed thermite charges. They will self-ignite at a certain design temperature independently of any other system, destroying the internal structure apart, allowing individual parts to demise on their own. Thermite ignition is expected at around 40km altitude.

This report will begin with a comparison and justification for our choice of Launch provider. Next our Trajectory section will describe how our mission timeline was modelled with an analysis of space weather, atmospheric models and thrusters to calculate our expected mission time and ideal launch window. The Mechanical and Structural design section will use an analysis of the Launch Environment to design the CubeSat frame to survive the harsh forces and vibrations during launch, as well as internal component placement. The electronics section will explain how data will be processed and successfully transmitted through the iridium network, before describing the how the power budget is being managed. Following that, the instrumentation section will describe the various design choices that went into selecting components and sensors, before describing their use. Most importantly, this section describes the altitude tracking system, attitude control system, and atmospheric composition analysis. Next the Aerothermal section describes the expected environment during orbital and re-entry periods through several simulations and calculations, informing the expected demise window and maintaining the internals in their operational temperature window. Finally, the estimated costs and expected risks of the project will be summarised briefly, before concluding statements are made.

**Surviving Launch**

While the thermal attributes of the CubeSat were designed to survive the harsh environment of space, it was necessary to design the mechanical aspects of the CubeSat to survive the launch phase. Two major causes of failure were considered. The first was resonance, which considers the random vibrations during launch and ensures they do not induce large enough vibrations in the CubeSat such that the frame fails. The second was acceleration loading, which considers the load through the CubeSat during launch due to its self-weight at the high g-forces it would experience during launch.

**Resonance**

Modelling

Figure 2 shows how the CubeSat was modelled for vibrational analysis, a frame with n frames and m columns, whilst being symmetrical in the x and y axis. The bottom floor is fixed to the baseplate, where the vibrations enter the system. Each floor is assumed to hold an equal portion of the total CubeSat mass. It followed to model this as a horizontal mass-spring system, with the bending of the supports producing spring-like action. The spring constant was calculated from the support height, second moment of area and the Youngs modulus of material, as shown in Figure 2 and below. This analysis only considered horizontal vibrations as vertical vibrations are prevented by the fixed baseplate, and any elastic behaviour along the length of a strut is considered negligible when compared to the horizontal displacements of the floors.

A line on a graph paper

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Figure – HLT page 130

The analysis point of figure 1 was taken as the midpoint between each floor such that and where h is floor height and is the horizontal floor displacement. Substituting and rearranging into the form to find the spring constant gave the following.

A diagram of a floor

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Figure 2

The equations of motion of the modelled system can be expressed in matrix form as:

Where is a vector of horizontal floor displacements and is the floor mass. The comes from summing the spring constants of all supports within the square shape.

Assuming a sinusoidal solution for with natural frequency gives:

Solving for gives us the natural frequencies of the system. Ideally, we design these frequencies to be in the low power areas of the vibrational power spectral density – shown in figure 3. It is important to note that this analysis assumes no damping, which means that the real system would have resonant peaks at slightly different frequencies to those calculated by this method.

Vibrational PSD for RocketLab Electron launch


Figure 3 – Following the CubeSat plot. From Electron User Payload Guide

Simulation

Figure 3 shows the power spectral density (PSD) of random vibrations the CubeSat would experience during launch. Using MATLAB, the PSD was used to generate a set of sample signals to simulate the system vibrations. Summing these signals into the time domain produces a single signal. The flowcharts in Figures 4,5 and 6 describe the entire process.

A diagram of a flowchart

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Figure 4 – Overall flow chart of vibrational analysis program

With the PSD’s maximum frequency being 2000Hz, to avoid aliasing the signals, a dt of seconds was chosen, for a sampling rate of 4000Hz, satisfying the Nyquist frequency limit.

The natural frequencies are calculated using the process described in the modelling section prior.

A diagram of a machine

AI-generated content may be incorrect.A diagram of a flowchart

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Figure 5 – Simulate in Time block Figure 6 – Generation of base acceleration signal

Validation

Due to the relatively simple modelling approach, validation of this simulation was achieved by comparison of a solved base case – the single mass-spring system with a sinusoidal forcing function, for which the equation of motion for is:

This has two different solutions depending on the value of . The first is where giving;

Which is simply a sum of coherent sinusoidal functions, which produces a single output sinusoid.

The second case is where ; which has the solution:

Which produces a sinusoid which has a growing oscillatory response, bounded by the line , showing resonance.

To test this base case, a two-floor model was used, with a single, manually generated sinusoidal input. The two-floor model matches the single spring -damper model due to the single set of supports between the base and the only unfixed floor. Firstly, the case was tested in a 1 second simulation, as shown in figure 7.

A screen shot of a graph

Description automatically generated

Figure 7

Floor 1 is the fixed floor, which showed some movement as the displacements are all taken relative to the n-1 displacement of the fixed base. Otherwise, the second floor behaved as expected, following a sinusoid of fixed amplitude

The same parameters were tested again, using an input signal at the systems natural frequency