CubeSat Project Logbook

Team B

Fizza Naqvi

# Common part

## Team members

Claudio Vestini

Alex Berresford

Fizza Naqvi

Hani Moussa

## Code of Conduct

This Code of Conduct establishes guidelines for behaviour and collaboration among members of the Team B group. We aim to create a respectful, inclusive, and productive environment for all participants.

## Summary of the project and objectives

This project involves the design of a CubeSat intended to investigate material behaviour and satellite demise during atmospheric re-entry. The primary objective is to test different ablative materials mounted on the exterior of the satellite, assessing their performance under extreme thermal and mechanical loads during hypersonic descent. The satellite will be equipped with sensors to capture data on heating rates, ablation, and structural integrity.

A secondary objective is to evaluate the environmental impact of re-entry, by analysing the composition of ablated material using onboard instrumentation such as a miniaturised spectrometer. The project encompasses orbital planning, controlled deorbit manoeuvres using cold gas thrusters, and the implementation of a spin stabilisation system using reaction wheels to ensure even material exposure.

By completing this project, we aim to develop a deeper understanding of re-entry physics, test the feasibility of CubeSat-based material experimentation, and contribute to more sustainable satellite design.

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# 2024-10-18 Notes and Research on possible scientific goals

# Possible scientific goals:

* Earth observation and remote sensing
* Capture high resolution images of Earth’s surface
* Could be for environmental monitoring
* Would require LEO
* Might need a polar orbit for global coverage or sun-synchronous orbit to observe the same areas under similar lightning conditions
* Would require a stable orbit
* Propulsion may be necessary due to orbital decay
* Space weather monitoring
* Measure certain space weather parameters
* Ionospheric density measurements
* Ionospheric disruption due to re-entry impact
* Validate certain technologies such as propulsion systems
* Could change orbits to demonstrate propulsion capabilities
* Debris tracking
* Have cubesat in LEO as most space debris exists here
* Active propulsion may be necessary or tracking to avoid collisions

### References

Different Types of Orbits in Space: Types & their Applications| UPSC Notes. (n.d.). Retrieved January 31, 2025, from <https://testbook.com/ias-preparation/types-of-orbits>

*Types of Earth observation satellites – JAXA Earth-graphy / Space Technology Directorate I*. (n.d.). Retrieved January 31, 2025, from <https://earth.jaxa.jp/en/eo-knowledge/eosatellite-type/index.html>

# 2024-10-21 First meeting

Present: Claudio Vestini, Hani Moussa, Alex Berresford, Fizza Naqvi

Apologies: None

Location and time: RSL Study Room 4 at 14:00

Author of minutes: Claudio Vestini

* Discussion of project organisation:
  + File system (GitHub repository, GitHub Projects roadmap (Gantt chart))
  + Google Drive folder
  + Report LaTeX file
  + References (.bib master file)
  + Meetings and WhatsApp group for communications
* Allocation of tasks (initial draft):
  + Claudio:
    - Aerothermal
    - Instrumentation
  + Hani:
    - Electronics
    - Interfaces
  + Fizza:
    - Trajectory
    - Internal heat generation
  + Alex:
    - Mechanical
    - Launch service provider
    - Launch environment
* Discussion of scientific goals:
  + CubeSat constraints dictated by launch service provider (size, weight, center of mass, electronics, stress response) - Alex
  + Ionospheric disruption due to re-entry impact - Fizza
  + Consideration of Magnus Effect during hypersonic re-entry – Alex
  + Budget analysis - everyone
  + Model Predictive Control for maintaining trajectory attitude (both in orbit and during re-entry). Use of cold gas thrusters as actuators - Claudio
  + Black box (GPS-tracked, ablative-protected) for retaining re-entry data – Alex
  + Materials testing for re-entry – Hani
  + Communications: information transfer during blackout – Claudio
  + Modelling the aerothermal environment in different re-entry stages – Claudio

### Actions

* Discuss scientific goals with supervisor

# 2024-10-22 Second meeting

Present: Alex, Claudio, Hani, Fizza, Tobias (Supervisor)

Apologies:

Location and time:LR7 at 2:00pm

Author of minutes: Alex Berresford

Briefing Tobias on our progress, file system, organisation etc

* Mendeley for .bib file for automatically referencing papers

Briefing Tobias on project ideas

* Ionosphere disturbances
* Feedback: Interesting, but a bit of a secondary goal, not directly related to re-entry
* Decided to go with this as it’s quite interesting and applicable, however it isn’t entirely related to satellite demise therefore it’s a secondary goal
* Materials for re-entry
* Use Cubesat as a test rig for materials and how they demise in extreme flow conditions
* Feedback: On topic, very current bit of research for space industry
* How would you mitigate inequalities in material conditions
* Sample sphere’s inside sacrificial shell
* We decided to go for this as our primary goal as it’s directly applicable to a demise experiment
* Altitude control using spin
* Magnus effect
* Feedback: Could be used to control material conditions to allow for testing
* Serious control problem
* Overall Feedback:
* Find rough bounds to problem through research and rough calculations
* Budget unlimited, but must be justified
* Black box vs Comms system

Both realistic, depends on specific design choices

### Deadlines

Research Tasks by 29/10/2024

-Hani – sensors for material degradation

-Claudio – Magnus effect, and realism of generating spin

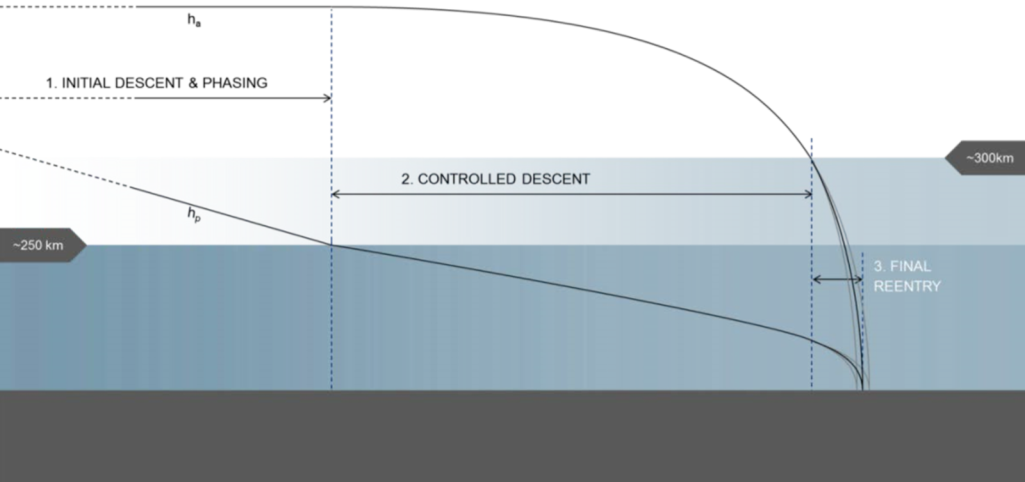
-Fizza – Look into trajectory, expected burn altitude and ideal orbital altitude as well as ionosphere

-Alex - Investigate different cubesat geometries, costs, pros, cons et. Keep up with Launch provider research

# 2024-10-25 Notes and Research on trajectory ideas and secondary objective ideas

# Burn up research:

* Typical burn up/demise altitude for CubeSats re-entering from LEO is 80-120km, although the precise altitude depends on various factors like the cubesat’s size, mass, orientation and material composition
* For small, standard cubesat sizes (1U,3U) complete atmospheric demise is expected because of the small size and simpler structure, so they break up under high temperatures caused by friction with dense atmospheric layers
* NASA analyses suggest that most cubesats will burn up entirely under 120km so there’s limited risk to ground populations [1][2][3]
* LEO is typically between 160km and 2000km above Earth’s surface [4] D4D - Design for Demise
* Space Debris Mitigation requirements state that there must be a less than 1 in 10,000 chance of someone being hit by falling space debris
* design alternatives that would cause the satellite to “disintegrate” (demise) during the reentry in atmosphere [5]
* objective of this study was to find a middle ground between complete lack of control and using a lot of energy to force re-entry over a very specific area
* spacecraft is made to re-enter the atmosphere within a set number of orbits, so that operators can predict where pieces of the spacecraft will fall
* first and last parts of the entry would be uncontrolled, but the middle part would be carefully controlled
* process requires 1000 times less force – and therefore much less fuel – than controlled re-entry, but is far less risky than uncontrolled re-entry
* much less thrust needed, satellites could use electrical propulsion systems instead of the more powerful chemical propulsion systems that fully controlled re-entry requires- much cheaper and more energy efficient [6]



* Semi-controlled re-entry is great for medium-sized spacecraft, where casualty risk could be up to five times lower using electrical propulsion systems Some form of controlled re-entry is necessary due to the growing amount of debris in LEO and also the increasing regulations relating to deorbitation
* basic approach to perform a deorbitation is to lower the perigee (point in orbit where its closest to the earth) of your satellite until the moment when the atmospheric will slowly drag the spacecraft down and make it burn or crash on ground.

Controlled re-entry:

* entering the atmosphere with a steep angle so that it ensures the fallout of the debris within a relatively small area, chosen to have a low-density population
* common practice is to enter the atmosphere with an angle of -1.5/°
* target to fall within the South Pacific Ocean Uninhabited Area (SPOUA)- largest unpopulated ocean space on the planet
* Basically have no other choice for larger satellites but we have a choice

Semi-controlled re-entry:

* semi-controlled re-entry. Instead of a specific region, one can target the fall of the debris within less than one orbit
* spacecraft only has to lower its perigee until it reaches an altitude where the drag is sufficient to slow it down progressively
* no need for high thrust propulsion systems, which makes lighter the constraints over the mission and the spacecraft
* it does not hit the atmosphere with a steep angle, the spacecraft will spend a significant time in it, undergoing complex, fluctuating and, thus, hardly predictable interactions
* Even during the last orbit, uncertainty over the remaining lifetime of roughly 10% or more is expected, meaning that a 10 min error leads to about 4800 kilometres of uncertainty concerning the impact point [reference:  Dr. Patera, Dr Ailor: “The reality of Reentry Disposal”]
* satellite makes repeated passes through low altitudes where the International Space Station as well as many other active satellites are orbiting, posing an additional threat of collision in these critical altitudes [7]
* Rough relationship between satellite altitude and lifetime: [8]

Satellite Altitude Lifetime

200 km 1 day

300 km 1 month

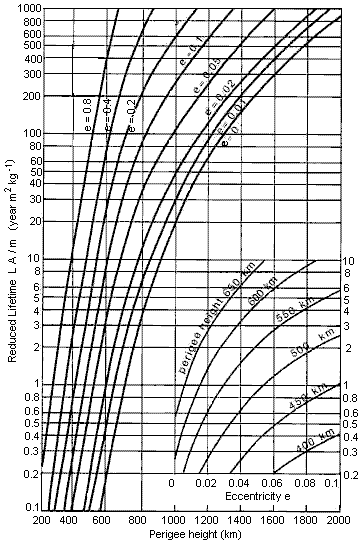
400 km 1 year

500 km 10 years

1. 100 years
2. 1000 years

* Reduced lifetime in years can be calculated from:  [reference: King-Hele (1987)]

L= L\* ( m / A )



This figure shows the relationship between reduced lifetime and perigee. Can be used to estimate the lifetime of the satellite at a specific altitude.

Trajectory research:

* de Cecio Alfredo Locarini, F. (2018). *Modeling and simulation of a CubeSat atmospheric re-entry trajectory*
* ^Thesis on modelling and simulation of a cubesat atmospheric re-entry trajectory
* Jacchia J71 model- empirical atmospheric density model; designed to predict the density of the Earth’s atmosphere at high altitude
* Most significant source of variability in predicting upper atmosphere density is represented by solar activity. When the Sun is particularly active, adds extra energy to the atmosphere heating it. Low density layers of air at LEO altitudes rise and are replaced by higher density layers that were previously at lower altitudes. Since drag force is closely related to density, in these conditions decay rate would increase

Ionosphere research:

* Ionosphere is where radio waves are reflected and refraction, enabling long distance communication
* Monitor how atmospheric composition changes as some materials might remain in the ionosphere temporarily, changing its composition
* Use spectrometers to identify specific atomic emissions
* We can compare the emission lines in the visible spectrum to the materials we’re testing, but if something we didn’t anticipate appears it can cause problems
* Also could be problematic as there may be too many materials in the cubesat that don’t relate to the materials testing but are within the electronics
* Recording and transmitting this data would follow the same mechanism as the data that is being saved from the sensors used to carry out materials sensing

### References

[1] Chandra Nagavarapu, S., Chandran, A., & Hastings, D. E. (n.d.). *ORBITAL DECAY ANALYSIS FOR DEBRIS DEORBITING CUBESATS IN LEO: A CASE STUDY FOR THE VELOX-II DEORBIT MISSION*. Retrieved January 31, 2025, from <http://conference.sdo.esoc.esa.int>,

[2] Ostrom, C. L., & Opiela, J. N. (n.d.). *ORBITAL DEBRIS MITIGATION AND CUBESATS*. Retrieved January 31, 2025, from <http://conference.sdo.esoc.esa.int>,

[3]*END-OF-LIFE CONSIDERATIONS FOR CUBESATS*. (2022). Pdf from <https://indico.esa.int/event/416/contributions/7431/attachments/4890/7502/CSID22_2_End-of-Life%20Considerations%20for%20CubeSats%20-%20presentation.pdf>

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[5]*ESA - Design For Demise – A First Look*. (n.d.). Retrieved January 31, 2025, from <https://www.esa.int/Enabling_Support/Space_Engineering_Technology/CDF/Design_For_Demise_A_First_Look>

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[7] *Basics about controlled and semi-controlled reentry – The Clean Space blog*. (n.d.). Retrieved January 31, 2025, from <https://blogs.esa.int/cleanspace/2018/11/16/basics-about-controlled-and-semi-controlled-reentry/>

[8] *Orbital Lifetimes*. (n.d.). Retrieved January 31, 2025, from <https://www.spaceacademy.net.au/watch/debris/orblife.htm>

# 2024-10-28 Third meeting

Present: Claudio Vestini, Hani Moussa, Alex Berresford, Fizza Naqvi

Apologies: None

Location and time: RSL Study Room 2 at 13:00

Author of minutes: Fizza Naqvi

* Discussion on how to get Mendeley working for references
* Hani’s research: discussion on the different types of sensors that already exist
  + Accoustic emission sensor
  + Recession sensors (used to measure how thermal protection systems are damaged as they enter the atmosphere); NASA and ESA has used this before so there’s lots of information available
  + Look into what we’re actually going to measure before deciding on what sensors we should use
  + Ensure that our experiment cannot be easily conducted on Earth
* Claudio’s research: magnus effect and MPC
  + Magnus effect at hypersonic speeds works very differently
  + Most research is done on sphere’s but calculations might be able to be manipulated to work with a cube
  + Looking at simulations- the ones that are currently available are limited as it won’t test everything we need
  + Magnus effect can be tested when we have our CAD models
  + For control: our main options are cold gas thrusters
  + Reaction wheels- cheapest, easiest to manufacture, least risk involved but takes up lots of space, quite heavy
  + other forms of thrust such as hypergolic- mainly used in thrust systems in capsules or small satellites; easy however it’s extremely toxic; slightly more expensive
  + MPC
  + Find a company that has architecture already made up for this or make it from scratch
  + We need 2 separate controllers
* Fizza’s research:
  + Burn up altitude is typically 80-120km but depends on size, mass orientation and material composition
  + Design for Design study- use semi controlled re-entry
  + Trajectory model that simulated Cubesat re-entry trajectory; lots of assumptions are made on the atmosphere calculations and dynamic calculations
  + Ionospheric impact research- the range at which satellite demise occurs overlaps with the “E region” which reflects radiowaves and is essential for long distance communication
  + Could monitor atmospheric composition changes because materials from the cubesat could remain in the ionosphere temporarily- use spectrometers to detect the wavelengths and see how the different material affects the ionosphere composition, therefore radio wave reflection and long distance communication
* Alex’s research:
  + ASA has info on different possible cubesat sizes- we want to do a 1U size due to how easy the geometry is, but we could expand greater if needed
  + Endurosat- cost calculator; limited to a 1.5U platform

### Actions

* Ask Tobias about what data would be good for our measurements

# 2024-10-29 Fourth meeting

Present: Alex, Claudio, Hani, Fizza, Luke (Supervisor)

Apologies: None

Location and time:LR7 at 2:00pm

Author of minutes: Hani Moussa

* Discussion of mission (material testing for hypersonic re-entry)
  + Recession sensors/Acoustic emission sensors
  + Experimental use of sensors is viable if well-researched
  + Acoustic environment information could be researched
* Thrust for deorbit
  + Low orbits will be brought in by drag
  + Active re-entry is likely more practical
  + Consider price/how well-established each technology for thrust is
    - Ion thrusters are for longer missions
    - Cold gas thrusters may be more practical/cheaper
* Launch Service Provider
  + Can get in touch with providers/external companies/physics department
    - Be upfront and professional
    - Can get basic information on launch costs
  + Materials not easily comparable between companies
* Model Predictive Control
  + Model needed for cube tumbling into atmosphere
  + Relation to materials testing
    - Initial idea - even tumbling on all sides
    - Speed of trajectory/speed of tumbling need to be considered relatively
* Possible secondary mission objectives
  + Magnus effect in orbit
  + Ionosphere experimentation
    - Difficult to measure through the atmosphere
    - Good to look at environmental effects of satellite demise
* Transmitting data
  + Blackbox/Comms system options
  + Formalise choice process/create spreadsheet and compare qualities
    - Quantity of data
    - Rate of data
    - Likelihood of survivability
    - Price
  + Justification should be in logbook and report
  + Can carry out a similar process for sensors
* Originality of design
  + Use necessary qualities of product to pick items off the shelf
  + Microcontrollers/thrusters etc.
  + Need to be space-certified or need to be tested (legislation side of things)
* Deciding next steps
  + Need to add numbers to decisions
  + Batteries and reaction wheels
  + Comms/Blackbox
  + Mass limit and Budget need to be considered

### Actions

* Alex - Re-entry breakup (Blackbox system), cold gas thruster comparison
* Claudio - Spin rate vs re-entry rate, motors needed for reaction wheels and their weight
* Fizza – Ionosphere measurement specifics, background trajectory information
* Hani - Compare possible options for sensors in more depth
* Long term considerations – get in contact with relevant companies for information

# 2024-11-02 Notes and Research on evaluating methods for obtaining data for the secondary objective

* ESA have done 2 experiments to examine the atmospheric impact of spacecraft demise during re-entry [1]
* Using these existing 2 methods to examine the environmental impact feels out of scope for our CubeSat project
* We are incorporating sensors in our satellite anyway, so using sensors to detect these materials and then obtaining the data in the same way as the data from the other sensors is easier
* However this could be a good idea as these studies have already been done by space agencies related to ESA, but i think we have limited technology for our project to carry out the same degree of evaluation of potential ozone depletion from re-entry events

Main justification for why we should do this secondary objective:

* Long-term simulations were six years long for the ARA study and ten years long for the ATISPADE study. In both cases, it was shown that the greatest impact is observed in the mesosphere and the upper stratosphere and is only significant in polar regions. Even in the worst-case scenario, the average annual global mean ozone loss is found to be between 0.17×10–4 % and 8×10–4 %, while the Antarctic local ozone concentration change can reach about 0.05%. [1]
* These numbers are seemingly low, but we could justify carrying out this objective because the number of satellites released is constantly increasing
* Regulations are also being introduced now more than when space research started
* Measurements show that about 10% of the aerosol particles in the stratosphere contain aluminum and other metals that originated from the “burn-up” of satellites and rocket stages during reentry. Although direct health or environmental impacts at ground level are unlikely, these measurements have broad implications for the stratosphere and higher altitudes. With many more launches planned in the coming decades, metals from spacecraft reentry could induce changes in the stratospheric aerosol layer. [2]

Methods of measuring ionospheric data:

|  |  |  |
| --- | --- | --- |
| Method | Benefits | Challenges |
| Onboard miniaturised spectrometer | * Optical spectrometers can directly detect elements by observing their unique spectral lines, so real-time data would be provided on materials * Miniaturised versions available for CubeSat missions | * The idea of doing this during satellite demise has never been done before, but measurements have been taken during an ESA mission (QARMAN) for a CubeSat do survive during satellite re-entry * Would need sufficient protection against high temperatures and vibrations * Could be high cost as it’s miniaturised * Challenging due to onboard storage and telemetry difficulties but QARMAN successfully transmitted data to the Iridium satellite network * Required onboard power and storage * Not the greatest resolution- affected by size and power constraints |
| Ground-based spectroscopy | * Easy to store data locally * Setup complexity isn’t massively difficult * High resolution, no limitations on space and power (no onboard constraints) * Issues of in-flight transmission is avoided so analysis can be straightforward | * Requires ground-based infrastructure and timing * Setup does require alignment with re-entry path * Requires access to ground-based spectrometers * Strong reliance on clear skies and appropriate atmospheric conditions- unpredictable * Any deviation in trajectory or timing could result in missed data * The use of high altitude balloons may require permissions |

Onboard miniaturised spectrometer:

We would essentially have a spectrometer inside the CubeSat to measure data on the light emissions produced by atmospheric reactions, so we can understand the composition of gases and particles interacting with or generated by the CubeSat

QARMAN:

The spectrometer was placed behind a cork-based ablative thermal shield so the instrumentation was protected. The spectrometer was installed with an outwards facing window/view port that allowed it to observe the plasma outside while being shielded from direct exposure

Did mention that in the future they would be looking to do the experiment again with a blackbox [3] [4]

Mass spectrometers: [5] [6]

Can be specifically designed for nanosatellites and can directly analyse particles and gases, identifying specific ions or molecules released during the degradation of materials

However, these work best in stable conditions so it not a feasible idea for our re-entry experiment. Additionally, they are more expensive and larger than optical emission spectrometers

Ground based spectroscopy:

* Companies include LeoLabs often track satellite movements and could potentially help with re-entry plume observations. [7]
* Companies like World View Enterprises [8] provide high-altitude balloons that can carry observational instruments up to the stratosphere. Equip them with spectrometers or cameras to capture re-entry data at closer proximity than ground-based observations
* Some balloon companies may offer customisable payloads with sensors, cameras, and data collection tools
* Spaceports often monitor objects entering and leaving the atmosphere for launch and debris tracking [9]
  + May only be good for objects and not gas traces like we need

### References

### [1] On the atmospheric Impact of Spacecraft Demise upon Reentry – The Clean Space blog. (n.d.). Retrieved January 31, 2025, from <https://blogs.esa.int/cleanspace/2022/08/11/on-the-atmospheric-impact-of-spacecraft-demise-upon-reentry/>

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[3] *QARMAN (QubeSat for Aerothermodynamic Research and Measurements on Ablation) - eoPortal*. (n.d.). Retrieved January 31, 2025, from <https://www.eoportal.org/satellite-missions/qarman>

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[7] *Tracking - LeoLabs | Persistent Orbital Intelligence*. (n.d.). Retrieved April 8, 2025, from https://leolabs.space/tracking/

[8] *Stratospheric Remote Sensing | High-Altitude Platforms HAPs, C4ISR, Asset Monitoring*. (n.d.). Retrieved April 8, 2025, from <https://www.worldview.space/remote-sensing>

[9] *UK Space Facilities Spaceports*. (n.d.). Retrieved April 8, 2025, from https://www.ukspacefacilities.stfc.ac.uk/Pages/Spaceports.aspx

# 2024-11-04 Fifth meeting

Present: Claudio, Alex, Fizza, Hani

Apologies: None

Location and time: RSL at 5pm

Author of minutes: Claudio

* Alex – re-entry system:
  + Blackbox Idea not going to work due to weight restrictions, 4.0 kg + housing -> 8.6kg
  + Thrusters: factsheets -> possible choices (not clear, contact companies):
    - 300g mass, 100uN to 10mN thrust – hydrazene
    - HPGC thruster – low toxicity, low freeze point, 40g mass (no nozzle),
  + Batteries:
    - Optimus 30: large dimensions, 268g 30wHR
    - B14 modular: 375g, 45Whr, no NASA certification
* Fizza:
  + Ionosphere:
    - studies by ESA, cannot use as classified
    - Remote sensing – companies:
      * Ground-based: higher resolution, no data storage problem
      * Balloons: difficult, coordination complexity, path complexity, time complexity
    - Justification of secondary objective due to regulations
* Hani:
  + Sensors:
    - Spreadsheet of several sensors for comparison:
    - Recession sensors not readily available – emerging technology, could build ourselves or contact ESA for purchase
    - GENERAL POINT: if price is not available, estimate in report
    - RSComponents website (not made for space, but cheap and used in the past in space applications), could lower price significantly
    - Papers: types of sensors used in projects – thermocouples (light, cheap, use several), mosaic core (infrared camera, not made for space so not certain we can certify it, 21mm largest dimension – viable (used in cubesats in the past))
    - Can we certify things that have not been certified for space? (ASK TOMORROW). How do we design tests.
    - Could be the case that we do not need to be as rigorous with certification as it is only necessary if you stay in atmosphere for a long time - > our satellite demises so could get away w/o certification if launch company is okay with it -> Ask someone at the company
* Claudio:
  + Book for general understanding of hypersonic regimes, for both trajectory and aerothermal environment – relations can be found nicely displayed in graphs
  + Mass of typical re-entry attitude control system below 200g – very slow rotation rates and very weak forces. Ditched idea of controlling during re-entry but could easily spin up using loads of time to do so before hitting atmosphere
  + Paper on reaction wheels design and modelling -need 3 of them
  + Found a paper on the design of a reaction wheel-controlled cubesat – very useful as it contains lots of pictures and cad files of the architecture – should use as reference when designing our own satellite (BEESAT)
  + Paper on empirical results of hypersonic testing of cubesat topologies.

### References

BEESAT: A Pico Satellite for the On Orbit Verification of Micro Wheels

### Actions

* Alex: document choice of no black box
* Fizza: document choice of ionosphere effects as secondary objective, document choice of ground sensing (why are alternatives not viable?)
* Hani: decide on recession sensors
* Claudio: look at thermal transfer rates for different spin rates

# 2024-11-05 Sixth meeting

Present: ALex, Claudio, Fizza, Hani

Apologies: Name4

Location and time: 14:00 at IEB LR7

Author of minutes: Alex Berresford

Catching up Tobias on design choices

Rule out Black box

Settled for cold gas for altitude control

Spectroscopy

Use Fibre coupled spectrometer (Thor labs), multiple fibres possible per spectrometer, one on each face is possible.

Ground observation difficult due to range.

Space certification is on launch provider and not strictly legislative. Minimise risk where possible.

Devices that will function in a space environment difficult to find:

Electronics want to be certified to ensure they won’t be damaged by radiation.

Simpler components e.g. thermocouple/mechanical frame are more case by case.

Problem obtaining technical components (e.g. recession sensors)

Make a mock up CAD and reference a paper describing use.

Based on component sizing, 1U design unrealistic.

Possibility of de-orbit using ISS “trash” system – Nanoracks deployment goes via ISS anyway. – solves deorbit issue.

Spin up in vacuum during de-orbit but before colliding with atmosphere to avoid competing with aerodynamic forces.

Dependent on launch provider altitude.

Roshko number – ND group for describing oscillating flow mechanisms.

For electronics, heating needs to be critically considered. Build up models from 0D to having a heating solution.

Shielding should be considered for digital information stream to prevent bit flips, unnecessary for analogue streams.

### Actions

Fizza – Design an orbit to allow for burn at apogee, followed by a spin up in vacuum before reaching atmosphere.

Hani-Background reading on heating for CubeSat electronic, followed by having another look at thermocouple and recession sensor implementation.

Claudio- Roshko number, Strouhal number and CFD hypersonics.

Alex – begin CAD modelling to get idea of internal design.

# 2024-11-12 Seventh meeting

Present: ALex, Claudio, Fizza, Hani

Apologies: None

Location and time: 13:30 in Holder Building

Author of minutes: Fizza Naqvi

Fizza

* How far out we need to be to generate enough spin to get into the atmosphere
* spawning the cubesat too far out burns a lot more energy from getting the ‘spawn’ place to the atmosphere

Claudio

* Looking at the Knudsen number and mean free path; how the interactions of particles can affect the trajectory
* CFD examples that could be used when we have CAD files
* Strouhal number

Hani

* reading on cooling electronics; dealing with heat generation from electronics; some cubesat’s have heat pipes linked from components themselves to the other components to deal with the heat
* -phase-change material – stores lots of energy; commonly used for cubesat
* looked into recession sensors; what materials work best (nickel)

Alex

* Start making CAD files
* Used some existing components and made some files
* Found some reaction wheels of various sizes

Discussion with Luke:

* Treat the trajectory simulations as separate to the spin calculations
* Look at steady state models, perform calculations
* If flow speed and spin speed time scales are equal, the system isn’t into steady state
* Validity of the steady state calculations/analysis
* To consider the thermal environment of the electronics, create a heat transfer flow analysis to consider how heat transfer affects each component
* Obtain a set of equations to solve what the steady state temperature would be

Discussion with Tobi:

* You would need time-accurate simulations to resolve some of the terms, but this is beyond our scope
* Use a matrix method to do the heat transfer analysis
* grid convergence study- typically done with FEA and CFD simulations
* In the report, include flow charts to represent complex code instead of directly incorporating the code into the report

### Actions

Hani- look at what temperatures the electronics can deal with; what does the heating scenario look like when simply being in orbit; look further into certain components such as battery choices and microcontrollers

Alex- email manufacturers for necessary CAD file components; work on CAD design

Fizza- Modelling and simulation of aerospace vehicles by Peter Zipfel; do some calculations on the required spin, distance, time, impulse of thrusters etc.

Claudio- look at the requirements for systems to be in steady state, quasi steady state, etc; continue CFD analysis

# 2024-11-15 Notes and Research on possible spin rates and components for attitude control

* typical mass for a 3U cubesat is 4kg [1]
* the deorbit altitude is approximately 120km altitude
* typical relative velocity between a satellite in LEO and Earth is 7.7km/s [2]
* Vacco Micro Propulsion System (MiPS) offer cold gas thrusters with thrust levels ranging from 1mN to 25mN [3] [4]
* Commonly used in CubeSat missions for spin-up, attitude control
* NanoAvionics propulsion systems can also provide customisable thrust levels?
* Large spacecraft like Mir Space station reached around 0.125Hz as it descended through altitudes of approx 60km [5]
* Automated Transfer Vehicle (ATV) had an intitial spin rate of approximately 0.028Hz during controlled re-entry [5]
* Spin Rates Between 1 and 3 RPM (0.0167 to 0.05 Hz) are ideal [5]
* This range is often used for re-entry experiments
* Spin rates lower than this might not provide sufficient rotational speed to achieve even heating across all surfaces of the satellite. Conversely, higher rates could be challenging to maintain and may lead to instability or mechanical issues, particularly if the CubeSat's thrusters or structure are not designed to withstand the resulting forces.
* The Space Shuttle typically completed its descent from orbital velocity (28,000 km/h=77.78) to landing in about 45 minutes from deorbit burn, which gives a good benchmark for many spacecraft

Rough trajectory notes:

* I feel more comfortable with coding with MATLAB so I will continue refining the simulation code in MATLAB instead of python
* Start at altitude of 400km
* Then the satellite will perform de-orbit burn using cold gas thrusters
* De-orbit burn can take anywhere between 30s and 10 minutes- really depends on the spacecraft
* During re-entry, we could use some kind of a feedback system to help the cold thrusters or reaction wheels keep the spin rate constant
* This could be done using gyroscopes, so the sensors measure the spin rate and then feedback to adjust the controllers operation
* Either use a PID controller or an on/off method for the thrusters

### References

[1] Rafano Carná, S. F., & Bevilacqua, R. (2019). High fidelity model for the atmospheric re-entry of CubeSats equipped with the Drag De-Orbit Device. *Acta Astronautica*, *156*, 134–156. https://doi.org/10.1016/J.ACTAASTRO.2018.05.049

[2]*Lecture 4-1*. (n.d.). Retrieved January 31, 2025, from <https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html>

[3] *Features Operating Parameters*. (n.d.). Retrieved January 31, 2025, from [www.vacco.com](http://www.vacco.com)

[4] *Standard Propulsion System*. (n.d.). Retrieved January 31, 2025, from [www.vacco.com](http://www.vacco.com)

[5] Fritsche, B., & Koppenwallner, G. (n.d.). *COMPUTATION OF DESTRUCTIVE SATELLITE RE-ENTRIES*.

# 2024-11-18 Eighth meeting

Present: ALex, Claudio, Fizza, Hani

Apologies: None

Location and time: 14:30 at RSL

Author of minutes: Hani Moussa

* Timeline discussion
  + Logbook review next week – clean up
  + Speaker tomorrow
* Hani’s Microcontroller/Battery choice
  + List of common processors on CubeSats
  + Many possible OBCS
  + Specific decisions dependant on mission requirements
  + Battery material Types
* Alex’s Communication with suppliers
  + Rejected information request for propulsion system
  + Modular, customisable component dependant on customer requirements
* Possible collision
  + Avoidable with reaction wheels/planning/thrust
* Fizza’s Trajectory Calculation
  + Starting at 400km (ISS level), spinning until Deorbit burn (250km)
  + Altitude control could be done with thrusters – would not require high mass (~1 gram)
    - Harder to design than reaction wheels
      * Research available for mathematics of reaction wheel use
  + Stability requires low frequency (1Hz order of magnitude)
  + Thruster required not to affect spin
    - Deorbit thrust could occur before spin
    - If spin thrust comes first, timing makes a harder problem
* Magnus effect
  + spin is slow for magnus effect
* Re-entry timeline and Sizing Considerations
  + re-entry burn, Attitude activation, Burn up
  + Control for 3U CubeSat
    - Stable re-entry aided by positioning of centre of mass
    - Entry surface can be one of the smaller faces if spinning around longer axis
    - Alternative re-entry surface and slightly misaligned centre of mass causes unintended spin
    - Thermal equilibrium not reached for Materials testing
  + Larger satellite Considerable?
    - 8U would benefit the material testing experiment
    - Larger satellite may require higher budget
  + Split 3U into 1U detachment for material testing experiment
    - Advantages
      * Simplifies design for 1U section
    - Disadvantages
      * Detachment is difficult (wiring/batteries/Side of 1U)
      * Positioning of components is difficult
      * Trajectory will be affected
  + 1U CubeSat
    - theoretically possible, but fitting everything may be possible
    - Launch may be expensive
    - Layered design as in BEESAT
* Claudio’s Research on Aerodynamics situation
  + Thermal load/velocity stream on example satellite
  + CFD runs
  + Strouhal Number has a low order of magnitude with low frequency
    - Time to go between steady states is very low
    - allows assumption of constant steady state

# 2024-11-19 Ninth meeting

Present: ALex, Claudio, Fizza, Hani

Apologies: None

Location and time: 14:00 at IEB LR7

Author of minutes: Hani Moussa

Belstead Re-entry Talk

* Destructive re-entry
  + Some debris can survive
* Uncertainties
  + Aerothermodynamics
    - Thin parts get hot first (titanium bipod test)
    - Calculations are not necessarily strong predictors, testing required
  + Fragmentation
    - Electronics box
      * Housing fails
      * aluminium warps under oxide layer influence
      * steel pins survive longer
      * electronics card survives past metals
  + Material Response
    - Liquid droplets, oxide layers on stainless steel
* Knowns
  + Demise qualities
  + Continuum heating dependant on length scale
* Unknowns
  + Rarefied heating
  + Structure failure mode in re-entry
  + Materials responses to failure
    - Metals
    - Ceramics
    - Composites
* QnA
  + Predictions
    - Speed/air density/size define drag/heating
    - Use literature
    - High up for CubeSats
    - Box of doom
  + Tumbling
    - Tumble-averaging heat flux, thermal approximation
    - Numerical extrapolation

Experiment assessment

* Fragmentation causes casualty risk
* Experiments to this end
  + EntrySat
  + Qarman
* Flight recorder
  + Transmits after blackout
  + Parachutes/buoyant
  + Difficult to apply to CubeSat
* Dedicated vehicles
  + Qarman survives blackout
    - Heatshield
    - Aerodynamically stable
  + VAST + VASP
    - Large vehicles
    - Thermally insulated electronics
    - Not applicable to 3U
* Measurements
  + Images and video are very helpful
    - Not necessarily high resolution
    - High number of low res >> low number of high res
  + Thermocouple/pressure traces aren’t helpful by themselves
  + Images are data hungry, however
  + Thermocouple data high priority
    - Doesn’t require high data rates
* Repeatability
  + Demise behaviour may vary from CubeSat to CubeSat
  + Repeatable CubeSat is very valuable – allows consistent scientific results
* QnA
  + Blackbox idea
    - Great in theory
    - Issue is lack of volume in a CubeSat
  + Difficulty of transmitting data
    - Transmit through radar-transparent material
    - Spherical sat (e.g. iball) has wide ability to transmit
    - Aerodynamically stable sat allows simple transmit direction
    - IRIDIUM satellite network

Discussion with Tobias

* Don’t expect us to solve every problem
  + >=50% expectation of working
* Transmitting information
  + No spin allows transmitting out the back of the satellite
  + Tumbling could use multidirectional antenna
* Size
  + Smaller = simpler
  + Size decision (1U) allows boundaries for power/size/cost
* Materials not possible on every side due to size constraint
  + Could have material for testing on not every side/on 80% of sides
* Timeline
  + Current idea as described in yesterday’s meeting
  + Transmission requires radio-transparent materials
* Transmission
  + Tumbling limits window of transmission for single-direction antenna
  + Side panel with unidirectional antenna not part of material experiment
  + Choice comes down to data-rate required/instrumentation
* Mission objective
  + Secondary objective is beneficial to materials testing customers – track environmental impact
  + Spectrometer is large for 1U, would work for 8U
* Sensor on outside
  + Glue – easy to take off
  + Solder – wire will be broken down
  + Bore-hole – measure under the surface, but doesn’t measure true surface temperature
* Logbook review next week
  + Go over logbooks
  + Tidy up logbooks till then
  + Not examinable till end of project

# 2024-11-20 Notes and Research on calculations to determine delta V for deorbit burn and torque for spin rate

**A math equations on a white background

AI-generated content may be incorrect.**

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AI-generated content may be incorrect.**

# 2024-11-23 Notes and Research on numerical methods for simulations

Numerical method in the simulation:

* The equations that govern orbital motion and atmospheric drag are non-linear and can’t be solved analytically
* So a type of numerical methods, such as Runge Kutta, is necessary to approximate the solutions over time
* There’s a solver in MATLAB that uses a specific method of Runge-Kutta to solve equations of orders of 4/5 called ode45 [1]
* This essentially adapts the step size during simulation to balance accuracy and computational efficiency
* This method is also known to have a high accuracy for smooth problems such as orbital motion

Atmospheric drag models:

* 1. Exponential atmospheric density model [2]
* Based on the barometric formula that assumes that atmospheric density decreases exponentially with altitude
* Used for altitudes up to 100km
* Simple and effective for low altitudes where the atmosphere is dense and the exponential decay of density with altitude is a good approximation
* ρ = ρo exp ( - h / H )
* ρo is the density at the surface of the planet
* h is the height above the surface
* H is the scale height
  1. Jacchia Atmospheric Model (J71) [3]
* Designed to specifically estimate atmospheric density at higher altitudes, typically from 100km to 2500km
* Accounts for more factors than the exponential model such as the time of day and solar activity, so it’s more accurate in simulating drag at higher altitudes
* Variations in solar radiation and the geomagnetic field can significantly affect atmospheric density
* ρ(h)=ρ0⋅(Re/r​)2⋅exp(−h/H​)
* r is the distance from Earth’s centre
* Re is the Earth’s radius
* H is the scale height that changes with altitude
* MATLAB code downloaded [4]

### References

[1] *ode45*. (n.d.). Retrieved April 8, 2025, from <https://uk.mathworks.com/help/matlab/ref/ode45.html>

[2] *Earth Atmosphere Density Approximations*. (n.d.). Retrieved April 8, 2025, from https://www.spaceacademy.net.au/watch/debris/atmosmod.htm

[3] *Jacchia Reference Atmosphere - Wikipedia*. (n.d.). Retrieved April 8, 2025, from https://en.wikipedia.org/wiki/Jacchia\_Reference\_Atmosphere

[4] *(PDF) Jacchia-Bowman Atmospheric Density Model (MATLAB code)*. (n.d.). Retrieved April 8, 2025, from https://www.researchgate.net/publication/337085065\_Jacchia-Bowman\_Atmospheric\_Density\_Model\_MATLAB\_code

# 2024-11-26 Tenth meeting

Present: Alex, Claudio, Fizza, Hani

Apologies: None

Location and time:LR7 at 15:00

Author of minutes: Alex Berresford

Presentation sum up from Tobias

-Total 20 minute presentation

~ 5 minutes each

-cohesive, not 4 individual presentations

-Give enough detail so the audience knows what’s going on and can make a judgement

-In general pitch to audiences understanding

-For undecided options, present both and give a conclusion to how that decision will be made.

-Referencing

-Ideally on the slide, abbreviation ok

-Sum up references on final slide alongside abbreviated on slide referencing

-Not formally assessed, purely for feedback

-OK to present present work done, not based on pure calculations e.g. for mechanical/electrical

-Present on work done

How detailed should trajectory calculation be after re-entry?

Velocity and force balance every ~ 0.5km

Google slides vs Beamer vs Powerpoint Online

-Beamer decided as it will develop useful Latex skills

1U vs 8U

-1U is simpler and far cheaper for materials testing rig

-1U has very limited volume limitations

Diagonal OBC and battery?

-8U still cube for tumbling

-8U allows space for secondary objectives, e.g. Ionosphere

-No packing problem

Sum up chosen components in spreadsheet for mass estimate of prototype

Presentation for next Tuesday 2nd Dec – meeting Friday 29th Nov

-Begin with primary objectives

-Give cohesive, continuous presentation

-1U vs 8U “debate” heavily featured

More detailed plan below

Presentation plan


### Actions

Everyone to prepare content for their assigned slides – see plan by the next meeting – 29/11/24

# 2024-11-26 Eleventh meeting

Present: Alex, Claudio, Fizza, Hani

Apologies: None

Location and time: Teams (online), 13/12/2024 at 10am

Author of minutes:Fizza Naqvi

Decision made to go with 8U

* allows us more freedom to do “more engineering”
* easier to design/fit components in
* materials on the outside can be thicker

Decision needs to be made on which materials to use

* look at ablatives typically used by other companies
* think about how long it would take certain materials to break down

Communication

* Look at where we can and can’t communicate properly
* Potentially reconsider blackbox idea
* With the ablatives on the outside, it may be difficult to communicate through the materials
* Potentially have an antenna on most of the faces
* Biggest project risk- not getting data

Power

* Number of batteries/type of battery depends on how much power we will consume

### Actions

Alex

* Look at the vibrational model

Fizza

* GMAT simulation

Claudio

* Look at the materials

Hani

* Look at the comms and what can be done

# 2024-12-27 Notes and Research on position of perigee

Main reasons for a LEO instead of another type of orbit (for inclusion in the report):

* Atmospheric drag in LEO naturally shortens orbital lifetimes, reducing the time and energy required to bring the CubeSat to reentry altitude for testing. This is one of the key force shown in the figure below
* Lower launch costs- LEO's proximity reduces costs for placing the CubeSat into orbit
* Spatial density of objects increases drastically at higher altitudes (500km>), so a lower orbit reduces chance of collision

Simple diagram of the forces acting on a satellite in LEO: [1]

A diagram of a solar system

Description automatically generated

Position of perigee:

* In previous models, the deorbit burn was performed to put the perigee at 100km so it re-enters at this point. However, upon evaluation, this would not be entirely realistic
* At perigee, the satellite experiences maximum atmospheric density and drag. However, the satellite will continue to move along its trajectory.
* Re-entry (burn-up, breakup, or significant deceleration) occurs progressively after passing the perigee as the satellite descends into even denser atmospheric layers.
* At perigee, he satellite loses significant kinetic energy due to drag at perigee, reducing its orbital altitude further.
* Atmospheric re-entry begins at altitudes between 120km-150km, so perigee should be placed between these altitudes
* Choosing perigee altitude required a trade-off between faster re-entry and time to for experimentation
  + 120–130 km: Rapid re-entry within one orbit due to intense drag. Ideal for immediate re-entry.
  + 140–150 km: Allows for a slightly longer trajectory, useful for materials testing and atmospheric composition analysis.
  + Higher perigee does have more opportunities for experimentation during descent but risks incomplete burn up

### References

[1] Orbital, S., & Calculations, D. (n.d.). *IPS RADIO AND SPACE SERVICES*. Retrieved January 31, 2025, from [www.ips.gov.au](http://www.ips.gov.au)

# 2024-12-29 Notes and Research on the atmosphere model

Atmosphere model research: the effects of solar radiation on atmospheric density (for altitudes above 180km)

* Solar radiation affects Earth’s upper atmosphere, particularly the thermosphere and ionosphere [1], which are regions influence the environmental conditions experienced by our cubesat, particularly in LEO.
* This layer of Earth’s atmosphere is composed of sparse air and is sensitive to variations in solar activity
* The interaction of atmospheric particles with solar radiation ionises them, increasing their energy, leading to an overall expansion of the thermosphere. This contributed directly to changes in atmospheric density. [2]
* Solar radiation varies over the solar cycle, which is the natural 11-year cycle of the sun as it transitions between high and low activity
* The solar maximum is the most active part of the cycle, during which there is an increase in coronal mass ejections, solar flares, and the intensity of solar radiation
* Heightened radiation =increase in thermosphere’s temperature= thermosphere expansion=density of atmosphere decreases at these altitudes
* This has the effect of decreasing the drag force, as it’s proportional to density as seen in the formula Fdrag​=1/2ρv2CD​A
* The solar maximum also increases the temperature of the thermosphere leading to more energetic particles. These faster-moving particles result in a high momentum transfer to the satellite, effectively resulting in an increase in drag despite the lower density.
* The combined effect of reduced atmospheric density and increased particle velocity leads to a net increase in drag on satellite in LEO during periods of solar maximum
* Conversely, during the solar minimum, the Sun’s radiation decreases leading to a contraction of the thermosphere and an increase in atmospheric density
* This results in lower atmospheric drag, which directly affects the satellite’s orbital decay rate
* These fluctuations can significantly influence the satellite orbits
* Ap index quantifies geomagnetic activity, which is driven by interactions between the solar wind and the Earth’s magnetosphere
* Scientists can use indices such as the solar radio flux (F10.7) to predict how solar activity will influence atmospheric density
* This figure shows how the predicted and actual values are fairly accurate for F10.7:

[3]

A graph of a solar flux

Description automatically generated

Solar flux:

* Solar flux is the amount of energy per unit area from the sun, and can be used to estimate the amount of solar radiation affecting the Earth’s atmosphere
* The solar radio flux at a 10.7cm wavelength (2800MHz) is a commonly used indicator of solar activity [4]
* It acts as a proxy for the total solar X-ray flux, which plays a significant role in influencing atmospheric density. This flux ranges from approximately 65 to over 300 Solar Flux Units (SFU), with 1 SFU equivalent to 10−22 W/m2/Hz
* The figure shows how accurate it can be using data from 1947-2016

Atmosphere model: [5]

The set of defining equations for the model are given by:

T = 900 + 2.5 ( F10.7 - 70 ) + 1.5 Ap (Kelvin)

m = 27 - 0.012 ( h - 200 ) 180 < h(km) < 500

H = T / m (km)

ρ = 6x10-10 exp ( - ( h - 175 ) / H ) ( kg m-3 )

* The model used is not suitable for satellites with orbits above 500km
* This is because at higher altitudes, density variations become more complex due to additional factors such as non-uniform heating, interactions with solar wind, and the transition to the exosphere where the atmosphere becomes collisions
* The simple exponential model doesn’t account for these anomalies, as is therefore suitable for when atmospheric density decreases somewhat predictably
* The model includes the use of an effective atmospheric molecular mass m that includes both the actual variation in molecular mass with height and a compensation term for the variation in temperature over the considered range from 180 to 500 km.
* As we decided on a re-entry altitude of ~400km, this model will suffice up to 180km and more sophisticated atmospheric models, like the NRLMSISE-00 or JB2008, that are typically used are not necessary at this point as they account for these other complexities
* Atmospheric density is specified by a simple exponential with variable scale height H, which varies with altitude h at a fixed exospheric temperature T

### References

[1] Kutiev, I., Tsagouri, I., Perrone, L., Pancheva, D., Mukhtarov, P., Mikhailov, A., Lastovicka, J., Jakowski, N., Buresova, D., Blanch, E., Andonov, B., Altadill, D., Magdaleno, S., Parisi, M., & Miquel Torta, J. (2013). Solar activity impact on the Earth’s upper atmosphere. *Journal of Space Weather and Space Climate*, *3*, A06. <https://doi.org/10.1051/SWSC/2013028>

[2] Liu, L. B., Wan, W. X., Chen, Y. D., & Le, H. J. (2011). Solar activity effects of the ionosphere: A brief review. *Chinese Science Bulletin*, *56*(12), 1202–1211. <https://doi.org/10.1007/S11434-010-4226-9>

[3] *The variation of the observed and modelled solar flux F10.7. The blue... | Download Scientific Diagram*. (n.d.). Retrieved January 31, 2025, from <https://www.researchgate.net/figure/The-variation-of-the-observed-and-modelled-solar-flux-F107-The-blue-and-black-lines_fig3_362668738>

[4] de Cecio Alfredo Locarini, F. (2018). *Modeling and simulation of a CubeSat atmospheric re-entry trajectory* (stored in Mendeley)

[5] Orbital, S., & Calculations, D. (n.d.). *IPS RADIO AND SPACE SERVICES*. Retrieved January 31, 2025, from [www.ips.gov.au](http://www.ips.gov.au)

# 2024-12-29 Notes and Research the effect of controlled spin up on velocity

* The spin up phase doesn’t significantly affect the trajectory of the CubeSat as its effects of velocity are quite minor
  + In terms of orbital velocity, the effect of spinning up the CubeSat would be minor. The CubeSat's spin is a rotational motion, while its orbital motion is translational. Spin does not directly affect the translational velocity unless there is a significant change in mass distribution or a transfer of angular momentum that could induce some force (like gyroscopic effects or torque).
  + Angular momentum: The spin will cause changes in the CubeSat’s orientation, but it won’t directly affect its velocity in the orbit because no net force is being applied in the direction of motion. The reaction wheels would only change the CubeSat's angular velocity, not its translational velocity.
  + Momentum Conservation: The CubeSat's total momentum is conserved. When you spin it up, the thrusters are imparting angular momentum, but since the force is applied along the CubeSat's centre of mass (assuming it's a well-centred application), there won't be a noticeable change in the satellite's velocity.

# 2025-01-05 Notes and Research on LEO perturbations

* Generally looking at a 2 body problem
* Higher fidelity models->more complexity
* Major LEO perturbations that could be considered:
  + Earth’s oblateness- causes variations in orbital decay rates due to the J2 effect
  + Atmospheric winds
  + Solar radiation pressure
  + Moon and sun gravitational forces
    - these considerations would extend the problem to being beyond a perturbed 2-body problem
    - Using Newton’s law of gravitation, the gravitational force between the satellite and the moon is around the order of 10^-4, and the force between the sun and the satellite is of the order of 10^-2. These values are small enough to neglect, especially considering that the length of the mission isn’t long enough for the additional gravitational forces to cause significant perturbations in the satellites trajectory
* Earth’s oblateness can add a correction term to the Gravitational potential U:[1]



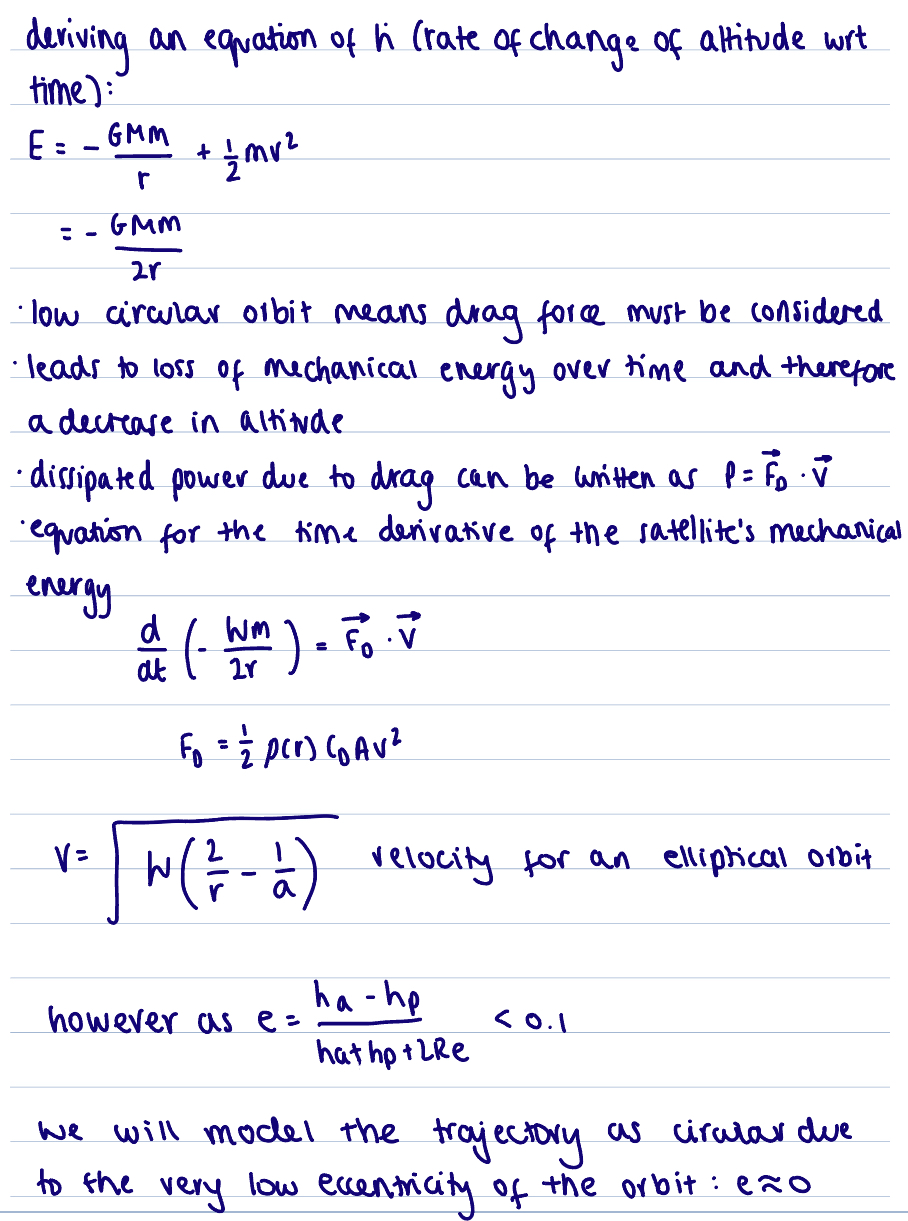
* + J2​: Oblateness coefficient for Earth (~0.00108).
  + Re​: Earth's mean radius.
  + ϕ: Geocentric latitude- variable
* This may need to be considered because perturbations due to Earth's oblateness are most pronounced in low Earth orbits, where the satellite is closer to the source of the irregular gravitational field

### References

[1] de Lafontaine, J., & Garg, S. C. (1982). A review of satellite lifetime and orbit decay prediction\*. *Pro¢. Indian Acad. Sci. (Engg. Sci.)*, *5*(3), 97–258.

# 2025-01-10 Notes and Research on MATLAB trajectory simulations

* The derivation below derives dh/dt (the rate of change with altitude with respect to time
* This is only used in the simulation between the initial altitude and 180km due to the limitations of the atmospheric density model (ASWA) [1]
* A math equations on a piece of paper

  AI-generated content may be incorrect.Since orbital eccentricity is small (< 0.02), the orbit remains close to circular throughout its trajectory. The assumption is typically used when the eccentricity is small enough that the variations in altitude from periapsis to apoapsis (which would affect the orbit's shape) are negligible.



Key variables:

* 8U cubesat (we previously considered 3U but the decision was made to go with 8U instead)
* The cD value used is 2.2 (averaged value for a CubeSat [3]
* Area is the cross sectional area 0.04m^2 (does not currently account for variations in the reference area)
* Mass of cubesat is 12kg (approximate mass for a 12U cubesat

Functions:

A screenshot of a computer program

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**A screenshot of a computer

AI-generated content may be incorrect.**

**A screenshot of a computer

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Results:



Evaluation:

* The initial plan was to use MATLAB’s ODE45 function as the solver, however this did not produce proper results as there may have been some coding errors when implementing the solver. It didn’t plot properly
* Therefore I resorted to using RK4 (which is very similar to ODE45) to simulate the trajectory up to 180km using the ASWA atmospheric density model

### References

[1] Kutiev, I., Tsagouri, I., Perrone, L., Pancheva, D., Mukhtarov, P., Mikhailov, A., Lastovicka, J., Jakowski, N., Buresova, D., Blanch, E., Andonov, B., Altadill, D., Magdaleno, S., Parisi, M., & Miquel Torta, J. (2013). Solar activity impact on the Earth’s upper atmosphere. *Journal of Space Weather and Space Climate*, *3*, A06. <https://doi.org/10.1051/SWSC/2013028>

[2] Fiolhais, M. C. N., Gonzalez-Urbina, L., Milewski, T., Chaparro, C., Ferroglia, A., & González-Urbina, L. (n.d.). *Orbital decay in the classroom Orbital decay in the classroom Orbital decay in the classroom*. Retrieved April 8, 2025, from <https://academicworks.cuny.edu>

[3] Oltrogge, D. L., & Leveque, K. (n.d.). An Evaluation of CubeSat Orbital Decay. *25 Th Annual AIAA/USU Conference on Small Satellites*.

# 2025-01-23 Notes and Research on the method of assessing environmental impact during re-entry

**Secondary objective research:**

Instrumentation:

* Ensure onboard instruments are calibrated to provide precise and quantitative measurements
* Use spectrometers (UV/visible/NIR) to detect and record emission lines corresponding to specific elements and molecules released during ablation
  + Good for detecting the ablation process in real-time (eg metal oxides or carbon-based emissions) and are effective for studying how materials interact with the atmosphere
* Mass spectrometer- directly samples the atmosphere to quantify species concentrations
  + Mass spectrometers provide more quantitative data, but are bulkier, heavier and consume more power and storage space than a spectrometer
  + provide detailed post-ablation chemical analysis, such as concentrations of metal particles, atmospheric gases, and combustion products.
* Langmuir probe- measure electron density and plasma properties caused by re-entry ionisation
  + Potential instrument not certain
* Temperature and pressure sensors will already be onboard to obtain data for the primary objective; for the secondary objective they will provide environmental context for the observed data
* Onboard GPS or inertial navigation
  + AsteRx SBi3 Pro GNSS/INS multi-frequency receiver delivers reliable centimeter level positioning together with 3D orientation in challenging environments. Thanks to the built-in inertial sensor, it provides orientation (heading, pitch and roll) as well as dead reckoning making it ideal for systems that require positioning under any condition.[1]
  + Size 102 × 36 × 118 mm

Data collection:

* Record the intensity of emissions (using spectrometers) or ionised particles (using mass spectrometer) at predefined intervals during the descent
* Onboard GPS or inertial navigation so timestamped altitude data can be recorded to correlate measurements with specific altitudes

Data analysis:

* Use databases like the NIST Atomic Spectra Database to map emission lines to specific species
* Apply the Boltzmann or Saha equations to convert emission intensities into species concentrations
* Plot concentration vs time for key species (e.g., SiO, Al₂O₃, NOx).
* Identify trends in the release of ablation products as the CubeSat descends through varying atmospheric layers
* Combine data with multiple timestamps to correlate the measured species concentrations with specific altitude ranges
* Use interpolation methods to create continuous profiles of species concentration over altitude
* Overlay the collected data with atmospheric density models to adjust for variations in background density and pressure at different altitudes
* Calculate the total mass of ablated material released into the atmosphere by integrating concentration data over time and altitude
* Compare the measured data with baseline atmospheric models to quantify deviations caused by re-entry
* This will allow us to assess the relative environmental impact of our materials

More detailed process of assessing the environmental impact:

* Measure Emission Intensities
  + Use the spectrometer to record emission spectra during CubeSat re-entry.
  + Identify key emission lines that correspond to species of interest (e.g., SiO, Al₂O₃, NOx) using the NIST Atomic Spectra Database or similar resources.
  + Determine the wavelength of each emission line observed.
  + Record data at multiple time intervals or altitudes as the CubeSat descends to capture emissions during the re-entry process.
* Identify Energy Transitions
  + Identify the specific energy transitions corresponding to the measured emission lines.
  + Use the NIST Atomic Spectra Database to find the energy levels Ej and Ei​ for the species involved in the transitions.
  + Calculate the energy difference between the excited and ground states for each species using the relation: Ej - Ei​ =hc/λ where h is Planck's constant, c is the speed of light, and λ is the wavelength of the emission line.
* Estimate Temperature During Re-entry
  + Use atmospheric models to estimate the temperature at various altitudes during re-entry. You can use empirical temperature-altitude profiles or derive temperature from atmospheric density models.
  + Estimate the re-entry temperature based on altitude data (from GPS or inertial navigation) and known re-entry dynamics.
  + Account for variations in temperature during the descent, as temperature affects the population of species in excited states.
* Apply the Boltzmann Distribution
  + Apply the Boltzmann distribution to calculate the relative populations of species in their excited states at each temperature: [2]

A mathematical equation with black text

Description automatically generated

* + Where:
    - Ni​ is the population in the i-th energy state.
    - Gi is the degeneracy of the i-th energy state.
    - q is the partition function.
    - Ei is the energy of the state.
    - kB​ is the Boltzmann constant.
    - T is the temperature at the current altitude.
  + For emission lines, calculate the population difference between two states (e.g., excited state and ground state).
* Convert Emission Intensities to Population Differences
  + Use the Einstein coefficients for spontaneous emission Aji​ to relate the emission intensity Iji to the population difference Nj−Ni​: Iji =Aji (Nj−Ni)
  + Rearrange this equation to calculate the population difference: Nj−Ni= Iji / Aji
  + This gives the population difference between the excited and ground states.
* Estimate Species Concentrations
  + Use the population difference to estimate the concentration of the species in the atmosphere. This can be done by:
    - Comparing the calculated population difference to known calibration curves or using the relationship between population and concentration (which may require specific assumptions or data on the total species present).
    - Scaling the population difference to the total number of particles in the system or volume of the atmosphere being sampled.
  + Apply this procedure to each species of interest to estimate their concentrations.
* Collect and Correlate Data with Altitude
  + Combine the measured emission intensities with timestamped altitude data (from GPS or inertial navigation).
  + Correlate the emission spectra with altitude by plotting the measured species concentrations against altitude or time.
  + Track the changes in concentration as the CubeSat descends through varying atmospheric layers.
* Analyse Trends in Species Concentrations
  + Identify trends in the release of ablation products, such as SiO, Al₂O₃, NOx, as the CubeSat descends through the atmosphere.
  + Use interpolation methods to create a continuous profile of species concentration over altitude.
  + Identify key changes in concentration corresponding to specific layers of the atmosphere (e.g., mesosphere, thermosphere).
* Overlay with Atmospheric Density Models
  + Overlay the species concentration data with atmospheric density models to adjust for variations in background density and pressure at different altitudes.
  + Use standard atmospheric models (e.g., US Standard Atmosphere) or your own model to account for changes in atmospheric conditions during re-entry.
  + Adjust your species concentration data to reflect these atmospheric changes and refine your analysis.
* Quantify the Environmental Impact
  + Integrate species concentration over time or altitude to estimate the total mass of ablated material released into the atmosphere.
  + Use mass conservation principles and known molecular weights of the species to convert concentration data into mass.
  + Compare your measurements with baseline atmospheric models to quantify deviations caused by re-entry and assess the environmental impact of your CubeSat’s materials.

Challenges/risks and mitigation:

* Challenge: Limited measurement resolution
  + Solution: Use high-sensitivity instruments with a fast sampling rate to capture rapid changes during re-entry
* Challenge: Re-entry blackout
  + Solution: ??
  + Potentially design the onboard storage system in a way that there is sufficient capacity
  + Prioritise critical data during storage
* Challenge: Data interpretation
  + Validate measurement with pre-mission simulations?

### References

[1] *AsteRx SBi3 Pro Ruggedized GNSS/INS Receiver*. (n.d.). Retrieved April 8, 2025, from <https://www.septentrio.com/en/products/gnss-ins-receivers/ins-rugged-boxes/asterx-sbi3-pro#resources>

[2] *1.5: The Boltzmann Distribution and the Statistical Definition of Entropy - Chemistry LibreTexts*. (n.d.). Retrieved April 8, 2025, from <https://chem.libretexts.org/Courses/Western_Washington_University/Biophysical_Chemistry_(Smirnov_and_McCarty)/01%3A_Biochemical_Thermodynamics/1.05%3A_The_Boltzmann_Distribution_and_the_Statistical_Definition_of_Entropy>

2025-1-21 Twelfth Meeting

Present: Claudio, Hani

Apologies: Fizza, Alex

Location and time: RSL GSR3, 14:00

Author of minutes: Hani Moussa

* Spoke with Luke on Logbook layout, conclusions below:
  + Make references clearer
    - i.e. just the title doesn’t help
    - Need to say downloaded, or full citation
  + Make your own conclusions separate from the paper summary
    - Currently confusing as to which bullet points are from paper vs my own thoughts
  + Behind on design at the moment
    - Can rectify this by making decisions in net group meeting
  + Turn into a pdf before submitting logbook
  + Meant to be continuable by someone else
* Meeting with Nafiz
  + Decided on 8U, CAD Model in progress
  + Need models and numbers
    - Model needs to be validated against experimental data, not just algebraic model
  + Sensors + Data
    - Bit rate and sampling frequency
      * Consider Nyquist, natural frequency (2x)
    - Example sensor layouts, then propose them (pros + cons, e.g. cost)
    - Redundancies for data – otherwise useless experiment
    - Encrypted? Existence previous space missions
    - Email people who have done this previously
    - Ground station, how is it collected + who?
  + Flow + rotation
    - Currently considering reaction wheels
    - Aerodynamically unstable allows small spin rate which causes spin to keep going

2025-1-27 Thirteenth Meeting

Present: Alex, Claudio, Fizza, Hani

Apologies: None

Location and time: RSL GSR3, 14:00

Author of minutes: Hani Moussa

* Claudio
  + List of known materials for calculations exist
    - In actual design, clients decide on final materials to test
  + Finite volume method to solve aerothermal
    - 1D, then 2D
    - Verify results with similar literature
    - Temperature, pressure, sheer stress distribution across line/surface
  + Model predictive control possible
  + Milan papers on thermite to ensure demise of CubeSat, hypersonic re-entry can start the reaction
  + Report writing is upcoming work
* Alex
  + Matlab code for vibrational analysis
    - Modelled in time
    - Small vibrations resulted
    - Companies have PSD for vibration for each frequency, used to make model
    - Requires finishing work (small errors)
* Hani
  + Comms background research
    - Types of antennae
    - CubeSat comms in the past
  + Plasma sheath
    - Relection/Absorption of material increases with speed
    - Needs unpractically high Gain to get through
    - QARMAN transmitted back to iridum from back of CubeSat
  + Omnidirectional antennae could allow comms backward to iridum
    - Surpasses plasma sheath, but low gain
    - Materials need to allow transmission
  + Solutions
    - Blackbox can be reconsidered with increase in size
    - Idea to direct antenna backward?
      * Low frequency of rotation, so this may be possible
* Fizza
  + Simulation for trajectory
    - Changed perigee
    - Elliptical orbit, but essentially circular for calculations due to low eccentricity
  + Research atmosphere model
    - Current simulation capped at 180km, cannot go below
  + Secondary objective
    - Spectrometer detects lines of elements -> intensity/concentration approximations
    - Mass Spectrometer more specific, but requires more power/storage
    - Equations/method found to assess impact with spectrometer data
      * Conc over altitude –> GPS required, unless barometer can be used?
    - Pressure/temperature sensors may be needed

# 2025-01-28 Fourteenth meeting

Present: Alex, Claudio, Fizza, Hani

Apologies: None

Location and time: LR7 14:00

Author of minutes: Fizza Naqvi

Logbook review:

* Ensure that references are clearer ( need to change the format) so it’s not just the link
* Include code or description of code in the logbook, especially next to images

Discussion with Luke:

Hani

* We are thinking about checking about what side the plasma sheath is on to orientate the receiver during re-entry/tumbling
* This will help solve one of the communication issues
* This hasn’t been done before for this specific purpose

Alex

* Increase samples in the vibrational model to avoid aliasing
* The vibrational model needs to be compared to existing research to ensure that the model is suitable
* All models should be compared to existing data or an analytical model

Claudio

* Verifying the solution for a flat plate
* Tried a 1D and 2D model
* 1D model works fine for smooth solutions
* Start with a simple, subsonic model
* Finite difference doesn’t work well with Navier-Stokes equations
* Discretisation has limitations- must satisfy Fourier number etc.

Fizza

* Verification of simulations:
* Initial velocity should be higher and then decrease
* Consider what it would look like if it was straight or if it was spiralling for example
* Quantify by looking at the angles for example
* Think about the resolution of the spectrometers- may be significantly impacted by the high velocities
* Shock waves can affect the pressure/velocity too

Discussion with Tobias:

* The spectrometer itself needs to be protected from heat so it should be placed sort of near the centre of the cubesat
* The fibre optic cable that is attached to the spectrometer faces a small hole in the heat shield, but is slightly further back at the beginning of the hole rather than at the end so it’s more protected
* The fibre optic cable itself is quite sturdy so his shouldn’t be a problem
* It can then take measurements on the radiation around the cubesat

### Actions

Hani:

* Create a system diagram to help visualise the comms system

Alex:

* Compare simulations to actual research

Fizza:

* Look into verifying simulations
* Look into the spectrometer

Claudio:

* Work on python solver

# 2025-02-04 Fifteenth meeting

Present: Alex, Fizza

Apologies: Hani, Claudio

Location and time: LR7 14:00

Author of minutes: Fizza Naqvi & Alex Berresford

Updates

Alex

Qualitative validation of vibrational model using base case and natural frequency testing.

Supervisor Feedback

Tobi

Do Quantitative analysis for validation of the vibrational model using an analytical model for the “2 floor” base case.

It’s okay to just propose a theoretical design as long as you have thought through the requirements and assumptions

To measure orientation because the attitude control can affect the spectrometer readings:

* Gyroscopes
* Accelerometers gives rates so needs to be integrate in 6 direction
* Pressure sensors at different faces to see what’s facing free stream vs wake

2 possible questions regarding what measurements can be taken

We don’t know whether materials are ablating due to the materials in the free stream or whether it’s everywhere around the material -> make the assumption that it’s averaged

Consider calibration methods:

* Calibration with an integrating sphere- a lamp that has a known output to know the intensity at every wavelength; include in cost calculations
* Spectral radiance
* Put the spectrometer in front of the lamp and get a calibration factor
* Apply the calibration factor to the real data
* have an idea of the flow field
* Only measurements in the shock layer (hot radiation) will get excited and be able to be measured
* Optical fibre has a certain expectance angle
* This angle forms a cone shape, and the cone shape can be found on manufacturers website
* Things are only measured inside the cone
* See how many cubic metres are found inside the shock wave (he heated radiation/excited particles will not appear beyond the shock wave so get an idea of the thickness of this boundary layer)
* Identify/measure the particle density per cubic metre, multiply this by the cone volume (the volume measured), to get the number of particles in the volume
* Make an assumption about the total volume of the shock wave region to estimate/extrapolate the data for the total article density of that material that is “released”

Verification:

* Verify and validate
* Verify whether the code is solving the equations
* Validate whether it is correctly doing it
* Test it for a base case for example a ball falling at g
* Compare to existing cases

Atmosphere model example: NASA 76 is a good simple model

American institute for aeronautics-> journals

### Actions

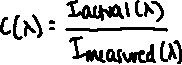
Alex- do an analytical model of the 2 floor vibrational model to validate base case simulations.

Fizza- develop a clear method for the secondary objective research

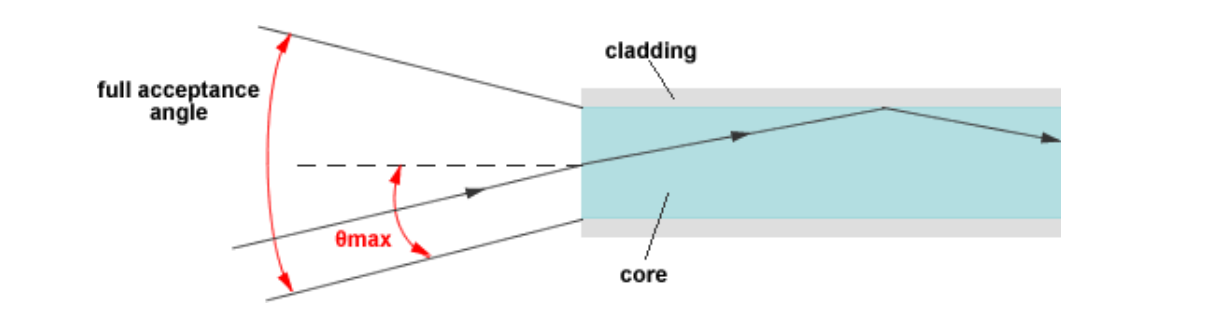
2025-02-09 Notes and Research on evaluating the method of assessing environmental impact during re-entry

This is the same method I previously proposed in my notes, with some adjustments or additional comments added based on feedback from the supervisors:

* Pre-flight calibration
  + Calibration is required due to instrument response, optical depth, and variations in local plasma to prevent systematic errors
  + This can be done using an integrating sphere and known lamps to verify intensity at various wavelengths before the experiment
  + Calibration is performed in controlled conditions to set baseline spectral intensities and gain factors
  + The lamp emits light at known intensities and wavelengths
  + The actual spectral intensity of the calibration lamp at each wavelength is known from the manufacturer’s data or a reference database
  + Calibration factor C(lambda) at each wavelength



* + These are applied to real data to correct for any potential biases in the spectrometer’s readings
* Measure Emission Intensities
  + Use the spectrometer to record emission spectra, intensity of light emitted by species undergoing transitions between energy states and the wavelengths of the emission lines to identify species during CubeSat re-entry.
  + Measurements will be limited to the shock layer, where particles are heated enough to excite species and generate measurable radiation.
  + The optical fibre’s acceptance angle forms a cone-shaped measurement region. [4]



* + The volume of this cone can be calculated using manufacturer’s specifications, and it limits the spatial region where emissions can be measured in that part of the shock layer.
  + Identify key emission lines that correspond to species of interest (e.g., SiO, Al₂O₃, NOx) using the NIST Atomic Spectra Database or similar resources.
  + Determine the wavelength of each emission line observed.
  + Record data at multiple time intervals or altitudes as the CubeSat descends to capture emissions during the re-entry process.
* Identify Energy Transitions
  + Identify the specific energy transitions corresponding to the measured ,
  + Calculate the energy difference between the excited and ground states for each species using the relation: Ej - Ei​ =hc/λ where h is Planck's constant, c is the speed of light, and λ is the wavelength of the emission line.
  + Might be difficult to distinguish between certain species if some emission lines are close together
* Estimate Temperature During Re-entry
  + Account for variations in temperature during the descent, as temperature affects the population of species in excited states.
  + Temperature sensor used for primary objective measurements on the materials can be used.
  + This would be a much easier way of knowing the temperature of the species in the shock layer, not just the ambient atmospheric temperature.
  + In the event that there is an issue with using this data, comparisons with CFD or previous hypersonic test data can be made to get realistic temperature values for different species.
  + It is assumed that the temperature distribution within the shock layer is uniform enough to allow for an accurate estimation of particle density based on the measurement radiation.
  + This is probably valid due to the fact that the CubeSat will be spinning to attempt to uniformly heat.
* Apply the Boltzmann Distribution
  + Apply the Boltzmann distribution to calculate the relative populations of species in their excited states at each temperature: [2]

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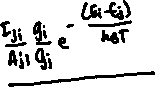
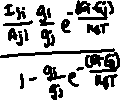
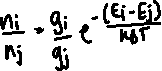
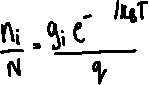
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* + Where:
    - ni​ is the population in the i-th energy state.
    - N
    - Gi is the degeneracy of the i-th energy state- number of available quantum states for a given energy kevel I; can be found in atomic or molecular databases for the species in question
    - q is the partition function.
    - Ei is the energy of the state.
    - kB​ is the Boltzmann constant.
    - T is the temperature at the current altitude.
  + For emission lines, calculate the population difference between two states (e.g., excited state and ground state).
* Convert Emission Intensities to Population Differences
  + The raw measured intensity values are multiplied by the calibration factor to obtain the absolute intensity values Iji.

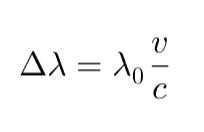


* + Use the Einstein coefficients[1] for spontaneous emission Aji​ to relate the emission intensity Iji to the population difference Nj−Ni​: Iji =Aji (Nj−Ni)
  + Rearrange this equation to calculate the population difference: Nj−Ni= Iji / Aji
  + This gives the population difference between the excited and ground states based on the emission intensity and the known Einstein coefficient Aji for the species of interest
  + These are standard equations used in radiative transfer.
  + Calibration is required
* Estimate Species Concentrations
  + Use the population difference to estimate the concentration of the species in the atmosphere. This can be done by:
    - Comparing the calculated population difference to known calibration curves or using the relationship between population and concentration (which may require specific assumptions or data on the total species present).
    - Scaling the population difference to the total number of particles in the system or volume of the atmosphere being sampled.
  + Apply this procedure to each species of interest to estimate their concentrations.
  + The particle density in the region of the shock wave measured by the optical fibre can then be determined
  + An assumption about the total volume of the shock layer can be made to extrapolate the measured particle density to the entire shock layer region.
  + Requires assumptions about total particle density, which varies with altitude
  + Could be potentially better to use a relative concentration approach, comparing species rather than absolute values
* Collect and Correlate Data with Altitude
  + Combine the measured emission intensities with timestamped altitude data (from GPS or inertial navigation).
  + Correlate the emission spectra with altitude by plotting the measured species concentrations against altitude or time.
  + Track the changes in concentration as the CubeSat descends through varying atmospheric layers.
  + If GPS signal is lost, inertial measurement unit (IMU) can be used as a backup for altitude tracking-> accelerometers and gyroscopes
* Analyse Trends in Species Concentrations
  + Identify trends in the release of ablation products, such as SiO, Al₂O₃, NOx, as the CubeSat descends through the atmosphere.
  + Use interpolation methods to create a continuous profile of species concentration over altitude.
  + Identify key changes in concentration corresponding to specific layers of the atmosphere (e.g., mesosphere, thermosphere).
  + High-speed re-entry could limit the time available for measurements, so a time-series interpolation method e.g. spline fitting (look into this further) could be used to create smoother profiles
* Overlay with Atmospheric Density Models
  + Overlay the species concentration data with atmospheric density models to adjust for variations in background density and pressure at different altitudes.
  + Use standard atmospheric models (e.g., US Standard Atmosphere) or my own model to account for changes in atmospheric conditions during re-entry.
  + Adjust my species concentration data to reflect these atmospheric changes, assess variability, and refine my analysis.
* Quantify the Environmental Impact
  + Integrate species concentration over time or altitude to estimate the total mass of ablated material released into the atmosphere.
  + Use mass conservation principles and known molecular weights of the species to convert concentration data into mass.
  + Compare measurements with baseline atmospheric models to quantify deviations caused by re-entry and assess the environmental impact of the CubeSat’s materials.

Calculation details:

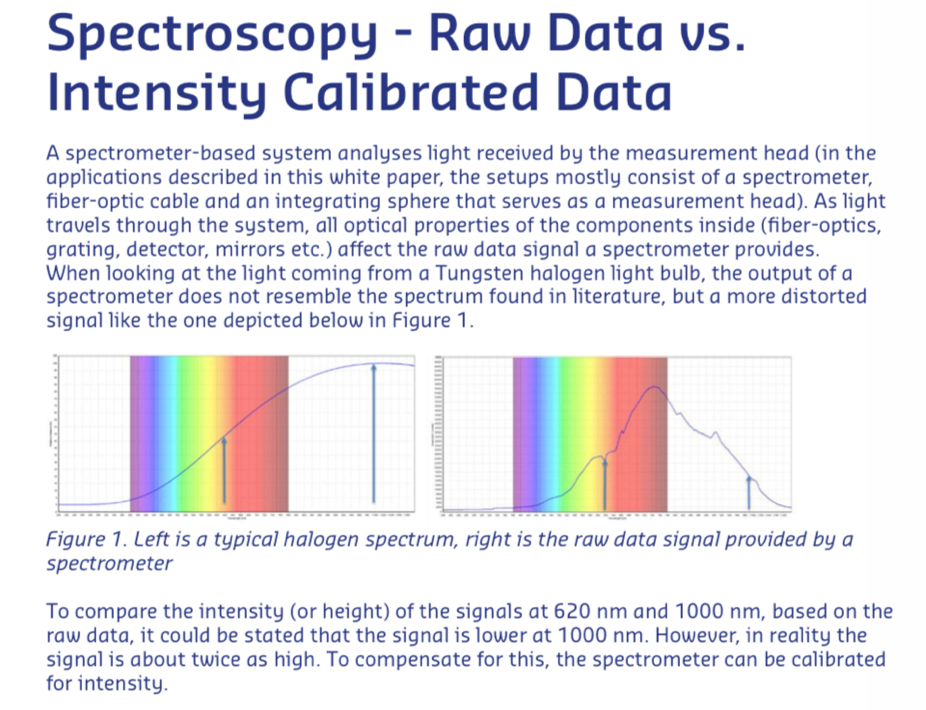


Additional notes on simplifications and assumptions, reflecting on my discussion with my supervisors:

* One assumption made is ignoring the effects of Doppler shifting: high speed re-entry may cause slight shift in emission wavelength, requiring correction
  + 
  + Assuming a re-entry velocity of around 8km/s and a characteristic emission line for SiO, for example, at 250nm, the Doppler shift is around the order of magnitude of 10^-12
  + The resolution of of a typical spectrometer is around the order of 0.1 to 1nm (the spectrometer we are using is 2nm resolution), so I will make the assumption that the Doppler shift can be ignored in this context
  + Moreover, I am making the assumption that the ablated species are distributed around the CubeSat rather than being ejected in a single direction, so radiation is approximately emitted equally in all directions (or at least a roughly symmetric pattern around the CubeSat). Some emission sources will have a small positive Doppler effect and some will have a small negative Doppler effect, effectively cancelling and reduces the overall effect.
* Moreover, the directionality of an ablation plume during re-entry depends on several factors
  + At this point, it is assumed that the CubeSat will ablate at an altitude of around 80km
  + In this altitude, there is a rarefied flow field
  + The Knudsen number (ratio of mean free path to characteristic length) is high, meaning that molecular interactions are minimal.
  + Ablation products tend to expand isotropically in this region rather than forming a strongly directional plume, in comparison to at a lower altitude where continuum flow begins to dominate, and a more directional flow pattern can emerge. [2]
* Local Thermodynamic Equilibrium (LTE) assumption
  + Assumes that the population of excited states follows the Boltzmann distribution at a well-defined temperature
  + Justified if collisional processes dominate over radiative transitions -> confirm this
* Optical thin plasma approximation
  + Assumed that the emitted radiation escapes the plasma without significant reabsorption or scattering
  + Allows direct use of Einstein coefficients to relate emission intensity to population differences
* Assume that excitation and de-excitation processes reach a quasi-steady state, meaning population levels remain constant over short timescales
  + Check that the radiative lifetime is much shorter than the timescales of interest
* Assume homogenous shock layer within the measurement cone
  + Assume that temperature, density, and composition are roughly uniform within the optical fibre’s acceptance cone
    - Justified if the shock layer is thin relative to the spatial resolution of the spectrometer -> confirm this

Extra info on calibration: [3]

* All optical components inside the spectrometer affect the raw data
* The figure below shows output of a spectrometer for light coming from a Tungsten halogen light bulb
* Looks different to the spectrum from literature
* The raw data makes it look like the signal is lower at 1000nm than it is at 620nm, however in reality it’s twice as high
* So spectrometer needs to be calibrated for intensity



Notes on spectrometer choice: [5]

* The spectrometer we will be using is a AvaSpec-Mini2048CL Small and Powerful OEM Spectrometer
* 2nm resolution
* Operating range of 0-55 degrees Celsius so it will be placed inside the CubeSat beneath the ablatives so it’s temperature can stay in this operating range
* The range of detectable wavelengths is 200nm-1100nm
* This is suitable because metals typically emit in the UV (200-400nm) range
* Silica-based materials emit in the UV and Visible (200-500nm) range
* Carbon-based composites emit in the UV and visible range but may have some IR signatures -> near IR is the 700nm-2.5 micrometre range, so all of them may not be captured but they don’t all exist outside of the detectable wavelength range for the spectrometer, so I think it is okay
* Fibre optic needed:
  + A multi-furcated fibre optic cable, the FC6-UVIR400-2 [6], selected
  + This cable features six 400 µm fibres, each terminated with an SMA connector, and has a total length of 2 meters.
  + 400 µm core size balances sufficient light collection and maintaining a high signal-to-noise ratio. This size ensures that enough light is gathered without excessive scattering or loss of resolution, which is particularly important in high-temperature environments like the shock layer
  + The fibres are split evenly from the central splitting point, providing a significant increase in light throughput compared to single-fibre options, ensuring adequate light capture from multiple areas of the shock layer
  + Fibre bundle design allows for multiple sampling points, which enhances the robustness of the measurements. The fibres can be positioned at different points around the shock layer, providing a broader and more accurate representation of the radiation emitted during re-entry
* A cosine corrector would be needed as part of the instrumentation
  + Without a cosine corrector, optical fibres may preferentially collect light from certain angles, leading to inaccurate intensity measurements
  + The corrector ensures that the collected light intensity is proportional to the cosine of the incident angle (Lambertian response)
  + Improves radiometric accuracy
  + Ensures accurate spectral intensity measurements from a plasma that emits radiation in multiple directions
  + CC-UV/VIS/NIR-8MM [7] is the selected Avantes cosine corrector that is compatible with the selected fibre optic cable
  + 180° FOV (field of view), which is good for collecting light over a broad area
  + Since the FC6-UVIR400-2 cable features multiple fibers, the broader FOV will complement the cable's ability to gather light from multiple points around the shock layer during re-entry

Avantes spectrometer:

A usb cable with a blue rectangular box

AI-generated content may be incorrect.

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[3] Loop, G. (n.d.). Intensity Calibration in Spectroscopy and Radiometry. Avantes. Retrieved from <https://www.electrooptics.com/sites/default/files/content/white-paper/pdfs/White%20Paper%20-%20Intensity%20Calibration%20-%20Radiometry.pdf>

[4] Luna-Moreno, D., Villatoro, J., & Monzón-Hernández, D. (2005). Performance comparison of two sensors based on surface plasmon resonance in a plastic optical fiber. Sensors and Actuators B: Chemical, 105(2), 332–338. <https://doi.org/10.1016/j.snb.2004.05.008>

[5] *AvaSpec-Mini2048CL - Avantes*. (n.d.). Retrieved March 25, 2025, from <https://www.avantes.com/products/spectrometers/compactline/avantes-spectrometer-mini-2048cl/>

[6] *Multi-Furcated Fiber-Optic Cables - Avantes*. (n.d.). Retrieved March 18, 2025, from <https://www.avantes.com/products/fiber-optics/optical-fibers/multi-furcated-fiber-optic-cables/>

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# 2025-02-11 Sixteenth Meeting

Present: Alex, Claudio, Fizza, Hani

Apologies: None

Location and time: 14:00 at IEB LR7

Author of minutes: Hani

* Report Writing Presentation
  + Start report early
  + Can give one draft report – general pointers will be returned, not specifics
  + Can have collaborative sections or mark initials after section title if one person made it
  + Final presentation in Trinity
  + Exam regulations
    - 4th Week trinity report hand-in
    - Numbered pages, more details on slides
    - Plagiarism has serious consequences (use citations + sources)
    - Consistent presentation of report
  + Voice/tense
    - 3rd person, active voice
    - Clinical tone (examples on slides)
    - Be as clear as possible (objective + complete statements)
      * Conise English (not fancy words, but scientific), not too many sentences to say one thing
      * “As Seen in Figure 55..”
      * Write bullet points to plan paragraphs, then write as sentences
      * Every sentence needs to be there for a reason
      * Form (paragraph, headings etc.) helps the reader
        + but use it carefully (don’t overspilt)
        + Entry sentence to section (In this section…)
        + Summary/conclusion for section
        + This doesn’t need to be on paragraph, definitely on chapter
      * Get out of your own head – remove your own interpretation as a necessary precursor to reading report
        + Don’t assume result is obvious
    - Logical order + endpoint is what matters
      * Avoid storytelling (like logbook) – explain logical order to present information
      * Only include failed result if key result
      * High level concept, then get detail
    - Past tense for work done, present for factual statements, future for future work
  + Consider reader needs when justifying decisions – not all the detail must be included if irrelevant
  + Can edit something written after a while – fresh eyes help
  + Can discuss sentences as a group
  + Resist filling the page
  + Structure
    - Executive summary/abstract
      * Short (1 page max)
      * Summarise highest level conclusions for technical side
      * Cost/time/what doing
      * “We have designed CubeSat to answer…”
      * Highlight clever stuff
    - Introduction
      * Background – motivations for work
      * Overview of strategy (constraints, how will it works simply)
      * Explain rest of report (process flow diagram, key components, chapters…)
    - Detailed design of sub-systems
      * Marked the most – engineering work
      * Clarity
      * Appropriate, simply explained details
      * Flowcharts/diagrams/costing
      * Contains:
        + Launch/trajectory/mech/elec etc.
        + Systems engineering + failure modes
    - Full system analysis
      * Cost analysis
      * Safety of Operation
        + Data loss/ground population risk/design cert. + legislation
    - Conclusion
      * Takeaway message – cherry-pick best of report
      * Headline of success
      * Unique data
      * Additional work
      * Cost
      * Recommended scheme? (Sales pitch)
    - References
      * Not a bibliography
      * [] used in technical reports
      * Consistent referencing style
  + Figures
    - MUST be legible
    - Don’t cover up data
    - Units, explain what’s going on in caption
    - Only include if referenced in text
  + Equations + Functions
    - Consistency
    - Can derivation go to appendix?
      * Appendix counts as part of 30 pages
    - Tell reader what the parameters are – careful with others in group
    - Accuracy matters most
  + Italics
    - Numerical variable should be italic
    - Lowercase Greek is italic
    - Units (e.g. micrometres) upright with space after value
* Conversation with team
  + Component decision needs to be finalised for further work (e.g. Heat generation)
    - Student project sometimes struggles to get information from companies
    - Mechanical design uses leeway right now
    - Ablative size needs to be considered
    - Alex and Hani will meet at some point to decide
  + Drag coefficient is around 0.6-0.8
  + Can have thermocouple, recession sensor per side
  + Hani will look into recession sensor/email materials department if relevant
  + Discussion on deorbit burn calculations due to assumed circular orbit
  + Other cubesats should give a vague idea of how much power required
  + Thermite to help ensure demise
  + Demise about 8km – around 30 mins of demise
  + Secondary objective
    - Calibration, Measurement, data processing
    - How much of scientific analysis included in report?

# 2025-02-18 Seventeenth meeting

Present: Alex, Fizza, Hani, Claudio

Apologies:

Location and time: 14:00 LR7

Author of minutes: Alex Berresford

Alex

-Analysed various Reaction wheels for estimated 8U geometry and inertia to maximise momentum storage for minimum size and weight. Decided on **Granstal GS-RW10**.

Hani

-Researched OBCs and directional Comms systems. Decided on an OBC with a software defined radio which turns data into a comms signal without the need for an external system. **ICEPS Spacecraft System Core: All-in-one.** It also includes 3 axis accelerometer attitudes.

-Directional comms system involves several flat antennae adjacent in plane along with phase shifters to change phase of each antenna to control directionality. Rotman lens can be used to generate phase of each array automatically. Using a 2x3 array of **L-band Path1L-R from Space Antenna.**

-Type K thermocouples have highest temperature range, which will be ideal for our goals.

Thermal conditions:

Cube shaped allows even heating – orientation to sun doesn’t matter.

Concerned by lower temperature range, as there will be large losses when passing through Earth’s shadow. Tobias suggested a 0d heat simulation.

Internal heat generation will be dominated by reaction wheels, so they should be kept external to comms, which we expect to be the temperature critical system. If ablatives are sufficiently insulating, internal heat should be fairly constant.

Altitude determination:

Using multiple sensors we can estimate altitude:

Radar altimeter uses radio waves reflected off the earth to measure altitude.

Magnetometer measures the size and direction of the Earths magnetic field to estimate altitude.

Gyroscope measures acceleration, which can be integrated twice to estimate distance travelled.

Fizza

-Investigated spectrometers but hasn’t found an acceptable one yet. Thor labs one doesn’t have electrical requirements listed and has a very small acceptable temperature range.

Actions

Hani- Look into the maths of the comms system.

Claudio – Do a worst-case external heat balance model over an orbit.

Alex – Contact Rocket Lab and SpaceX, try and find examples of minor sensors.

Fizza – Continue looking into spectrometers and atmosphere models.

# 2025-02-25 Eighteenth Meeting

Present: Alex, Fizza, Hani, Claudio

Apologies:

Location and time: 14:00 LR7

Author of minutes: Hani

* Claudio
  + Without ablatives, demise time within an hour
  + Thermite can passively ignite, causing demise within around a km
    - Useful to decrease risk of damage on ground
    - This gives us a high range for ablative dimensions
    - Reaching 700K is the goal
  + Worst case materials can be used for heat calculations
  + Orbital period, safe operating range for electronics needed
  + Need to find temperature around orbit
* Alex
  + Pressure sensor/magnetometer found
    - Allows estimation of altitude
  + Emailed RocketLab about cost estimation
  + Slides could be in chronological order of what happens when
* Fizza
  + 400km for orbital period
* Hani
  + Iridium has technical specifications
  + New, much smaller, antenna found
  + Need to do calculations to see if beamforming or just antenna on each side work – latter is simpler
  + Need to make battery choice
* Supervisor Talk with Luke
  + There is always more to be done
  + Can consider what to do with data after project
    - Worthwhile discussing, but not absolutely necessary
    - Could discuss as part of why that data was chosen – as a justification
    - Scientific objective requires more input on data use
  + Sensor choice and data rate needs engineering justification – how much data do we need to get a good reading on what’s happening
  + Don’t underestimate document writing time requirement
* Actions to take
  + Claudio – Look into thermite more, bounds for ablative thickness
  + Alex – Start on slides (less slides, more talking), CAD model at some point
  + Fizza – Simulations, secondary objective
  + Hani – Comms + beamforming consideration

2025-03-03 Notes and Research on Kalman Filter design with Sensor fusion for altitude and attitude tracking

* Accurate attitude and altitude tracking is crucial for correlating material ablation data with re-entry conditions.
* Hypersonic re-entry introduces sensor noise, drift, and measurement errors due to extreme conditions.
* Sensor fusion using a Kalman filter combines data from an IMU (accelerometer + gyroscope) and a barometer to improve reliability and accuracy.

Sensor Roles:

* IMU
  + Accelerometer measures linear acceleration; used to estimate pitch and roll via trigonometric relationships.
  + Gyroscope measures angular velocity; subject to drift over time.
* Barometer
  + Measures pressure and calculates altitude using a pressure-altitude relation.
  + Sensitive to atmospheric changes; fusion corrects for inaccuracies.

System Dynamics & Kalman Filter:

* System modeled in discrete-time state-space form with process and measurement noise.
* State vector includes roll and pitch angles and their biases.
* Kalman filter used for real-time estimation via prediction and measurement update steps.
* Filter assumptions: zero-mean, white noise, uncorrelated process and measurement noise.

Instrumentation Models:

* Gyroscope: Non-linear mapping from body-frame angular velocities to Euler angle rates.
* Accelerometer: Estimates pitch and roll assuming gravity is dominant force.
* Barometer: Altitude computed from pressure readings using standard formula.

Benefits:

* Kalman filter improves robustness against sensor drift, noise, and external acceleration disturbances.
* Ensures precise attitude for retrograde burn orientation and accurate altitude tracking for material demise analysis.

A close-up of a piece of paper

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A whiteboard with text and equations

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General system dynamics/state space form [3] :

A number and mathematical symbols

AI-generated content may be incorrect.

Accelerometer equations [4]:

A diagram of a line of rectangular objects

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* This diagram uses slightly different notation
* They have rho as the pitch (which is actually represented by theta in my system)
* Phi is the correct equation/notation corresponding to yaw
* These angles are in radians so I’m going to multiply by 180/pi to convert them to degrees

Gyroscope equations [5]:

A close-up of a math problem

AI-generated content may be incorrect.

Barometer equation [2]:

*A black text on a white background

AI-generated content may be incorrect.*

A white paper with text on it

AI-generated content may be incorrect.A close-up of a paper

AI-generated content may be incorrect.

References

[1] Papachristodoulou, A. (2024). *B15 Optimal Control: Kalman Filtering*. Lecture notes, University of Oxford. Accessed: 28 March 2025.

[2] Tanigawa, Makoto, et al. "Drift-free dynamic height sensor using MEMS IMU aided by MEMS pressure sensor." 2008 5th Workshop on Positioning, Navigation and Communication. IEEE, 2008

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[4] *Using the Accelerometer – HUSSTECH*. (n.d.). Retrieved March 29, 2025, from <http://husstechlabs.com/projects/atb1/using-the-accelerometer/>

[5] Kothari, M. (n.d.). *Attitude Representation and Transformation Matrices*.

2025-03-12 Notes and Research on completing MATLAB trajectory simulations

* I requested and attempted to use other simulation software (for simulation validation purposes), such as DAS by NASA, however there were problems opening up the software and getting it running
* NASA did not respond to any emails so it will be difficult to validate the MATLAB simulation without any other cases that follow a similar trajectory that can be put into the code to ensure it is correct

F10.7 and Ap:

* In the previous simulation that was done, F10.7 and Ap values used were arbitrarily picked from a random day
* The new values used are based on predicted values for a potential launch day in 2026
* A screenshot of a graph

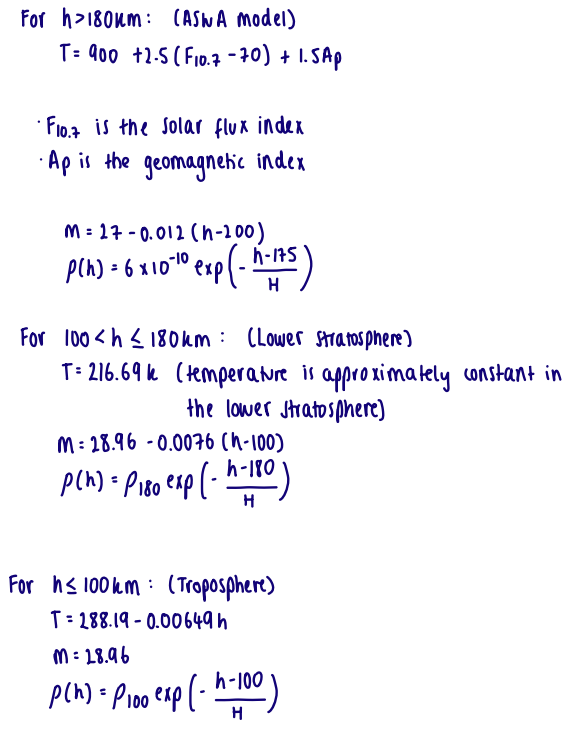
  AI-generated content may be incorrect.F10.7 represents solar activity based on emissions at 10.7cm wavelength, following an 11-year cycle so long-term predictions are possible
* The figure [1] above shows the variation in actual and predicted F10.7 values
* The predicted F10.7 value in December 2026, our potential plan for a launch date, is 125
* Ap geomagnetic index measured geomagnetic disturbances caused by solar wind and interplanetary magnetic field (IMF) interactions with Earth’s magnetosphere
* It is highly variable as, unlike F10.7, it doesn’t follow a smooth cycle but instead reacts to unpredictable solar events e.g. coronal mass ejections or solar flares
* Therefore, the Ap value used is an averaged value across December 2026, which is 10.8

Atmospheric density model:

* The previous MATLAB simulation for the trajectory did not consider what happens to the satellite below 180km
* The ASWA model that is used is based on an exponential atmosphere model with a variable scale height
* However, as this model was limited to an altitude of 180km (due to the equation m(h) only being valid between 180<h<500km)
* If the original model is used below 180km, it would incorrectly extrapolate molecular mass variation
* I have created a new piecewise model, which is an adaptation of ASWA’s model, using NASA’s Earth atmosphere model that ensures smooth transitions between different atmospheric layers while accounting for mass and temperature variations
* This piecewise function uses the previous altitude range’s atmospheric density to ensure that the function does not have any discontinuities
* It accounts for the variable temperature and masses in each of the ranges
* The 180<h<500km range still uses the ASWA model that was previously implemented into the code
* The 100<h<180km and <100km ranges use NASA’s Earth atmosphere model [2] for the lower Stratosphere and Troposphere temperature and mass variations respectively
* The molecular mass m represents the average mass of the atmospheric particles at a given altitude. It varies due to the changing composition of atmospheric gases as altitude changes
* The molecular mass in the lower Stratosphere is modelled to vary linearly
* The molecular mass in the Troposphere is modelled to be approximately constant

A white paper with blue writing

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Other changes to the simulation:

* Previously, the area used was the cross-sectional area 0.04m2
* Claudio’s derivation of the averaged reference area tells us that the average reference area = 0.25\*total surface area
* So in the new simulation code, A=0.06m2

MATLAB results:

A graph with a blue line

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Evaluation of MATLAB results:

* This tells us that the total duration of our CubeSat’s de-orbit is 456.93 hours
* This value is highly dependent on
  + mass (which could still change depending on when components are completely finalised)
  + F10.7 and Ap -> many trajectory simulations assume an average value of Ap so I think this assumption is reasonable, however F10.7 varies significantly so the duration of the mission will very much depend on what month it is chosen to be launched in
  + Reference area- the previous assumption of a constant reference area that was equivalent to the cross-sectional area was not valid
* 300km is where the atmospheric drag begins to decay noticeably
  + At altitudes above 300 km, the satellite experiences a relatively gradual decrease in altitude due to lower atmospheric density. However, as it reaches the denser regions below 300 km, the effect of drag increases more substantially, leading to a steeper decline in altitude.
  + This model is in line with expectations based on atmospheric drag, as this behaviour is typical for satellites in low Earth orbit, where drag becomes a dominant factor in orbital decay at these altitudes
* The average F10.7 value for December 2026 is 125, however the range of forecasted values for the month is 116.3-134.8
* Running the simulation for those 2 results gives 2 other time values

|  |  |
| --- | --- |
| Forecasted F10.7 | De-orbit duration |
| 116.3 | 500.26 hours |
| 125 | 456.93 hours |
| 134.8 | 414.59 hours |

* This means that there is high variability in the de-orbit duration, and it could vary even more depending on if it chosen to be launched in a different month entirely
* Therefore, the simulation has to be re-run again when the launch date is specified

References

[1] *Solar Cycle Progression | NOAA / NWS Space Weather Prediction Center*. (n.d.). Retrieved March 13, 2025, from <https://www.swpc.noaa.gov/products/solar-cycle-progression>

[2] *Earth Atmosphere Model - Metric Units*. (n.d.). Retrieved March 13, 2025, from <https://www.grc.nasa.gov/www/k-12/airplane/atmosmet.html>

[3] Picone, J. M., Hedin, A. E., Drob, D. P., & Aikin, A. C. (2002). NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues. *Journal of Geophysical Research: Space Physics, 107*(A12), 1468. <https://doi.org/10.1029/2002JA009430>

2025-03-13 Notes and Research on the propulsion system for the de-orbit burn

* We contemplated removing the propulsion thrusters to optimise space on the CubeSat, but re-arrangements were made in the design so these could be fitted
* The cold gas thrusters are necessary to perform a de-orbit burn (in conjunction with the Model Predictive Control system for attitude control to ensure the CubeSat doesn’t have the thrusters pushing it out of orbit)
* Without the burn, the satellite gradually loses altitude due to atmospheric drag at 400km, which could take a significant amount of time
* With the burn, the satellite will reach perigee at 140km. At this altitude, atmospheric drag is exponentially stronger, removing energy rapidly and leading to a much shorter re-entry time
* The time it takes to do a deorbit burn is very short so the actual altitude change at 400km is negligible-> the burn is modelled as an impulse burn
* A retrograde burn will need to be performed where the thrusters fire in the exact opposite direction to the satellite’s velocity vector
* This will be done by alignment using the model predictive control system

Requirements for a CubeSat propulsion system:

* + Siza and weight
  + Specific impulse
  + Operating power
  + Delta-V capability
* For a de-orbit burn at 400km to achieve a target perigee of 100-150km, a delta V of at least 60m/s is need [1]

Propulsion system options:

* “Enpulsion Nano- Heritage Model”
  + This is a Field Emission Electric Propulsion (FEEP) system that that uses a strong electric field to extract and accelerate metal ions from a liquid surface [2]
  + As it operates at extremely high specific impulses, it is ideal for precise, low-thrust applications
  + The table below is from the data sheet [3] for the system
  + As this isn’t applicable to impulse, high-thrust burn, this is not the propulsion system we will go for

A table with text and numbers

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* AST's miniaturized nitrogen cold gas thrusters provide a thrust of 42 mN at more than 69 s specific impulse.
  + 6 of these would provide a sufficient delta-V
* VACCO’s CuSP Propulsion System [4]
  + Cold gas Micro Propulsion System (MiPS) provides attitude control and orbital manoeuvring
  + Approximately 0.3U in volume
  + Uses 4 25mN cold gas thrusters to develop 69s of specific impulse, which is a measure of how efficiently a reaction mass engine generates thrust; it is essentially the ratio of impulse per mass of propellant
  + Each propulsion system has an allowed propellant mass of 177g
  + This is the system I want to go for

Delta-V calculations:

* We don’t currently have a finalised value for the CubeSat mass but the average mass of a 8U cubesat is about 12kg, so this is the mass I used for my calculations
* Tsialkovsky’s rocket equation [5] is



Where:

* + Isp is specific impulse
  + G0 is the standard gravity, 9,8m/s2
  + Mf and mi are the masses of the CubeSat after and before the de-orbit burn respectively
* For 3 Vacco MiPS, a Delta-V of 87.8m/s is allowed
* As the Delta-V of 77m/s is required for the de-orbit burn alone, this means that there is an extra 11m/s of allowable delta-V
* Time for burn to occur [6]:



* For one MiPS, tb=1198s
* As we are using 3 MiPS, tb=399s
* On the scale of the whole mission time, this burn time is extremely slow, and the altitude change for this duration will be negligible

References

[1] Bacon, J. B. (n.d.). *MINIMUM DV FOR TARGETED SPACECRAFT DISPOSAL*. Retrieved March 21, 2025, from <http://spacedebris2017.sdo.esoc.esa.int>,

[2] *Order - Enpulsion*. (n.d.). Retrieved March 21, 2025, from https://www.enpulsion.com/order/

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[4] *CuSP Propulsion System | VACCO Industries*. (n.d.). Retrieved March 25, 2025, from https://cubesat-propulsion.com/cusp-propulsion-system/

[5] *Tsiolkovsky rocket equation - Wikipedia*. (n.d.). Retrieved March 22, 2025, from <https://en.wikipedia.org/wiki/Tsiolkovsky_rocket_equation>

[6] Rocket Propulsion Elements, 7th Edition by George P. Sutton, Oscar Biblarz

2025-03-15 Notes and Research on GMAT simulation for verification

* Comparison to real satellites can’t be performed for validation as there isn’t any data available for any existing missions that have performed the same trajectory plan with the same deorbit burn (to achieve the same delta V with the same target perigee)
* I think that the best way of validating the MATLAB code is to use a simulator to ensure that the code does do what we need it to do
* One way of doing this is to use NASA’s General Mission Analysis Tool (GMAT) to model the decay
* GMAT is an open-source orbital dynamics software that numerically propagates spacecraft trajectories under various forces, including atmospheric drag and propulsion effects
* This will tell us how correct the MATLAB simulation is, particularly with the RK4 (Runge-Kutta 4) implementation

GMAT simulation:

The simulation was configured with the following key steps:

* Initial Orbit: ~400 km altitude, near-circular orbit
* Deorbit Burn: A retrograde manoeuvre applied to reduce perigee to 140 km
* Atmospheric Model: A density model was implemented to account for drag forces
* Propagation: The satellite’s trajectory was propagated until atmospheric re-entry

Mission setup:

CubeSat.Epoch = '01 Dec 2026 12:00:00.000';

CubeSat.DryMass = 12; % kg

CubeSat.Cd = 2.2;

CubeSat.Cr = 1.3;

CubeSat.DragArea = 0.06; % m^2

CubeSat.SRPArea = 0.06; % m^2

CubeSat.OrbitColor = Red;

CubeSat.OrbitStateType = Keplerian;

CubeSat.CoordinateSystem = EarthMJ2000Eq;

CubeSat.SMA = 6778.137; % km (400 km altitude)

CubeSat.ECC = 0.02;

CubeSat.INC = 55; % degrees (Random inclination)

CubeSat.RAAN = 0;

CubeSat.AOP = 0;

CubeSat.TA = 0;

Force Model (Earth Gravity, Drag, SRP):

Create ForceModel EarthForces;

EarthForces.CentralBody = Earth;

EarthForces.GravityField.Degree = 8;

EarthForces.GravityField.Order = 8;

EarthForces.Drag.AtmosphereModel = MSISE90;

EarthForces.Drag.F107 = 125;

EarthForces.Drag.Ap = 10.8;

EarthForces.SRP = On;

EarthForces.SRP.Flux = 1367;

EarthForces.SRP.NominalDistance = 1;

Propulsion System (Retrograde Burn):

Create ImpulsiveBurn DeorbitBurn;

DeorbitBurn.CoordinateSystem = LocalOrbital;

DeorbitBurn.Origin = Earth;

DeorbitBurn.Axes = VNB;

DeorbitBurn.Element1 = -77; % m/s retrograde burn

DeorbitBurn.Element2 = 0;

DeorbitBurn.Element3 = 0;

Propagator sequence:

Create Propagator BeforeBurn;

BeforeBurn.FM = EarthForces;

Create Propagator AfterBurn;

AfterBurn.FM = EarthForces;

Results:

The outputted data is saved to a .csv file and is plotted on a smooth curve on the same figure as the MATLAB model results for comparison



* The two predictions follow each other very closely
* This verifies the accuracy of the MATLAB model’s implementation of the aerodynamic decay equation using RK4 (4th order Runge-Kutta)
* Overall, there is a 2.46% difference in the final time to reach an altitude of 40km (the point at which thermite breakup begins), which seems reasonable
* Minor differences above 300km may be due to the way the equations are iteratively solved
* In the MATLAB model, due to the short duration of the impulse burn, the altitude model is assumed negligible at 400km
* In the GMAT simulation, the retrograde burn is applied and it noticeably has a minimal effect on the initial altitude change, but still achieved it’s desired effect in ensuring rapid re-entry
* The greatest deviation is below 300km, where the effects of drag begin to dominate, so the deviation may be due to the MATLAB model using a simplified drag model, which becomes more apparent here

2025-03-17 Notes and Research on collision analysis

* NASA’s orbital debris requirements: Probability of collision with space objects larger than 10cm in diameter is less than 0.001 [1

Using Poisson distribution to calculate the probability of collisions in LEO [2]

* Probability is proportional to cross-sectional area, as a larger satellite presents a bigger target for debris, increasing the likelihood of impact

A whiteboard with text and arrows

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* Average orbital velocity=7.5km/s
* T is the time of duration for the whole mission- estimated from simulations
* Calculating spatial density
  + The figure below visually shows NASA’s most recently available data on the current debris environment in LEO [3]

A graph of a graph

AI-generated content may be incorrect.

* This gives a spatial density of approximately 9.992e-10 objects/km3 i.e 1e-9 objects/km3. This value is obtained by summing the averaged spatial density values over 50km intervals up to 400km.
* Probability is calculated to be 0.000657, which is less than NASA’s threshold for collision risk for unmanned spaceflight, therefore I think it is safe to assume that the probability of collision is negligible

References

[1] *Orbital Debris Management & Risk Mitigation*. (n.d.). Retrieved March 26, 2025, from www.nasa.gov

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[3] *Orbital Debris Quarterly News A publication of The NASA Orbital Debris Program Office*. (2009). [www.orbitaldebris.jsc.nasa.gov](http://www.orbitaldebris.jsc.nasa.gov)