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 [Project Name] group. We aim to create a respectful, inclusive, and productive environment for all participants.

Please continue from here.

## Summary of the project and objectives

This project…

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# 2024-10-18 Notes and Research

# 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

<https://testbook.com/ias-preparation/types-of-orbits>

<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

### References

### 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

### References

### Actions

### Deadlines

Research Tasks by 29/10/2024

-Hani – sensors for material degradation

-Claudio – Magnus effect, and realism of generating spin

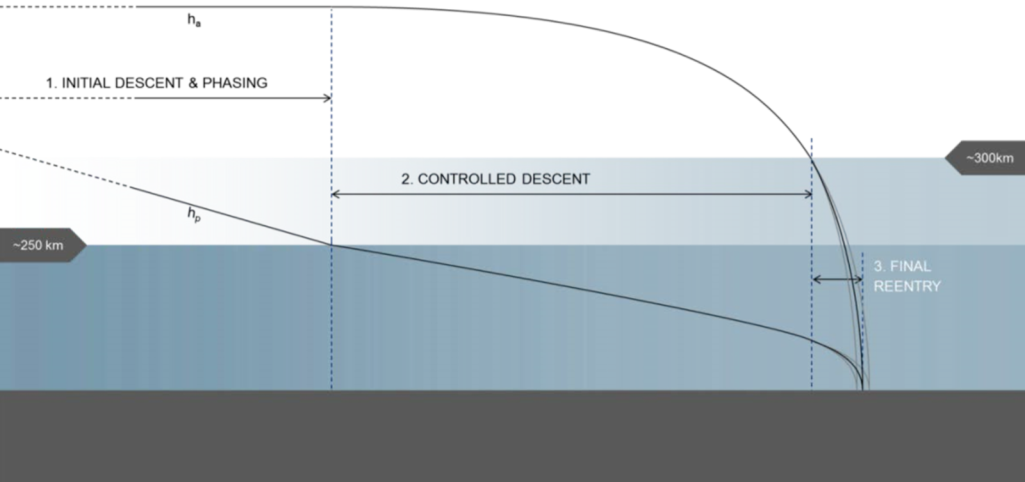
-Fizza – Look into trajectory, expected burn altitude and ideal orbital altitude as well as ionosphere

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

# 2024-10-25 Notes and Research

# 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]

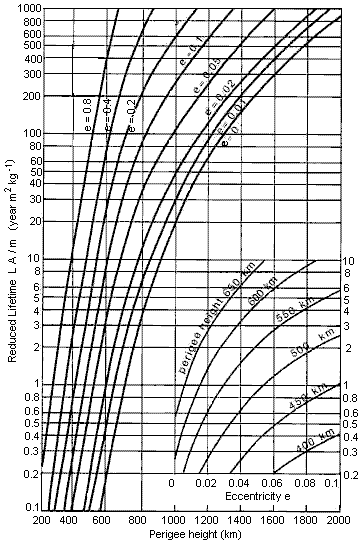


* Semi-controlled re-entry is great for medium-sized spacecraft, where casualty risk could be up to five times lower using electrical propulsion systems Some form of controlled re-entry is necessary due to the growing amount of debris in LEO and also the increasing regulations relating to deorbitation
* 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]
* Reduced lifetime in years can be calculated from:  [reference: King-Hele (1987)]
* L = L\* ( m / A )
* 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

900 km 1000 years

Trajectory research:

* <https://amslaurea.unibo.it/19043/1/Thesis_DeCecio.pdf>
* Amazing 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 [9]
* 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] <https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/297/SDC8-paper297.pdf>

[2] <https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/143/SDC8-paper143.pdf>

[3]<https://indico.esa.int/event/416/contributions/7431/attachments/4890/7502/CSID22_2_End-of-Life%20Considerations%20for%20CubeSats%20-%20presentation.pdf>

[4] <https://www.nasa.gov/humans-in-space/leo-economy-frequently-asked-questions/#:~:text=What%20is%20LEO%20>

[5]<https://www.esa.int/Enabling_Support/Space_Engineering_Technology/CDF/Design_For_Demise_A_First_Look>

[6]<https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Design_for_demise_bringing_spacecraft_down_safely_and_efficiently>

[7] <https://blogs.esa.int/cleanspace/2018/11/16/basics-about-controlled-and-semi-controlled-reentry/>

[8] <https://www.spaceacademy.net.au/watch/debris/orblife.htm>

[9] <https://newspaceeconomy.ca/2024/08/12/the-ionosphere-earths-vital-interface-with-space/#:~:text=As%20these%20satellites%20orbit%20at,metallic%20particles%20and%20plasma%20formation>

# 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:
  + NASA 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

### References

### Actions

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

### Deadlines

# 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

### References

### 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

### Deadlines

# 2024-11-02 Notes and Research

* 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, Planet Labs, and some geospatial analytics firms. These companies often track satellite movements and could potentially help with re-entry plume observations.
* Companies like World View Enterprises or Near Space Corporation provide high-altitude balloons that can carry observational instruments up to the stratosphere. You can equip them with spectrometers or cameras to capture re-entry data at closer proximity than ground-based observations
* Some balloon companies may offer customizable payloads with sensors, cameras, and data collection tools
* Spaceports often monitor objects entering and leaving the atmosphere for launch and debris tracking
  + May only be good for objects and not gas traces like we need

### References

### [1] <https://blogs.esa.int/cleanspace/2022/08/11/on-the-atmospheric-impact-of-spacecraft-demise-upon-reentry/>

[2] <https://www.pnas.org/doi/10.1073/pnas.2313374120>

[3] <https://www.eoportal.org/satellite-missions/qarman>

[4] <https://www.eoportal.org/satellite-missions/qarman#eop-quick-facts-section>

[5] <https://indico.esa.int/event/493/timetable/?view=standard_inline_minutes>

[6]<https://strathprints.strath.ac.uk/78407/1/Graham_etal_IAC_2021_The_design_of_a_fragmentation_experiment_for_a_CubeSat_during_atmospheric_re_entry.pdf>

# 

# 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

### Deadlines

# 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.

### References

### 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.

### Deadlines

# 2024-11-10 Notes and Research

* Writing some simulations in python to visualise an orbit that allows for burn at apogee, followed be spinning up in the vacuum of space before reaching the atmosphere
* Upon reflection of my code (general plans for the code are noted below), I came to the conclusion that starting too far out would require more fuel as the effects of orbital decay are less, so the satellite will take much longer to naturally decay.
* Therefore it is better to start at a lower altitude for spin-up and de-orbit burn
* I wrote the code in python so I could implement a python package ‘Poliastro’- this package is conventionally used for astrodynamics and orbital mechanics simulations
* allows you to propagate orbital trajectories over time using various integrators, both for elliptical and non-elliptical orbits
* helps in simulating orbital maneuvers such as burns (impulses or finite burns), orbit transfers, and interplanetary missions
* Poliastro integrates with **matplotlib** to plot orbits in 2D or 3D

**Simulating a simple re-entry trajectory (simple\_re-entry\_simulation):**

* Only considers the gravitational forces
* Dynamics are in the x-y plane and since there’s no initial velocity in the y-direction, it’s just a straight line

**Simulating a re-entry where the orbit is designed so that re-entry begins at apogee (re-entry\_at\_apogee):**

* Model a highly elliptical orbit
* Create an initial orbit where the satellite’s perigee is above Earth’s atmosphere

Rough plan:

1. Orbital parameters:

* Perigee: 300km (so r initial is 6771km)
* Apogee: 7000km

2. Initial orbit:

* Semi- major axis a=(r\_perigee + r\_apogee)/2
* to describe the size of the elliptical orbit
* longest distance from the centre of the ellipse to its edge
* larger a = longer orbit
* Eccentricity i.e. the elongation of the ellipse
* e = (r\_perigee - r\_apogee)/(r\_perigee + r\_apogee)

3. Initial conditions for re-entry

* initialise velocity and position at this point
* orbital mechanics equations
* initial velocity is 7.8km/s (typical speed for an object in LEO)

4. re-entry dynamics

* atmospheric drag
* gravitational force
* add drag into the dynamics once re-entry begins

**To include velocity plots (re-entry\_at\_apogee\_with\_velocity\_plot):**

1. define parameters

* Radius of Earth
* Gravitational parameter mu
* Initial altitude at apogee (400km)
* Eccentricity = 0.1 (slightly elliptical orbit)
* Eccentricity = 0 at a circular orbit and 1 at a parabolic orbit
* We need eccentricity 0<e<1 (typical for satellites)

2. compute the semi major axis

3. calculate initial distance and velocity at apogee

4. re-entry dynamics function

* Gravitational acceleration
* Atmospheric drag which is only applicable below 100km altitude
* Use exponential atmosphere model- suitable for low accuracy and quick simulations
* Approximate drag coefficient = 2.2
* Calculate total accelerations in x and y (gravity and drag)

5. time span for simulation

6. solve differential equation

* solve\_ivp to solve initial value problems of differential equation
* solution = solve\_ivp(reentry\_dynamics, t\_span, initial\_state, t\_eval=t\_eval)
* re-entry dynamics defines the equations of motion
* t\_span is the time range for the simulation
* initial\_state specifies the start position and velocity
* results extracted

7. find re-entry point

8. plot the trajectory

Explaining the graphs:

* Once the satellite gets below 100km, atmospheric drag acts on it so the drag force increases
* Drag force is proportional to velocity squared so the force strongly opposes the satellite’s motion and rapidly slows it down

**Improving the model above (re-entry\_at\_apogee\_with\_velocity\_plot2):**

* In the first model, drag only activated at a specific altitude
* Whereas the new model updates dynamically as the speed and altitude transitions within the atmosphere
* In the new model gravitational and drag forces are calculated at each time step based on the position and velocity so the simulation of how the velocity changes is more realistic
* The previous model didn’t simulate how the satellite gradually slows down by atmospheric drag
* However the problems with this model is that is models the velocity to increase and decrease over time, which isn’t accurate to what would actually happen

# 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

### References

### 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

### Deadlines

# 2024-11-15 Notes and Research

* 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

Notes on MATLAB simulations:

* I feel more comfortable with coding with MATLAB so I decided to continue refining the simulation code in MATLAB instead of python
* The model begins with a spin-up at an altitude of 400km using cold thrusters and reaches target spin rate by around 250km (in the typical altitude range for orbital decay)
* Then the satellite will perform de-orbit burn using different cold thrusters
* The simulations are not accurate because it assumes a constant orbital velocity of 7.8km/s,resulting in it taking the cubesat on 0.6 minutes (36s) to go from ISS to the Earth’s atmosphere
* Realistically, the velocity will be varied, especially if we are performing a de-orbit burn to reduce the velocity enough for re-entry
* 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 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] <https://www.sciencedirect.com/science/article/pii/S009457651731336X>

[2]<https://www.unoosa.org/documents/pdf/psa/hsti/KiboCUBE/KiboCUBEAcademy2021/KiboCUBE_Academy_Day4/KiboCUBE_Academy_2021_UNISEC_4-1_Kuwahara.pdf>

[3] <https://www.cubesat-propulsion.com/wp-content/uploads/2017/08/X16038000-01-data-sheet-080217.pdf>

[4] <https://cubesat-propulsion.com/wp-content/uploads/2019/08/Standard-MiPS-datasheet-080119.pdf>

[5] <https://conference.sdo.esoc.esa.int/proceedings/sdc3/paper/54/SDC3-paper54.pdf>

# 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

### References

### Actions

### Deadlines

# 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

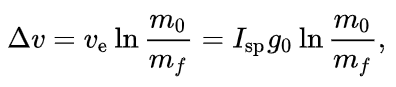
# 2024-11-20 Notes and Research

* During the eighth meeting, we decided to have the CubeSat perform it’s de-orbit burn, then spin-up during decay.
* Doing this at an altitude of 400km is likely to be a very slow process as the natural process of decay will take much longer due to a weaker force of gravity further out.

Initial code: **simulation1.m** in the folder “Second set of simulations”

**De-orbit burn:**

* Before de-orbit burn, the CubeSat is in a circular orbit at an altitude of 400km
* After de-orbit burn, the CubeSat moves from a circular orbit to an elliptical orbit so it’s perigee is 100km
* The de-orbit burn changes the orbit from a circular orbit to an elliptical orbit v\_initial is calculated using v\_initial = sqrt(mu / r\_initial)
* v\_after\_burn represented the velocity immediately after the de-orbit burn v\_after\_burn = v\_initial - deltaV
* v\_final (velocity at the point where the CubeSat reaches its perigee in the elliptical orbit after the de-orbit burn, assuming no further burns or changes to the orbit) is calculated using the calculation for the semi-major axis
* Tsiolkovsky rocket equation: [1]



* This is the equation I will use to calculate the amount of propellant required for my calculated delta V required for de-orbit burn to around the Kalman line
* ve=Ispg0 is the effective exhaust velocity where Isp is the specific impulse and Ispg0 is standard gravity
* m0 is the initial total mass, including propellant i.e. the wet mass
* mf is the final total mass without propellant i.e. dry mass
* This equation is quite precise because it accounts for the exponential nature of mass loss
* The initial calculation for distance travelled during the de-orbit burn that my code calculates results in a much larger distance than what would be realistic for a CubeSat performing a de-orbit burn
* This is because the time for de-orbit burn was initially at 9 hours- this was with a cold gas thrusters force of 10mN, so increasing the force to 25mN reduced the burn time to around 3 hours (233 minutes). This is a lot shorter and more realistic but still longer than the time it normally takes (30 minutes to 1 hour)
* Using cold gas thrusters that have a greater force than this (perhaps up to 50mN) would help resolve this issue
* Also, the distance travelled was also calculated using distance\_travelled = average\_velocity \* burn\_time where distance\_travelled = average\_velocity \* burn\_time
* This equation doesn’t consider the elliptical trajectory that’ governed by gravitational forces and should be calculated using orbital mechanics; the velocity vector shouldn’t be purely radial but contain tangential and radial components
* These issues will fixed in the new code **Simulation2.m**

**Adjustments in the distance travelled during de-orbit calculation:**

There are 2 possible methods for doing this:

Method 1:

* Use Kepler’s equation to find the CubeSat’s position in the elliptical orbit at each time step
* True anomaly represents the angular position of an object in orbit relative to the periapsis (the closest point to the focus of the orbit, which is usually the centre of the central body, like Earth); in simple terms it’s the angle between the periapsis and the current position of the object in orbit [2]
* Calculate this using Kepler’s equation and the eccentric anomaly
* Use the true anomaly to calculate the orbital distance travelled between 2 points along the orbit
* The distance travelled along the orbit can be computed by integrating the speed over time, or by calculating the arc length between two points on the orbit
* This method is good for long-term simulations, especially in elliptical orbit, but that doesn’t really apply here

Method 2: This is the method I chose because it’s more applicable to my elliptical orbit as there are external forces like drag present

* Elliptical motion and arc length
* Directly integrates the velocity over time using the equation of motion to find the distance travelled
* Uses numerical methods to solve the differential equations ((I implemented ode45)
* This method is more flexible as it can account for non-constant drag, perturbations etc.
* However it’s based on numerical integration so it could introduce possible errors
* The time to perigee, calculated in the code, is the time it takes to get from apogee to perigee
* It’s calculated using the orbital period, which is calculated using Kepler’s law

**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 [6]
* 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 [3]
* 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) [4]
* 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 [5]

### References

[1] <https://en.wikipedia.org/wiki/Tsiolkovsky_rocket_equation>

[2] <https://www.britannica.com/science/anomaly-astronomy#ref105658>

[3] <https://www.spaceacademy.net.au/watch/debris/atmosmod.htm>

[4] <https://en.wikipedia.org/wiki/Jacchia_Reference_Atmosphere>

[5] <https://www.researchgate.net/publication/337085065_Jacchia-Bowman_Atmospheric_Density_Model_MATLAB_code>

[6] <https://uk.mathworks.com/help/matlab/ref/ode45.html>

# 

# 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


### References

### Actions

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

### Deadlines

# 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

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.
* Lower launch costs- LEO's proximity reduces costs for placing the CubeSat into orbit

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] <https://www.sws.bom.gov.au/Category/Educational/Space%20Weather/Space%20Weather%20Effects/SatelliteOrbitalDecayCalculations.pdf>

# 2024-12-29 Notes and Research

Atmosphere model research: the effects of solar radiation on atmospheric density (for altitudes above 100km)

* 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
* MATLAB file Solarfluxindex.m in the folder “Fifth set of simulations”- the code written produces the following plot to demonstrate how variations in F10.7 and Ap result in variations in atmospheric density; signifies the impact of solar radiation on atmospheric density models; altitude vs log density
* Ap index quantifies geomagnetic activity, which is driven by interactions between the solar wind and the Earth’s magnetosphere
* Uses ‘real’ data- needs to be put in [5]

A graph of different colored lines

Description automatically generated

* 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: [6]

* 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] <https://www.swsc-journal.org/articles/swsc/full_html/2013/01/swsc120043/swsc120043.html>

[2] <https://www.researchgate.net/publication/226578234_Solar_activity_effects_of_the_ionosphere_A_brief_review>

[3] <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] text file

[6] <https://www.sws.bom.gov.au/Category/Educational/Space%20Weather/Space%20Weather%20Effects/SatelliteOrbitalDecayCalculations.pdf>

# 2024-12-29 Notes and Research

* The Australian Space Agency’s (ASWA) atmospheric model is only valid up to 180km
* So I have decided to use this to model the decay up to this point before atmospheric effects become more intense and it is trickier to model
* The spin up phase of the trajectory is going to happen at 180km
* The spin up phase doesn’t actually affect the trajectory of the CubeSat as it’s 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 cold gas thrusters 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 center of mass (assuming it's a well-centered application), there won't be a noticeable change in the satellite's velocity.

# 2025-01-05 Notes and Research

* Generally looking at a 2 body problem
* Higher fidelity models->more complexity
* Major LEO pertubations 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 pertubations in the satellites trajectory
* Earth’s oblateness can add a correction term to the Gravitational potential U:
  + U=−μ/r​(1−J2​rRe2​​(3/2sin2ϕ−1/2​))
  + 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
* The derivation below derives dr/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]
* 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.

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From the MATLAB file Simulation4withdrag.m from my folder “Sixth set of simulations”:

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* 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 MATLAB’s RK4 (which is very similar to ODE45) to simulate the trajectory up to 180km using the ASWA atmospheric density model

### References

[1] <https://www.swsc-journal.org/articles/swsc/full_html/2013/01/swsc120043/swsc120043.html>

# 2025-01-23 Notes and Research

**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]

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* + 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] <https://www.septentrio.com/en/products/gnss-ins-receivers/ins-rugged-boxes/asterx-sbi3-pro#resources>

[2] <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#:~:text=Key%20Result:%20The%20Boltzmann%20distribution,Ei/kBT>.