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

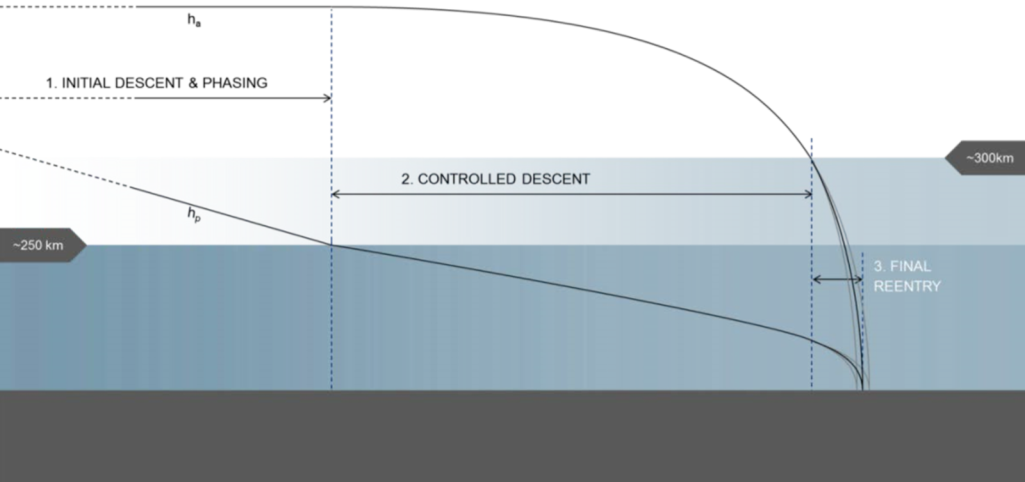
-Fizza – Look into trajectory, expected burn altitude and ideal orbital altitude as well as ionosphere

-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]

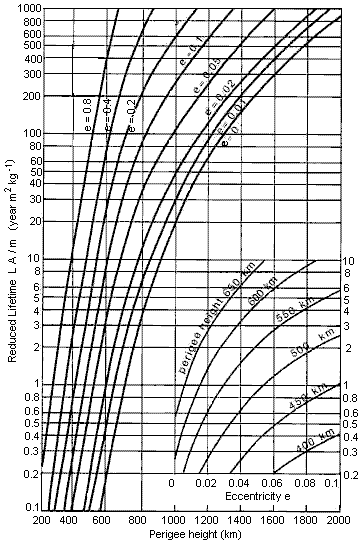


* Semi-controlled re-entry is great for medium-sized spacecraft, where casualty risk could be up to five times lower using electrical propulsion systems Some form of controlled re-entry is necessary due to the growing amount of debris in LEO and also the increasing regulations relating to deorbitation
* 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

* From the eighth meeting, we decided to have the CubeSat perform it’s de-orbit burn, then spin-up during decay.
* Doing this at an altitiude 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.
* Therefore, I have decided to reduce the start altitude