THE UNIVERSITY OF SYDNEY

LUNAR ATMOSPHERIC INVESTIGATIONS with CUBE-SATS

LUNATICS

UNISEC Mission Ideas Contest 9
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Background & Motivation

- The Moon has a very thin, tenuous **atmosphere**.
- But we don't know that much about it… only:
  - Basic **elemental composition** (Ar, He, Ne, etc.)
  - Overall **atmospheric density** $(\sim 3 \times 10^{-15}\ \mathrm{atm})$
  - Dust grain size.
- Questions:
  - Is **elemental distribution** uniform? Does **composition** change with altitude? Does **density** change with altitude? Does **dust** change with altitude? Does the atmosphere have "**layers**" with different behaviours like Earth's?
- Humanity is going back to the Moon (to stay)!
- Robust atmosphere model would allow for:
  - Better-informed **infrastructure** designs.
  - Better predictions/understanding of atmospheric **chemical reactions**.
  - Greater **simulation accuracy** for satellite or surface **missions**.
  - **Business opportunities** on/using the Moon and its resources.

Table 1. Measured concentrations of elements in the Lunar exosphere [1].

Element	Concentration (atoms/cm^3)
Argon (Ar)	20,000–100,000
Helium (He)	5,000–30,000
Neon (Ne)	≤ 20,000
Sodium (Na)	70
Potassium (K)	17
Hydrogen (H)	< 17

Mission Overview

AIM

To improve scientific understanding of the **Lunar Exosphere** through developing a robust **atmospheric model** through quantitative results.

OBJECTIVES

(1) Map the **distribution of gaseous elements** (local relative concentrations).

(2) Develop a **mathematical model** of atmospheric **density vs. altitude**.

(3) Determine **relationship between altitude and dust** (concentration & grain size).

USING…

TWO **6U CubeSats**, each with THREE scientific instruments:

- **Ultraviolet-Visible Light Spectrometer** (UVS) [Objective (1)].
- **Neutral Mass Spectrometer** (NMS) [Objectives (1), (2)].
- **Dust sensor** [Objectives (2), (3)].

Concept of Operations

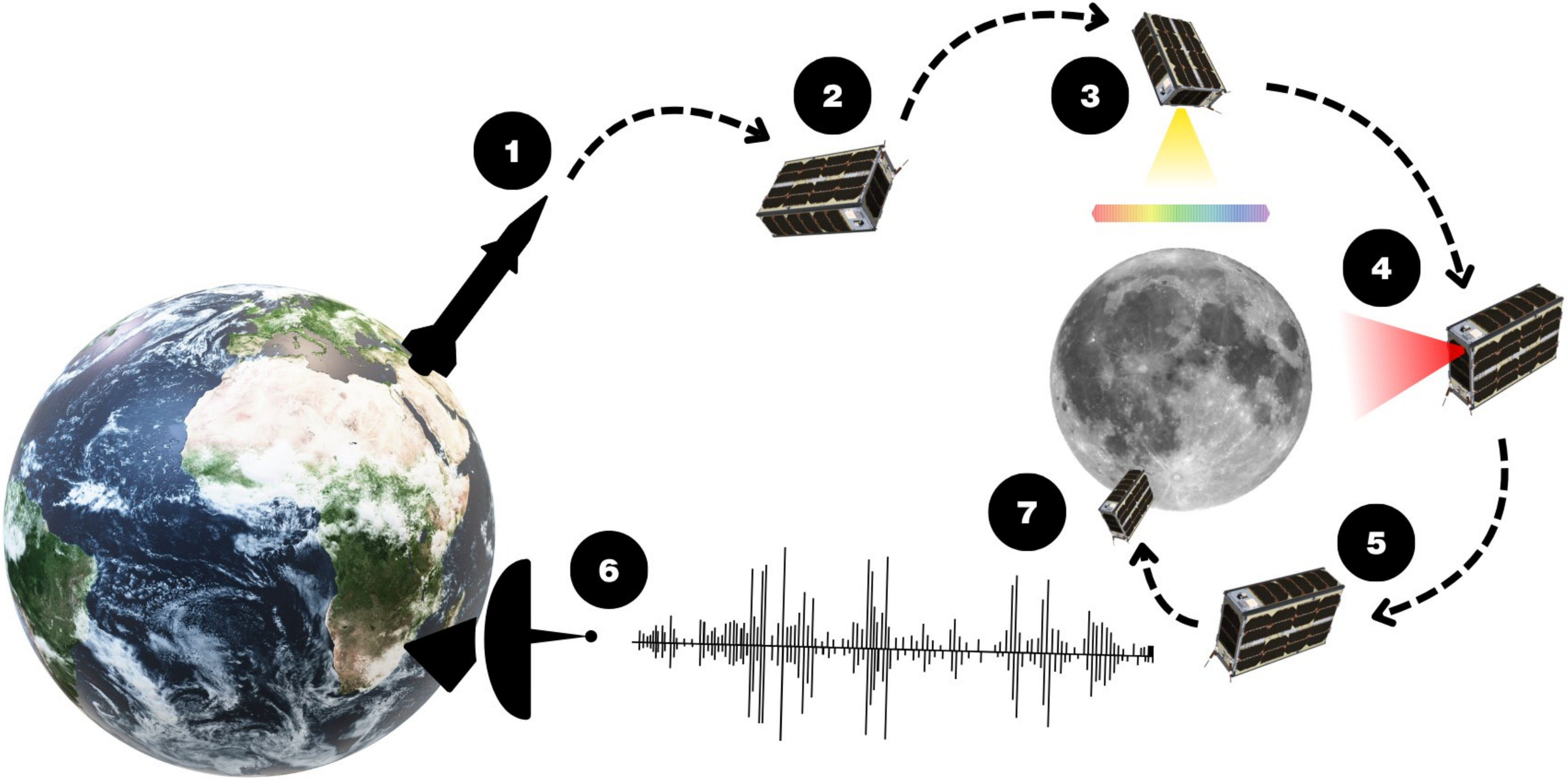


Figure 1: CONOPS

Key Performance Parameters

SYSTEM STABILITY

Maintaining operational temperature to ensure CubeSat can properly record, store and transmit the collected data.

POINT ACCURACY

Maintaining a **pointing vector accuracy** of $\leq \pm 0.15°$ ensuring the validity of the data.

SATELLITE COVERAGE

Full coverage of the Lunar exosphere within **mission timeframe of 29 days** with orbit:

Circular
100 km altitude
90˚ inclination
RAAN of 0° and 120°

LUNATICS

SUBSYSTEM DESIGN

Structures Design

- 6U frame design
- Chassis frame made from CNC'd aluminium
- Aluminium 6061 - optimised for strength properties and weight
- Mass for structure is 0.970 kg
- Dimensions of 340.5 x 226.3 x 100
- Joined together with M3 and M2 Countersunk Screws

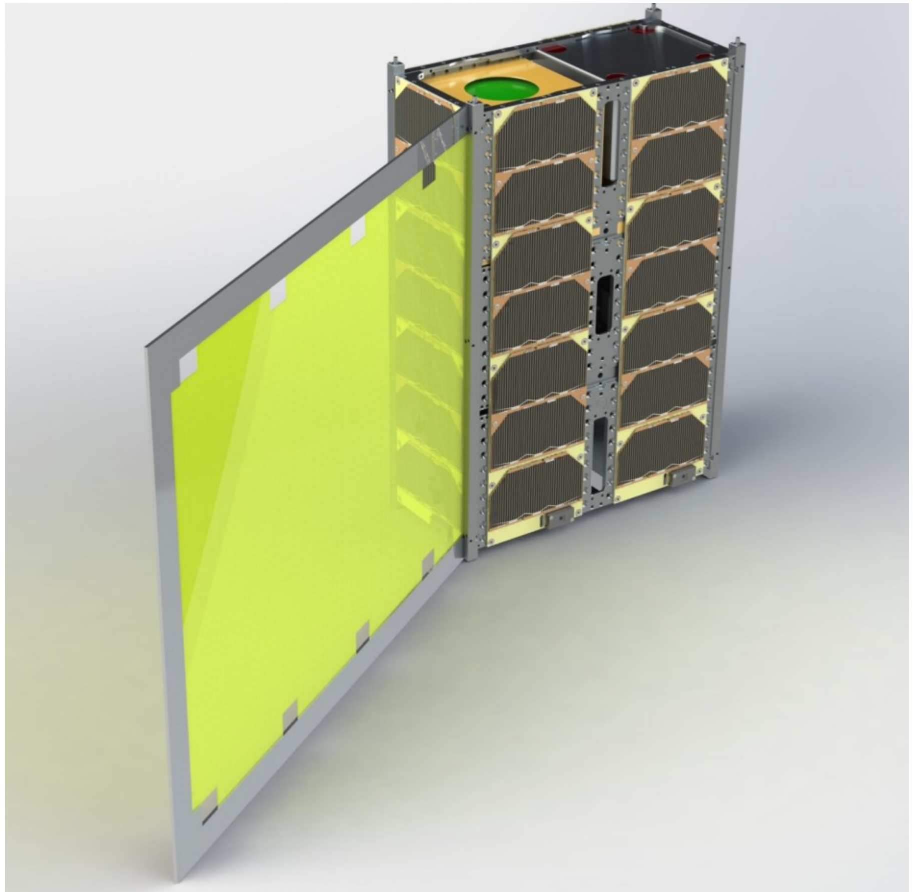


Figure 2: 3D Render of the 6U CubeSat

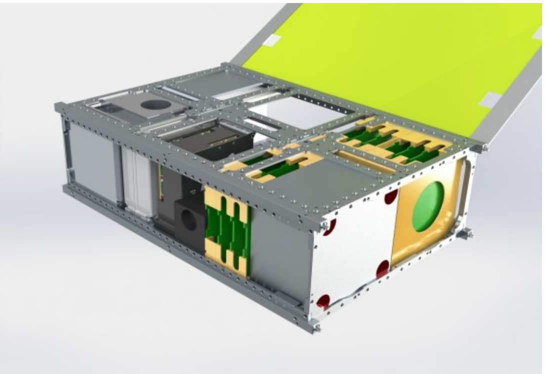


Figure 3: Horizontal view of the CubeSat Without Solar Panels

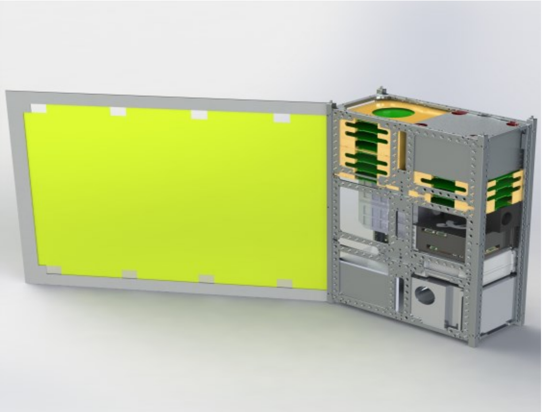


Figure 4: Vertical view of the CubeSat Without Solar Panels

Structures FEA Results

- **Simplified** design to observe **deformation**.
- Uses frictional contacts on the screws and stack separators.
- **Grid size of 2.5mm**
- High deformation in the stack operator – **informed design choices**

Table 2: FEA maximum stress and deformation results

Load Case	Max Stress (MPa)	Max Deformation (m)
Quasi-static Acceleration	10.7	1.04e-5
Sinusoidal Vibration	2.27	2.14e-6
Random Vibration	61.1	4.64e-5
Shock Loads	**180.1**	**1.79e-3**

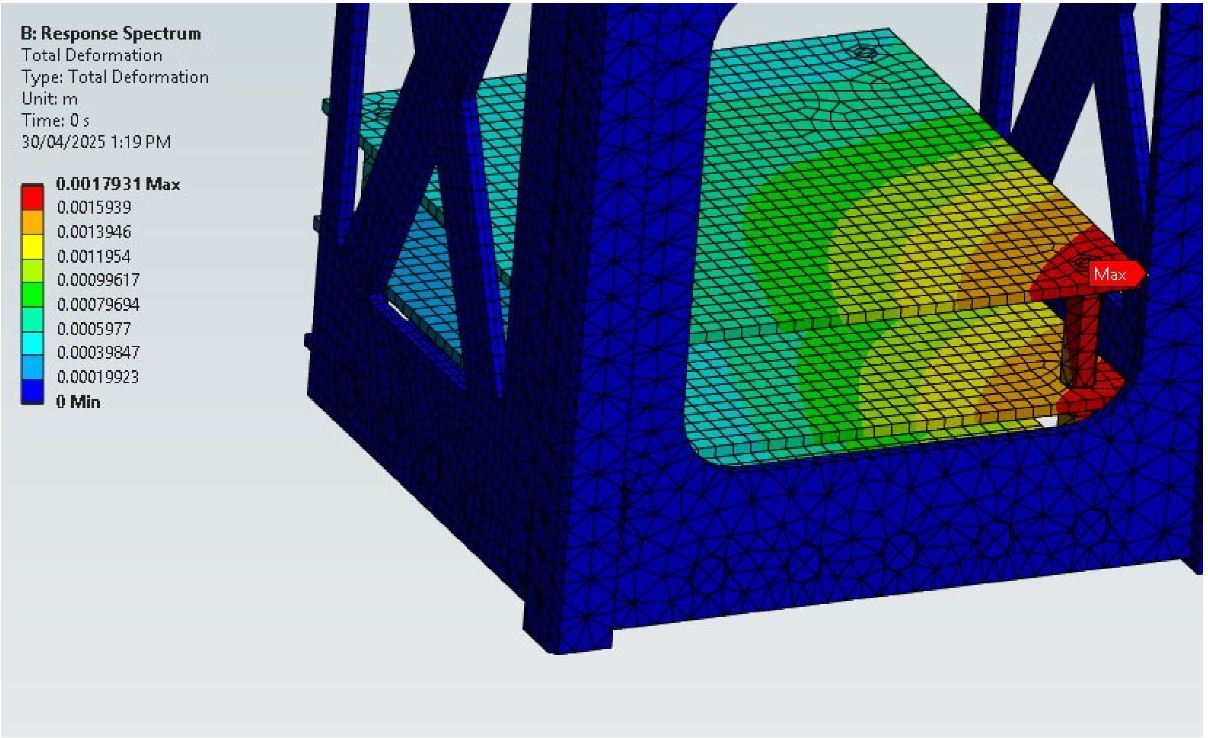
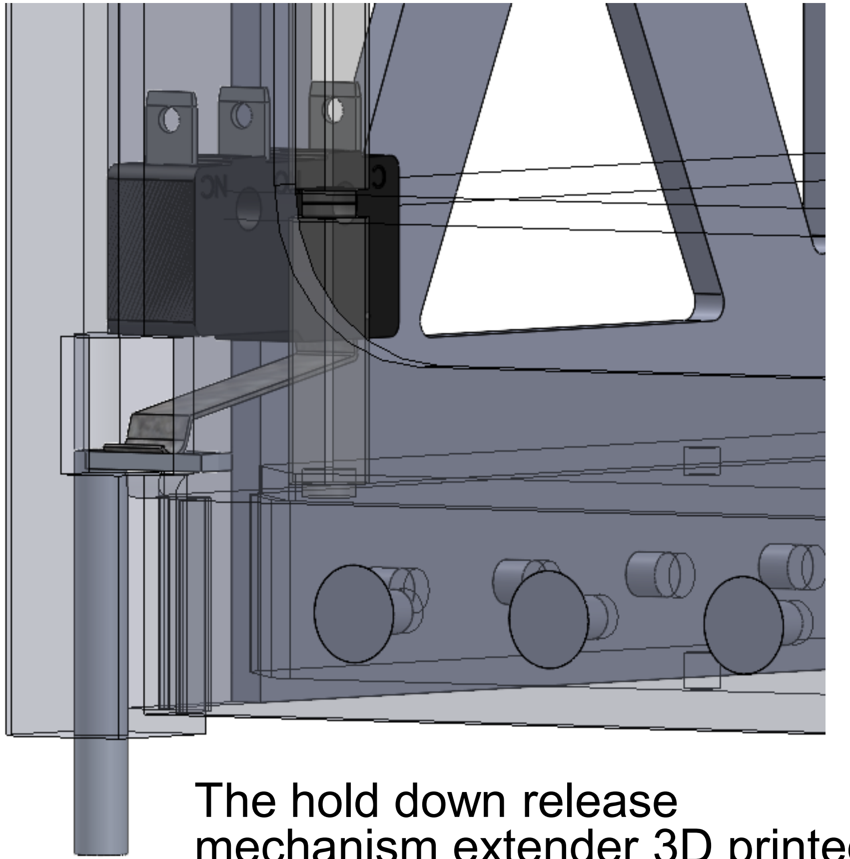


Figure 5: Deformation due to shock

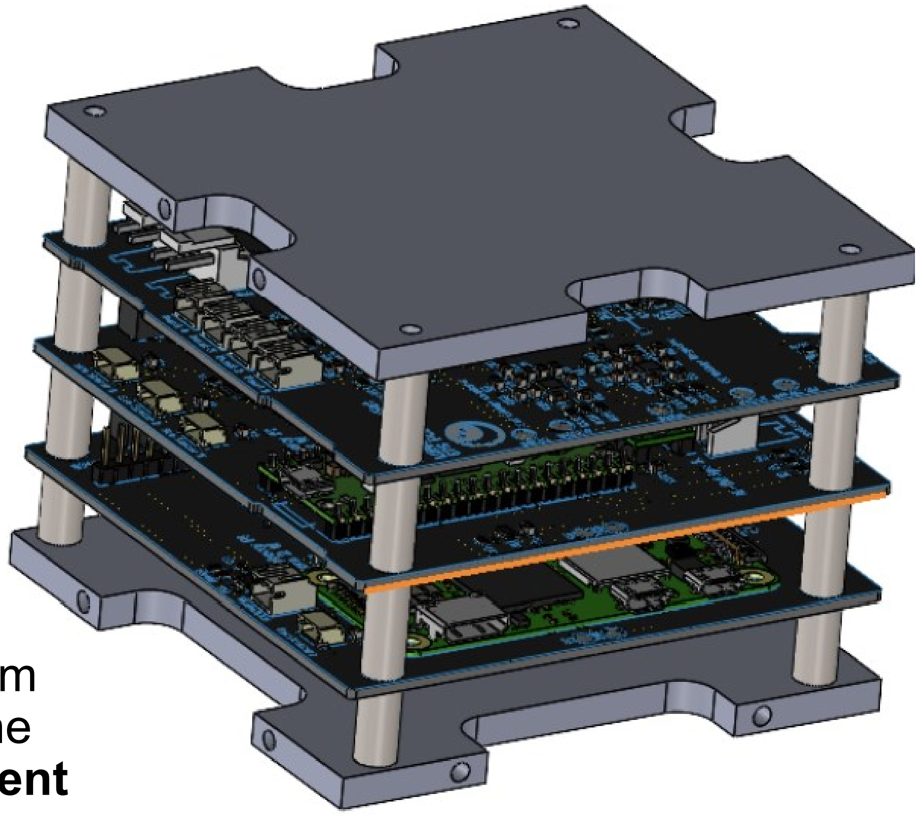
Structures HDRM & PCB Assembly



The hold down release mechanism extender 3D printed and joined with an M1 screw.

Figure 6: Hold Down Release Mechanism assembly

Standoffs in the PCBS are made from steel.



Top and bottom plate join to the frame to **prevent large stresses** and deformation from vibrations

Figure 7: PCB assembly

Payload

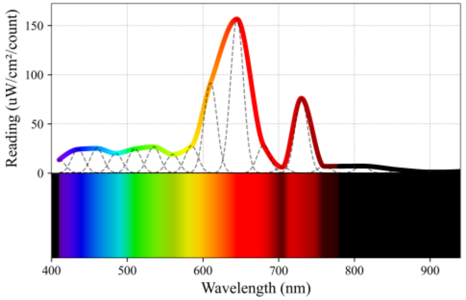
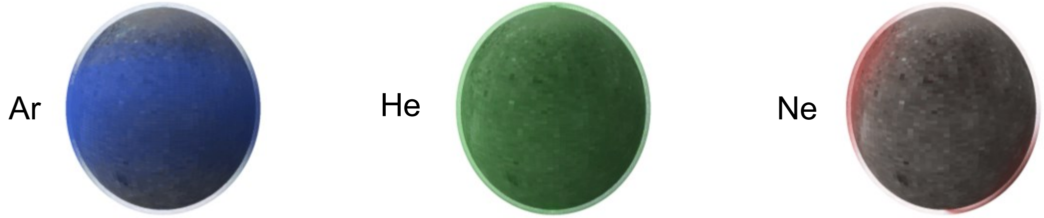


Figure 8: Mock atmospheric results & "maps" of different elements.



ULTRAVIOLET-VISIBLE SPECTROMETER (UVS)

- Adapted version of *Thoth Argus 1000 Spectrometer* (currently IR only) [2]
- 190–900nm range, 6nm resolution
- Detect spectral signatures ("fingerprints") of different gaseous elements. Creates a "map" of distribution across surface
- Points down at surface along nadir

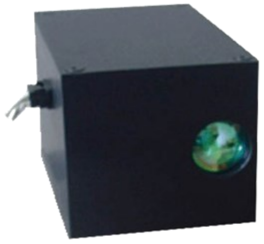


Figure 9: Thoth Argus 1000 Spectrometer [2].

NEUTRAL MASS SPECTROMETER (NMS)

- *Mini Ion Neutral Mass Spectrometer* developed by NASA [3]
- Detects ion and isotope concentrations and densities
- Adds detail to element map
- Points in direction of motion to capture particles

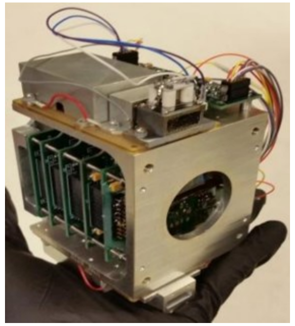


Figure 10: Mini Ion NMS [3].

DUST SENSOR

- Based on *ASTERISC CubeSat* [4]
- 300x400mm fold-out film with piezoelectric sensors
- Detects dust particles of diameter $> 4\mu m$
- Measures impact frequency (dust density) and force (dust size)
- Used whilst de-orbiting to measure at different altitudes.

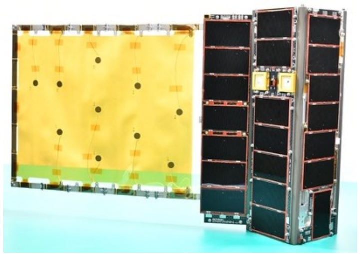


Figure 11: ASTERISC CubeSat [4].

Thermal FEA

Thermal cycling from -40°C to +80°C at 1°C/min was simulated to mimic orbital conditions, followed by a reverse ramp.

Bakeout at 80°C for 3 hours modelled vacuum conditions using only conduction and radiation for heat transfer.

To ensure that the components stay within the temperature range, these thermal controls will be used:

- AZ-93 White Thermal Control Coating
- Mylar Layers
- Kapton Tape

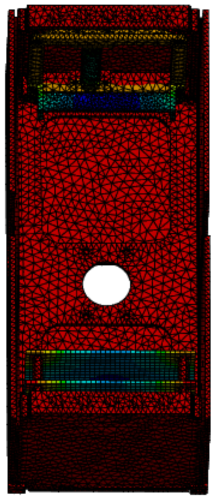


Figure 13: Temperature distribution at the peak of the Cyclic test

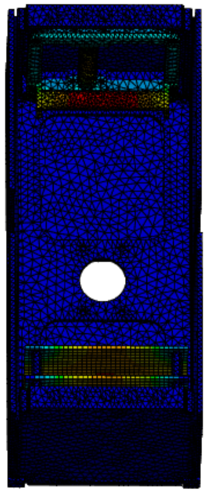


Figure 14: Temperature distribution at the trough of the Cyclic test

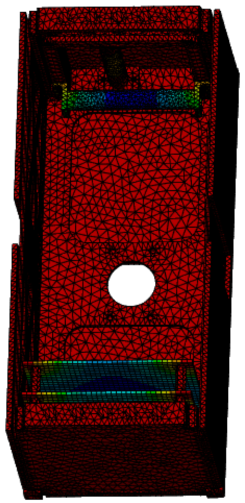


Figure 16: Temperature Distribution throughout the Bake Out test

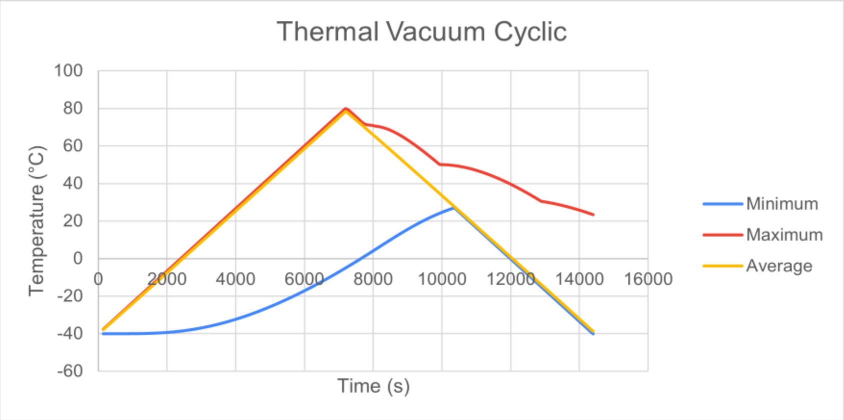


Figure 15: Temperature Distribution throughout the Cyclic test

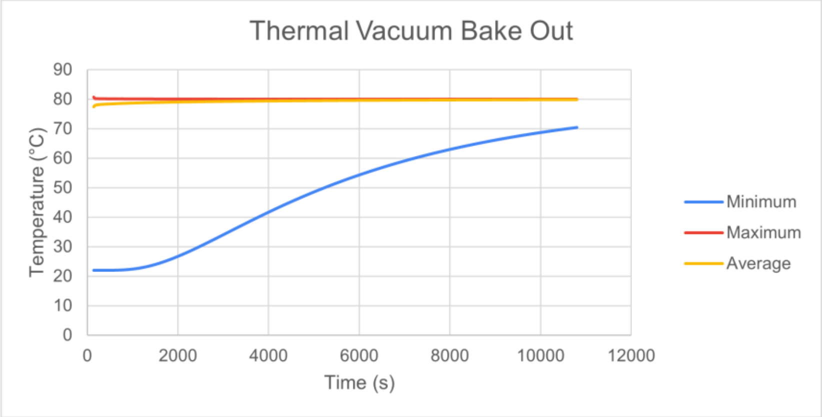


Figure 17: Thermal Distribution at the end of the Bake Out

ADCS

Attitude Determination:

- Required pointing accuracy for UVS: ± 0.15° [2]
- XACT-50 package from Blue Canyon Technology [5].
    - Includes star trackers, sun sensors and attitude determination algorithms
    - Pointing accuracy of XACT-50: 0.003°

Attitude Control:

- External Torque: 5.767e-7 Nm
- Control wheels from XACT-50 package
- Control wheel desaturation by VACCO Micro Propulsion System (MIPS) [6]
    - Includes control algorithms
    - Max. torque by MIPS = 6e-3 Nm

Figure 18: XACT-50 ADCS

Figure 19: VACCO Micro Propulsion System

TT&C

Downlink

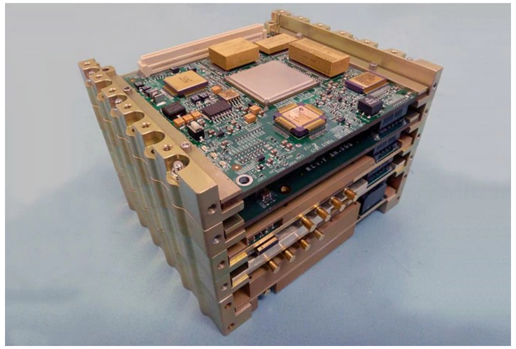


Figure 20: JPL Iris Transponder

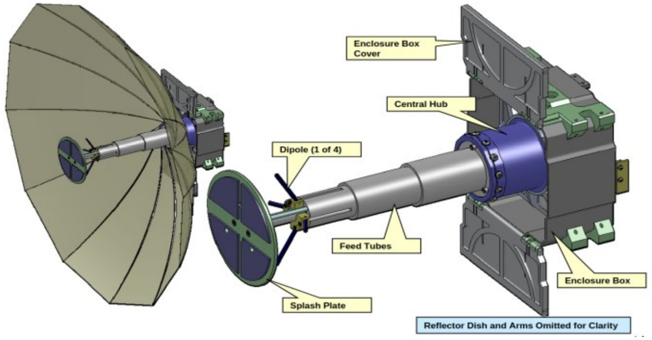


Figure 21: Boeing Phantom Work Deployable High Gain Antenna

Uplink

Figure 22: Near Earth Network (NEN) Commercial station in Dongara, Australia.

Table 3: Link Budget

UPLINK Budget	Value (dB)
Total Losses	250.1242
Eb/No	31.2414
Link Margin	**21.6414**

Table 4: Link Budget

DOWNLINK Budget	Value (dB)
Total Losses	250.1242
Eb/No	16.6588
Link Margin	**7.0588**

OBC

Motherboard: Raspberry Pi Zero 2W

- Quad Core 64 bit ARM Cortex-A53 processor clocked at 1GHz [7]
- 512MB of SDRAM
- Sufficient IO

PCB

- Custom made PCB to interact with all peripherals within small space of the CubeSat.

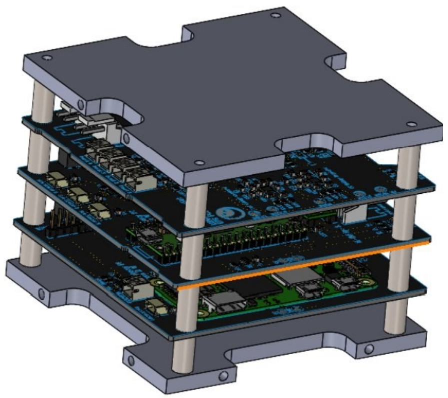


Figure 20: Custom PCB stack design to fit in a 1U box

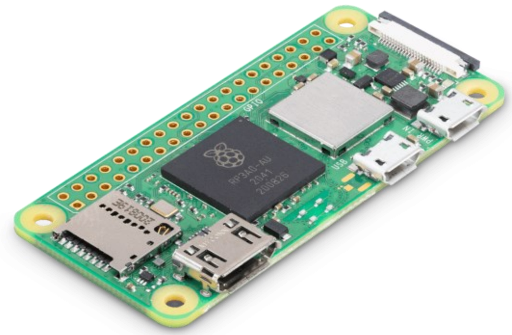


Figure 21: Raspberry Pi Zero 2W

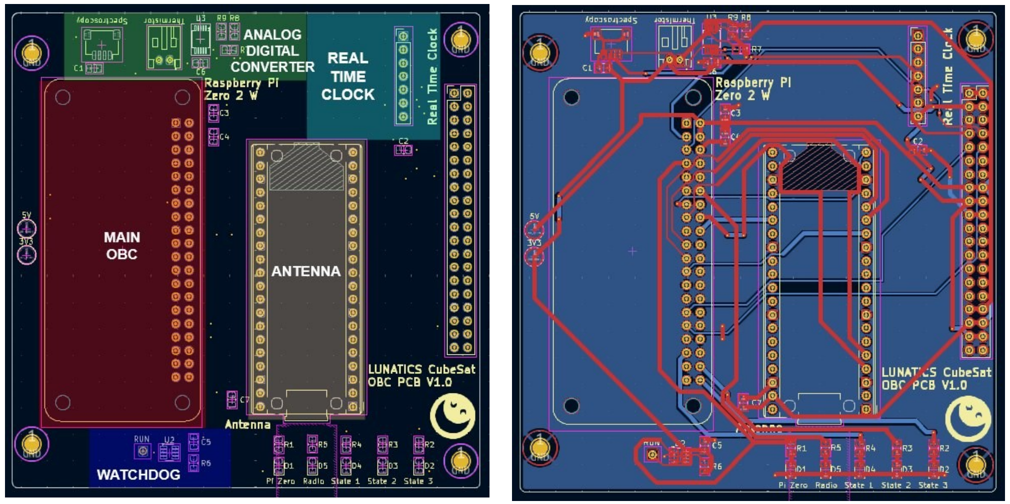


Figure 22: PCB Traces in initial design, showing Raspberry Pi with RTC, watchdog, current sensors, etc.

EPS

Solar Panels

- GomSpace NanoPower MSP Panels
- Max power of **1.14 W** per cell at EOL [8]

Regulator and Battery Pack

- P80 power regulation and distribution board [9]
- BP8 Li-Ion battery pack with **80 Wh** capacity [10]

Overall Power Generation

- Maximum power production of **18.5 W** at EOL, average of **12.3 W** during sunlit conditions
- Average power consumption of **6.14 W**, a **50%** power margin
- Peak consumption of **18.3 W** during TX mode – can be sustained for over 4 hours with fully charged battery

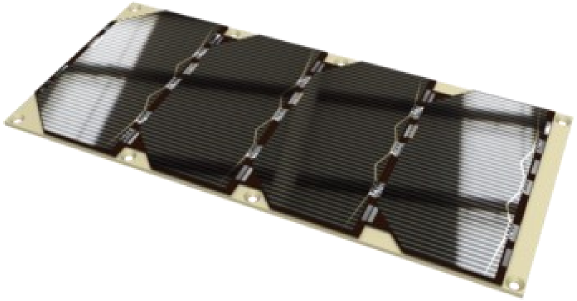


Figure 23: GomSpace NanoPower MSP 4-cell configuration

Figure 24: P80 EPS (left) and BP8 Li-Ion battery pack (right)

Power Budget

Table 5: System Power Budget

Subsystem	Component	Power Consumption by Mode (W)			
		Idle	Pointing	Science	Transmission
ADCS	XACT50	2.83	2.83	2.83	2.83
	MiPS	0.00	10.00	0.00	0.00
OBC	Raspberry Pi Zero	2.07	2.07	2.07	2.07
EPS	MSP Solar Panels	0.00	0.00	0.00	0.00
	P80 EPS	0.60	0.60	0.60	0.60
TT&C	Iris Deep Space Transponder	0.64	0.64	0.64	12.80
	X-Band Antenna	0.00	0.00	0.00	0.00
Payload	UV-VIS Spectrometer	0.00	0.00	1.00	0.00
	Neutral Mass Spectrometer	0.00	0.00	1.80	0.00
	Dust Sensor	0.00	0.00	1.00	0.00
Total Power Consumption (W)		6.14	16.14	9.94	18.30
Total Power Generation (W)		12.30	12.30	12.30	12.30
Margin		**50%**	**-26%**	**24%**	**-49%**

Delta V Budget and Orbit Description

Orbit Description

- Two 6U CubeSats in 100 km circular polar lunar orbits (i = 90°).
- Each separated by 120° RAAN → full global coverage and data redundancy.
- Orbital period: 1.96 hours → complete surface mapping in 29 days.
- Post-mission: natural lunar perturbations cause gradual descent to surface (~150 days).

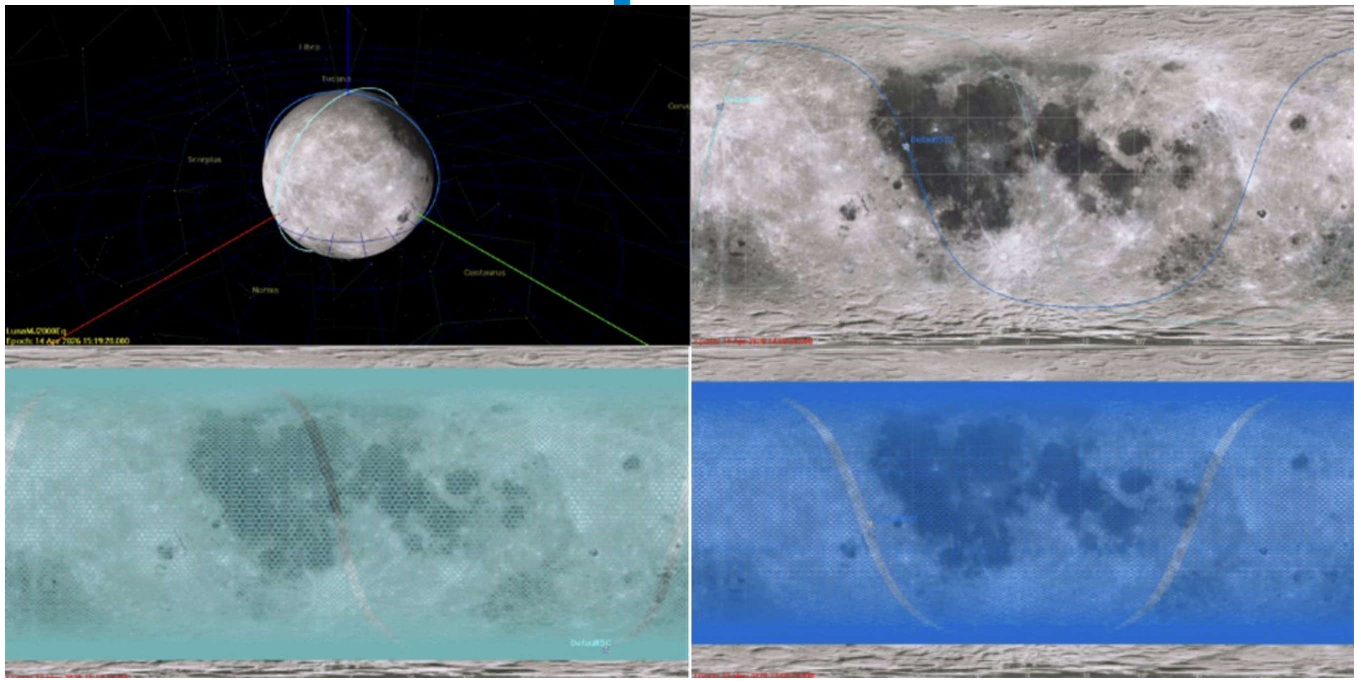


Figure 25: Sensor coverage from mission orbit

Delta V Budget

Propulsion system: Dual VACCO MiPS cold gas micro-thrusters.

Functions:

- Detumbling and reaction wheel desaturation
- Station-keeping & attitude trimming
- Final deorbit manoeuvre

Table 6: Delta V Budget [6][11]

Delta V Summary	m/s
Required	10.9
Available	38.2
Margin	**250%**

Project Organisation

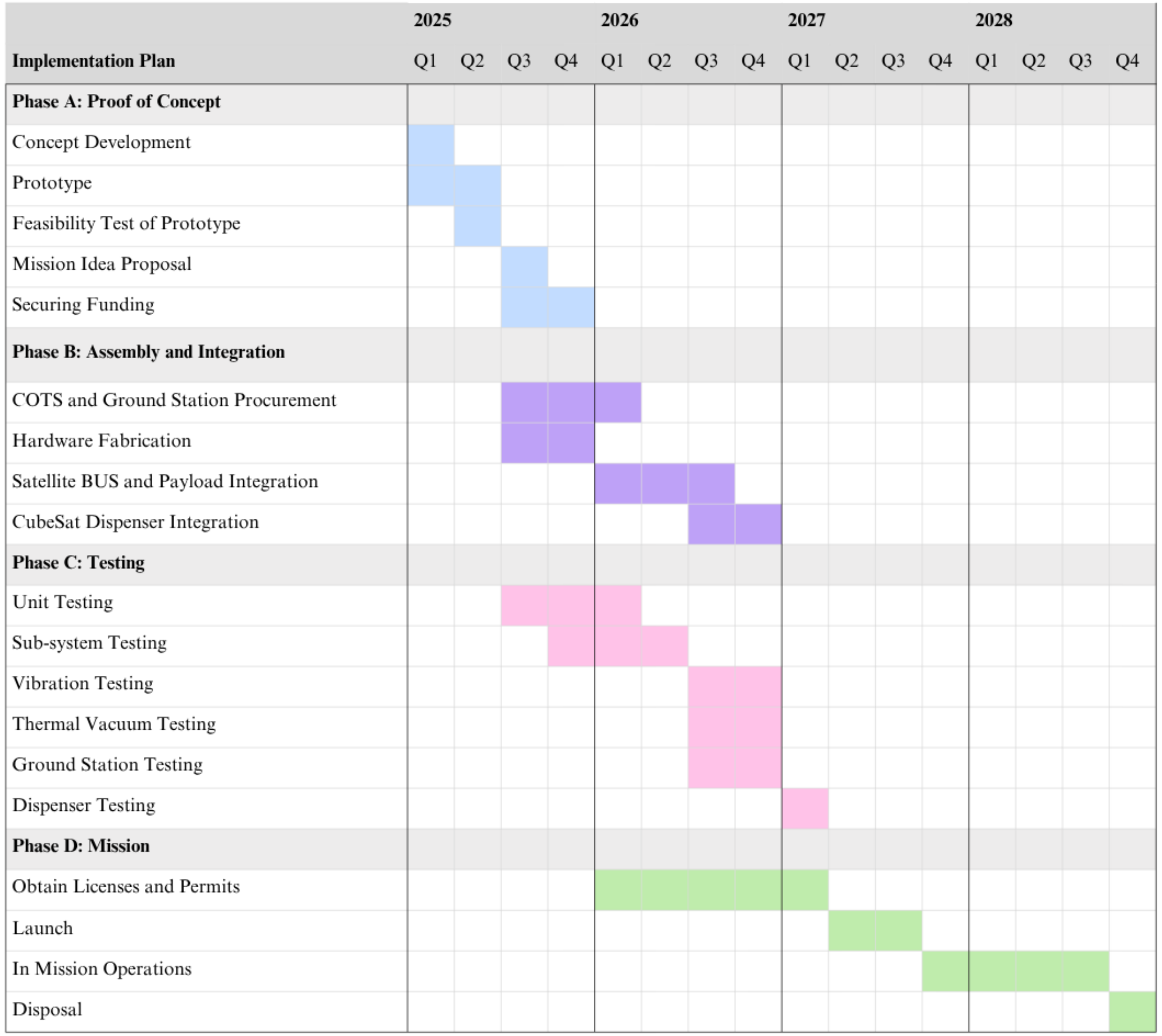


Figure 26: Gantt Chart

Table 7: Total Life Cycle Cost

Activity	Cost (USD)
Subsystem Components	600,000
Payload	200,000
Testing and Licensing	100,000
Launch	1.6 million
Mission Ops	1 million (per year)
Disposal	0
Total	**3.5 million**

Project risks:

- Communication failures
- Financial struggle
- ADCS failures
- Power failures
- Failing tests

Required Facilities

PROTOTYPING

University of Sydney

- Soldering Equipment
- Hand Tools
- Power Supplies
- 3D Printers
- Air Bearing Table
- Thermal Vacuum Chamber

LICENSING

Australian National University [12]

- Cleanroom Facilities
- Vacuum thermal cycling and soak
- Thruster Test Configuration
- Vibration and Shock Test Facilities

Australian Nuclear Science & Technology Organisation [13]

- Radiation Test (SEE, TID, DDD)

LAUNCHING

- Obtain defence export control certificate
- Testing with Dhruva Space Satellite Orbital Deployer 6U
- Shipping to NASA for integration and testing with Orion stage adapter

THANKYOU

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