4.8 ADCS (Attitude Determination and Control Subsystem)

The ADCS subsystem of the satellite controls and maintains the orientation of the spacecraft to ensure that the payload points towards the target, the antennas are properly aligned during line of sight communication and the solar arrays are oriented perfectly normal to the incident solar radiation to charge the batteries. However, this is given secondary preference in pointing as the first priority is to get antennas aligned during line of sight communication for Uplink/Downlink.

The disturbances countered by the ADCS subsystem include Magnetic field, Aerodynamic drag, Gravity gradient, and solar radiation. The total torque generated by combination of four reaction wheels and magnetotorquer = 0.4006Nm, calculation of which is in the appendix shows that this is sufficient to counter the total torque due to these disturbances.

Disturbance	Magnetic Field	Aerodynamic Drag	Gravity Gradient	Solar Radiation	Total
Torque [Nm]	0.00075	0.000082	0.0016	0.000035	0.002467

4.8.1 Sensors Design

Following components were selected to operate the ADCS system in their respective modes:

- Sun Sensor by AQUILA-DO2 for Sun-Search Mode: To orient the solar panels towards the Sun for power generation and to provide attitude knowledge during the sunlight phase.
- Star tracker by sagitta for Star-Tracker Mode: To provide uninterrupted attitude knowledge during the eclipse phase when the sun sensor cannot provide data.
- Horizon sensor by CubeSense Earth Horizon Sensor Mode: To determine the orientation relative to Earth for accurate antenna pointing.
- GPS module NGPS-03-422 for precise orbit determination to aid in performing orbit correction maneuvers.

4.8.2 Actuator Design

- MTQ800 Magnetotorquers for initially de-tumbling the satellite post lauch and to provide attitude correction when reaction wheels desaturate. These are suitable for satellites of mass 50-200kgs, with a 5040 mW power consumption at peak dipole moment of 20Am^2 while providing a full 3_axis control
- Reaction Wheels by Rocket Lab used to point the antennas and solar arrays. Four reaction wheels are used in our setup in a pyramid configuration to satisfy redundancy requirement and also provide maximum torque performance. A single reaction wheel provides a torque of 100mNm at 0.8Nms with a nominal momentum of 1.0Nms

Appendix:

ADCS subsystem:

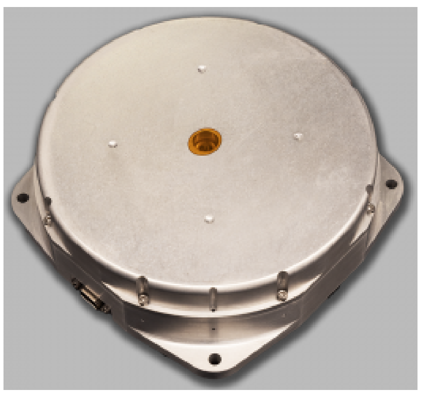
1. Actuators on board Specification:

   1.1 MTQ800 Magnetotorquer:

Category	Specification
Dimensions	
Torquer rods	250 x 67 x 35 mm
Driver Enclosure	60 x 70 x 14 mm
Environmental	
Operating temperature range	-45 to +45 °C
Maximum acceleration load	10 g (X, Y, Z axes)
Electrical Specifications	
Design dipole moment	15 Am^2
Peak dipole moment	30 Am^2
Control accuracy (Design dipole moment)	+/- 2 % (of setpoint)
Control accuracy (Peak dipole moment)	+/- 10 % (of setpoint)
Supply Voltage	
Min.	8 V

Typ.	12 V
Max.	12.5 V
Power and Current Consumption	
Idle	144 - 180 mW
Dipole moment of 10 Am^2	1440 - 1632 mW
Dipole moment of 20 Am^2	4800 - 5520 mW
Maximum dipole moment	13200 mW

1.2 Rocket Lab Reaction wheels Specification

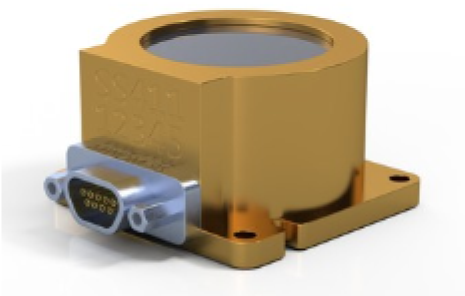


Category	Specification
Momentum	Nominal: 1.0 Nms
Torque	100 mNm at 0.8 Nms (at 28 V supply)
Control Mode	Speed or torque, with built-in control CPU
Command/Telemetry	Redundant RS-485, with galvanic isolation from primary
MECHANICAL	
Dimensions	154 mm x 146 mm x 45 mm
Mass	1380 g
SUPPLY VOLTAGE	
Nominal	24 V to 34 V

Maximum	50 V

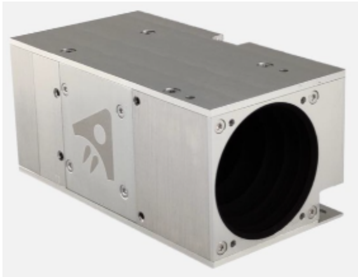
2. Sensors

2.1 Sun-Sensor:



Specification	**Details**
Placement	5 out of 6 faces of the satellite, excluding nadir face
Model	AQUILA-DO2
Mass	Less than 35 grams
Update Rate	5 Hz
Field of View (FOV) Accuracy	≤ 0.1° RMS error over 120° FOV
Features	Embedded calibration, simple UART interface
Usage	Used with magnetometer for simple attitude control
Coverage	Four sensors provide full sky coverage

2.2 Star Tracker:



Specification	Details
Model	Sagitta Star Tracker
Cross-boresight Accuracy	2” (1σ)
Around-boresight Accuracy	10” (1σ)
Star Magnitude	Up to magnitude 7
Number of Stars Tracked	64
Update Rate	10 Hz
Field of View (FOV)	25.4°
Calibration	Autonomous with lost-in-space algorithm
Usage	Complementary to sun-sensor during eclipse phase

2.3 Horizon Sensor

Category	Specification
Performance	
Accuracy	0.2° (roll and elevation) 2-sigma

Max Slew Rate	14°/s
Detection Field of View	Horizontal/Vertical: 166°, Diagonal: 176°
Update Rate	Up to 2 Hz
Physical	
Dimensions	35 mm x 24 mm x 22 mm
Mass	15 g
Power and Data	
Supply Voltage	3.3 V
Peak Power	174 mW
Average Power	100 mW
Data Bus	CAN/UART/RS-485 (I2C available for custom solutions)
Connector	Molex Micro-Lock Plus
Environmental	
Radiation	24 kRad
Random Vibration	14.16 g RMS (NASA GEVS)
Thermal Vacuum	-20 °C to 80 °C
Thermal Cold and Hot Start	-35 °C to 70 °C

2.4 NGPS-03422 GPS Receiver:

Category	Specification
Functional Characteristics	
Position Accuracy [1σ]	<10 m
Velocity Accuracy [1σ]	<25 cm/s
Update Rate	1 Hz
Operating Frequency	L1 (1575.42 MHz)
Physical Characteristics	
Dimensions	96 mm x 91 mm x 18 mm
Mass	<130 g
Power	1 W (excluding active antenna)
Environmental Characteristics	
Thermal (Acceptance)	-10 °C to +50 °C
Mechanical Tests (Qualification)	14 gRMS (random)
Radiation (TID) (Qualification)	10 krad (component level)
Interfaces	
Power Supply	5 VDC and 3.3 VDC
Data	RS-422 or TTL UART
Antenna (NANT-PTCL1) Characteristics	
Frequency	1575.42 MHz
Active Gain	≥16 dBiC (@ Zenith)

3. Calculations for torque requirements:

Given Mass of satellite = 111.87 kg, Volume = 0.03 m^3, Surface area = 9.16 m^2
Center of mass: (meters)   X = 0.12   Y = 0.01   Z = 0.00
Satellite's moments of inertia: (kgm^2), taken at the center of mass obtained from CAD model:
I_{xx} = 44.26

I_{yy} = 48.11
I_{zz} = 10.79

Total torque generated by Magnetotorquer is given by:

τ = m × B equation (1)

where m is the maximum dipole moment and B is the magnetic field of Earth at a height of 900kms from the surface
At the surface of Earth the magnetic field ranges from approximately 25 to 65 microteslas (μT),
In this case, we are assuming a magnetic field strength of 37 μT as it is more common in European regions, especially given the reference ground station in Kiruna,Sweden used for Link calculations.

Calculation of magnetic field strength of earth at a height of $B_{surface}$= 37μT, *h*= 900 kms, R_{Earth} = 6371 kms

$$B(h) = B_{surface} * \left(\frac{R_{Earth}}{R_{Earth} + h}\right)^3 \approx 25\ \mu T \quad \text{equation (2)}$$

Substituting the values, of **m** = 30 Am^2 and **B** = 25 μT in equation (2), we obtain maximum torque from magnetotorquer as follows:

τ = 30 Am^2 * 25 μT = 0.00075Nm

Torque from four reaction wheels = 4* 0.1Nm = 0.4Nm

Total maximum torque generated by magnetotorquer and reaction wheels together = 0.40075Nm

To determine if this torque can counter the torque generated by each of the disturbances following calculation were made:

1. Aerodynamic drag torque

$$\tau_{drag} = \frac{1}{2}.\rho.\ \upsilon^2.\ C_d.A.\ L$$

Where, ρ: Atmospheric density at 900 km ≈ $10^{-10} kg/m^3$
υ: Orbital velocity at 900 km ≈ 7.4 km/s
C_d: Drag coefficient (assuming ≈ 2.2 for a satellite)
A: Reference area perpendicular to flow (assume half of the surface area) ≈ 4.58 m^2
L: Distance from the center of mass to the point of force application (assume ≈ 0.5 m)

Substituting these values, $\tau_{drag} = 0.000082Nm$

2. Gravity Gradient Torque:

$$\tau_{drag} = 3.\mu.\frac{R_E^3}{r^3}.\left|I_{xx} - I_{yy}\right|.\ sin\ (2\theta)$$

where μ: Earth's gravitational constant = 3.986 × $10^{14}\ m^3/s^2$

R_{Earth} : Radius of Earth = 6371 kms

r: Orbital height = 7271 kms

I_{xx}, I_{yy}: Principal moments of inertia

θ: Angle between the satellite's long axis and the local vertical = 45 degrees (assumption for easy calculation)

Substituting above values gives us τ_{drag} = 0.0016Nm

3. Solar radiation pressure torque:

$$\tau_{srp} = \frac{P.A.L}{c}$$

where P: Solar Radiation Pressure = 4.57 × 10^{-6} N/m^2

A: Cross-sectional area exposed to the Sun (assuming half of the surface area≈ 4.58 m^2

L: Distance from the center of mass to the point of force application (assuming ≈ 0.5 m)

c: Speed of light ≈ 3* 10^8 m/s

Substituting above values gives us τ_{srp} = 0.000035Nm

4. Magnetic Torque at 900kms

This is the value same as that generated by the magnetotorquer on board = 0.00075 Nm

Hence the total torque generated by these disturbances is:

τ_{total} = 0.000082+0.0016+0.000035+0.00075 Nm = 0.002467 Nm

This shows that our actuators can generate sufficient torque to counter these disturbances thus being able to provide appropriate satellite orientation.