Orbital data center, 1 kW GPU asleep in eclipse, dawn-dusk SSO 550 km

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MISSION (ORBIT, PROPULSION, DISPOSAL)

GO

POWER CLOSES WITH CONDITIONS · NEEDS REVIEW

THERMAL CLOSES WITH CONDITIONS · NEEDS REVIEW · BINDING BY DEFAULT

ATTITUDE CLOSES · NEEDS REVIEW

The orbit, propulsion and disposal close. Inserted at 550 km, its operational altitude, the satellite needs no transfer; the propellant covers 5 years of operations and disposal with 0.36 kg to spare, and lowering to 429 km at the end of the mission meets the 5-year re-entry limit. GMAT re-flew 3 of 3 runs; every compared number agrees within tolerance or meets its requirement. Subsystems at Phase 0/A, beside this verdict, which covers the orbit, propulsion and disposal only: power closes with conditions; thermal closes with conditions; attitude closes.

TRANSFER	PROPELLANT	DISPOSAL	GMAT VERIFICATION
None	**2.64** kg	**429** km	**3 / 3**
inserted at 550 km, its operational orbit	needed with margin · 3.00 kg loaded	lowering orbit · re-entry 3.6 y (GMAT, Schatten −2σ)	all agree or meet their requirement

15 MAR 2027
Insertion at 550 km; operations start (no transfer)

14 MAR 2032
End of mission (5 y)

20 OCT 2035
Re-entry (GMAT, Schatten −2σ)

Document control

TITLE	Orbital data center, 1 kW GPU asleep in eclipse, dawn-dusk SSO 550 km · Mission feasibility report (Phase 0/A engineering estimate)
DOCUMENT NUMBER	TBD
ISSUE	TBD
REVISION	TBD
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STATUS	Draft: no review or approval recorded

PREPARED BY	TBD
CHECKED BY	TBD
APPROVED BY	TBD
DISTRIBUTION	TBD
CLASSIFICATION	TBD

The revision is the mission's revision in Mission Composer. What is not decided yet is printed TBD and listed under Assumptions, TBD and TBC (9 items).

Change record

REVISION	DATE	REASON FOR CHANGE
TBD	22 Oct 2026	Generated by Mission Composer 1.0.0

Applicable and reference documents

REF.	DOCUMENT	DETAIL
AD	None declared (TBD)	
RD-1	ECSS-E-TM-10-25A Annex D.1 margins ECSS-E-TM-10-25A, Engineering design model data exchange (CDF), 20 October 2010, Annex D (informative), D.1 Margins	`policy file ecss_tm_10_25a_d1@1, SHA-256 b5f38f4bb3264fc0bc0907a0e1dde79c67bb8188966f0d621840912623aa419c`
RD-2	GMAT R2025a, General Mission Analysis Tool NASA Goddard Space Flight Center and partners, Apache License 2.0	`the independent propagator the verification runs`

Acronyms

AD Applicable document; **AOCS** Attitude and orbit control system; **BOL** Beginning of life; **CDF** Concurrent Design Facility (ESA); **DOD** Depth of discharge; **ECSS** European Cooperation for Space Standardization; **EOL** End of life; **F10.7** Solar radio flux at 10.7 cm, the solar activity index; **GMAT** General Mission Analysis Tool (NASA GSFC); **LTAN** Local time of the ascending node; **RAAN** Right ascension of the ascending node; **RD** Reference document; **TBC** To be confirmed; **TBD** To be defined; **TN** Technical note.

Margin policy applied

RD-1 ECSS-E-TM-10-25A Annex D.1 margins. ECSS-E-TM-10-25A, Engineering design model data exchange (CDF), 20 October 2010, Annex D (informative), D.1 Margins, pp. 27-28. Policy file `ecss_tm_10_25a_d1@1`, SHA-256 `b5f38f4bb3264fc0bc0907a0e1dde79c67bb8188966f0d621840912623aa419c`: Mission Composer's default policy.

MARGIN	VALUE	CLAUSE	CLAUSE TEXT
Equipment maturity margin, per class	A/B 5 %, C 10 %, D 20 %	D.1 b	5 % for fully developed items
Subsystem margin (weighting method)	Method only	D.1 b	The subsystem margin is the weighted average of the equipment margins
System mass margin	20 %	D.1 a	a 20 % system margin shall be provided for the Dry Mass
Propellant margin, manoeuvres	5 %	D.1 b (second list)	5 % for manoeuvres

MARGIN	VALUE	CLAUSE	CLAUSE TEXT
Propellant margin, AOCS thrusters	100 %	D.1 b (second list)	100 % for the AOCS thruster propellant
Launcher margin	≥ 10 %	D.1 c	a 10 % margin is recommended
Delta-v margin	≥ 5 %	D.1 d	Delta-V margin of at least 5 %
Mass memory margin	≥ 50 %	D.1 e	50 % for mass memory
Computing power margin	≥ 100 %	D.1 e	100 % for computing power
Link margin	≥ 3 dB	D.1 f	a 3dB margin in the communications link budget
Equipment temperature margin	± 10 K	D.1 g	±10°C margin in equipment temperatures
System power margin	20 %	D.1 h	a 20 % margin in the total required spacecraft system power budget

Propellant. 10 % of the need: the spec's constraints.propellant_margin_fraction, binding. The policy's delta-v margin (D.1 d, ≥ 5 %) is shown per manoeuvre under Delta-v budget, informative.

Mass. Maturity margins per class (D.1 b: A/B 5 %, C 10 %, D 20 %) and a system margin of 20 % (D.1 a), on the nominal dry mass.

Power. Maturity margins per class (D.1 b) and a system margin of 20 % (D.1 h: 20 %) on the nominal power, in the margined balance.

Thermal. ±10 K on equipment temperatures (D.1 g).

D.1 b (second list): not applied together with dv_margin_min_frac.

Checks

PASS **Power for the thruster.** The thruster needs 400 W and the bus provides 636 W in sunlight. The thruster fires only in sunlight.

PASS **Transfer time.** Inserted at 550 km, its operational altitude: no transfer.

INFO **Local time of the node.** At 550 km and 97.59 deg the node drifts +0.00 h of local time per year (+0.0 h over the mission). Staying sun-synchronous at this altitude needs 97.59 deg.

PASS **Propellant.** 2.40 kg needed plus 0.24 kg of margin, 3.00 kg loaded: 0.36 kg to spare.

PASS **Re-entry within 5 years (fast model).** Left alone at 550 km the satellite would stay up 58 years with a weak solar cycle. Lowering it to 429 km (67 m/s, 2.27 kg) brings it down 4.5 years after the end of the mission (limit 5).

INFO **Drag coefficient sensitivity.** With Cd·A/m 30% higher, drag make-up takes 0.1650 kg instead of 0.1269 kg: 2.68 kg needed with the margin, 3.00 kg loaded. With Cd·A/m 30% lower, the planned disposal brings it down 6.6 years after the end of the mission, against 4.5 as planned (limit 5 years, weak solar cycle). Information only: constraints.drag_uncertainty_binding makes it count in the verdict.

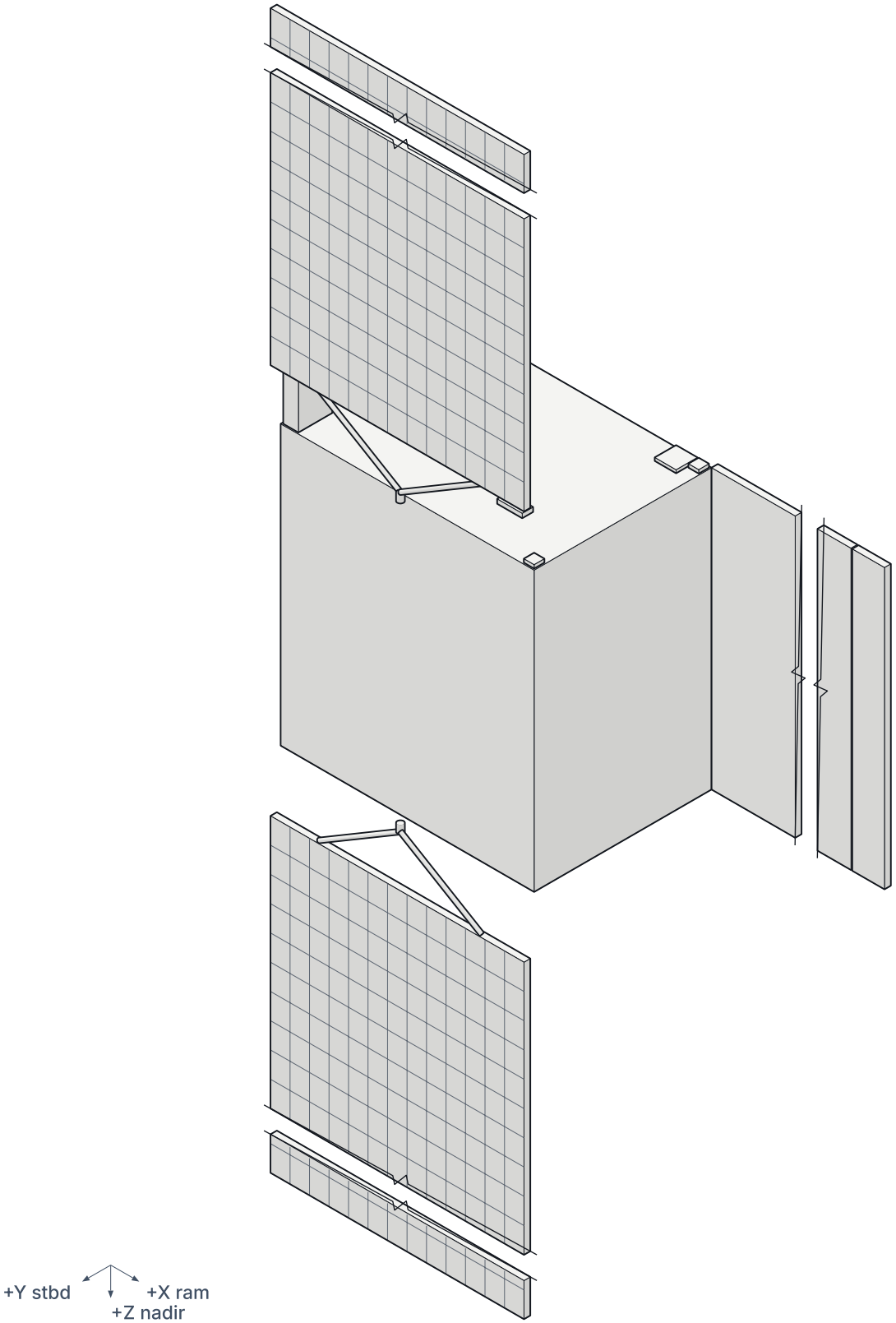
INFO **GMAT: drag model.** Not run: at 550 km the orbit decays about 394 m in 60 days, below what GMAT's mean elements resolve. Drag make-up there is 3.8 m/s, so it does not drive the budget; the re-entry runs test the atmosphere where it matters.

PASS **GMAT: drag, strong solar cycle.** Decay of 10.8 m/day in GMAT against 13.4 m/day in the fast model (+24%). F10.7 = 160. The strong solar cycle is the one the drag make-up budget is sized with.

PASS **GMAT: re-entry, Schatten nominal.** GMAT re-enters the satellite 2.8 years after the end of the mission with the Schatten nominal solar prediction (limit 5 years).

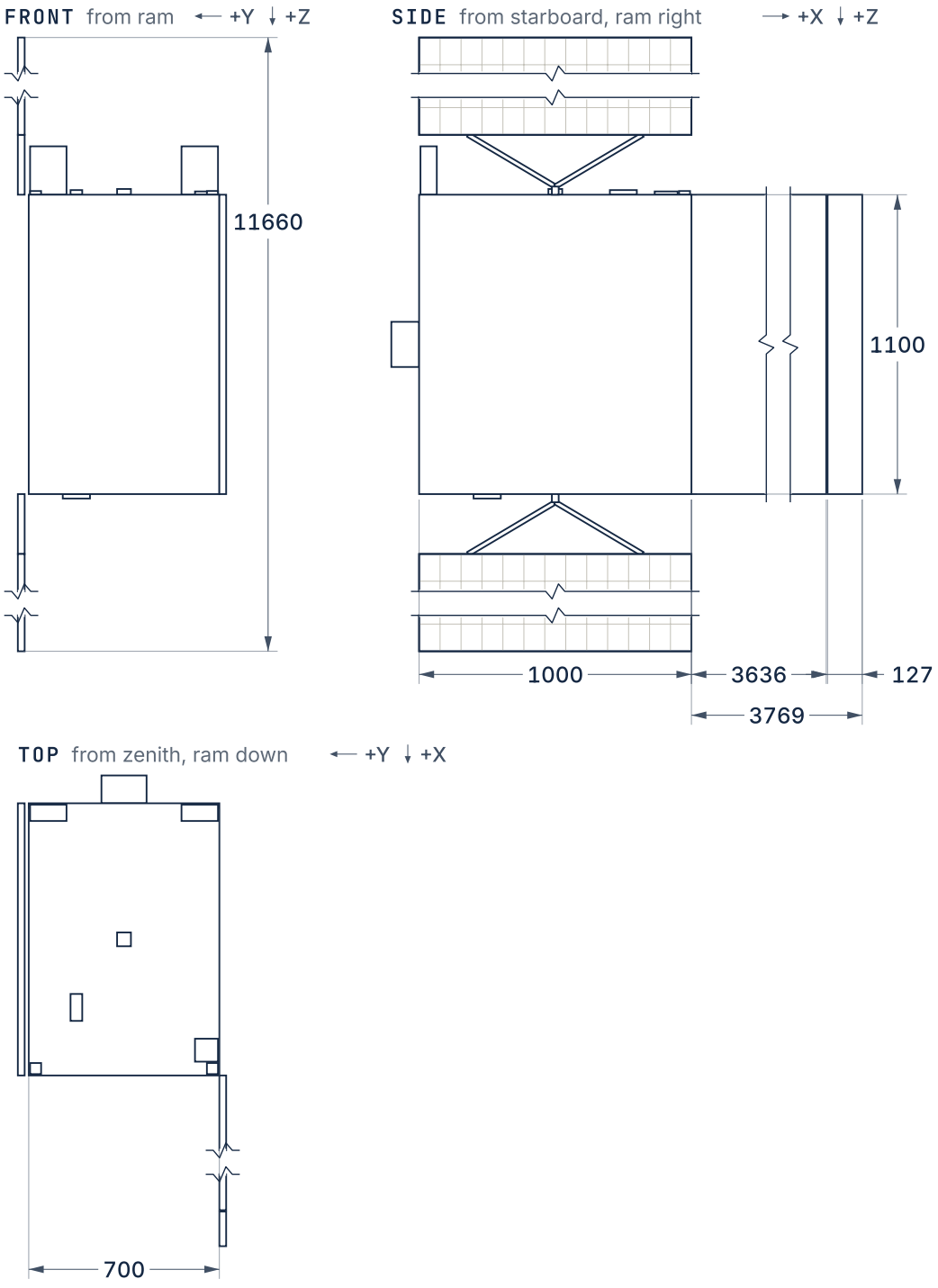
PASS **GMAT: re-entry, Schatten −2σ.** GMAT re-enters the satellite 3.6 years after the end of the mission with the Schatten −2σ solar prediction (limit 5 years).

Spacecraft



Isometric, deployed, seen from ram, starboard and zenith, long appendages broken · not to scale; scale and dimensions in the views overleaf. Axes: +X ram, +Y starboard, +Z nadir.

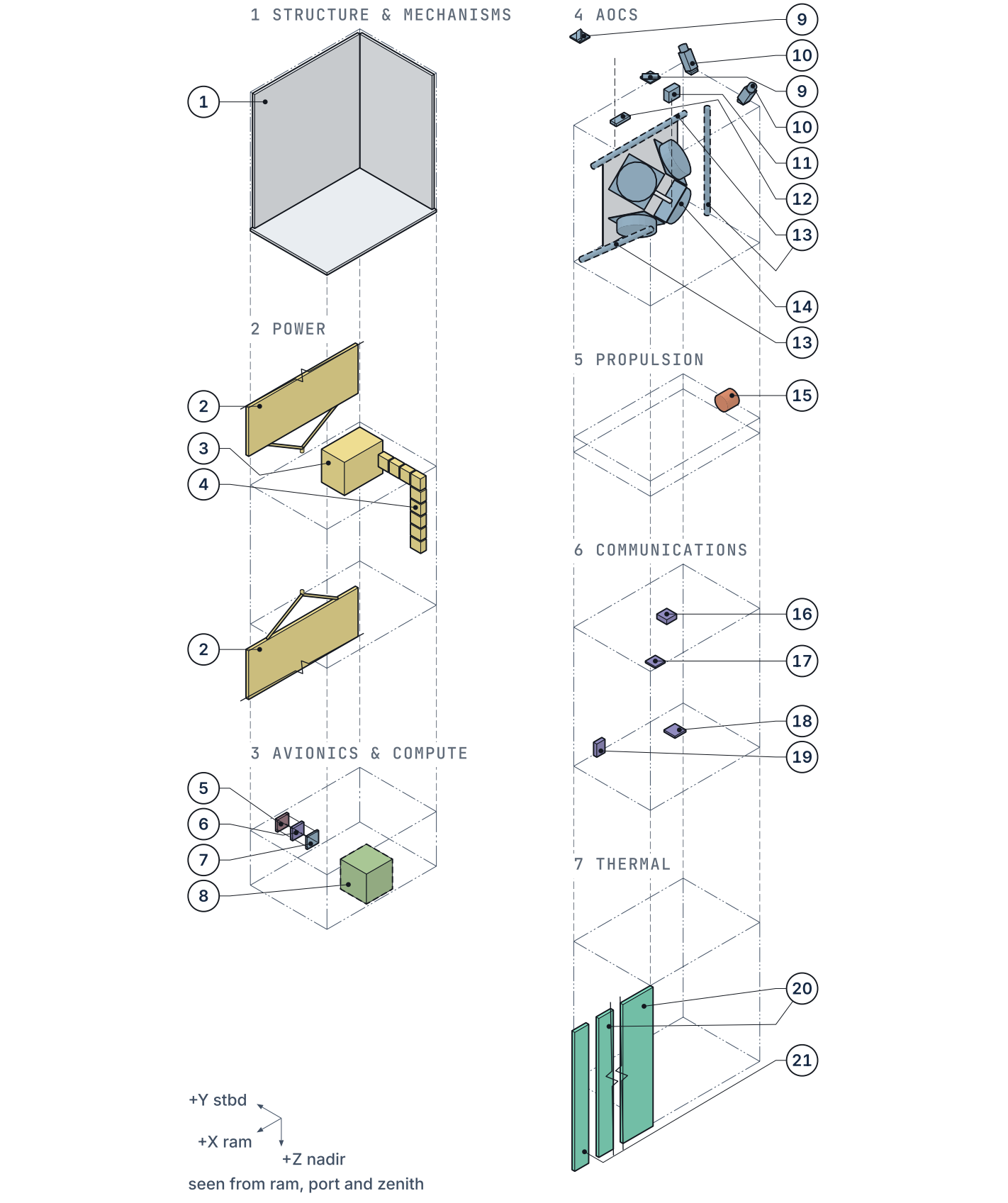
Built from parts · drawn to scale 1:25 on the printed A4 page, first-angle projection, dimensions in millimetres · long appendages shortened (break lines), their dimensions true.



MISSION	Orbital data center, 1 kW GPU a… · built from parts	SCALE	1:25	DATE	22 Oct 2026
DRY MASS	461.41 kg · from parts				
POWER FOR THRUSTER	635.9 W · from parts · 2,377 W array − 1,741 W of listed loads				
PROPULSION	Astra Spacecraft Engine (ASE) · 25 mN · 1,400 s · from parts				
VENDOR PARTS	Anywaves S-Band TT&C Antenna (antenna) · and 14 more				
DIMENSIONS	body 1,000 × 700 × 1,100 mm (length × width × height) · span 11,660 mm, deployed				
PARTS	16 from vendors' datasheets · 7 generic or illustrative				

Internal arrangement

Exploded isometric by level, seen from ram, port and zenith · not to scale: each level is the slice of the bus that holds its parts (phantom lines), moved along the build axis, its parts at their true places in it; the PC/104 stack exploded along its rods; a part hidden among others lifted out, a dashed line down to where it sits; long appendages broken; small parts drawn enlarged; a dashed outline: an envelope assumed from the part's mass (the configuration gives no size).



NO.	PART	SUBSYSTEM	MASS	ENVELOPE	MOUNTED
STRUCTURE & MECHANISMS					
1	Microsatellite box	Structure	–	1,000 × 700 × 1,100 mm	–
POWER					
2	Solar wing × 2	Power	68.3 kg	5 panels of 1,000 × 1,000 mm	starboard face, zenith edge and nadir edge, on a yoke, fixed
3	Airbus Crisa EVO PCDU	Power	19.7 kg	210 × 262 × 350 mm	starboard panel
4	Ibeos B28-135 SmallSat Battery × 9	Power	7.65 kg	51 × 89 × 94 mm	aft panel
AVIONICS & COMPUTE					
5	AAC Clyde Space Sirius OBC LEON3FT	Data handling	0.13 kg	17 × 90 × 96 mm	PC/104 stack on 4 rods, starboard panel
6	Satlab SRS-4	Communications	0.25 kg	18 × 87 × 93 mm	PC/104 stack on 4 rods, starboard panel
7	SSTL SGR-Ligo GNSS receiver	AOCS	0.09 kg	12 × 87 × 92 mm	PC/104 stack on 4 rods, starboard panel
8	GPU compute payload	Payload	20.0 kg	237 × 237 × 237 mm, assumed from mass	port panel (placed for the drawing)
AOCS					
9	Solar MEMS Technologies nanoSSOC-D60 digital sun sensor × 2	AOCS	0.01 kg	6 × 14 × 43 mm	zenith face, forward starboard and forward port corners, canted 40° on a wedge
10	Jena-Optronik ASTRO CL star tracker × 2	AOCS	0.64 kg	60 × 60 × 129 mm	zenith face, aft starboard and aft port corners, canted 30° on a wedge
11	Safran Navigation & Timing STIM300 IMU	AOCS	0.06 kg	22 × 39 × 45 mm	on the wheel bracket's post
12	NewSpace Systems NMRM-Bn25o485 magnetometer	AOCS	0.09 kg	17 × 43 × 99 mm	zenith face, forward starboard corner
13	IAI (Tamam) magnetotorquer P/N 1286-0008 × 3	AOCS	14.9 kg	Ø 39 × 844 mm, Ø assumed from mass	starboard panel, along X; ram panel, along Y, canted 41.3°; aft panel, along Z (placed for the drawing)
14	Rocket Lab RW4-12.0 reaction wheel × 4	AOCS	20.0 kg	68 × 257 × 257 mm	pyramid bracket on the starboard panel, spin axes at 54.74°
PROPULSION					
15	Astra Spacecraft Engine (ASE)	Propulsion	7.60 kg	Ø 120 mm	aft face, on the thrust axis
COMMUNICATIONS					
16	AAC Clyde Space ANT-GPS-A GPS antenna	Communications	0.08 kg	21 × 51 × 51 mm	zenith face, centre
17	Anywaves S-Band TT&C Antenna	Communications	0.14 kg	12 × 84 × 84 mm	zenith face, forward port corner
18	Anywaves Compact X-Band Payload Telemetry Antenna	Communications	0.07 kg	16 × 100 × 100 mm	nadir face, aft starboard corner
19	IQ spacecom XLink-X	Communications	0.20 kg	25 × 65 × 90 mm	starboard panel
THERMAL					
20	Deployable radiator, 4 m² panel	Thermal	39.2 kg	4 m² panel, 3,636 × 1,100 mm	in the port face's plane, deployed forward from its ram edge
21	Deployable radiator, 0.14 m² panel	Thermal	1.37 kg	0.14 m² panel, 127 × 1,100 mm	in the port face's plane, at the far end of 20

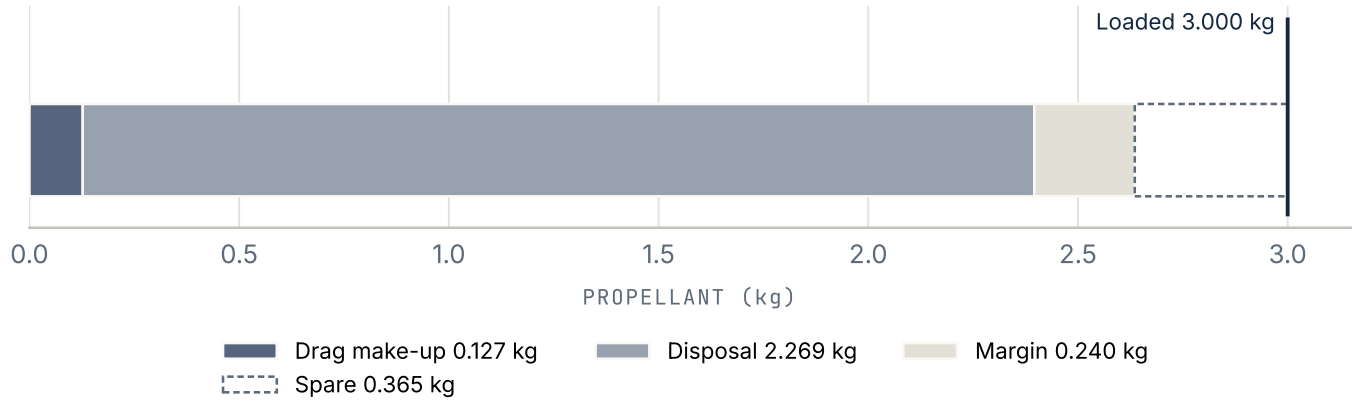
Mass allocations (no hardware): Harness allowance; Thermal allowance.

Mass: each part's dry mass, all its units, as the parts configuration gives it (– where it gives none). AOCS: attitude and orbit control.

Transfer to the operational orbit

QUANTITY	VALUE	HOW IT WAS OBTAINED
Orbit	550 km, 97.59°	Insertion and operations: node at 06:00 local time on 15 Mar 2027
Transfer	None	Inserted at 550 km, its operational altitude: no transfer. Delta-v 0 m/s, no propellant spent; operations start at insertion

Propellant budget



ITEM	PROPELLANT	BASIS
Transfer	0.000 kg	None: inserted at its operational orbit
Drag make-up	0.127 kg	3.8 m/s over 5 years with a strong solar cycle (expected cycle: 2.2 m/s)
Disposal	2.269 kg	Lowering to 429 km
Margin	0.240 kg	10% of the need
Needed	**2.635 kg**	Loaded: 3.000 kg · 0.365 kg to spare

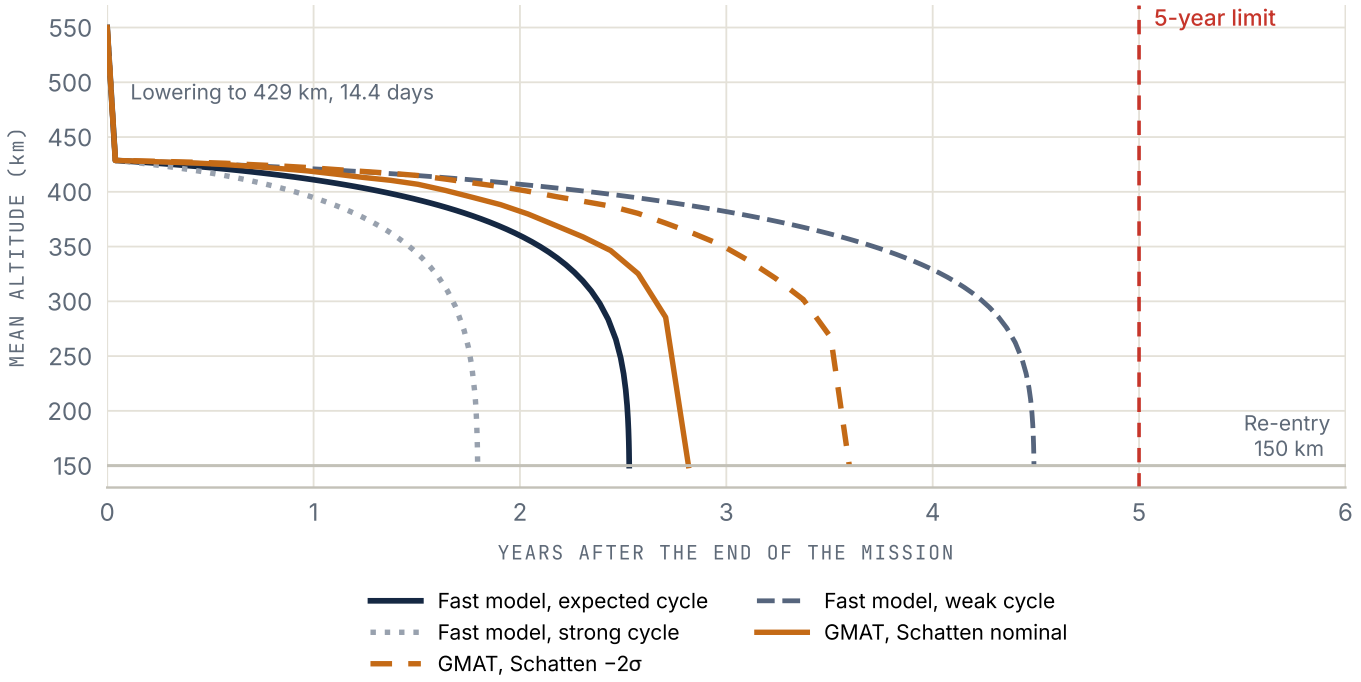
Drag coefficient sensitivity: With Cd·A/m 30% higher, drag make-up takes 0.1650 kg instead of 0.1269 kg: 2.68 kg needed with the margin, 3.00 kg loaded.

Delta-v budget

MANOEUVRE	DELTA-V	MARGIN	CLAUSE	MARGIN	WITH MARGIN	PROPELLANT
Drag make-up 5 years, strong solar cycle	3.75 m/s	5 %	D.1 d	0.19 m/s	3.94 m/s	0.127 kg
Disposal Lowering to 429 km	67.26 m/s	5 %	D.1 d	3.36 m/s	70.62 m/s	2.269 kg
Attitude control (AOCS) Not in the budget: attitude control uses no propellant in Mission Composer's model (TBD)	TBD	100 %	D.1 b (second list)	–	–	–
Total	**71.01 m/s**			**3.55 m/s**	**74.56 m/s**	

The per-manoeuvre margins are informative: D.1 d (≥ 5 %) adds 3.6 m/s, 5 % of the 71.0 m/s budgeted. The binding margin is the propellant budget's 10 % of the need (0.240 kg, the spec's constraints.propellant_margin_fraction), which covers that share (10 % ≥ 5 %). Nothing the verdict reads changes. The policy file marks D.1 d as not applied together with propellant margin, manoeuvres, propellant margin, aocs thrusters. The propellant column is the budget's, before its margin.

End of life and re-entry



Left at 550 km after 5 years of operations, the satellite would outlive the 5-year rule with a weak solar cycle. The plan lowers it to 429 km in 14.4 days (67 m/s, 2.27 kg), the highest orbit that still re-enters 4.5 years after the end of the mission with a weak cycle (0.5 years of margin on the limit).

SOLAR ACTIVITY	LEFT AT 550 KM	AFTER LOWERING TO 429 KM
Expected solar cycle (f10.7 70-180)	21.4 y	2.5 y
Weak solar cycle (f10.7 65-120)	57.7 y	4.5 y
Strong solar cycle (f10.7 75-240)	11.4 y	1.8 y

Years from the end of the mission to re-entry (150 km). The weak cycle is the design case for disposal; the strong cycle is the design case for drag make-up.

Drag coefficient sensitivity: With Cd·A/m 30% lower, the planned disposal brings it down 6.6 years after the end of the mission, against 4.5 as planned (limit 5 years, weak solar cycle).

Subsystems at Phase 0/A

First-order analyses at Phase 0/A feasibility level, run on this spacecraft's parts configuration: power, thermal (steady state) and attitude control (momentum, dumping and thrust offset). They are not a design and not a design sign-off. **"CLOSES" means the first-order balance closes with the stated margins**; it is not a PDR result, a qualification argument or an ECSS compliance statement. Each discipline's status is shown beside the mission verdict, never as it, except where a discipline binds: thermal binds by default, so a bindable thermal check that fails adds a combined headline on the first page. Every key number is labelled with what checked it: an estimate is a number nothing independent recomputed for this mission.

Statuses: CLOSES, every check passes or is information; CLOSES WITH CONDITIONS, no fail and nothing missing, but some warn; OPEN, no fail, but a needed input is missing; DOES NOT CLOSE, some check fails; NOT ASSESSED, the discipline cannot run. Input tags: [cat] from the parts catalogue; [entered] typed by the team; [V] verified against the cited source; [D] derived; [B] from a book or common practice, not re-checked: needs review; [A] a Mission Composer assumption: needs review; [U] unknown: asked, and what it feeds is not assessed. NEEDS REVIEW marks a number or a check that rests on an [A] or [B] figure or a class estimate. Computed on the parts catalogue of 2026-10-01 with power model 9, rules 3; thermal model 8, rules 3; attitude model 5, rules 2 (subsystems document 7eede5d778c4df9b9710f913). Parts added to the catalogue after that date: airbus-crisa-evo-pcdu, iai-tamam-1286-0008, newspace-systems-nmrm-bn25o485, rocket-lab-rw4-12-0.

DISCIPLINE	STATUS	BINDING	HEADLINE NUMBER	VERIFICATION LABEL
Power	CLOSES WITH CONDITIONS NEEDS REVIEW	No	Energy margin, worst orbit: 15.0% NEEDS REVIEW	Estimate
Thermal	CLOSES WITH CONDITIONS NEEDS REVIEW	Yes, by default	Bus temperature, hot, operations (H1): 23.2 °C NEEDS REVIEW	Estimate
Attitude	CLOSES NEEDS REVIEW	No	Wheel momentum needed per orbit: 2.60 N m s NEEDS REVIEW	Estimate
Communications	Coming in a later release			
Structures	Coming in a later release			
Radiation	Coming in a later release			

Power CLOSES WITH CONDITIONS NEEDS REVIEW

Energy margin, worst orbit

15.0% NEEDS REVIEW

operations, margined loads, 22 Dec 2031 (beta -59.0°, eclipse 21.7 min)

ESTIMATE

Worst depth of discharge

18.4% NEEDS REVIEW

operations, margined, 21 Dec 2027 (beta -58.9°, eclipse 21.7 min); against 41.5 % allowed for 7302 cycles

ESTIMATE

Minimum battery capacity (BOL)

537 Wh NEEDS REVIEW

what it would take: the configuration carries 1215 Wh

ESTIMATE

Minimum end-of-life array power

2,683 W NEEDS REVIEW

what it would take: 0.87 x the arrays' installed 3082 W (end of life, normal incidence, 1 AU, every array scaled alike)

ESTIMATE

End-of-life factor

0.839 NEEDS REVIEW

the power budget uses 0.8

ESTIMATE

Beta minimum, operations

-89.8 deg

on 09 Apr 2029; operations from -89.8 to -58.9 deg; shown beside GMAT (env) without a tolerance (beyond the first year)

ESTIMATE

Beta maximum, operations

-58.9 deg

on 21 Dec 2027; operations from -89.8 to -58.9 deg; shown beside GMAT (env) without a tolerance (beyond the first year)

ESTIMATE

Longest eclipse

21.7 min

21 Dec 2027, operations, beta -58.9 deg, 550 km; cylindrical shadow; GMAT (env) agrees within the dual-cone band

VERIFIED FOR THIS MISSION: GMAT (ENV)

INPUTS

Assumed, needs review: `array_temp_C` 46.1 °C [D] · `distribution_efficiency` 0.92 [B] · `battery_efficiency` 0.9 [A] · `battery_eol_capacity` 0.8 [B] (load-bearing) · `safe_mode` sun [A] · `distribution_efficiency_bus` 0.99 [B] · `cell_kappa` -0.0023 /K [D] · `array-1#0.bol_W` 1,735 W [A] · `array-1#0.eol_W` 1,388 W [A] · `array-1.power.cell_technology` multijunction [A] · `array-1#1.bol_W` 1,735 W [A] · `array-1#1.eol_W` 1,388 W [A] · `degradation_per_yr_multijunction` 0.015 /yr [B] · `harness_loss_W` 36.0 W [A] · `heater_safe_W` 0.981 W [D] · `heater_ops_W` 0 W [D] · `heater_eclipse_W` 180 W [D] · `heater_bus_eclipse_W` 0 W [D] · `heater_loop_C1_sunlit_W` 382 W [D] · `heater_loop_C1_sunlit_installed_W` 545 W [D] · `heater_loop_C1_eclipse_W` 133 W [D] · `heater_loop_C1_eclipse_installed_W` 191 W [D] · `heater_loop_C2_sunlit_W` 89.6 W [D] · `heater_loop_C2_sunlit_installed_W` 128 W [D] · `heater_loop_C2_eclipse_W` 127 W [D] · `heater_loop_C2_eclipse_installed_W` 182 W [D] · `battery_dod_max` 0.415 [B] (load-bearing) · `array_peak_temp_C` 28.0 °C [A].

From a standard or published source: `margin.system_power` 0.2 [V] · `margin.maturity[A/B]` 0.05 [V] · `margin.maturity[D]` 0.2 [V] · `margin.maturity[C]` 0.1 [V].

From your parts or inputs: `conversion_efficiency` 0.98 [entered] · `ops_mode` nadir [entered] · `distribution_efficiency_eps_line` 1.00 [D] · `eps-1.power_W` 10.0 W [entered] · `gnss-1.power_W` 0.5 W [cat] · `load-1.power_W` 1,000 W [entered] · `magnetorquer-1.power_W` 6.50 W [cat] · `obc-1.power_W` 1.30 W [cat] · `radio-1.power_W` 10.8 W [cat] · `radio-2.power_W` 16.0 W [cat] · `reaction-wheel-1.power_W` 40.0 W [cat] · `sensor-1.power_W` 0.75 W [cat] · `sensor-2.power_W` 1.50 W [cat] · `star-tracker-1.power_W` 1.20 W [cat] · `sun-sensor-1.power_W` 0.01 W [cat] · `battery-1.capacity_Wh` 135 Wh [cat] · `battery-1.chemistry` li-ion [cat] · `battery-1.power.battery_discharge_max_A` 10.0 A [cat] · `battery-1.power.battery_charge_max_A` not published [U] · `battery-1.power.battery_voltage_min_V` 22.0 V [entered] · `eps-1.rated_power_W` not published [U] · `eps-1.rated_power_line_max_W` 4,000 W [cat].

METHOD

An orbit-by-orbit energy balance, sampled daily along the mission as the fast model flies it (SMAD 3rd ed. §11.4): beta, eclipse and Sun distance per day come from the fast model's orbit with a cylindrical shadow. Array power starts from the vendor's beginning-of-life figure, scaled by cell temperature, ageing, conversion and distribution efficiencies, seasonal flux and each array's incidence in the nadir, sun-pointing and tumbling attitudes. Loads are the power budget's lines at their duty with the ECSS maturity and system margins, plus thermal's heater need and, on firing orbits, the thruster. The battery is an energy store: each orbit's depth of discharge at the end-of-life capacity is checked against a cycle-life table for the cycles flown, and the smallest battery and array that would close are found by bisection.

CHECKS

PASS **PWR-1 Energy balance in operations.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 6 more. m >= 0 with margined loads every operations day: worst 15 % on 22 Dec 2031 (beta -59.0°, eclipse 21.7 min). Basis: Policy margins (ECSS-E-TM-10-25A D.1 b, D.1 h; ESA SRE-PA/2011.097 R-P-1, R-P-3); SMAD 3rd ed. §11.4.

PASS **PWR-2 Battery DOD for the cycles flown.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 8 more. Worst DOD 18.4 % margined (14.7 % nominal) on 21 Dec 2027 (beta -58.9°, eclipse 21.7 min), against 41.5 % allowed for 7302 cycles; end-of-life capacity 972 Wh (80 % of 1215 Wh). Basis: Cycle-life table power.battery_cycle_life [B, placeholder to transcribe]; S11 eq. 77; at the end-of-life capacity.

PASS **PWR-3 Safe mode.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 10 more. Safe mode (sun-pointing, +Y to the Sun): worst m = 455 % margined on 22 Dec 2031 (beta -59.0°, eclipse 21.7 min); worst DOD 18.1 % margined (14.4 % nominal) against 41.5 % allowed. Basis: As PWR-1 and PWR-2, with the safe-mode loads and attitude.

PASS **PWR-4 Power for the transfer.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 8 more. Every one of the 16 orbits evaluated over the descent closes margined, the thruster at 400 W x duty 1 in sunlight, as the fast model fires it: worst m = 16.1 % on 14 Mar 2032 (beta -79.3°, eclipse 0.0 min). Basis: The fast model's firing assumption (duty, fires_in_eclipse); one orbit per grid point: daily, 0.25-day steps while the altitude changes faster than 10 km/day; the DOD judged on what the thruster adds (§9.9 item 20).

WARN **PWR-5 Power for drag make-up.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 8 more. 1764 of 1827 operations days (96.6 %) can host a thrusting orbit with margined loads, 1827 (100 %) with nominal loads (the thruster at duty 1, the orbit treated as periodic; the DOD judged on what the thruster adds); drag make-up needs 0.0464 % of operations spent thrusting, so enough days host it when they make up at least that share, firing on every orbit of them. Of the days that cannot with margined loads: on 63 the thrusting orbit is not power-positive (energy: the arrays, or the thruster's power or duty). Seasons to avoid: 11 Dec 2030 to 31 Dec 2030; 01 Dec 2031 to 11 Jan 2032. Basis: The share of operations that must be spent thrusting, f_reb (method step 4). A day hosts a thrusting orbit when that orbit, treated as periodic, is power-positive and the thruster adds no DOD above the allowed one (§9.9 item 20). Pass: every day hosts it with margined loads; warn: enough days (at least f_reb of operations, firing on every orbit of them) host it, margined in some seasons or with nominal loads only; fail: not enough days host it even with nominal loads (§9.9 item 29).

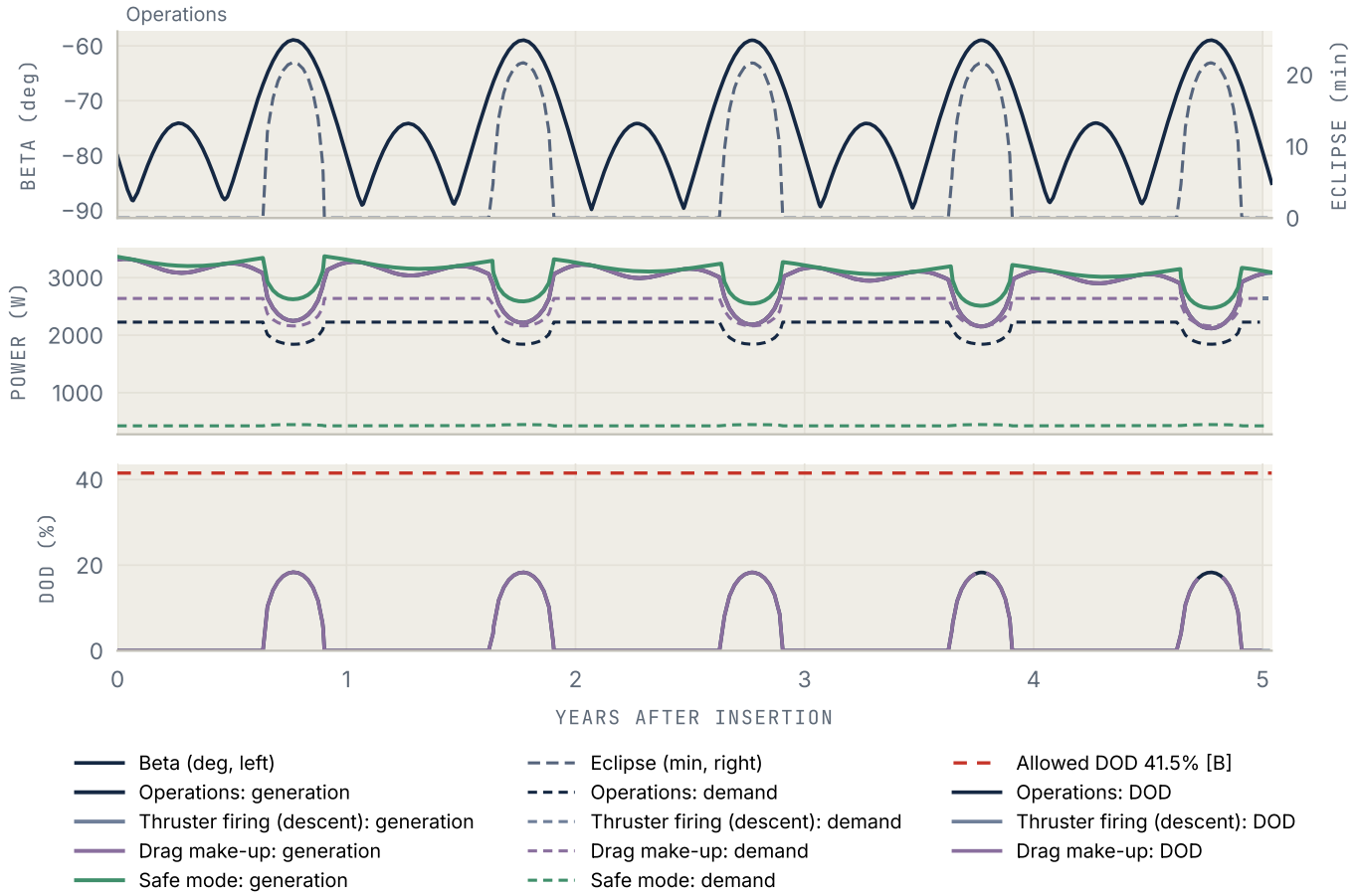
PASS **PWR-7 Peak power and charge rate.** NEEDS REVIEW Rests on assumed figures: harness loss W 36 W [A]; array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; and 8 more. Battery limit 1980 W (90 A x 22 V): eclipse peak 776 W (thermal's cold-operations heater at its installed 216 W included, margined, in both peaks) (thermal's other heaters at their installed ratings, margined, in their windows' peaks) leaves 1192 W; sunlit peak 3001 W with 2739 W of lowest sunlit array output leaves 1628 W. Charge current 6.94 A in sunlight (no published charge limit: reported only). Basis: Coincident peaks and the pack's published current limits (method step 7); never a fail.

PASS **PWR-8 Tumbling after separation.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; distribution efficiency 92 % [B]; battery round-trip efficiency 90 % [A]; distribution efficiency bus 99 % [B]; cell temperature coefficient -0.0023 1/K [D]; cell ageing (multijunction) 1.5 %/yr [B]; and 6 more. Power-positive tumbling at the 1/4 factor with margined safe loads on separation day (15 Mar 2027): m = 98.6 %. Basis: Cauchy: a tumbling body's arrays average 1/4 of their area; safe-mode loads; never a fail.

INFO **PWR-9 End-of-life factor.** NEEDS REVIEW Rests on assumed figures: array temperature 46.1 °C [D]; cell temperature coefficient -0.0023 1/K [D]; distribution efficiency 92 % [B]; cell ageing (multijunction) 1.5 %/yr [B]; distribution efficiency bus 99 % [B]. End-of-life factor 0.839 here (K_T 0.958 x ageing over 5.04 years x conversion 0.98 x distribution 0.964, the bus loads' load-weighted figure (each line at its own; the harness's I2R beyond the distribution efficiency, 43.2 W margined at the bus, a loss of its own)); the power budget uses 0.8 (ageing, heat and harness / MPPT losses: the same scope). At 0.839 the budget's sunlit array power, 2377 W, would be 2492 W; the budget is not changed (§2.1). Consistency (§2.8): the budget counts 0.856 of the fixed arrays' output in sunlight on its design day, 21 Dec 2027 (beta -58.9°, eclipse 21.7 min), the day of the mission with the least power left after the bus loads (power.orbit_incidence@1 in nadir pointing); in nadir pointing the same faces average 0.951 over sunlight (0.856 at worst) and 0.908 over the orbit, eclipses included, across operations. The budget takes the Sun at 1 AU: on its design day it is at 0.984 AU, 3.32 % more flux than it counts (conservative). The descent is flown pitched 180° (+Z to zenith) so the wings on +Y stay lit; a yaw flip would turn them to the dark side. Shown, never corrected: the budget sets available_for_propulsion_W. Basis: Method step 2: K_EOL = K_T x L_d x eta_conv x eta_dist, like for like.

WARN **PWR-10 EPS rating against the arrays' peak.** NEEDS REVIEW Rests on assumed figures: arrays at their peak at 28 °C [A]; 2 part figures from Mission Composer rules. The arrays' peak, 3589 W (their beginning-of-life output at 28 °C, the BOL's rating temperature, at the best incidence any attitude gives them, at the Sun's closest over the mission, 0.9833 AU on 04 Jan 2031): Airbus Crisa EVO PCDU (Power Conditioning and Distribution Unit) publishes no rated power for the configured unit, only an upper bound, so whether it takes the peak is not established (it is within the product line's maximum, 4000 W, above which no configuration takes the arrays). The configured unit's rating, from its vendor, answers it. The peak is the most the arrays give, at

beginning of life, not PWR-7's lowest sunlit array output (the least, at end of life). Basis: The EPS item's published rated power for the configured unit (a product line's maximum only as an upper bound), as published (no conversion efficiency credited), against the arrays' beginning-of-life output at 28 °C (the BOL's rating temperature), at the best incidence any attitude gives them, at the Sun's closest distance over the mission (QA of 2026-10-17, B7).



Beta and eclipse; generation against demand per mode; DOD against the allowed line: generation: orbit-average array output; demand: the array power the margined loads need (E_req over the orbit); DOD at the end-of-life capacity on power-positive orbits; drawn over one another: operations and drag make-up generation, operations and drag make-up DOD; no transfer is flown: the thruster firing mode is drawn over the descent alone; the shaded bands are the mission's phases: operations, then descent (descent too short to be named on the chart).

WHAT IT WOULD TAKE

- **Minimum battery capacity (BOL): 537 Wh.** C = drawdown / (DOD x EOL capacity) = 179 Wh / (41.5 % x 80 %), governed by operations, 21 Dec 2027 (beta -58.9°, eclipse 21.7 min); the configuration carries 1215 Wh.
- **Minimum end-of-life array power: 2,683 W.** Every array scaled by 0.87 brings the worst margined orbit to m = 0 (operations, 22 Dec 2031 (beta -59.0°, eclipse 21.7 min)); the arrays give 3082 W at end of life, normal incidence and 1 AU (K_T 0.958, ageing to the end of the mission).

VERIFICATION

Verified for this mission against GMAT: 10 of 13 compared quantities agree within tolerance.

FIDELITY AND NOT MODELLED

An orbit-by-orbit energy balance sampled daily over the mission (360 samples per orbit), not a power system design: the fast model's altitude, J2 + J4 node, low-precision Sun and cylindrical shadow; arrays from the vendor's BOL with temperature, ageing, conversion and distribution factors, seasonal flux, and incidence for nadir, sun-pointing and tumbling; the battery as an energy store whose DOD per orbit is checked against a cycle-life table that is still a placeholder to transcribe. The margins, depths of discharge and sizing numbers are estimates: no independent reference recomputes them. Only the orbit geometry they read (beta and eclipses) has one: the GMAT env run, which re-flies it with the mission's GMAT verification. Beta and eclipses (GMAT env): verified for this mission by GMAT (env) for beta in the first year of operations, longest eclipse, eclipses a day at the longest eclipse and at the largest beta (21 Dec 2027), eclipse duration on the worst power-margin day (20 Dec 2031), eclipses a day on the worst power-margin day (20 Dec 2031), eclipse duration at the smallest beta (09 Apr 2029), eclipses a day at the smallest beta (09 Apr 2029), season edge where eclipses begin (02 Nov 2027), season edge where eclipses end (07 Feb 2028), orbit-average sun fraction; beta minimum over operations, beta maximum over operations, beta in the later years of operations shown beside GMAT (env) without a tolerance: an estimate.

Not modelled: bus voltages and currents, I-V curves, strings and mismatch, MPPT dynamics, harness drop; the EPS's limits other than its rated power (section currents, tracking voltage range); the battery's state of charge carried across orbits; capacity against temperature and discharge rate; cell failures; self-shadowing, albedo and Earth IR on the cells, pointing errors and slews, attitudes other than nadir, sun-pointing and tumbling;

array temperature from a thermal model, until thermal runs; radiation damage from the actual fluence, until phase 2; load timing inside the orbit (a pass in eclipse is not placed there), except the peak check; transients, inrush, pyro and deployment loads, passivation; the time actually spent in safe mode: it is checked as a steady state that can last.

Thermal

CLOSES WITH CONDITIONS · NEEDS REVIEW · BINDING BY DEFAULT

Assumed, no source. This result rests on these figures until data exists; each is a requirement on its supplier.

- Assumed, no source: link conductance G 100 W/K (the payload loop, Other equipment to Deployable radiator); requirement on the loop supplier G ≥ 95.4 W/K (T1's break-even at the panel's 4 m²); T2's plate heater is sized at 100 W/K (a larger G needs a larger heater).
- Assumed, no source: link conductance G_off 1 W/K (the payload loop stopped, Other equipment to Deployable radiator); requirement on the loop supplier G_off ≤ 1 W/K (the keep-warm heaters of T2 and T7 are sized on it).
- Assumed, no source: link conductance G 100 W/K (the bus panel's switched link, on, Deployable radiator); requirement on the link supplier G ≥ 0.401 W/K (T1's break-even at the panel's 0.14 m²).
- Assumed, no source: link conductance G_off 1 W/K (the bus panel's switched link, off, Deployable radiator); requirement on the link supplier G_off ≤ 1 W/K (the cold cases count its leak at it: T2, T3, T4 and T7 rest on it).

Bus temperature, hot, operations (H1)

23.2 °C NEEDS REVIEW

with the 0.88 m² radiator at its cap and the bus panel in place (148 °C without them); beta -67.5 deg, 550 km, STEM comb extreme (high inclination, 5400 s average): albedo 0.26, OLR 244 W/m2; a bus-average estimate

ESTIMATE

Bus temperature, hot, firing (H2)

28.1 °C NEEDS REVIEW

with the 0.88 m² radiator at its cap and the bus panel in place (157 °C without them); beta -67.5 deg, 550 km, STEM comb extreme (high inclination, 5400 s average): albedo 0.26, OLR 244 W/m2; a bus-average estimate

ESTIMATE

Bus temperature, cold, operations (C1)

2.25 °C NEEDS REVIEW

with the radiator in place; beta -90 deg, 550 km, STEM olr extreme (high inclination, 5400 s average): albedo 0.26, OLR 193 W/m2; a bus-average estimate

ESTIMATE

Bus temperature, cold, after separation (tumbling) (C2)

1.35 °C NEEDS REVIEW

with the radiator in place; beta -59 deg, 550 km, STEM olr extreme (high inclination, 5400 s average): albedo 0.26, OLR 193 W/m2; a bus-average estimate

ESTIMATE

Window maximum (op_max less the margin)

35.0 °C

the limiting unit's operating maximum (a pack's charge maximum when lower: a heater cannot cool it) less the policy margin

ESTIMATE

Window minimum (op_min plus the margin)

-10.0 °C

the limiting unit's operating minimum plus the policy margin; a battery's minima are held by its own heater (T3), a propulsion unit's operating minimum applies only while it fires (T4) and a unit narrower than twice the margin is left out (T5)

ESTIMATE

Radiator area

0.924 m² NEEDS REVIEW

on -Y, 84 % of its free area; assumed well coupled

ESTIMATE

Heater power, cold operations (installed)

0 W NEEDS REVIEW

0 W needed at 70 % maximum duty (GSFC-STD-1000), bus heaters

ESTIMATE

Heater power, survival (installed)

0 W NEEDS REVIEW

0 W needed at 70 % maximum duty (GSFC-STD-1000), bus heaters

ESTIMATE

Thermal time constant (shortest case)

16,451 s NEEDS REVIEW

H1: M c_p T0 / (4 Q0) on the dry mass, c_p 900 J/(kg K) [B]; STEM reads the 5400 s row

ESTIMATE

Environmental heat absorbed, H1

2,391 W NEEDS REVIEW

Sun, albedo and Earth IR on the faces at the H1 point (a heat load, not a temperature)

METHOD CHECKED AGAINST PUBLISHED CASES: NASA/TM-2001-211222 TABLES 2.1, 3.2 AND 3.3 (STEM), REPRODUCED BY THERMAL.ENVIRONMENT_CASE@1

Payload loop node, hot (H1, H2)

34.4 °C

the node the 4 m² panel holds at its hottest point through G 100 W/K, the units' power while on; T_allow,max 35 °C

ESTIMATE

Payload loop panel, stopped (coldest)

-123 °C

C1 in eclipse: its own equilibrium, cold optics, STEM's 16 s row at the coldest extreme, no mass credited

ESTIMATE

Heat the bus panel carries (hot, largest)

16.4 W

what -Y's radiator at its cap (0.88 m²) leaves at T_allow,max, orbit average

ESTIMATE

Heat the bus panel holds beyond what it carries (hot, least)

54.2 W

at its 0.14 m², at T_allow,max through G, where least over the hot points: heat the model leaves out counts against it

ESTIMATE

Bus panel's leak, cold, operations (C1)

22.8 W

through the switched link off, G_off 1 W/K, at the design point (the bus at 2.25 °C), the panel at its own balance per arc

ESTIMATE

Bus panel's leak, cold, after separation (tumbling) (C2)

28.4 W

through the switched link off, G_off 1 W/K, at the design point (the bus at 1.35 °C), the panel at its own balance per arc

ESTIMATE

Beta minimum, operations

-89.8 deg

on 09 Apr 2029; operations from -89.8 to -58.9 deg; shown beside GMAT (env) without a tolerance (beyond the first year)

ESTIMATE

Beta maximum, operations

-58.9 deg

on 21 Dec 2027; operations from -89.8 to -58.9 deg; shown beside GMAT (env) without a tolerance (beyond the first year)

ESTIMATE

Longest eclipse

21.7 min

21 Dec 2027, operations, beta -58.9 deg, 550 km; cylindrical shadow; GMAT (env) agrees within the dual-cone band

VERIFIED FOR THIS MISSION: GMAT (ENV)

INPUTS

Assumed, needs review: `exterior_design` blanketed bus, sized radiator [A] · `mli_outer.alpha` 1.00 [A] · `mli_outer.epsilon` 1.00 [A] · `mli_outer.alpha_cold` 0.95 [cat] · `mli_outer.epsilon_hot` 0.85 [cat] · `mli_eps` 0.05 [B] (load-bearing) · `heat_capacity_J_kgK` 900 J/(kg K) [B] · `concentration_share` 0.25 [A] · `radiator_fit` 0.8 [A] · `radiator.alpha` 0.17 [cat] · `radiator.epsilon` 0.89 [cat] · `eol_dalpha_az93_z93` 0.04 [B] · `eol_leo_alt_max_km` 2,000 km [A] · `bus_allowance_W` 713 W [A] · `battery_efficiency` 0.9 [A] · `distribution_efficiency` 0.92 [B] · `eol_factor` 0.8 [A] · `harness_loss_W` 36.0 W [A] · `distribution_efficiency_bus` 0.99 [B] · `pack_emittance` 1.00 [A] · `heater_control_band_K` 2.00 K [A] · `thruster-1.envelope_m2` 0.123 m² [D] · `loop.conductance_W_K` 100 W/K [A] · `loop.off_conductance_W_K` 1.00 W/K [A] · `bus_panel.conductance_W_K` 100 W/K [A] · `bus_panel.off_conductance_W_K` 1.00 W/K [A] · `cell_alpha` 0.91 [A] · `cell_epsilon` 0.85 [B] · `cold_eps_heat` 1.00 [A] (load-bearing).

From a standard or published source: `margin.temperature_K` 10.0 K [V] · `environment` mission_critical [V].

From your parts or inputs: `conversion_efficiency` 0.98 [entered] · `dry_mass_kg` 461 kg [entered] · `thruster_input_W` 400 W [D] · `ppu_efficiency` 0.95 [cat] · `thruster_heat_to_bus_W` 4.00 W [entered] · `thruster_jet_W` 172 W [D] · `distribution_efficiency_eps_line` 1.00 [D] · `battery-1.temp_operating_C` 0 to 45.0 °C [cat] · `battery-1.heater_W` 180 W [cat] · `battery-1.envelope_m2` 0.319 m² [D] · `eps-1.temp_operating_C` -35.0 to 70.0 °C [cat] · `gnss-1.temp_operating_C` -20.0 to 50.0 °C [cat] · `load-1.temp_operating_C` 0 to 45.0 °C [entered] · `magnetorquer-1.temp_operating_C` -30.0 to 70.0 °C [cat] · `obc-1.temp_operating_C` -30.0 to 60.0 °C [cat] · `radio-1.temp_operating_C` -40.0 to 70.0 °C [cat] · `radio-2.temp_operating_C` -20.0 to 60.0 °C [cat] · `reaction-wheel-1.temp_operating_C` -20.0 to 60.0 °C [cat] · `reaction-wheel-1.thermal.temp_survival_C` -25.0 to 65.0 °C [cat] · `sensor-1.temp_operating_C` -20.0 to 65.0 °C [entered] · `sensor-2.temp_operating_C` -40.0 to 85.0 °C [cat] · `star-tracker-1.temp_operating_C` -35.0 to 50.0 °C [cat] · `sun-sensor-1.temp_operating_C` -30.0 to 85.0 °C [cat] · `thruster-1.temp_min_C` -20.0 °C [entered] · `thruster-1.temp_survival_min_C` -30.0 °C [entered] · `loop.area_m2` 4.00 m² [entered] · `loop.alpha` 0.17 [cat] · `loop.epsilon_hot` 0.89 [cat] · `loop.alpha_cold` 0.13 [cat] · `loop.epsilon` 0.93 [cat] · `loop.fluid_freeze_C` -185 °C [entered] · `bus_panel.area_m2` 0.14 m² [entered] · `bus_panel.alpha` 0.17 [cat] · `bus_panel.epsilon_hot` 0.89 [cat] · `bus_panel.alpha_cold` 0.13 [cat] · `bus_panel.epsilon` 0.93 [cat] · `radiator.alpha_cold` 0.13 [cat] · `radiator.epsilon_cold` 0.93 [cat].

Missing (2): Which finishes cover the bus faces? No face has an entered finish, and the finish moves the answer more than any other input. Until they are entered the analysis uses Mission Composer's default design, a blanketed bus with a sized radiator as Phase 0/A designs start: MLI blankets with a black outer layer (a choice, not a bound: conservative for the hot window only) on the faces without cells, the cell finish on the faces with body cells, and an AZ-93 white radiator sized on the face with the least hot flux (offered below). The bare-anodised exterior of the first release (alpha 0.422 / eps 0.765, STEM's default input) stays available: set blanket: false on a face with no finish. Or enter AZ-93 white, a black paint, silver FEP tape, or your blankets. Offered, never applied silently: blanketed bus, sized radiator [A]. · Which propellant does the thruster store (Astra Astra Spacecraft Engine (ASE): "Xenon or Krypton")? T4 shows the adverse of the candidates until it is known.

METHOD

One isothermal bus node with six faces, each with its own finish, and a surface node per blanketed face, in steady orbit-average balance. The Sun (1317 to 1419 W/m²), albedo and Earth IR come from NASA's STEM design environments over the mission's beta range and altitudes, with exact Earth view factors at 72 orbit points. Internal heat comes from the power budget's load lines in four cases: hot in operations (H1) and while firing (H2), cold in operations (C1) and tumbling after separation (C2). The window is the internal units' operating ranges narrowed by the margin, with batteries and propulsion modules checked on their own (T3, T4); a radiator is sized for the hot cases and heaters, at 70 % duty, for the cold ones. The result is a bus-average temperature, not unit temperatures.

CHECKS

WARN **T1 Hot window.** NEEDS REVIEW Assumes exterior_design (blanketed bus, sized radiator) [A], mli_outer.alpha 1 [A], mli_outer.epsilon 1 [A], mli_outer.alpha_cold 0.95 [cat] and more. Bus H1 23.3 °C; H2 28.1 °C holds T_allow,max 35 °C (Ibeos B28-135 SmallSat Battery's maximum less 10 K) with -Y's radiator at its cap and the bus panel in place: the radiator needed exceeds 80 % of the free area of every candidate face (the smallest, 0.924 m² on -Y, against 1.1 m² free). For reference only (not the design): with no radiator the bus would reach H1 148 °C; H2 157 °C. With -Y's radiator at its cap, 0.88 m², the bus panel (Deployable radiator, 0.14 m² on -Y, both sides radiating, a switched link, on in the hot cases) carries the rest, up to 16.4 W (the heat the capped radiator leaves at T_allow,max; at the governing point, H2 beta -67.5 deg, 16.4 W): it needs 0.0321 m² at T_allow,max through G 100 W/K: the panel holds it. At its 0.14 m² the break-even G 0.401 W/K. It holds 54.2 W more than it carries (its spare at T_allow,max through G, where least over the hot points): heat the model leaves out counts against it (Not modelled: the panel's views of the body and the other deployables, among others; the harness's I2R beyond the distribution efficiency, 36 W, is counted). Assumed, no source [A]: G 100 W/K is the team's allocation, not a read figure: G ≥ 0.401 W/K is a requirement on the link supplier. The panel's two sides read thermal.orbit_heat_loads@1 at every hot point, at the case's own orbit averages and STEM pair (its heat reaches the bus node, whose time constant is hours; a load that swings round the orbit rejects at least what its average does). At end of life the radiator on -Y, the loop panel (Deployable radiator) and the bus panel (Deployable radiator) read their finish's sourced increment (+0.04 for AZ-93/Z-93 over the 5-year design life in LEO, a conservative margin including contamination [B]: MISSE measured 0 to 0.01 (NASA/TP-2013-217498, NASA/TM-2008-215173)); T1 tolerates a further uniform 0.0042. The single node spreads Rocket Lab RW4-12.0 reaction wheel (12.0 Nms RWA, rad-hard)'s 176 W over the whole bus; it needs its own conduction path to a radiator, which is not sized here. Loop (Other equipment on Deployable radiator, 4 m² on -Y, both sides radiating): the units' 1200 W while on in sunlight (their power with its maturity margin, never averaged over the orbit) need 3.92 m² at the node's T_allow,max 35 °C (Other equipment's maximum less 10 K) through G 100 W/K: the panel holds it. At its 4 m² the break-even G 95.4 W/K; at G 100 W/K the break-even interface maximum 44.4 °C (the node the panel holds, plus the 10 K margin). Assumed, no source [A]: G 100 W/K is the team's allocation, not a read figure: G ≥ 95.4 W/K is a requirement on the loop supplier. The panel's two sides read thermal.orbit_heat_loads@1 at every H1 and H2 point, in the sunlit arc and in eclipse, at STEM's 16 s row and each point's hottest extreme type (a panel's time constant is minutes, not the bus's hours). Basis: T_hot + m <= every op_max (§3.2 T1); radiator <= 80 % of the free face.

WARN **T2 Cold window, heaters.** NEEDS REVIEW Assumes exterior_design (blanketed bus, sized radiator) [A], mli_outer.alpha 1 [A], mli_outer.epsilon 1 [A], mli_outer.alpha_cold 0.95 [cat] and more. Bus C1 2.25 °C with the radiator in place holds T_allow,min -10 °C (SSTL (Surrey Satellite Technology) SGR-Ligo GNSS receiver's minimum plus 10 K) with no heaters. C1 counts the EPS losses of the loads it runs (the owner's rule of 2026-10-16): 38.8 W at its design point (conversion 24.7 W, distribution 14.1 W, the battery's round trip 0 W), credited at their orbit average (the conversion loss falls in sunlight and the battery's in eclipse, which warms the eclipse minimum a steady node cannot resolve); the heaters' own EPS losses are charged by power only. The bus panel (Deployable radiator, 0.14 m² on -Y) is switched off in the cold cases: its link takes 22.8 W from the bus at C1's design point (the bus at 2.25 °C) through G_off 1 W/K, the panel at its own balance with the leak (down to -20.6 °C), per arc; counted in the bus heaters. Assumed, no source [A]: G_off 1 W/K is the team's allocation, not a read figure: G_off ≤ 1 W/K is a requirement on the link supplier (its leak is counted at it). Loop (Other equipment on Deployable radiator, C1): running in sunlight at 1000 W the node is at -6.22 °C at the arc's coldest point (beta -59 deg), below its T_allow,min 10 °C: a heater of 382 W on the units' plate holds it (545 W installed at 70 % duty), drawn in sunlight while they run; stopped in eclipse, they are held at 10 °C (their operating minimum plus the margin: they must restart) by a keep-warm heater of 133 W: G_off 1 W/K x the 133 K to the panel at -123 °C, its own equilibrium, no unit mass credited (191 W installed at 70 % duty), drawn in eclipse. Its heaters take 607 W of sunlit array power (recharged through eclipse where they run in it): 371 W of it would come from the power the budget leaves for propulsion, which is not changed here. Assumed, no source [A]: the loop's G_off 1 W/K is the team's allocation, not a read figure: G_off ≤ 1 W/K is a requirement on the loop supplier (the keep-warm heaters are sized on it). Assumed, no source [A]: the plate heater is sized at the loop's G 100 W/K, the team's allocation (T1): a larger G needs a larger heater. Basis: T_cold - m >= every op_min; heaters at 70 % duty (GSFC-STD-1000).

WARN **T3 Battery.** NEEDS REVIEW Assumes exterior_design (blanketed bus, sized radiator) [A], mli_outer.alpha 1 [A], mli_outer.epsilon 1 [A], mli_outer.alpha_cold 0.95 [cat] and more. Ibeos B28-135 SmallSat Battery: C1 bus 2.25 °C - 10 K is below its 0 °C charge minimum: met with its own 180 W heater (it needs 0 W to hold it at 2 °C, its minimum plus the 2 K control band (none at the predicted bus temperature: a thermostat holds it should the bus run colder), within 70 % of its rating); C2 bus 1.35 °C - 10 K is below its 0 °C discharge or survival minimum: met with its own 180 W heater (it needs 0.981 W to hold it at 2 °C, its minimum plus the 2 K control band, within 70 % of its rating); met at the bus temperatures in hot 28.1 °C. A battery's heater holds the pack, not the bus: its envelope radiates to the bus interior (emittance 1 [A], no conduction counted), its set point the minimum plus the 2 K control band [A] with one margin, the heater's 70 % duty; its heat stays in the bus (T2, T7) and power counts the heater, drawn evenly round the orbit. Basis: hot T + m <= max (fail: a heater cannot cool it); cold T - m >= charge min (C1), discharge or survival min (C2), else met with its own heater or one sized here (warn).

WARN **T4 Propellant.** NEEDS REVIEW Assumes exterior_design (blanketed bus, sized radiator) [A], mli_outer.alpha 1 [A], mli_outer.epsilon 1 [A], mli_outer.alpha_cold 0.95 [cat] and more. The propellant is ambiguous (Astra Astra Spacecraft Engine (ASE): "Xenon or Krypton"); the adverse of xenon, krypton is shown: While it fires (C1, cold operations) the bus is at 2.25 °C; less the 10 K margin, -7.75 °C holds Astra Astra Spacecraft Engine (ASE)'s -20 °C operating minimum (entered). Dormant (between burns and after separation): In C2 the bus is at 1.35 °C; less the 10 K margin, -8.65 °C is above xenon's -30 °C, the module's survival minimum (entered). Below 16.59 °C xenon is stored two-phase: confirm the feed system accepts it. Basis: cold T - m >= the module's minimum or the phase floor (NIST); xenon two-phase warn.

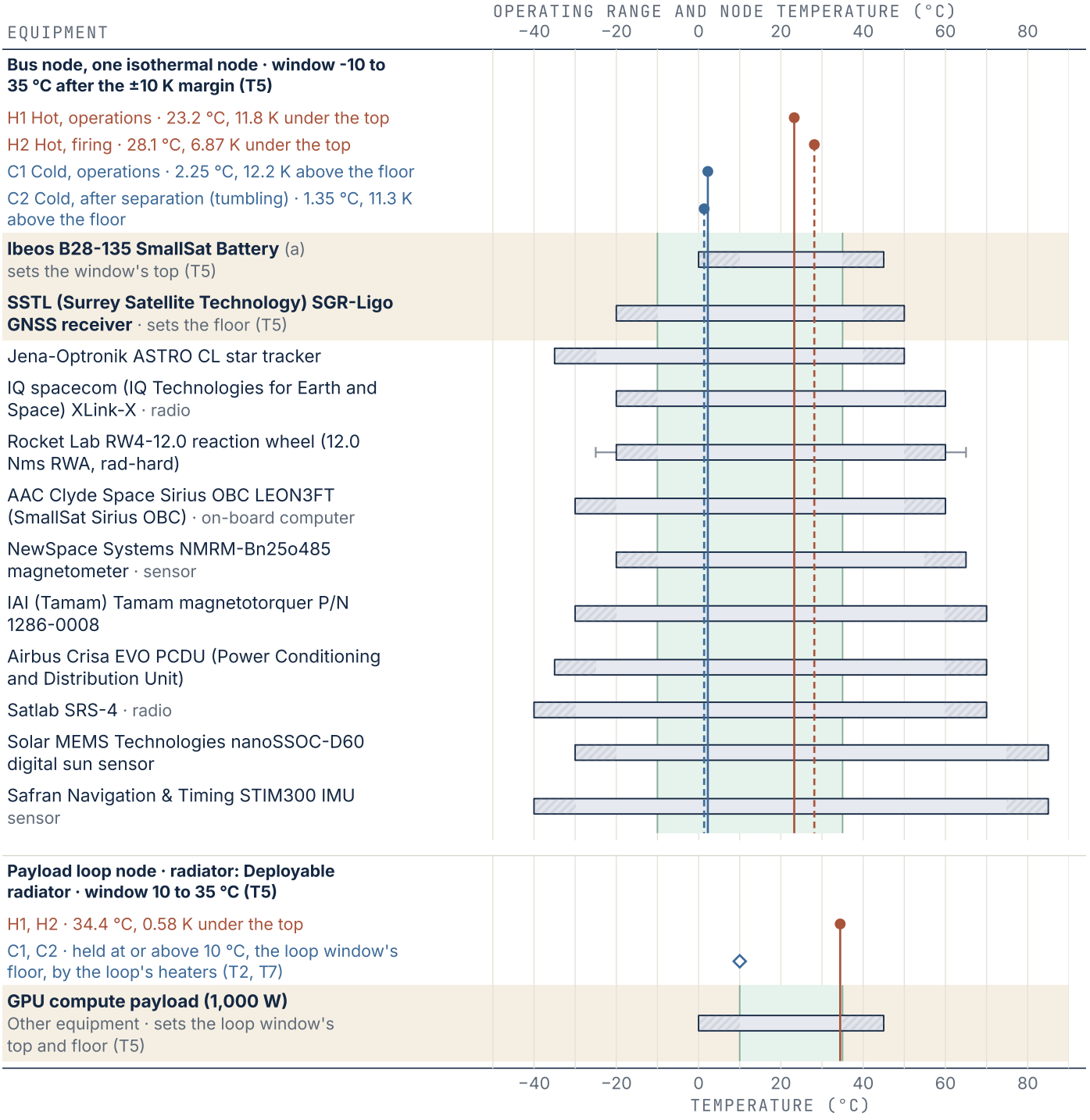
PASS **T5 Window exists.** Window -10 °C to 35 °C after ±10 K: SSTL (Surrey Satellite Technology) SGR-Ligo GNSS receiver sets the floor, Ibeos B28-135 SmallSat Battery the ceiling. Loop window 10 °C to 35 °C after ±10 K: Other equipment sets the floor, Other

equipment the ceiling. Basis: T_allow,min < T_allow,max after the margins; a unit no wider than twice the margin is left out and named (warn).

PASS **T6 Coverage.** All 13 internal units have operating limits. Basis: every internal unit has operating limits (no table of typical ranges).

WARN **T7 Survival (C2).** NEEDS REVIEW Assumes exterior_design (blanketed bus, sized radiator) [A], mli_outer.alpha 1 [A], mli_outer.epsilon 1 [A], mli_outer.alpha_cold 0.95 [cat] and more. Bus C2 1.35 °C (tumbling, SAFE loads) holds -10 °C (SSTL (Surrey Satellite Technology) SGR-Ligo GNSS receiver's operating (no survival range published) minimum plus 10 K). C2 counts the EPS losses of the loads it runs (the owner's rule of 2026-10-16): 13.2 W at its design point (conversion 4.2 W, distribution 3.96 W, the battery's round trip 5.05 W), credited at their orbit average (the conversion loss falls in sunlight and the battery's in eclipse, which warms the eclipse minimum a steady node cannot resolve); the heaters' own EPS losses are charged by power only. The bus panel (Deployable radiator, 0.14 m² on -Y) is switched off in the cold cases: its link takes 28.4 W from the bus at C2's design point (the bus at 1.35 °C) through G_off 1 W/K, the panel at its own balance with the leak (down to -32.6 °C), per arc; counted in the bus heaters. Assumed, no source [A]: G_off 1 W/K is the team's allocation, not a read figure: G_off ≤ 1 W/K is a requirement on the link supplier (its leak is counted at it). Loop (Other equipment on Deployable radiator, C2): stopped in sunlight, they are held at 10 °C (their operating minimum plus the margin: no survival range published) by a keep-warm heater of 89.6 W: G_off 1 W/K x the 89.6 K to the panel at -79.6 °C, its own equilibrium, no unit mass credited (128 W installed at 70 % duty), drawn in sunlight; stopped in eclipse, they are held at 10 °C (their operating minimum plus the margin: no survival range published) by a keep-warm heater of 127 W: G_off 1 W/K x the 127 K to the panel at -117 °C, its own equilibrium, no unit mass credited (182 W installed at 70 % duty), drawn in eclipse; the stopped panel's coldest is -123 °C (C1, in eclipse), above the loop fluid's -185 °C freezing point. Its heaters take 187 W of sunlit array power (recharged through eclipse where they run in it), within the headroom. Assumed, no source [A]: the loop's G_off 1 W/K is the team's allocation, not a read figure: G_off ≤ 1 W/K is a requirement on the loop supplier (the keep-warm heaters are sized on it). Basis: C2 within every survival range (operating where none is published).

INFO **T8 Deployed wings.** Solar wing: 46.1 °C in the hot case at efficiency 0.204. Basis: power.array_temperature@1 at 1419 W/m2, normal incidence (information).



Operating range, as the part's datasheet or the team gives it

Node window: the units' limits narrowed by the margin; bus and payload loop each their own (T5)

Design margin: ±10 K inside each limit, hatched (margin.temperature_K [V]: ECSS-E-TM-10-25A Annex D.1 margins, D.1 g: "±10°C margin in equipment temperatures"). A predicted node temperature must fall in the clear part of a unit's bar.

Survival (non-operating) range, where published

The unit that sets an edge of its node's window, in bold, first in its group (T5)

Hot case (H1 solid; H2 dashed): the node's steady orbit-average temperature

Cold case (C1 solid; C2 dashed): steady orbit-average node temperature; C2 against survival ranges (T7)

A payload loop's cold cases: held at its floor by the loop's heaters, no node temperature drawn (T2, T7)

(a) a battery: its minima are held by its own heater (T3), so they do not set the window's floor.

Temperature window: each unit's operating range against the steady node temperatures of the four cases; bus and payload loop drawn on their own nodes; a case gives its node temperature and how far it lies under the top or above the floor of its node's window; rows: the units that set a window edge first, then by upper operating limit, the nearest the hot edge first.

WHAT IT WOULD TAKE

- **Radiator area to hold the hot window: 0.924 m².** on -Y, the radiator finish (az-technology-az-93: alpha 0.21 hot at end of life, eps 0.89)

- **Heater power, cold, operations (installed): 0 W.** none needed
- **Heater power, cold, after separation (tumbling) (installed): 0 W.** none needed
- **Largest thruster heat to the bus that H2 tolerates: 58.2 W.** while firing; H2 closes at or below it (with the radiator grown to its largest fit, 0.88 m² on -Y)
- **Largest end-of-life absorptance increment T1 tolerates: 0.00425.** added to every finish's end-of-life alpha (its sourced increment where one applies, else beginning of life; a published or entered end-of-life alpha stays)
- **Payload loop panel area that holds its node: 3.92 m².** both sides radiating, at the node's T_allow,max through G
- **Least link conductance that holds the loop node: 95.4 W/K.** at the panel's 4 m²
- **Least interface maximum the loop holds: 44.4 °C.** the node the panel holds through G 100 W/K, plus the 10 K margin
- **Payload loop floor heater, running, cold, operations (in sunlight, installed): 545 W.** at 70 % duty
- **Payload loop keep-warm heater, stopped, cold, operations (in eclipse, installed): 191 W.** at 70 % duty
- **Payload loop keep-warm heater, stopped, cold, after separation (tumbling) (in sunlight, installed): 128 W.** at 70 % duty
- **Payload loop keep-warm heater, stopped, cold, after separation (tumbling) (in eclipse, installed): 182 W.** at 70 % duty
- **Bus panel area that holds the hot window (the face's radiator at its cap): 0.0321 m².** both sides radiating, at T_allow,max through G
- **Least link conductance that holds the bus with the panel: 0.401 W/K.** at the panel's 0.14 m²

VERIFICATION

Verified for this mission against GMAT: 10 of 13 compared quantities agree within tolerance. Published cases the code reproduces in the test suite (method checked, not this mission's numbers): STEM Table 3.2 (TH-STEM-1): T0, tau, loads, extreme types; STEM Table 3.3 (TH-STEM-2, -3, -4); STEM Table 2.1, all ten beta rows. Still to transcribe: SATMO against Thermal Desktop (per-face fluxes, transients); Libertad 2 single-node 3U over a year of beta. The STEM cases check the environment method (tables, albedo correction, averaging-time and extreme-type rules, T^4 balance, tau); they do not prove box-face view factors or a multi-face spacecraft. No temperature is checked for this mission.

FIDELITY AND NOT MODELLED

A sizing estimate, not a thermal model: one isothermal bus node with six faces, each with its own finish, and a surface node per blanketed face; steady orbit-average hot and cold cases over the mission's beta range and altitudes; NASA STEM hot and cold albedo and Earth IR (ERBE data, NASA/TM-2001-211222), solar 1317-1419 W/m2, cylindrical shadow, exact Earth view factors at 72 orbit points. It gives a bus-average temperature, not unit temperatures. No accuracy is quoted: the SATMO / Thermal Desktop and Libertad 2 comparisons are to transcribe (R3); until then the report states the margin applied (±10 K), not an accuracy. Per-mission temperatures are estimates. The environmental heat loads follow STEM's method, checked against the TM's published cases as heat loads only, never as temperatures. Internal heat is the power budget's load lines; in the hot and the cold cases it carries the EPS conversion and distribution losses of the loads each case runs, the distribution line by line, and the battery's round trip, at the power discipline's efficiencies (every watt the arrays give is a load's, leaves the craft, or is heat inside it). A payload loop is one node at its units' interface, linked to a deployed panel whose two sides radiate by one conductance (to the panel's mean radiating surface, fin efficiency included), steady in each arc of the orbit. A deployable bus panel radiates from both sides, linked to the bus node by one conductance (on in the hot cases; a switched link off in the cold ones leaks its off conductance), the panel at its own balance with the heat it takes, at the bus cases' orbit-average loads (per arc for the cold leak). Beta and eclipses (GMAT env): verified for this mission by GMAT (env) for beta in the first year of operations, longest eclipse, eclipses a day at the longest eclipse and at the largest beta (21 Dec 2027), eclipse duration on the worst power-margin day (20 Dec 2031), eclipses a day on the worst power-margin day (20 Dec 2031), eclipse duration at the smallest beta (09 Apr 2029), eclipses a day at the smallest beta (09 Apr 2029), season edge where eclipses begin (02 Nov 2027), season edge where eclipses end (07 Feb 2028), orbit-average sun fraction; beta minimum over operations, beta maximum over operations, beta in the later years of operations shown beside GMAT (env) without a tolerance: an estimate.

Not modelled: the orbit swing (one-node Radau transient with a thermostat): R3; power takes the cold-operations heater's orbit-average need, day by day, as its energy per orbit, drawn in eclipse at no more than its installed rating (an upper bound); unit-level thermal control: a battery's heater is sized on its envelope radiating to the bus (no conduction path); a unit whose range is no wider than twice the margin needs dedicated control, not sized here; SATMO / Thermal Desktop per-face and transient comparisons, and Libertad 2: R3; unit temperatures, conduction paths and face gradients (flagged, not computed, for concentrated dissipation); wings and appendages in the bus balance, except a deployed wing's steady temperature; thruster and plume heat, except H2's heat to the bus; soak-back after chemical burns; catalyst-bed and tank heaters during burns; launch and ascent; louvers, heat pipes and heat switches; emittance degradation (the owner's sources give absorptance increments only; AZ-93 publishes under 1 % emittance change after exposure), and the absorptance degradation of a finish with no sourced increment (the rules' 0 placeholder; T1 at best warn on a mission over a year); albedo near the terminator (first-order cos theta model); albedo converted by the cells; day-by-day environment: STEM's design envelope is used whatever the date; the EPS losses' timing in the cold cases: counted at their orbit average, while the conversion loss falls in sunlight and the battery's in eclipse, which warms the eclipse minimum a steady node cannot resolve (the cold checks are re-evaluated with none of the [B] or [A] efficiencies' credit); the heaters' own EPS losses (charged by power only: conservative for the heaters); radiated RF (not subtracted in the hot case: conservative); on the payload loop: transients (each arc is steady state, no unit or panel mass credited) and set-point regulation; the units' radiative exchange with the bus; the panel's views of the body (coplanar with its mount face it has none of that face; its view of the +X face's blanket, about 0.1) and of the wings; the stowed panel; on the bus panel: the switch's or heat pipe's own regulation band (on at T_allow,max in the hot cases, off in the cold ones), transients, its views of the body and of the other deployables (coplanar with its mount face it has none of that face), the stowed panel.

Attitude CLOSES NEEDS REVIEW

Sizing disturbance torque

4.02×10^{-4} N m NEEDS REVIEW

gravity gradient, controlled descent at 429 km; method checked against New SMAD §19 (FireSat II, SCS) in the test suite

ESTIMATE

Thrust-offset torque

6.23×10^{-4} N m NEEDS REVIEW

lever 24.9 mm with the thrust line through the CoG, operations; against the 3.81e-04 N m gravity gradient torque; as the automatic packing leaves the thrust line (55.4 mm off the CoG): lever 80.3 mm, 0.00201 N m

ESTIMATE

Thrust-offset momentum per orbit

3.57 N m s NEEDS REVIEW

operations: 6.23e-04 N m x 95.6 min of firing; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 11.5 N m s

ESTIMATE

Wheel momentum needed per orbit

2.60 N m s NEEDS REVIEW

operations, on a coasting orbit, dumped once per orbit; 16% of the wheel's 16 N m s; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 2.6 N m s in the operations

ESTIMATE

Magnetic dumping per orbit

26.7 N m s NEEDS REVIEW

controlled descent: 4.44 x the need (6.01 N m s collected per orbit); an upper bound; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 1.91 x the need (14 N m s collected in the controlled descent)

ESTIMATE

Largest firing fraction the torquers sustain

1.00 NEEDS REVIEW

controlled descent: modelled 1.00; firing on every orbit the torquers dump 6.78 times its thrust-offset momentum; shown, never fed back; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 1.00

ESTIMATE

S9 single-torque wheel storage

0.408 N m s NEEDS REVIEW

S9 Table 19-11: the worst disturbance (gravity gradient, controlled descent) over a quarter orbit; information beside the envelope

ESTIMATE

S9 torquer dipole at the maximum field

8.12 A m² NEEDS REVIEW

S9 Table 19-11: T_D / B, operations; a lower bound (S9 recommends margin: the field is that strong only twice per orbit)

ESTIMATE

INPUTS

Assumed, needs review: `offset_deg` 5.00 deg [A] · `cg_uncertainty_m` 0.01 m [A] (load-bearing) · `actuator_margin` 1.00 [A] · `dump` magnetic [A] · `dump_interval_h` 24.0 h [A] · `thruster_dump_reserve_share` 0.5 [A] · `torque_classification` S9 Table 19-4 [B] · `drag_coefficient` 2.20 [A] · `reflectivity_cr` 1.30 [A] · `thrust_line_offset_m` 0 m [A] · `thrust_line_offset_packed_m` 0.0554 m [D] · `wheel_bias_rpm` 0 rpm [A].

From a standard or published source: `solar_w_m2` 1,361 W/m² [V].

From your parts or inputs: `ops_mode` nadir [entered] · `residual_dipole_Am2` 7.40 A m² [entered] · `residual_dipole_total_Am2` 7.40 A m² [D] · `thrust_misalignment_deg` 1.00 deg [cat] · `reflectance_q` 0.3 [D] · `sun_distance_min_au` 0.983 AU [D] · `solar_flux_max_W_m2` 1,408 W/m² [D] · `thrust_N` 0.025 N [entered] · `exit_plane_distance_m` 0.855 m [D] · `isp_s` 1,400 s [entered] · `magnetorquer-1.attitude.torquer_dipole_Am2` 300 A m² [cat] · `reaction-wheel-1.attitude.wheel_momentum_Nms` 12.0 N m s [cat] · `reaction-wheel-1.attitude.wheel_torque_mNm` 200 mN m [cat] · `wheel_axis_credit` 1.33 [D] · `propellant_reserve_kg` 0.604 kg [D] · `dump_arm_m` 0.55 m [D] · `mass_properties` the parts layout's mass-properties model [D].

METHOD

New SMAD §19 closed forms on this mission's orbit, phase by phase: aerodynamic, gravity-gradient, magnetic and solar-pressure torques, with NRLMSISE-00 density at the strong solar cycle and a tilted dipole field. Cyclic torques are stored over a quarter orbit and secular torques summed on one axis, a conservative envelope. The thrust line's offset from the centre of mass, with the CoG uncertainty and the thruster's misalignment, gives the thrust-offset torque and its momentum over each firing arc; without a CAD model the thrust line is taken through the CoG and the automatic packing's offset is evaluated beside it. Wheels, torquers and thruster dumping are compared with twice the need, and the break-even residual dipole, CoG offset and firing fraction are reported; the transfer is not recomputed.

CHECKS

PASS **ATT-1 Wheel momentum, worst phase.** NEEDS REVIEW Assumes the x2 actuator margin [A], a CoG uncertainty of 10 mm [A], the thrust line through the CoG [A], a gravity-gradient offset of 5 deg [A], S9 Table 19-4's cyclic and secular torques [B] and magnetic momentum dumping [A]. The wheels' usable momentum on the worst axis, 16 N m s (1.33 x one wheel's range (4 wheels 54.74 deg from the set's axis, its worst direction) from rest [A] to its rating, of Rocket Lab RW4-12.0 reaction wheel (12.0 Nms RWA, rad-hard)'s 12 N m s), against 2.6 N m s needed in the operations (6.14 x the need), on a coasting orbit, dumped once per orbit: cyclic 0.39 N m s, secular torque 3.86e-04 N m, thrust offset 6.23e-04 N m over a 95.6 min arc, dumping 0.00465 N m. Basis: S9 Table 19-11 (momentum storage); §3.4 step 5; capacity >= (1 + m) x need with m the rules file's actuator margin (1.0, [A]; not an ECSS rule).

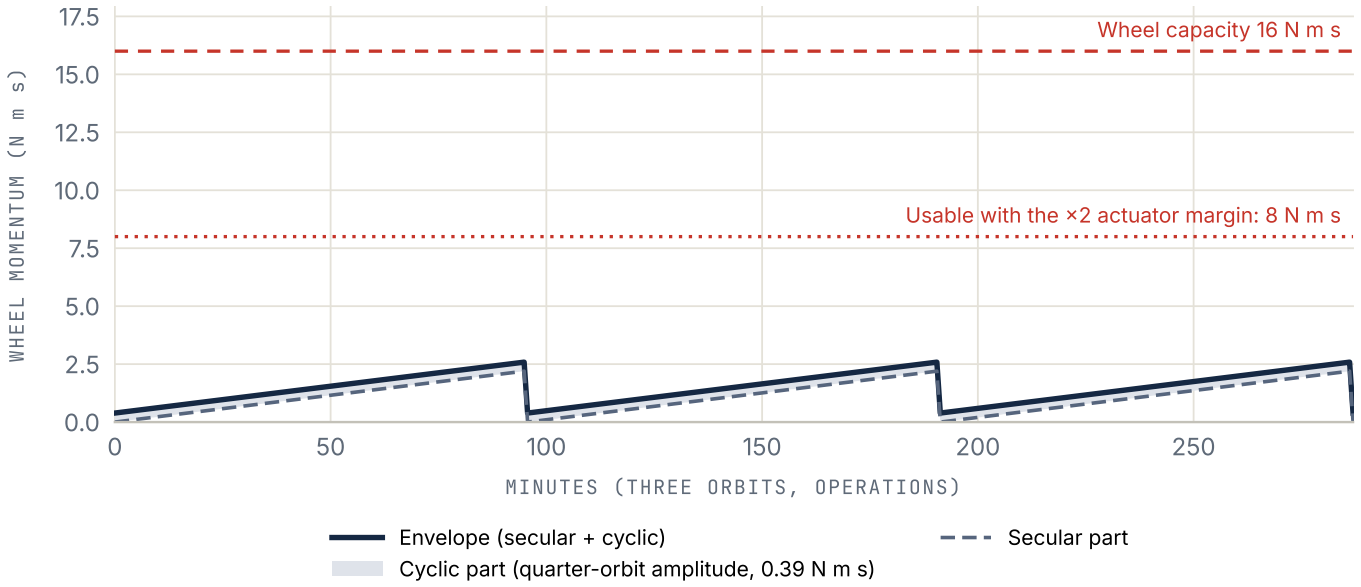
PASS **ATT-2 Wheel torque against the peak disturbance and the thrust offset.** NEEDS REVIEW Assumes the x2 actuator margin [A], a CoG uncertainty of 10 mm [A], the thrust line through the CoG [A] and a gravity-gradient offset of 5 deg [A]. One wheel's torque, 200 mN m, against 1.02 mN m in the controlled descent (195 x the need): the gravity gradient torque 4.02e-04 N m plus the thrust offset 6.23e-04 N m. As the automatic packing leaves the thrust line, 55.4 mm off the CoG, it needs 2.41 mN m of wheel torque in the controlled descent against one wheel's 200 mN m (83 x the need). Basis: S9 Table 19-11 (disturbance rejection); capacity >= (1 + m) x need with m the rules file's actuator margin (1.0, [A]; not an ECSS rule).

PASS **ATT-3 Momentum dumping per orbit against the secular and thrust-offset momentum.** NEEDS REVIEW Assumes the x2 actuator margin [A], a CoG uncertainty of 10 mm [A], the thrust line through the CoG [A], a gravity-gradient offset of 5 deg [A], S9 Table 19-4's cyclic and secular torques [B] and magnetic momentum dumping [A]. The torquers dump 26.7 N m s per orbit in the controlled descent (300 A m2 x mean |B x Z| 15.5 uT) against 6.01 N m s collected (4.44 x the need): secular 2.44 N m s, thrust offset 3.57 N m s. As the automatic packing leaves the thrust line, 55.4 mm off the CoG, it needs 14 N m s dumped per orbit in the

controlled descent against the torquers' 26.7 N m s (1.91 x the need). Basis: §3.4 step 5 (dumping capacity D_max x mean |B x e|, an upper bound); capacity >= (1 + m) x need with m the rules file's actuator margin (1.0, [A]; not an ECSS rule).

INFO **ATT-3i Largest firing fraction the torquers sustain.** NEEDS REVIEW Assumes a CoG uncertainty of 10 mm [A] and the thrust line through the CoG [A]. Without the margin, operations: every orbit (the torquers dump 6.84 times a whole orbit's firing) against 1.00 modelled (a drag make-up orbit's arc; 0.00044 averaged over the phase); controlled descent: every orbit (the torquers dump 6.78 times a whole orbit's firing) against 1.00 modelled. The fast model's firing fraction is not recomputed. As the automatic packing leaves the thrust line, 55.4 mm off the CoG: operations: every orbit (the torquers dump 2.12 times a whole orbit's firing); controlled descent: every orbit (the torquers dump 2.10 times a whole orbit's firing). Basis: §3.4: phi_max = (h_dump - h_sec)/(T_th P), shown and never fed back; the transfer is not recomputed.

INFO **ATT-9 Actuator data.** Every configured actuator gives the momentum, torque or dipole its checks read.



Wheel momentum over three orbits: orbit-average dumping at the torquers' capacity (an upper bound); the cyclic part as a band of its quarter-orbit amplitude.

WHAT IT WOULD TAKE

- **Wheel momentum needed (with the margin): 5.21 N m s.** 2.6 N m s in the operations, on a coasting orbit, dumped once per orbit, x2
- **Wheel torque needed (with the margin): 0.00205 N m.** the gravity gradient torque 4.02e-04 N m + the thrust offset 6.23e-04 N m in the controlled descent, x2; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 0.00482 N m
- **Torquer dipole to dump each orbit (with the margin): 135 A m².** 6.01 N m s per orbit in the controlled descent over mean |B x Z| 15.5 uT x 5739 s, x2; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 314 A m2
- **Torquer dipole for torquer-only control (with the margin): 91.3 A m².** 0.00102 N m over the smallest resolved field across an axis, in the controlled descent; as the automatic packing leaves the thrust line (55.4 mm off the CoG): 215 A m2
- **Break-even residual dipole: 20.0 A m².** above 20 A m2, the top of S9's range: not limiting; as the automatic packing leaves the thrust line (55.4 mm off the CoG): none: ATT-3 does not pass with the margin even with no residual dipole
- **Break-even lateral CoG offset: 0.0599 m.** thrust line to CoG, uncertainty included (now 10 mm with the thrust line through the CoG, the CoG uncertainty; the automatic packing leaves 65.4 mm: its 55.4 mm + 10 mm)
- **Break-even firing fraction (controlled descent): 1.00.** not limiting: the checks pass with the margin up to firing on every orbit; modelled 1.00, not recomputed; as the automatic packing leaves the thrust line (55.4 mm off the CoG): none: ATT-3 does not pass with the margin at the modelled 1.00 fraction, nor without firing

VERIFICATION

Cross-checked (same model, independent code) against trimesh: 12 of 12 compared quantities agree within tolerance. Published cases the code reproduces in the test suite (method checked, not this mission's numbers): New SMAD §19 [S9] FireSat II and SCS, Tables 19-4, 19-11, 19-12 (the calculators' goldens); New SMAD §19 [S9] FireSat II end to end: Table 19-4's torques, the 0.039 N m s storage and the 0.5 A m2 torquer. Trimesh recomputes the same mass-properties primitives (a cross-check, not a verification); no reference recomputes the torques or the momentum on this mission yet.

FIDELITY AND NOT MODELLED

A Phase 0/A first-order analysis: New SMAD §19 closed forms on this mission's orbit, with NRLMSISE-00 density at the strong solar cycle's maximum F10.7 (the along-orbit peak for torque, the orbit mean for momentum per orbit) and a centred tilted dipole (the strongest field for the magnetic disturbance, the weakest for dumping). Mass properties come from the parts layout or CAD; without CAD the thrust line's offset from the CoG is the automatic packing's, so the status takes the thrust line through the CoG and the packed offset is evaluated beside it (a pass that fails as packed warns). Momentum is a worst-case envelope with all secular torques on one axis; magnetic dumping capacity is an upper bound. The results are sizing numbers with margins and break-evens, not a control simulation; every number is an estimate. The wheels hold chemical burns

unless the team says otherwise, and each firing is set against their usable momentum (a speed cap and bias when entered, one wheel's range per axis unless the set's geometry is entered). GMAT does not model attitude and is not used here. Slew (ATT-6), pointing (ATT-7) and detumble (ATT-8) come in a later release, and so does the IGRF re-fly of the field and momentum.

Not modelled: dynamics and control laws, settling, jitter, sensor noise; wheel dynamics: zero crossings and friction (a speed cap and a bias are read only for the momentum they leave usable), and the null-space management of a pyramid (its worst direction is credited); B-dot dynamics; flexible modes and propellant slosh; IGRF in the analysis: a dipole only (the re-fly comes later), the South Atlantic Anomaly, albedo and IR pressure; plume impingement, and off-pulsing's control when the team credits it (burn_hold: off_pulsing; computed only for thrusters named as an RCS); time-domain pointing (relative pointing error, stability); mass-property uncertainty beyond the CoG uncertainty; the thruster's designed position: without CAD the thrust line's offset from the CoG is the automatic packing's (evaluated beside the aligned status, never failing on its own); the roll-yaw exchange of an Earth-pointing frame (all secular torques on one axis instead); the dipole's lost authority about an axis while the field lies along it (sized on resolved minima and orbit means).

Power budget by mode

EQUIPMENT	WINDOW	P ON	P STBY	DUTY	MARGIN	OPS		TRANSFER		REBOOST		SAFE		TUMBLING	
						SUN	ECL.	SUN	ECL.	SUN	ECL.	SUN	ECL.	SUN	ECL.
Airbus Crisa EVO PCDU (Power Conditioning and Distribution Unit)	always	10.00	0.00	1.00	A/B 5 %	9.20	9.20	9.20	9.20	9.20	9.20	9.20	9.20	9.20	9.20
SSTL (Surrey Satellite Technology) SGR-Ligo GNSS receiver	always	0.50	0.00	1.00	A/B 5 %	0.50	0.50	0.50	0.50	0.50	0.50	off		off	
Other equipment	sunlit	1000.00	0.00	1.00	D 20 %	929.29	0.00	929.29	0.00	929.29	0.00	off		off	
3 × IAI (Tamam) Tamam magnetotorquer P/N 1286-0008	always	6.50	0.00	1.00	C 10 %	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50	19.50
AAC Clyde Space Sirius OBC LEON3FT (SmallSat Sirius OBC)	always	1.30	0.00	1.00	A/B 5 %	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
Satlab SRS-4	always	10.80	1.50	0.05	A/B 5 %	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96	1.96
IQ spacecom (IQ Technologies for Earth and Space) XLink-X	always	16.00	0.00	0.05	A/B 5 %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
4 × Rocket Lab RW4-12.0 reaction wheel (12.0 Nms RWA, rad-hard)	always	40.00	0.00	1.00	C 10 %	148.69	148.69	148.69	148.69	148.69	148.69	148.69	148.69	148.69	148.69
NewSpace Systems NMRM-Bn25o485 magnetometer	always	0.75	0.00	1.00	A/B 5 %	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Safran Navigation & Timing STIM300 IMU	always	1.50	0.00	1.00	A/B 5 %	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
2 × Jena-Optronik ASTRO CL star tracker	always	1.20	0.00	1.00	A/B 5 %	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
2 × Solar MEMS Technologies nanoSSOC-D60 digital sun sensor	always	0.01	0.00	1.00	A/B 5 %	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Harness I2R beyond the distribution efficiency	always	36.00	0.00	1.00	–	33.12	33.12	33.12	33.12	33.12	33.12	33.12	33.12	33.12	33.12
Electric thruster (firing)	sunlit	400.00	0.00	1.00	–	off		371.72	0.00	371.72	0.00	off		off	
Thermal's survival heaters	always	0.98	0.00	1.00	–	off		off		off		0.91	0.91	0.91	0.91
the payload loop's floor heater (running)	sunlit	381.55	0.00	1.00	–	354.58	0.00	354.58	0.00	354.58	0.00	off		off	
the payload loop's keep-warm heater (stopped)	eclipse	133.41	0.00	1.00	–	0.00	123.97	0.00	123.97	0.00	123.97	off		off	
the payload loop's keep-warm heater (stopped)	sunlit	89.65	0.00	1.00	–	off		off		off		83.31	0.00	83.31	0.00
the payload loop's keep-warm heater (stopped)	eclipse	127.28	0.00	1.00	–	off		off		off		0.00	118.28	0.00	118.28
Total w/o margins						**1503.61**	**343.72**	**1875.33**	**343.72**	**1875.33**	**343.72**	**303.46**	**338.43**	**303.46**	**338.43**
Maturity margins (per equipment)						203.60	17.74	203.60	17.74	203.60	17.74	17.72	17.72	17.72	17.72
System margin 20 %						300.72	68.74	300.72	68.74	300.72	68.74	60.69	67.69	60.69	67.69
Total with margins						**2007.93**	**430.20**	**2379.65**	**430.20**	**2379.65**	**430.20**	**381.87**	**423.83**	**381.87**	**423.83**

W: the loads the power discipline's energy balance draws in each mode (OPS, operations; TRANSFER, transfer; REBOOST, drag make-up; SAFE, safe mode; TUMBLING, tumbling after separation), duty-averaged in their window (sunlight, eclipse or all orbit) at their rail-equivalent power; "off" where the mode switches the line off. P on and P stby are per unit, as published or entered. Losses: the conversion (0.98), distribution (0.92) and battery (0.90) efficiencies are applied in the balance, not as a row; a harness I2R line, when given, is a row above. Thermal's cold-operations heaters are drawn on top, day by day (up to 0 W, as energy per orbit), not as a fixed line. Sized at end of life (EOL): the arrays' BOL power taken with temperature and ageing to end of life; the battery at 80 % of its BOL capacity [B]. The checks that judge these totals are under Subsystems at Phase 0/A.

Verification against GMAT

QUANTITY	FAST MODEL	GMAT	DIFF.	RESULT
Decay rate at the operational orbit, strong solar cycle Least-squares slope over 60 days, F10.7 = 160. Different atmosphere models (NRLMSISE-00 against MSISE-90).	13.4 m/day	10.8 m/day	+24.0% tol. ±30%	AGREES
Disposal descent propellant Lowering to 429 km.	2.27 kg	2.27 kg	+0.1% tol. ±5%	AGREES
Disposal descent time Drag helps the descent; solar inputs differ.	14.4 days	14.4 days	+0.1% tol. ±10%	AGREES
Re-entry after end of mission (Schatten nominal) Re-enters 2.82 years after the end of the mission (limit 5). The fast model's expected solar cycle is shown for reference; the solar inputs differ.	2.53 years	2.82 years	–	MET
Re-entry after end of mission (Schatten −2σ) Re-enters 3.60 years after the end of the mission (limit 5). The fast model's weak solar cycle is shown for reference; the solar inputs differ.	4.49 years	3.60 years	–	MET

Gauge under each difference: the green band is the tolerance, the amber diamond at its centre GMAT's number, the open square the fast model's, on the scale of the tolerance.

Drag, strong solar cycle

Coast 60 days at the operational altitude with constant solar activity and compare the decay rate of the mean semi-major axis (least-squares fit) with the fast model's density table (NRLMSISE-00 against GMAT's MSISE-90). The flux is the strong solar cycle's, the bound the drag make-up budget is sized with. Script: `drag_strong.script` · GMAT run time 7 s.

Re-entry (Schatten nominal)

Starting at the end of the mission, lower the orbit to 429 km, then let drag bring the satellite down, with the Schatten nominal solar-cycle prediction. The run stops at 150 km or 8 years after the end of the mission. Script: `disposal_nominal.script` · GMAT run time 107 s.

Re-entry (Schatten −2σ)

Starting at the end of the mission, lower the orbit to 429 km, then let drag bring the satellite down, with the Schatten −2σ (weak) solar-cycle prediction. The run stops at 150 km or 8 years after the end of the mission. Script: `disposal_minus2sigma.script` · GMAT run time 140 s.

Subsystem references

The subsystems' own references, kept apart from the comparisons above: none of them enters the mission verdict. “Verified for this mission” would need a reference with better physics that ran on this mission and agreed; “cross-checked” means another code ran the same model on this mission's inputs, which catches implementation errors, not modelling errors, and is not a verification.

Power. Verified for this mission against GMAT: 10 of 13 compared quantities agree within tolerance.

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
beta in the first year of operations (env) the largest difference over the first year's 14 rows (every 27 days from 15 Mar 2027), on 20 Sep 2027	-82.8 deg	-82.8 deg	+0.029 deg	+-0.5 deg in the first year of operations (§4.5): the fast model's low-precision Sun and its J2 + J4 secular node against GMAT's DE421 Sun and JGM-2 4×4 field; the node rates differ at the 1e-3 level, which grows past 0.5 deg after about a year	AGREES Verified for this mission: GMAT (env)

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
beta minimum over operations (env) GMAT's smallest beta on 09 Apr 2029, the fast model's on 09 Apr 2029, both at the run's 27-day rows; beyond the first year of operations, so shown without a tolerance	-89.8 deg	-89.9 deg	+0.10%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
beta maximum over operations (env) GMAT's largest beta on 21 Dec 2030, the fast model's on 22 Dec 2028, both at the run's 27-day rows; beyond the first year of operations, so shown without a tolerance	-59.0 deg	-59.0 deg	+0.02%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
beta in the later years of operations (env) the largest difference over the 54 later rows, on 08 Apr 2031; 1 row past the end of operations left out	-88.3 deg	-87.9 deg	-0.54%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
longest eclipse (env) GMAT: umbra 1272.4 s and penumbra 47.5 s on the eclipse starting 21 Dec 2027 01:25:49 UTC, where the cylinder gives 1303.7 s (agrees within 1252.4 to 1340.0 s); 14 whole eclipses compared, all inside, 2 touching the window's edges left out	21.7 min	21.2 min	+2.46%	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day at the longest eclipse and at the largest beta (21 Dec 2027) (env) GMAT: 16 eclipses in 1 day from 21 Dec 2027 00:00 UTC, 16 with umbra; agrees within 15 to 17	15.1 count	16.0 count	-0.945 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)
eclipse duration on the worst power-margin day (20 Dec 2031) (env) GMAT: umbra 1268.8 s and penumbra 47.7 s on the eclipse starting 20 Dec 2031 22:09:18 UTC, where the cylinder gives 1300.1 s (agrees within 1248.8 to 1336.5 s); 14 whole eclipses compared, all inside, 2 touching the window's edges left out	21.7 min	21.1 min	+2.46%	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day on the worst power-margin day (20 Dec 2031) (env) GMAT: 16 eclipses in 1 day from 20 Dec 2031 00:00 UTC, 16 with umbra; agrees within 15 to 17	15.1 count	16.0 count	-0.945 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)
eclipse duration at the smallest beta (09 Apr 2029) (env) GMAT finds no eclipse in the window; the cylinder gives 0.0 s at its middle	0 min	0 min	–	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day at the smallest beta (09 Apr 2029) (env) GMAT: 0 eclipses in 1 day from 09 Apr 2029 00:00 UTC, 0 with umbra; agrees within -1 to 1	0 count	0 count	0.000 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)
season edge where eclipses begin (02 Nov 2027) (env) days after insertion. GMAT's umbra begins at 232.26 and its penumbra at 230.53; the cylinder's edge is at 232.13; beta drifts 0.307 deg/day there	232 d	231 d	+0.738 d	+-2 days (§4.5): the shadow changes fast near the threshold. GMAT's date is the midpoint of its umbra and penumbra edges (dual cone), which lie about the Sun's angular radius in beta either side of the cylinder's	AGREES Verified for this mission: GMAT (env)

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
season edge where eclipses end (07 Feb 2028) (env) days after insertion. GMAT's umbra ends at 329.61 and its penumbra at 331.34; the cylinder's edge is at 329.68; beta drifts 0.310 deg/day there	330 d	330 d	-0.790 d	+-2 days (§4.5): the shadow changes fast near the threshold. GMAT's date is the midpoint of its umbra and penumbra edges (dual cone), which lie about the Sun's angular radius in beta either side of the cylinder's	AGREES Verified for this mission: GMAT (env)
orbit-average sun fraction (env) the largest difference over 15 orbits from 20 Dec 2031 (the worst power-margin day); mean GMAT 0.7731 against the cylinder's 0.7735	0.774	0.773	0.000	1 % of the orbit (§4.5): GMAT's dual-cone shadow against the cylinder, about 0.3 %	AGREES Verified for this mission: GMAT (env)

Thermal. Verified for this mission against GMAT: 10 of 13 compared quantities agree within tolerance. Published cases the code reproduces in the test suite (method checked, not this mission's numbers): STEM Table 3.2 (TH-STEM-1): T0, tau, loads, extreme types; STEM Table 3.3 (TH-STEM-2, -3, -4); STEM Table 2.1, all ten beta rows. Still to transcribe: SATMO against Thermal Desktop (per-face fluxes, transients); Libertad 2 single-node 3U over a year of beta. The STEM cases check the environment method (tables, albedo correction, averaging-time and extreme-type rules, T^4 balance, tau); they do not prove box-face view factors or a multi-face spacecraft. No temperature is checked for this mission.

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
beta in the first year of operations (env) the largest difference over the first year's 14 rows (every 27 days from 15 Mar 2027), on 20 Sep 2027	-82.8 deg	-82.8 deg	+0.029 deg	+-0.5 deg in the first year of operations (§4.5): the fast model's low-precision Sun and its J2 + J4 secular node against GMAT's DE421 Sun and JGM-2 4×4 field; the node rates differ at the 1e-3 level, which grows past 0.5 deg after about a year	AGREES Verified for this mission: GMAT (env)
beta minimum over operations (env) GMAT's smallest beta on 09 Apr 2029, the fast model's on 09 Apr 2029, both at the run's 27-day rows; beyond the first year of operations, so shown without a tolerance	-89.8 deg	-89.9 deg	+0.10%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
beta maximum over operations (env) GMAT's largest beta on 21 Dec 2030, the fast model's on 22 Dec 2028, both at the run's 27-day rows; beyond the first year of operations, so shown without a tolerance	-59.0 deg	-59.0 deg	+0.02%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
beta in the later years of operations (env) the largest difference over the 54 later rows, on 08 Apr 2031; 1 row past the end of operations left out	-88.3 deg	-87.9 deg	-0.54%	information, no tolerance (§4.5): beyond the first year the node rates' 1e-3 difference keeps growing	INFO Estimate
longest eclipse (env) GMAT: umbra 1272.4 s and penumbra 47.5 s on the eclipse starting 21 Dec 2027 01:25:49 UTC, where the cylinder gives 1303.7 s (agrees within 1252.4 to 1340.0 s); 14 whole eclipses compared, all inside, 2 touching the window's edges left out	21.7 min	21.2 min	+2.46%	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day at the longest eclipse and at the largest beta (21 Dec 2027) (env) GMAT: 16 eclipses in 1 day from 21 Dec 2027 00:00 UTC, 16 with umbra; agrees within 15 to 17	15.1 count	16.0 count	-0.945 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
eclipse duration on the worst power-margin day (20 Dec 2031) (env) GMAT: umbra 1268.8 s and penumbra 47.7 s on the eclipse starting 20 Dec 2031 22:09:18 UTC, where the cylinder gives 1300.1 s (agrees within 1248.8 to 1336.5 s); 14 whole eclipses compared, all inside, 2 touching the window's edges left out	21.7 min	21.1 min	+2.46%	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day on the worst power-margin day (20 Dec 2031) (env) GMAT: 16 eclipses in 1 day from 20 Dec 2031 00:00 UTC, 16 with umbra; agrees within 15 to 17	15.1 count	16.0 count	-0.945 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)
eclipse duration at the smallest beta (09 Apr 2029) (env) GMAT finds no eclipse in the window; the cylinder gives 0.0 s at its middle	0 min	0 min	–	umbra - t <= cylinder <= umbra + penumbra + t, t = max(1 %, 20 s) (§4.5): the cylinder's edge lies in the penumbra, about 8 s each side at 500 km	AGREES Verified for this mission: GMAT (env)
eclipses a day at the smallest beta (09 Apr 2029) (env) GMAT: 0 eclipses in 1 day from 09 Apr 2029 00:00 UTC, 0 with umbra; agrees within -1 to 1	0 count	0 count	0.000 count	+-1 eclipse a window (§4.5): window edges. GMAT's umbra events are the fewest and all its events, penumbra-only ones included, the most the cylinder may count: its edge lies in the penumbra	AGREES Verified for this mission: GMAT (env)
season edge where eclipses begin (02 Nov 2027) (env) days after insertion. GMAT's umbra begins at 232.26 and its penumbra at 230.53; the cylinder's edge is at 232.13; beta drifts 0.307 deg/day there	232 d	231 d	+0.738 d	+-2 days (§4.5): the shadow changes fast near the threshold. GMAT's date is the midpoint of its umbra and penumbra edges (dual cone), which lie about the Sun's angular radius in beta either side of the cylinder's	AGREES Verified for this mission: GMAT (env)
season edge where eclipses end (07 Feb 2028) (env) days after insertion. GMAT's umbra ends at 329.61 and its penumbra at 331.34; the cylinder's edge is at 329.68; beta drifts 0.310 deg/day there	330 d	330 d	-0.790 d	+-2 days (§4.5): the shadow changes fast near the threshold. GMAT's date is the midpoint of its umbra and penumbra edges (dual cone), which lie about the Sun's angular radius in beta either side of the cylinder's	AGREES Verified for this mission: GMAT (env)
orbit-average sun fraction (env) the largest difference over 15 orbits from 20 Dec 2031 (the worst power-margin day); mean GMAT 0.7731 against the cylinder's 0.7735	0.774	0.773	0.000	1 % of the orbit (§4.5): GMAT's dual-cone shadow against the cylinder, about 0.3 %	AGREES Verified for this mission: GMAT (env)

Attitude. Cross-checked (same model, independent code) against trimesh: 12 of 12 compared quantities agree within tolerance. Published cases the code reproduces in the test suite (method checked, not this mission's numbers): New SMAD §19 [S9] FireSat II and SCS, Tables 19-4, 19-11, 19-12 (the calculators' goldens); New SMAD §19 [S9] FireSat II end to end: Table 19-4's torques, the 0.039 N m s storage and the 0.5 A m2 torquer. Trimesh recomputes the same mass-properties primitives (a cross-check, not a verification); no reference recomputes the torques or the momentum on this mission yet.

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
CoG x (dry, deployed) same primitives, independent code	252.56 mm	252.56 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)
CoG y (dry, deployed) same primitives, independent code	52.82 mm	52.82 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)

QUANTITY	MISSION COMPOSER	REFERENCE	DIFF.	TOLERANCE	RESULT
CoG z (dry, deployed) same primitives, independent code	-16.70 mm	-16.70 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)
Smallest principal moment (dry, deployed) same primitives, independent code	438 kg m²	438 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)
Middle principal moment (dry, deployed) same primitives, independent code	1,269 kg m²	1,269 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)
Largest principal moment (dry, deployed) same primitives, independent code	1,652 kg m²	1,652 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (dry_deployed)
CoG x (wet, deployed) same primitives, independent code	250.93 mm	250.93 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)
CoG y (wet, deployed) same primitives, independent code	52.47 mm	52.47 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)
CoG z (wet, deployed) same primitives, independent code	-16.59 mm	-16.59 mm	0.000 mm	0.1 mm (§4.5)	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)
Smallest principal moment (wet, deployed) same primitives, independent code	439 kg m²	439 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)
Middle principal moment (wet, deployed) same primitives, independent code	1,269 kg m²	1,269 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)
Largest principal moment (wet, deployed) same primitives, independent code	1,653 kg m²	1,653 kg m²	0.00%	0.5 % of the reference (§4.5); mesh discretisation below 0.06 %	AGREES Cross-checked (same model, independent code): trimesh (wet_deployed)

Models and assumptions

TOPIC	FAST MODEL	GMAT VERIFICATION
Orbit	Near-circular, orbit-averaged; J2 nodal regression	Numerical integration (RK89), Brouwer-Lyddane mean elements
Gravity	Point mass + J2	JGM-2 4×4 during burns, J2 during multi-year coasts
Thrust	Constant thrust and Isp, tangential, off in the cylindrical Earth shadow	ElectricThruster fed by a SolarPowerSystem with dual-cone shadow
Atmosphere	NRLMSISE-00 averaged along the orbit (inclination and local time)	MSISE-90
Solar activity	expected solar cycle (F10.7 70-180): sinusoid with a 11-year period and its minimum in 2030; weak and strong bounds with the same timing	NASA Schatten predictions, nominal and −2σ, for re-entry; constant flux for the transfer (expected cycle) and the drag checks (expected and strong cycles)
Not modelled	Solar radiation pressure, third bodies, attitude constraints on thrusting, thruster start-up transients, ground-station contacts, collision avoidance manoeuvres.	

Subsystem models (Phase 0/A)

TOPIC	MODEL	INDEPENDENT REFERENCE	PER-MISSION CHECK
Power	Orbit-by-orbit energy balance sampled daily along the fast model's orbit (SMAD 3rd ed. §11.4): arrays from the vendor's beginning-of-life output with temperature, ageing, conversion and distribution factors and incidence in nadir, sun-pointing and tumbling attitudes; the battery as an energy store, its depth of discharge against a cycle-life table	None yet. The incidence closed forms, the SMAD equivalence and energy conservation are checked in the test suite; the published worked examples are still to be transcribed	The beta, eclipses and sun fraction power reads are re-flown in GMAT (the env run) with the mission's GMAT verification and labelled by it; margins, depths of discharge and sizing numbers are estimates
Thermal, steady state	One isothermal bus node with six faces and a surface node per blanket, in steady orbit-average hot and cold cases over the mission's beta range and altitudes; NASA STEM albedo and Earth IR, solar 1317-1419 W/m²; a radiator and heaters sized	NASA STEM reference cases (NASA/TM-2001-211222) reproduced in the test suite, for the environmental heat loads only, never temperatures	The beta and eclipses thermal reads are re-flown in GMAT (the env run) with the mission's GMAT verification and labelled by it; temperatures are estimates with the ±10 K margin applied; no accuracy is quoted
Attitude: momentum, dumping, thrust offset	New SMAD §19 closed forms on the mission's orbit: aerodynamic, gravity-gradient, magnetic and solar-pressure torques; wheel momentum and torque, magnetic dumping and the thrust-offset momentum against twice the need	New SMAD §19 (FireSat II and SCS) reproduced in the test suite	Mass properties cross-checked with trimesh (same model, independent code); torques and momentum are estimates. GMAT does not model attitude and is not used for it

The orbit model above still ignores solar radiation pressure and attitude constraints on thrusting, and the transfer is not recomputed for them. Their first-order checks are under Subsystems at Phase 0/A: the solar-pressure torque, the thrust-offset momentum and its dumping (ATT-3, ATT-3i) and the wheel torque against the peak disturbance and the thrust offset (ATT-2). What each discipline leaves out is listed in its section.

Assumptions, TBD and TBC

ID	KIND	ITEM	WHERE
TBD-01	TBD	Document number: The document number scheme (owner's decision).	Document control
TBD-02	TBD	Issue: How issues map to the mission's revisions (owner's decision); the revision is the mission's.	Document control
TBD-03	TBD	Prepared, checked and approved: Who prepares, checks and approves the report (owner's decision: TBD).	Document control
TBD-04	TBD	Distribution: The distribution list and the classification marking (owner's decision).	Document control
TBD-05	TBD	Attitude-control delta-v (AOCS propellant): not budgeted.	Delta-v budget
TBD-06	TBD	battery-1.power.battery_charge_max_A unknown: not published by the vendor	Power
TBD-07	TBD	eps-1.rated_power_W unknown: the part publishes only the other side of a bound	Power
TBD-08	TBD	Which finishes cover the bus faces? No face has an entered finish, and the finish moves the answer more than any other input. Until they are entered the analysis uses Mission Composer's default design, a blanketed bus with a sized radiator as Phase 0/A designs start: MLI blankets with a black outer layer (a choice, not a bound: conservative for the hot window only) on the faces without cells, the cell finish on the faces with body cells, and an AZ-93 white radiator sized on the face with the least hot flux (offered below). The bare-anodised exterior of the first release (alpha 0.422 / eps 0.765, STEM's default input) stays available: set blanket: false on a face with no finish. Or enter AZ-93 white, a black paint, silver FEP tape, or your blankets. (subsystems.thermal.faces.*.finish)	Thermal
TBD-09	TBD	Which propellant does the thruster store (Astra Astra Spacecraft Engine (ASE): "Xenon or Krypton")? T4 shows the adverse of the candidates until it is known. (propellant family)	Thermal

TBD: to be defined, no value yet. TBC: a value the analysis assumed, to be confirmed. The figures each discipline assumed are tagged in its own section ([A], [B]).

Reproducibility

SPEC SHA-256	`7e55c4ba8f57e6e8ebccdab36751338e616114050daa6b12395fbcf36ebb1a94`
INPUTS SHA-256	`6b34ae5e88912736b26a8c5fbe187e7ba52f1738f36aac121ddcb4f5a2a5c5a3`
MODELS	Fast model of Mission Composer 1.0.0; subsystem models: environment 2, massprops 1, spacecraft_rules 4, thermal None, power None, attitude None
DATA FILES	solar-flux predictions: the Schatten file bundled with GMAT R2025a, issued March 2025
GMAT	GMAT R2025a
CODE	Mission Composer 1.0.0, commit 42fd5eaf40596639457c3cac2b6ffd07a5d09c66 · source bc075d9572aa99db
SCRIPTS	`drag_strong.script` (Drag, strong solar cycle); `disposal_nominal.script` (Re-entry (Schatten nominal)); `disposal_minus2sigma.script` (Re-entry (Schatten −2σ))

The revision's evidence package, gmat.zip (the mission page's Download menu, Evidence package), holds the spec, the analysis, every GMAT script with what GMAT wrote, the report and a README on running each script again.

Inputs

```
name: Orbital data center, 1 kW GPU asleep in eclipse, dawn-dusk SSO 550 km
insertion_epoch_utc: '2027-03-15T00:00:00'
spacecraft:
  dry_mass_kg: 461.41
  propellant_kg: 3.0
  drag_area_m2: 1.11
  drag_coefficient: 2.2
  reflectivity_cr: 1.3
propulsion:
  kind: electric
  thrust_mN: 25.0
  isp_s: 1400.0
  input_power_W: 400.0
  duty_cycle: 1.0
  fires_in_eclipse: false
power:
  available_for_propulsion_W: 635.9
insertion_orbit:
  altitude_km: 550.0
  sun_synchronous: true
  ltan_hours: 6.0
operational_orbit:
  altitude_km: 550.0
  sun_synchronous: true
operations:
  duration_years: 5.0
  maintain_altitude: true
disposal:
  rule: fcc_5yr
  max_years_after_end_of_mission: 5.0
  design_margin_years: 0.5
constraints:
  max_transfer_days: 60.0
  propellant_margin_fraction: 0.1
notes: 'Orbital data center, the headline of tests_cloud/test_compute_sat.py. Payload:
  a GPU load of 1000 W and 20 kg, assumed (no module datasheet), on in sunlight only,
  asleep in eclipse (4.85 % of operations time lost, 5.40 % at i_SSO + 0.05 deg),
  off in safe mode, full load whenever on, on the raw bus (supply bus); its 0 to 45
  C interface is assumed, not a datasheet''s. Dawn-dusk SSO 550 km (06:00) from 2027-03-15,
  held five years, flown nadir; FCC 5-year rule. Body 1000 x 700 x 1100 mm. Astra
  ASE on xenon (400 W, ~25 mN, ~1400 s; data sheet 2023-01-13): its 7.6 kg includes
  the tank (Table 9), so the generic tank is removed; 3.0 kg of xenon, 0.36 kg to
  spare. Heat to the bus 4 W (Table 8 target) plus the PPU''s 20 W from its 0.95.
  Wings: two fixed 5.0 m2 off +Y (PWR-1 15.0 %, 11.9 % at i_SSO + 0.05 deg; PWR-4
  a plain pass, 16.1 %); the descent is flown pitched 180 deg so +Y stays lit. Nine
  B28-135 (1215 Wh, 22 V minimum entered): worst DOD 18.4 % margined against the placeholder
  table''s 41.5 % (its 0.7 adverse end 29 %). PCDU: an Airbus Crisa EVO with four
  APR MPPT GaN cards, 3 + 1 (datasheet 0261_24_1, M+1: three credited, 3 x 3 x 20
  A, 3.96 kW at the packs'' 22 V; > 98 %, entered as the conversion efficiency 0.98,
  its minimum; with the bus''s 0.99 that is 0.970, above the page''s unit figure,
  96 %, tied to no card type); the wings'' VOC <= 110 V unchecked; 19.69 kg [A] and
  idle 10 W [A], unpublished. Four RW4-12.0 at 54.74 deg; three Tamam 1286-0008 rods
  (300 A m2); residual dipole 7.4 A m2; as packed the thrust line is 55 mm off the
  CoG (to be aimed through it [A]). Radiators AZ-93, at end of life + 0.04 (the owner''s
  sourced margin of 2026-10-16, 5 years in LEO with contamination; MISSE measured
  0 to 0.01: NASA/TP-2013-217498). Gino''s decisions of 2026-10-17: (1) the GPU on
  a 4.00 m2 two-sided deployable radiator coplanar with -Y (the least that holds it
  at end of life is 3.93 m2; it needs 3.921 m2; at 4.00 m2 no check fails with the
  harness drawn); (2) the harness''s I2R, 36 W [A] (2 % of some 65 A on 28 V): thermal
  counts it as bus heat and power draws it; (3) link conductances with no source stay
  assumptions with no source [A], each with a visible warning until data exists: the
  loop''s G = 100 W/K is the owner''s allocation, a requirement on the loop supplier
  (G >= 95.4 W/K), its G_off 1 W/K (Q-Rad''s hinge as a comparable) <= 1 W/K. Loop:
  propylene (-185.2 C, NIST); 39.2 kg [A] (Q-Rad''s 4.9 kg/m2 per planform, twice).
  Bus: -Y''s radiator needs 0.924 m2, more than its 80 % rule allows (0.88 m2): a
  bus panel coplanar with -Y, AZ-93, on a switched link (G 100 W/K, break-even 0.40
  W/K; G_off 1 W/K; both the team''s allocations, no source [A]), 0.14 m2 (the owner''s
  choice among Q-F''s sizes), needing 0.032 m2 for 16.4 W, 54 W to spare, 1.37 kg
  [A]; its coupled leak 23 W in C1 and 28 W in C2, no bus heater. Thermal closes with
  conditions; power closes with conditions; attitude closes. Conditions, each a warn
  tests_cloud/test_compute_sat.py allows with its reason (T2, T3 and T7 added with
  the owner''s approval in chat, 2026-10-15, and PWR-10 on 2026-10-21; T1 and T3 back
  with the closure, pending the owner''s approval; PWR-5 by Gino''s decision (2)):
  PWR-10, the EVO''s ''Up to 4 kW @ 28 V'' an upper bound, no unit rating, the arrays''
  3.59 kW peak (BOL) within it; PWR-5, the harness drawn, 63 of 1827 days host no
  thrusting orbit (11 to 31 Dec 2030, 01 Dec 2031 to 11 Jan 2032); T1, the loop panel
```

```
  0.08 m2 above its end-of-life edge (a further 0.0042 in alpha), the wheels'' 176
  W on one node, both links'' G allocations; T2, the loop''s heaters in C1 (382 W
  on the running plate, 133 W keep-warm in eclipse; 371 W of the power for propulsion;
  at i_SSO + 0.05 deg they exceed the array; the restart needs the loop''s flow regulated);
  T3, the packs'' own heaters; T4, xenon two-phase below 16.59 C in C2; T7, the keep-warm
  in safe mode (90 W sunlit, 127 W in eclipse). Demoted: none. Needs review: PWR-1,
  2, 3, 4, 7, 8 and ATT-1, 2, 3. Not assessed: comms, radiation.'
```

Subsystems

```
subsystems:
  version: 1
  attitude:
    ops_mode: nadir
    residual_dipole_Am2: 7.4
    wheel_tilt_deg: 54.74
  power:
    conversion_efficiency: 0.98
    harness_loss_W: 36.0
  thermal:
    radiator:
      face: -Y
    thruster_heat_to_bus_W: 4.0
    loop:
      units:
      - load-1
      radiator: radiator-1
      conductance_W_K: 100.0
      off_conductance_W_K: 1.0
      finish:
        part: az-technology-az-93
      fluid_freeze_C: -185.2
      fluid_source: 'NIST WebBook, propene: Tfus 88.0 K (Streng, 1971), Ttriple 87.8
        +- 0.8 K'
      note: 'G and G_off are the team''s allocations, assumptions [A] with no source
        (Gino, 2026-10-17): requirements on the loop supplier; G_off the Q-Rad hinge''s
        1 W/K as a comparable'
    bus_panel:
      radiator: radiator-2
      link: switched
      conductance_W_K: 100.0
      off_conductance_W_K: 1.0
      finish:
        part: az-technology-az-93
      note: G and G_off are the team's allocations, requirements on the link supplier
        (G_off the Q-Rad hinge's 1 W/K as a comparable)
```

Mission Composer 1.0.0 · GMAT R2025a. This report is an engineering estimate for mission planning. It is not a certification, a regulatory determination or a licence application, and it does not replace review by a qualified engineer or by the licensing authority.

Spec SHA-256 7e55c4ba8f57e6e8ebccdab36751338e616114050daa6b12395fbcf36ebb1a94 (the mission's YAML as stored). The Inputs above are the part of it the analysis reads; their SHA-256 is 6b34ae5e88912736b26a8c5fbe187e7ba52f1738f36aac121ddcb4f5a2a5c5a3. Built by Mission Composer 1.0.0, commit 42fd5eaf40596639457c3cac2b6ffd07a5d09c66 · source bc075d9572aa99db.

Results come from Mission Composer's analytic model and from GMAT runs of scripts that Mission Composer generated from the inputs above, and both can be reproduced from them. They are only as good as those inputs, the models listed under Models and assumptions and the data files used (solar-flux predictions: the Schatten file bundled with GMAT R2025a, issued March 2025).

“Verified in GMAT” means the two results agree within the stated tolerance, or GMAT meets the requirement on its own; it is not independent validation. Parts of the specification may have been changed by the AI analyst at a user's request; every change is a recorded revision.

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