Kendra

SPACE MISSION ENGINEERING

USER MANUAL

Beta v1.0.4

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About this manual

This manual is your complete guide to using Kendra — AVRTEC's space-mission engineering tool. Kendra helps you design a small satellite mission end-to-end, from the orbit you fly in to the subsystems on board, the propellant you carry, and the cost of the programme. Every panel in the application is documented here in the same order it appears on screen.

The manual is split into three modules:

- Module I — Mission Design Analysis (the orbit, mass and cost picture).
- Module II — Subsystems (payload, comms, power, thermal, ADCS, propulsion).
- Module III — Outputs, simulation and export.

Each chapter begins with a short purpose statement, a glossary of the technical terms used on that panel, and a clear step-by-step instruction set. At the end of the manual you will find a worked example — AVRTEC-1, a 12U CubeSat — that walks you through every panel with realistic numbers.

Although the example is a 12U CubeSat, the same workflow applies to any spacecraft size. For a larger small-satellite (~50–500 kg ESPA-class) you simply enter larger payload, mass and power values. For PocketQubes (under 1 kg), use the AVRTEC-1-P preset as a starting point. The buttons, sliders, and outputs are identical.

Tip: Wherever you see a small ⓘ icon next to a label or output, you can click it to open a glossary popup. The popup appears at the bottom of the screen and explains the term in plain English. Click anywhere else, or press Esc, to dismiss it.

Chapter 1 — Getting started

What Kendra is, what you see on screen when you open it, and how to start your first mission. Read this before anything else.

1.1 What Kendra does

Kendra is a guided space mission engineering tool. You pick an orbit and a payload, and Kendra sizes every subsystem and computes the classic mission technical budgets — mass, power, ΔV (delta-V), RF link, data and pointing — live as you edit. The physics runs in a Python back-end and all of the formulas are based on accepted space mission analysis methodology.

1.2 Opening Kendra

1. Open your web browser.
2. Go to https://kendra.avrtec.space.
3. Wait for the launch page to appear. The page shows the AVRTEC arc, the word Kendra, and a 'Deploy' button.
4. Click Deploy. The mission design console opens with a reference mission already loaded.

> **Tip:** If you have not visited Kendra recently, the first request may take 20–30 seconds while the back-end wakes up. After that it is instant.

1.3 The workspace at a glance

The Kendra workspace is split into three vertical regions plus a top header bar.

Term	What it means
Header bar	Across the top: Kendra brand mark, the preset / new-mission selector, the mission name and central body, the Simulation button, the Excel export button and the theme switch.
Left side panel	The subsystem navigator. It is grouped in two sections — Mission Design (Orbit & Mission, Mass & Launch, Cost) and Subsystems (Payload, Comms/Link, Power, Thermal, ADCS, ΔV & Propulsion). Click any item to open its panel in the centre.
Centre panel	The active subsystem panel. Every panel has three labelled sections: INPUTS (sliders, numbers, switches), OUTPUTS (the computed metric cards) and DIAGRAMS (the charts).
Right side pane	The always-on technical budgets — Mass, Power, ΔV, Link, Data, Pointing — that update live as you change inputs.

1.4 Choosing how to start

Click the preset selector in the header. You have three options:

Term	What it means
New mission (from scratch)	Loads a complete editable starter mission with neutral defaults. Use this when you want to design your own mission and not be biased by an example.
AVRTEC-1-C · 12U CubeSat	Realistic 12U CubeSat in a sun-synchronous orbit. The reference design used in Chapter 14.
AVRTEC-1-P · 3P PocketQube	Realistic 3P PocketQube design with no propulsion. Useful for very small satellite trade studies.

Tip: A 'preset' is just a starting point — every field is still editable. Loading a preset never locks anything in.

1.5 Setting the mission name and central body

5. Click the mission-name text box in the header.
6. Type a memorable name for the mission, for example 'AVRTEC-1'.
7. Click the central-body dropdown to the right of the name.
8. Pick the body you want to orbit around. Earth is the default. Other options include Moon, Mars, Venus, Mercury, Jupiter and Sun.

Tip: Multi-body support primarily covers ORBITAL MECHANICS (period, velocity, geometry, J2 for that body). The power, thermal, atmospheric-drag/lifetime and disposal models are CALIBRATED FOR EARTH (Earth albedo and IR, Earth's atmospheric-density table, Earth/ESA-FCC-IADC disposal rules). Do not rely on those subsystem results unchanged for the Moon, Mars or other bodies.

1.6 The Simulation, Excel and Theme buttons

- 🛰 Simulation — opens a 3D view of the satellite orbiting the central body. See Chapter 12.
- ⭳ Excel — exports the full analysis to a multi-tab Excel workbook. See Chapter 13.
- Theme switch — three buttons for Dark, System and Light themes. Pick whichever you find most readable.

1.7 Reading the live status

The summary chips on the right of the header show key budget values that the right pane computes: launch mass, average power, total ΔV, link margin, ground resolution, programme cost. Each chip turns green, amber, or red depending on whether its budget closes. A small spinner appears while Kendra re-computes after you edit anything; the recompute is debounced and typically finishes in well under a second.

MODULE I

Mission Design Analysis — orbit, mass, cost

Chapter 2 — Orbit & Mission

The orbit drives almost every other subsystem: coverage geometry, eclipse fraction, link slant range, ΔV cost, even the lifetime. Set the orbit first.

2.1 Glossary

Term	What it means
Altitude	Mean height above the central body's surface, in km. Orbit radius = body radius + altitude.
Eccentricity	How non-circular the orbit is. 0 is a perfect circle. 0.1 is mildly elliptical. Leave at 0 unless you have a specific reason.
Inclination	Tilt of the orbit plane vs. the body's equator, in degrees. 0° = equatorial, 90° = polar, 97–98° = sun-synchronous around Earth.
RAAN	Right Ascension of the Ascending Node — the longitude in inertial space where the orbit crosses the equator going north. Sets the orbit's orientation.
Min elevation	Lowest angle a ground station accepts the satellite at, in degrees. 5° is the standard default; raising it shortens passes but improves link quality.
Design life	How many years the mission is expected to operate. Drives station-keeping ΔV and array degradation.
Hohmann transfer	A two-burn manoeuvre that moves a satellite between two circular orbits via an elliptical transfer.
Target altitude	The new circular altitude after a Hohmann transfer. Only used if you enable the transfer.
Plane change Δi	Change in orbit inclination (deg). If combined with a Hohmann transfer, the cheaper combined burn at apogee is used automatically.

2.2 Step-by-step

9. Click 'Orbit & Mission' under MISSION DESIGN in the left sidebar.
10. Drag the 'Altitude' slider to your operational altitude. For Earth LEO smallsats, 400–800 km is typical.
11. Drag the 'Inclination' slider to your orbit tilt. For a sun-synchronous orbit, Kendra will tell you 'Sun-synchronous: Yes' in the OUTPUTS section once you are close enough.
12. Set 'Eccentricity'. Leave at 0 for a circular orbit (the most common case).
13. Set 'Min elevation'. Keep 5° unless you know your station requires more.
14. Drag 'Design life' to the number of years the mission must operate.
15. Optional — Enable Hohmann transfer:
    - Click the 'Hohmann transfer' switch. A new 'Target altitude' slider appears.
    - Drag the target altitude to the altitude you want to transfer to.

16. Optional — set 'Plane change Δi' if you also need to tilt the orbit. Leave at 0 if no plane change is required.

2.3 Understanding the outputs

- Semi-major axis — orbit radius in km.
- Period — how long one orbit takes, in minutes.
- Orbital velocity — speed of the spacecraft in km/s.
- Ground-track speed — speed of the sub-satellite point on the ground.
- Revs/day — how many orbits per day; the hint tells you if the ground track repeats.
- Nodal regression — the J2-driven rotation of the orbit plane (deg/day).
- Max slant range — the longest line-of-sight distance from your ground station to the spacecraft at the chosen minimum elevation.
- Ground visibility footprint — the diameter of the ground access circle within which the satellite is visible above the minimum elevation angle ($2 \cdot \lambda \cdot R$). This is ground-station visibility geometry, not an imaging-sensor swath.
- Earth central angle — the half-angle covered from the satellite.
- Max eclipse — worst-case eclipse duration in minutes.
- Sun-synchronous — Yes/No, and the required inclination at this altitude.
- Hohmann ΔV (when transfer enabled) — total cost of the two burns.
- Transfer time — half-period of the transfer ellipse.
- Plane change ΔV — extra cost of the inclination change.
- Ground Track diagram — the path of the sub-satellite point over 3 orbits. Drawn from a FIXED default orientation (RAAN = 0 and the epoch at the ascending node); it is illustrative of the track SHAPE and is not anchored to a specific launch date or local time.
- Coverage vs. Altitude chart — how the Earth central angle scales.

> **Tip:** The Ground Track and the yearly β-angle / eclipse charts use a fixed default orbit orientation (RAAN = 0, epoch at the ascending node). A uniquely-anchored ground track or annual β-angle history needs the epoch, RAAN/LTAN and (for eccentric orbits) the argument of perigee and initial anomaly — these are not yet user inputs, so treat both charts as illustrative of shape and trend, not date-specific.

2.4 Tips and common pitfalls

- If you want sun-synchronous, set the altitude first, then adjust the inclination until 'Sun-synchronous: Yes' appears.
- Below ~300 km Earth orbit, drag dominates and station-keeping ΔV becomes huge. Kendra's Propulsion panel will warn you.
- Hohmann transfers are only useful between circular orbits. If you use a non-zero eccentricity, treat the Hohmann ΔV as a rough first estimate.
- Unless stated otherwise, Kendra's orbit, coverage, eclipse, slant-range and ground-track-speed outputs assume a circular or near-circular orbit (semi-major axis $a = R +$ altitude). Only the nodal regression and the sun-synchronous check use the eccentricity term, so for an appreciably eccentric orbit treat those geometry and eclipse numbers as first-order.

- A plane change is one of the most expensive things you can do in space. If you have a choice, do the plane change at the highest altitude (combined with a Hohmann transfer apogee burn) — Kendra does this automatically when both are enabled.

Chapter 3 — Mass & Launch

Every subsystem has a mass, and every space mission has a launch vehicle. This panel rolls up the mass budget, adds contingencies, and checks the launch capacity.

3.1 Glossary

Term	What it means
Base mass	Your estimate of the dry mass of one subsystem, in kg.
Contingency	Growth allowance per subsystem, as a percentage. Accounts for normal mass growth during design — 10–20 % is typical.
Subtotal	Base mass × (1 + contingency). This is what the row actually contributes to the dry mass.
Σ Sum of subtotals	The sum of every subsystem subtotal plus the payload (which always gets a fixed 5 % contingency from the Payload panel).
System margin	Top-level dry-mass margin applied to the sum of subtotals. Covers late additions and unknown unknowns. 15 % is a common default.
Dry mass (allocated)	Sum of subtotals × (1 + system margin). This is the dry mass the rocket equation uses.
Propellant	Propellant mass needed for the total ΔV (computed in the Propulsion panel).
Wet mass	Dry mass + propellant. The spacecraft mass at launch.
Deployer / adapter	The hardware that releases the spacecraft from the launch vehicle. Adds to launch mass but is not part of the spacecraft.
Launch mass	Wet mass + deployer. What the launch vehicle has to lift.
Launch vehicle	The rocket. Selecting one tells Kendra the capacity to compare against.

3.2 Step-by-step

17. Click 'Mass & Launch' under MISSION DESIGN.
18. Read the 'Bus subsystem masses' table. Each row is one bus subsystem. Payload is added automatically as a read-only top row.
19. For each subsystem, click in the 'Base mass (kg)' cell and enter your best estimate.
20. Enter the 'Contingency (%)' for each row. New designs typically use 15–20 %; mature units 5–10 %.
21. The 'Subtotal (kg)' column updates automatically; no input needed.
22. Click '+ Add subsystem' if you need a new row.
23. Click the ✕ button to remove a row you do not need.
24. Drag the 'System margin' slider to choose the top-level dry-mass margin (0–50 %). 15 % is a typical first-pass value.

25. Enter the 'Deployer / adapter (kg)' mass. For a 12U CubeSat it is around 1.1 kg; for ESPA-class it can be 5–10 kg.
26. Pick the 'Launch vehicle' from the drop-down. Choose the one that matches your mission orbit (rideshare options are tagged with their target orbits).

3.3 Understanding the outputs

- Dry mass (base) — the sum of base masses with no margin.
- With contingency — sum of subtotals.
- System margin — the % you chose.
- Dry mass (allocated) — the figure used by every other panel.
- Propellant — from the Propulsion panel.
- Wet mass — dry + propellant.
- Launch mass — wet + deployer.
- LV capacity — green if your launch mass fits the chosen vehicle's rideshare allocation, red if it exceeds.
- Dry-Mass Breakdown bar chart — visual comparison of every row.
- Launch Mass Composition bar chart — dry vs. propellant vs. adapter.

Tip: Every change to the Payload panel's 'Payload mass' value updates the payload row in this panel instantly. You can change payload mass on either panel — it is the same number.

Chapter 4 — Cost (ROM)

A rough-order-of-magnitude estimate of the programme cost. This is a first-order trade study tool — not a contract budget. Calibrate the complexity factor against your own builds for a tighter number.

4.1 Glossary

Term	What it means
Fiscal year	Year for inflation. The model converts dry mass × complexity into US dollars in this year.
Quantity	How many identical spacecraft you are building.
Complexity factor	Multiplier you can tune to match the model to known builds. Lower for student/CubeSat scale; higher for novel or radiation-hardened hardware. Typical range 0.5–2.5 (CubeSats ≈ 0.7–1.0; complex SAR or interplanetary ≈ 1.5–2.0).
Learning curve	Per-unit cost reduction when building multiple identical spacecraft. 0.85 means each doubling of quantity costs 85 % of the previous unit.

4.2 Step-by-step

27. Click 'Cost (ROM)' under MISSION DESIGN.
28. Enter the 'Fiscal year' for the estimate.
29. Set 'Quantity' to the number of spacecraft.
30. Drag the 'Complexity' slider. Start at 1.0 and adjust to match a known build you can compare against.
31. Drag the 'Learning curve' slider (only matters when quantity > 1).

4.3 Understanding the outputs

- Programme cost — total cost in millions of US dollars.
- Cost per unit — average per-spacecraft cost.
- Quantity-cost chart — how total cost scales with quantity, considering the learning curve.

> **Tip:** For a rigorous, defendable budget, use a bottoms-up parametric cost model. Kendra's ROM is a study tool and gives an order-of-magnitude figure only.

MODULE II

Subsystems — payload, comms, power, thermal, ADCS, propulsion

Chapter 5 — Payload

What the satellite is built to do. The payload's aperture, wavelength and power drive the ground resolution, the data rate, the power load, and ultimately the mission's purpose.

5.1 Glossary

Term	What it means
Type	Family of instrument. Options: Optical (visible), Infrared, Synthetic Aperture Radar (SAR), Communications.
Aperture	Diameter of the optical or RF collector, in metres. Drives the diffraction-limited resolution.
Wavelength	Operating wavelength of the instrument, in micrometres (µm).
Quantum efficiency	Fraction of incoming photons converted to signal. Cameras: 0.4–0.8 typical. Captured for documentation; it does not yet feed Kendra's diffraction-resolution or data-volume model (those depend on aperture, wavelength, altitude and rate).
Power	Electrical power consumed by the payload, in watts. This is also used by the Power panel as the 'payload load'.
Payload mass	Dry mass of the instrument, in kg. Flows into the Mass panel automatically.
Data rate	Raw data produced by the instrument while imaging, in megabits per second.
Duty cycle	Fraction of the orbit the instrument is actually collecting data. 1–10 % over land is typical for an Earth-observation mission.

5.2 Step-by-step

32. Click 'Payload' under SUBSYSTEMS in the left sidebar.
33. Pick 'Type' from the dropdown. Most demonstrator missions are Optical (visible).
34. Drag 'Aperture' to your instrument's collector diameter.
35. Enter the 'Wavelength' in µm. Visible imagers typically work at 0.5 µm.
36. Drag 'Power' to your instrument's electrical load. Use the data sheet of a comparable instrument as a guide.
37. Enter 'Payload mass' for the instrument.
38. Drag 'Data rate' to your raw downlink rate when the instrument is active.
39. Drag 'Duty cycle' to the fraction of the orbit you actually collect data — usually a small number.

5.3 Understanding the outputs

- Diffraction angle — theoretical resolving angle (in microradians).
- Ground resolution at nadir — the diffraction-limited (best-case) ground resolution looking straight down. Real ground sample distance is coarser (detector pitch, MTF, motion smear, atmosphere).

- Average data per orbit — depending on duty cycle.
- Generated data per day — total payload data volume generated per day. The on-board storage you actually need depends on the longest gap between successful downlinks, which Kendra does not model.
- Resolution vs. altitude chart — how the ground resolution scales with altitude.

Chapter 6 — Communications / Link

Every byte you record has to be downlinked. This panel builds the link budget for one or more RF links, typically a TT&C housekeeping channel plus one or more payload downlinks. Each link is analysed as a SPACE-TO-GROUND (downlink) budget; the command uplink (ground-to-space) is not modelled and must be budgeted separately for a complete TT&C design.

6.1 Glossary

Term	What it means
Link	One RF connection between the spacecraft and a ground station.
Role	Either 'TT&C' for housekeeping/command, or 'Payload' for the science downlink.
Band	UHF, S-band, X-band, Ka-band, etc. Affects antenna size and propagation.
Downlink frequency	Carrier frequency, in GHz.
Downlink rate	Information (user) data rate during a pass, in Mbps. The coding_overhead below accounts for channel coding.
TX power	Spacecraft transmitter output power, in watts.
S/C antenna	Spacecraft antenna diameter (metres). Used to compute gain unless an explicit gain is provided.
Ground station antenna	Ground antenna diameter (metres).
EIRP	Effective Isotropic Radiated Power: TX power × antenna gain × line loss. Higher EIRP = stronger signal.
G/T	Ground-station antenna gain divided by system noise temperature. The figure of merit for a receive station; bigger is better.
E_b/N_0	Bit-energy to noise-spectral-density ratio. The fundamental link quality metric — must exceed the modulation's required E_b/N_0 + margin to close.
Modulation	How bits are encoded on the carrier (BPSK, QPSK, etc.).
Required margin	Reserve above the modulation's minimum E_b/N_0 to cover unpredictable losses. 3 dB for payload, 6 dB for TT&C is conservative.
Passes per day	Average number of useful overflights of the ground station per day.
Contact min	Average minutes of contact per pass.

6.2 Step-by-step

40. Click 'Comms / Link' under SUBSYSTEMS.
41. Each existing link is a card. Click '+ Add link' to create a new one. Click the ✕ to remove a link.

42. For each link, set the basics first:
    - Name — a label you will recognise (e.g. 'TT&C', 'Payload S-band').
    - Role — TT&C or Payload.
    - Band — UHF, S-band, X-band, etc.
43. Enter the radio-frequency parameters:
    - Downlink frequency (GHz) — must lie inside the selected band.
    - Downlink rate (Mbps) — the information (user) data rate during a pass.
    - TX power (W) — your transmitter output.
44. Configure the spacecraft side:
    - Antenna type — patch, whip, parabolic, etc.
    - S/C antenna diameter (m).
    - S/C antenna gain (dBi) — optional override.
45. Configure the ground station side:
    - GS antenna diameter (m).
    - GS antenna gain — optional override; otherwise computed.
    - System noise temperature (K).
46. Pick the 'Modulation' from the dropdown.
47. Set 'Required margin' (dB).
48. Set 'Passes per day' and 'Contact min' from your station's geometry.
49. Repeat for every link you need.

6.3 Understanding the outputs

- For each link: frequency, EIRP, E_b/N_0, margin.
- Margin status — green if the link closes with at least the required margin, amber if marginal, red if it does not close.
- Link Margin by Link chart — at-a-glance comparison.
- Budget Breakdown waterfall for the worst link — shows where the dB go (EIRP, space loss, atmos+pointing, G/T, kB·R, margin).
- Margin vs. Range chart — shows how the margin degrades with slant range.
- Margin @ target (only when Hohmann is enabled) — the same link budget run again at the post-transfer altitude. Useful to check the link still closes after a Hohmann transfer.

> **Tip:** If a link is amber or red, the most effective fixes are: more TX power, a larger spacecraft antenna, a larger ground antenna, or a lower data rate.

Chapter 7 — Power (EPS)

Sizes the solar array and battery from the orbit's eclipse / sunlight split. Driven by the payload load (from Chapter 5) and the bus load you set here.

7.1 Glossary

Term	What it means
Solar cell	Cell technology. Multi-junction triple-junction is the smallsat workhorse (~29 % efficient).
Battery	Battery chemistry. Li-ion is standard. NiH2 is legacy high-DoD.
Bus load	Continuous electrical load of everything that is not the payload (avionics, ADCS, comms, thermal), in watts.
Solar panels	Number of independent solar panels/wings on the spacecraft.
Cell packing	Fraction of total panel area covered by active cells (rest is gaps and frame). 80–90 % is typical.
Sun pointing	Average solar incidence efficiency, accounting for cosine loss when the array is not perfectly tracking the Sun.
Battery DoD	Depth of Discharge — fraction of battery capacity actually used per cycle. Lower DoD = longer battery life. Li-ion smallsat batteries: 30–50 %.
Battery strings	Number of parallel cell strings.
Battery efficiency	Round-trip charge / discharge efficiency. Typically 90 %.
Design reserve	Extra solar-array sizing margin (10–25 %) on top of the required power.

7.2 Step-by-step

50. Click 'Power (EPS)' under SUBSYSTEMS.
51. Pick 'Solar cell' (Multi-junction triple is the default).
52. Pick 'Battery' (Li-ion is the default).
53. Drag 'Bus load' to your continuous bus electrical load in watts.
54. Set the solar array design:
    - Drag 'Solar panels' to the number of panels/wings.
    - Drag 'Cell packing' for the active fraction of panel area.
    - Drag 'Sun pointing' for the cosine-loss efficiency.
55. Set the battery design:
    - Drag 'Battery DoD' for the depth of discharge.
    - Drag 'Battery strings' for the number of parallel strings.
    - Drag 'Battery round-trip eff.' for the charge/discharge efficiency.

56. Drag 'Design reserve' for the array sizing margin.

7.3 Understanding the outputs

- Total load — payload + bus.
- Eclipse / Daylight duration — for the worst-case orbit.
- Array power (EOL) — end-of-life array power needed, in W.
- Total panel area — m^2 of panel surface required.
- Area per panel — divided by the number of panels.
- Active cell area — usable cell surface (panel × packing).
- Array EOL output — W per m^2 after degradation.
- Battery capacity — total Wh needed.
- Capacity per string — divided by the number of strings.
- Battery mass and array mass — first-cut estimates.
- Eclipse-over-the-year chart — eclipse minutes per orbit through all β-angle conditions. If Hohmann is on, the target altitude curve is also shown.
- Beta-angle chart — β-angle vs. day of year.
- Power balance — payload vs. bus vs. array bar chart.

> **Tip:** Kendra sizes the array AREA required to meet the load; the 'number of panels' input only splits that required area across panels — it does not add power. To close a power gap, raise cell efficiency, accept more total array area, improve array pointing (e.g. a one-axis solar-array drive), or reduce the load.

Chapter 8 — Thermal

Balances absorbed heat (solar + albedo + Earth IR + internal) against the heat radiated from the spacecraft's total external surface to give a first-cut equilibrium temperature, and separately sizes the dedicated radiator's heat-rejection capacity.

8.1 Glossary

Term	What it means
Absorptivity (α)	Fraction of incident solar power the surface absorbs. Lower α stays cooler.
Emissivity (ε)	Fraction of black-body IR power the surface radiates. Higher ε sheds heat better.
Internal load	Dissipation inside the spacecraft, in watts. Usually similar to the bus + payload electrical load.
Radiator area	Area of the dedicated radiator facing deep space, in m^2. It sizes how much internal heat can be rejected at the allowable temperature (the heat-rejection-margin check); it does NOT set the bulk equilibrium temperature, which is governed by the total radiating surface area.
Surface area	Total external area of the spacecraft, in m^2.
Projected area	Area presented to the Sun at any instant, in m^2.

8.2 Step-by-step

57. Click 'Thermal' under SUBSYSTEMS.
58. Drag 'Absorptivity α' to the value for your outer-surface material. White paint ~0.2; black anodise ~0.95.
59. Drag 'Emissivity ε'. White paint ~0.85; bare aluminium ~0.05.
60. Drag 'Internal load' to the total internal dissipation in watts.
61. Drag 'Radiator area' to the surface you have available for heat rejection.

8.3 Understanding the outputs

- Hot-case / cold-case equilibrium temperature — first-cut steady-state temperatures for an isothermal node radiating from the total surface area.
- Radiator capacity — heat the dedicated radiator can reject at the allowable temperature, in W.
- Heat-rejection margin — radiator capacity minus the internal dissipation it must reject (the lever the radiator-area input controls).
- Radiated power vs. temperature chart ($\varepsilon\sigma AT^4$).
- Equilibrium temperature vs. α/ε chart — sensitivity to surface choice.

> **Tip:** Real-world thermal design uses a node-by-node analysis. Kendra's model is a single-node estimator — useful for first-pass trade studies, not for the final flight design.

Chapter 9 — ADCS / Pointing

Attitude Determination and Control: how the spacecraft knows where it is pointing and how it changes that. The panel lets you stack arbitrary sensors and actuators.

9.1 Glossary

Term	What it means
Pointing requirement	Maximum angular error the payload tolerates, in degrees.
Control type	Architecture choice: 3-axis (reaction wheels), Spin-stabilised, Gravity-gradient, or Magnetic.
S/C dimension	Characteristic size of the spacecraft body, in metres.
Residual dipole	Magnetic dipole moment left in the spacecraft structure ($A \cdot m^2$).
CP-CG offset	Distance between centre of pressure and centre of gravity. Aero-drag torque scales with this.
Slew rate	Angular speed at which the satellite can re-point, in deg/s.
Sensors	Star tracker, sun sensor, magnetometer, IMU. (A GPS receiver may also be listed, but it provides position/time, not attitude, so it does not contribute to the pointing-knowledge budget.)
Actuators	Reaction wheel, magnetorquer, control moment gyroscope, thruster.
Pointing budget	Root-sum-square of all error contributors (alignment, sensor noise, control jitter).

9.2 Step-by-step

62. Click 'ADCS / Pointing' under SUBSYSTEMS.
63. Set 'Pointing requirement' to the tightest angular error your payload tolerates.
64. Pick 'Control type' from the dropdown.
65. Enter the geometry inputs: 'S/C dimension', 'Residual dipole', 'CP-CG offset', 'Slew rate'.
66. Manage the sensors and actuators list:
    - Click '+ Add unit' to add a new sensor or actuator.
    - Use the 'Kind' dropdown to pick from the library (Star tracker, Sun sensor, Magnetometer, IMU, Reaction wheel, Magnetorquer, etc.).
    - Set 'Count' if you have multiple of the same kind.
    - Click ✕ to remove a unit.

9.3 Understanding the outputs

- Disturbance torques — aero drag, gravity gradient, solar pressure, residual magnetic.
- Required control torque — what the actuators must produce.

- Pointing (RSS) — root-sum-square of error sources.
- Pointing margin — requirement vs. achieved (in the right pane).
- Disturbance torque bar chart — which torque dominates.
- Pointing error breakdown chart.

Chapter 10 — ΔV & Propulsion

Builds the life-cycle ΔV budget and sizes propellant via the rocket equation. This is also where you choose the end-of-life disposal strategy.

10.1 Glossary

Term	What it means
Propulsion type	Chemical or electric family. Cold gas, monoprop, biprop, electric, Hall effect, etc.
Specific impulse (Isp)	Propellant efficiency, in seconds. Higher Isp = less propellant for the same ΔV.
Auto station-keeping	When ON, station-keeping ΔV/yr is derived from altitude + ballistic coefficient. When OFF, the manual Δv/yr value is used.
Other manoeuvres Δv	Catch-all for ΔV that is not Hohmann or plane change (e.g. proximity ops, formation flying).
Δv margin	Reserve applied to the total ΔV before sizing propellant. 5–15 % is typical.
De-orbit strategy	How the spacecraft is removed at end of life: Active burn / Atmospheric drag / Drag sail / Not planned.
Target perigee	For an active burn — the perigee you lower to. ≤120 km gives rapid orbital decay (re-entry within days), but complete spacecraft demise still depends on materials and structure and requires a separate casualty-risk analysis per ESA/IADC requirements. Kendra does NOT model component-level demisability.
Ballistic coefficient	Spacecraft mass over (Cd × Area), in kg/m². Higher BC = slower decay.
Drag-sail area	Extra cross-section deployed at end of life to accelerate natural decay.
Disposal standard	Post-mission orbital-lifetime threshold that Kendra screens the design against. NOT a full compliance check — full ESA/FCC/IADC compliance also involves collision-probability limits, casualty-risk assessment and passivation, which Kendra does NOT evaluate. Four presets: ESA Zero Debris (≤ 5 yr, the default; current ESA policy since 2023, applies to ESA programmes and projects), FCC (≤ 5 yr, adopted 2022, compliance required from Sep 2024; applies to the relevant Part 25 plus experimental/amateur authorisations), IADC (≤ 25 yr — the current published international IADC mitigation guideline; less stringent than ESA/FCC but not formally superseded by the IADC consortium), and Custom (set your own limit).
Post-mission lifetime screening	Kendra's output is 'Within limit' or 'Exceeds limit' based on the estimated post-mission orbital lifetime versus the limit of the selected standard. This is a lifetime-only screen — it does NOT demonstrate full regulatory or agency compliance.

10.2 Step-by-step

67. Click 'ΔV & Propulsion' under SUBSYSTEMS.
68. Pick 'Type' from the dropdown.
69. Drag 'Specific impulse' to the Isp of your propulsion system.
70. Decide on station-keeping:
    - Leave 'Auto station-keeping Δv' ON for a physics-driven value.
    - Or turn it OFF and enter your own 'Manual maint. Δv/yr'.
71. Enter 'Other manoeuvres Δv' for non-Hohmann manoeuvres, if any.
72. Drag 'Δv margin' to the reserve fraction (5–15 % typical).
73. Pick 'De-orbit strategy':
    - Active de-orbit burn (perigee lowering) — set 'Target perigee' (default 120 km). NOTE: this is NOT a controlled re-entry (which targets a specific impact location); it is a perigee-lowering burn that drives re-entry by drag.
    - Atmospheric drag — set 'Ballistic coefficient'.
    - Drag sail — set 'Ballistic coefficient' and 'Drag-sail area'.
    - Not planned — leave the spacecraft in its operational orbit.
74. Pick 'Disposal standard':
    - ESA Zero Debris (≤ 5 yr in LEO) — DEFAULT. ESA's 2023 policy update to a 5-year maximum post-mission lifetime in LEO. Applies to ESA programmes and projects; also a sensible baseline for any new mission targeting protected LEO altitudes.
    - FCC (US-licensed LEO, ≤ 5 yr) — per FCC 22-74, adopted 2022 with compliance required from September 2024. Scope covers the relevant Part 25 systems plus associated experimental and amateur authorisations, not only commercial 'US-licensed' satellites. Several other operator obligations apply beyond lifetime; Kendra screens lifetime only.
    - IADC mitigation guideline (≤ 25 yr) — the published international IADC consortium guideline (still current; less stringent than the ESA/FCC rules but NOT formally superseded). Use when you are explicitly evaluating against the IADC baseline.
    - Custom — set your own limit (e.g. 10 yr for a specific agency requirement).

10.3 Understanding the outputs

- Station-keeping ΔV/yr and ΔV (life) — annual drag-correction cost.
- ΔV ADCS — life-cycle ADCS unloading cost.
- ΔV Hohmann transfer — populated from the Orbit panel when Hohmann is on.
- ΔV plane change — populated from the Orbit panel when Δi > 0.
- ΔV de-orbit — based on the strategy.
- Total ΔV — including margin.
- Mass ratio — m_initial / m_final.
- Propellant mass — from the rocket equation $M_p = M_{dry} \cdot (\exp(\Delta V / (I_{sp} \cdot g_0)) - 1)$. There is no 'few hundred grams' shortcut: low-Isp cold gas always needs kilograms of propellant for hundreds of m/s of ΔV.

- Est. orbit lifetime (passive/sail) — solar-cycle range, with screening against the selected standard's post-mission limit.
- Post-mission lifetime screening — 'Within limit' or 'Exceeds limit' against the chosen standard. This is a lifetime screen only; full regulatory compliance also requires a collision-probability budget, casualty-risk analysis and passivation, which Kendra does NOT evaluate.
- Hohmann transfer time (when transfer is enabled).
- ΔV breakdown bar chart.
- Propellant vs. Isp sensitivity chart.

Tip: If the 'Post-mission lifetime screening' metric is amber, your passive de-orbit lifetime is longer than the limit set by the selected standard. Switch to Active de-orbit burn, add a drag sail, or — if you have a defensible reason — change the standard (e.g. IADC 25-yr instead of ESA 5-yr) and document why.

MODULE III

Outputs, simulation and export

Chapter 11 — Reading the output metrics

Every panel produces a cluster of OUTPUTS cards and a set of DIAGRAMS. The right-side pane rolls them up into mission-level budgets. This chapter explains how to read them.

11.1 Output card anatomy

- Top row — the metric label and a small ⓘ if a glossary entry exists. Click the ⓘ to open the explanation.
- Big number — the value with its unit.
- Small hint — additional context (e.g. 'incl. 15 % reserve').
- Left-edge colour — green = within budget, amber = marginal, red = over budget.

11.2 The right-side budget pane

Always visible, regardless of which subsystem panel you're on. Each block shows one mission-level budget:

- Mass Budget — every subsystem subtotal, propellant, wet mass.
- Power Budget — payload load, bus load, array output and battery capacity.
- ΔV Budget — every line of the ΔV breakdown.
- Link Budgets — margin per link.
- Data Budget (per day) — generated vs. downlinked, with margin.
- Pointing Budget — requirement vs. achieved RSS.

11.3 The status dots in the sidebar

Every subsystem in the left sidebar carries a small dot showing its current status — green for OK, amber for warning, red for fail. Hover or click the dot to see which budget is driving the status.

11.4 Using the ⓘ icons

- Click any ⓘ next to an input label or output metric.
- The glossary popup rises at the bottom centre of the screen.
- Read the short explanation.
- Click anywhere outside the popup, or press Esc, to dismiss it.

Chapter 12 — 3D orbit simulation

A live WebGL view of the satellite orbiting the central body. Useful as a sanity check and to walk a non-engineer through what the mission actually looks like.

12.1 Opening the simulation

75. Click '🛰 Simulation' in the header. A full-screen window opens.
76. The textured central body appears with the orbit shown as a ring.
77. The satellite orbits the body automatically.

12.2 Camera and playback controls

- Drag with the left mouse button to orbit the camera.
- Scroll to zoom.
- Click '⏸ Pause' to halt the animation; click '▶ Play' to resume.
- Drag the 'Speed' slider to speed up or slow down.
- Click ✕ in the top-right of the window to close.

12.3 Orbit-mode checkboxes

Three checkboxes plus a 'Reset orbit' button drive the simulation:

Term	What it means
Transfer orbit	Available only when Hohmann transfer is enabled in the Orbit panel. Checking it begins the climb to the target orbit. Unchecking it begins the descent back. The dashed yellow line shows the transfer ellipse.
Mission orbit	Read-only indicator of the current operational orbit. With Hohmann enabled, it shows whether the spacecraft is currently on the 'initial' or 'target' orbit.
De-orbit	Available only when De-orbit strategy = Active in the Propulsion panel. Checking it begins the de-orbit sequence — irreversible until Reset. Ends with a stylised re-entry effect — labelled in the title bar as an illustrative animation, NOT a spacecraft demise analysis. A real re-entry / casualty-risk analysis is always required separately.
Reset orbit	Cancels any in-flight transition and returns the satellite to the mission orbit; un-checks the Transfer and De-orbit boxes.

12.4 HUD readouts

- Body, Altitude, Inclination, Period, Velocity — the orbit numbers.
- Target altitude — visible only when Hohmann is on.
- Phase — current animation phase (Mission, Transfer, De-orbit, Re-entry).
- True anomaly, Sub-lat, Sub-lon — live position readouts.
- Illumination — Sunlit / Eclipse. Sun-centric orbits never show Eclipse.

Chapter 13 — Excel export

Save your full analysis as a multi-tab Excel workbook. Useful for design reviews, traceability and for sharing the design with colleagues.

13.1 Exporting

78. Click '⭳ Excel' in the header.
79. Your browser downloads a .xlsx file named after the mission.
80. Open it in Excel, LibreOffice Calc, or Google Sheets.

13.2 Workbook contents

The workbook has one tab per subsystem plus a Summary tab.

- Summary — mission metadata, summary metrics, every technical budget rolled up.
- Orbit & Mission — all orbit inputs (flattened, dotted paths), all orbit outputs.
- Payload — payload inputs and outputs.
- Comms/Link — every link, one section each, with its full input set and output set.
- Power (EPS) — power inputs and sizing outputs.
- Thermal — thermal inputs and equilibrium outputs.
- ADCS/Pointing — ADCS inputs and the disturbance / pointing outputs.
- ΔV & Propulsion — full ΔV breakdown, propellant, lifetime.
- Mass & Launch — every mass item, system margin, launch mass.
- Cost (ROM) — cost inputs and outputs.

> **Tip:** The workbook always reflects the current state of the panels. Export again any time you change inputs to keep the file in sync.

WORKED EXAMPLE

AVRTEC-1 — a 12U CubeSat mission

Chapter 14 — Worked example: AVRTEC-1 (12U CubeSat)

A complete walk-through of a realistic 12U CubeSat mission. Every number in this chapter is produced live by the Kendra compute engine when this manual is built, so the worked example always agrees with what the app outputs for these inputs.

14.1 The mission concept

AVRTEC-1 is a 12U CubeSat that demonstrates an optical Earth-observation payload in a sun-synchronous orbit. The mission lasts 3 years.

Term	What it means
Form factor	12U CubeSat (~22 × 24 × 36 cm envelope).
Wet mass (Kendra)	21.7 kg wet; 22.8 kg incl. deployer (live-computed).
Orbit	Sun-synchronous, 550 km, 97.6° inclination.
Payload	Visible-light push-broom imager, 9 cm aperture.
Comms	UHF TT&C downlink + S-band payload downlink.
ADCS	3-axis with reaction wheels; star tracker + sun sensors.
Propulsion	Cold-gas thrusters; active de-orbit at end of life.

14.2 Starting the mission

81. Open Kendra at https://kendra.avrtec.space and click Deploy.
82. In the preset selector, pick 'AVRTEC-1-C · 12U CubeSat' to load a pre-filled starter. (Alternatively, pick 'New mission' for a blank slate.)
83. In the header, type 'AVRTEC-1' as the mission name.
84. Confirm the central body is set to 'Earth'.

14.3 Configuring the orbit

85. Click 'Orbit & Mission' in the left sidebar.
86. Set Altitude = 550 km.
87. Set Inclination = 97.6° (you should see 'Sun-synchronous: Yes').
88. Leave Eccentricity = 0.
89. Leave Min elevation = 5°.
90. Set Design life = 3 yr.
91. Leave Hohmann transfer OFF (we do not need to move altitude).
92. Leave Plane change = 0°.

Confirm in the OUTPUTS that Period ≈ 95.65 min, Orbital velocity ≈ 7.585 km/s, and Max eclipse ≈ 35.6 min. The two ground-track speeds will read approximately 6.983 km/s (inertial frame; matches SMAD §10) and 7.044 km/s (Earth-rotating frame; matches SMAD Table 8-11). For this near-polar SSO the two values differ only slightly because cos(97.6°) ≈ −0.13.

14.4 Defining the payload

93. Click 'Payload' under SUBSYSTEMS.
94. Type = Optical (visible).
95. Aperture = 0.09 m.
96. Wavelength = 0.55 µm.
97. Power = 8 W.
98. Payload mass = 3 kg.
99. Data rate = 45 Mbps.
100. Duty cycle = 0.02 (2 % of orbit imaging).

The OUTPUTS will show the DIFFRACTION-LIMITED ground resolution under BOTH common conventions (a best-case optical bound, not a detector-sampled GSD), so you can pick the one your reviewer expects:

- GSD floor (SMAD λ/D) — 3.36 m at nadir, matching SMAD Table 17-5 ("diffraction-limited resolution"). Diffraction angle θ = λ/D = 6.11 µrad.
- Rayleigh GSD (1.22·λ/D) — 4.10 m at nadir, the optics-textbook Rayleigh-resolvable criterion (Airy first dark ring). Diffraction angle θ = 1.22·λ/D = 7.46 µrad. 22 % more conservative than the SMAD floor for the same aperture.

Tip: Both numbers are diffraction limits only — they do NOT include detector pitch, MTF, motion smear, atmospheric blur or viewing geometry. The fielded GSD will be worse. Also: this model is valid for OPTICAL/IR payloads only. SAR range resolution is set by signal bandwidth, SAR azimuth resolution by the synthetic aperture, and a communications payload has no optical GSD. Do not read these numbers for SAR or comms payload kinds.

14.5 Setting up the comms / link budgets

101. Click 'Comms / Link'. Two links are already present in the AVRTEC-1-C preset; check both. If you started blank, add them.
102. Link 1 — TT&C (housekeeping):
    - Name = TT&C (housekeeping); Role = TT&C; Band = UHF.
    - Downlink frequency = 0.4375 GHz; Rate = 9.6 kbps (0.0096 Mbps).
    - TX power = 2 W; S/C antenna = whip 0.15 m, gain ≈ 0 dBi.
    - GS antenna = amateur UHF yagi (1 m, gain ≈ 16 dBi).
    - System noise temperature = 250 K; Modulation = BPSK uncoded.
    - Required margin = 6 dB; Passes/day = 6; Contact min = 9.
103. Link 2 — Payload downlink:
    - Name = Payload downlink; Role = Payload; Band = S-band.
    - Downlink frequency = 2.45 GHz; Rate = 25 Mbps.
    - TX power = 2 W; S/C antenna = patch 0.2 m, gain ≈ 6 dBi.
    - GS antenna = S-band 5.4 m (gain auto).

- System noise temperature = 135 K; Modulation = QPSK + Turbo/LDPC.
- Required margin = 3 dB; Passes/day = 6; Contact min = 11.

Both links should close (green). The waterfall chart for the S-band link shows where the dB are spent.

14.6 Sizing the power subsystem

104. Click 'Power (EPS)'.
105. Solar cell = Multi-junction (triple).
106. Battery = Li-ion.
107. Bus load = 9 W.
108. Solar panels = 2 (deployed wings).
109. Cell packing = 0.85 (85 % active area).
110. Sun pointing = 0.85 (good but not perfect).
111. Battery DoD = 0.30 (long life).
112. Battery strings = 1.
113. Battery round-trip eff = 0.90.
114. Design reserve = 0.20 (20 %).

In the OUTPUTS, 'Array power (EOL)' is the end-of-life array output Kendra sizes to meet the load — Kendra reports the required array AREA, not a fixed installed capacity — and the required area is modest for a 12U; Battery capacity is achievable in roughly 0.6 kg of Li-ion.

14.7 Thermal first pass

115. Click 'Thermal'.
116. Absorptivity α = 0.3 (white-coated panels).
117. Emissivity ε = 0.85.
118. Internal load = 15 W (rough estimate from payload + bus).
119. Radiator area = 0.06 m^2 (a single 25 × 25 cm face).

14.8 ADCS configuration

120. Click 'ADCS / Pointing'.
121. Pointing requirement = 0.1°.
122. Control type = 3-axis (reaction wheels).
123. S/C dimension = 0.34 m.
124. Residual dipole = 0.2 $A{\cdot}m^2$.
125. CP–CG offset = 0.02 m.
126. Slew rate = 1 deg/s.
127. Add the units: Star tracker, 5× Sun sensor (fine), MEMS IMU, Magnetometer, GPS receiver, 4× Reaction wheel, 3× Magnetorquer.

14.9 ΔV and propulsion

128. Click 'ΔV & Propulsion'.
129. Type = Cold gas.
130. Specific impulse = 65 s.
131. Auto station-keeping = ON.

132. Δv margin = 10 %.
133. De-orbit strategy = Active de-orbit burn (perigee lowering).
134. Target perigee = 120 km.
135. Ballistic coefficient = 50 kg/m² (typical 12U).
136. Disposal standard = ESA Zero Debris (≤ 5 yr in LEO). This is the current ESA default since 2023; switch to FCC (5 yr) for US-licensed missions or IADC (25 yr) only if you are explicitly evaluating against the international IADC mitigation guideline.

The OUTPUTS show a Hohmann ΔV of 0 (no Hohmann), a station-keeping ΔV ≈ 14.06 m/s/yr at 550 km, an active de-orbit burn of 122.5 m/s, and a total ΔV of 189.9 m/s (incl. margin). With Isp = 65 s and 16.1 kg dry mass, the rocket equation $M_p = M_{dry} \cdot (\exp(\Delta V/(Isp \cdot g_0)) - 1)$ gives a propellant mass of 5.60 kg — i.e. roughly a quarter of the wet mass.

Tip: The mass budget closes, but a 5.6 kg cold-gas (typically N_2) charge inside a 12U is NOT necessarily a feasible packaging. At a tank pressure of ~200 bar, 5.6 kg of N_2 alone occupies roughly 24 L — versus the ~12 L total internal volume of a 12U. Tank mass, pressure-vessel factor of safety, feed-system volume and overall packaging must be assessed separately; Kendra does NOT model these. Switching to a green monopropellant at Isp ≈ 230 s reduces the propellant to 1.40 kg for the same ΔV (live result from re-running this mission with Green monoprop (HAN)), which is a much more realistic 12U design point. See the 'Propellant vs. Isp' sensitivity chart for the full curve.

14.10 Mass roll-up

137. Click 'Mass & Launch'.
138. Use the AVRTEC-1-C defaults or, for a blank start, enter:

- Structure & Mechanisms 2.6 kg, 15 % contingency.
- ADCS 1.8 kg, 10 %.
- EPS (power) 2.1 kg, 10 %.
- TT&C / Comms 0.8 kg, 10 %.
- C&DH / Avionics 0.4 kg, 10 %.
- Thermal 0.3 kg, 15 %.
- Propulsion (dry) 1.2 kg, 10 %.
- Harness 0.5 kg, 20 %.

139. System margin = 15 %.
140. Deployer / adapter = 1.1 kg.
141. Launch vehicle = Rideshare — Falcon 9 Transporter (SSO).

Dry mass (allocated) comes out at 16.1 kg, wet mass 21.7 kg, launch mass 22.8 kg (incl. the 1.1 kg deployer) — comfortably inside the rideshare allocation. The big single line item is the cold-gas propellant; see §14.9 for why and how to reduce it.

14.11 Cost estimate

142. Click 'Cost (ROM)'.
143. Fiscal year = 2024.

144. Quantity = 1.
145. Complexity factor = 0.9 (CubeSat scale).
146. Learning curve = 0.95.

14.12 Verifying the design

- Open the right-side budget pane and confirm every block is green.
- Check that the summary chips in the header are all green.
- Click any orange or red item to find what's marginal.

14.13 Running the simulation

147. Click '🛰 Simulation' in the header.
148. Watch the satellite orbit Earth on the cyan ring.
149. Tick the 'De-orbit' checkbox. A red dashed ellipse appears and the spacecraft enters the de-orbit phase.
150. When the spacecraft reaches the target perigee the animation plays a stylised re-entry effect, then the satellite vanishes. READ THE BADGE in the title bar: 'Illustrative animation — not an engineering propagator'. The view does NOT model atmospheric drag, burn duration, multi-pass decay or component-level demisability. Use it as a communication tool, never as evidence that the spacecraft has fully burned up.
151. Click 'Reset orbit' to return to the mission orbit.
152. Close the simulation with ✕.

> **Tip:** A real re-entry analysis (ESA DRAMA / NASA ORSAT) is required for any flight programme. Kendra's role is to show that an active de-orbit burn lowers perigee enough that drag drives re-entry — not to certify the spacecraft burns up.

14.14 Exporting the analysis

153. Click '⭳ Excel' in the header.
154. Save the file with a name that includes the date and a version tag (e.g. 'AVRTEC-1_v3_2026-06-13.xlsx').
155. Open the file. Use the Summary tab for the cover slide of your design review and the subsystem tabs as backup material.

14.15 Scaling to other sizes

AVRTEC-1 is a 12U CubeSat, but the workflow you just used applies to every spacecraft size:

- PocketQube (sub-1 kg). Use the AVRTEC-1-P preset as a starting point. Shrink every mass and power number proportionally; reduce the payload aperture; switch to magnetorquer-only ADCS; pick 'None' for propulsion.
- 6U / 16U CubeSats. Same flow as AVRTEC-1. Scale masses, panel sizes and bus load up or down.
- ESPA-class smallsats (50–500 kg). Enter larger payload, mass, and power values; pick a different launch vehicle from the dropdown; switch to monoprop or electric propulsion for the right Isp regime.

- Beyond ~500 kg, Kendra is still useful for first-pass studies, but the cost CER will under-estimate — calibrate the complexity factor or use a dedicated cost model.

APPENDICES

Glossary, quick reference, model assumptions, revisions

Appendix A — Full glossary

Every technical term that appears in the application or this manual, in one place.

Term	What it means
Absorptivity (α)	Fraction of incident solar power the surface absorbs.
ADCS	Attitude Determination and Control System.
Aperture	Diameter of the optical or RF collector.
Apogee	Highest point of an elliptical orbit.
β-angle	Angle between the Sun direction and the orbit plane.
Ballistic coefficient (BC)	m / (Cd × A). Higher BC = slower orbital decay.
Battery DoD	Depth of Discharge — fraction of capacity used per cycle.
Bus load	Continuous electrical load of everything except the payload.
C/N_0	Carrier-to-noise-density ratio (dB-Hz).
Central body	The body the spacecraft orbits — Earth, Moon, Mars, etc.
Complexity factor	Cost-model multiplier to match the estimate to a known build.
Contingency	Mass growth allowance per subsystem (%).
Cosine loss	Reduction in solar power when the array is not perpendicular to the Sun.
ΔV (delta-V)	Total change of velocity the propulsion system must produce.
De-orbit strategy	How the spacecraft is removed at end of life: active burn / passive drag / drag sail / none.
Design life	Years the mission is expected to operate.
Design margin / reserve	Extra sizing margin to cover model uncertainty.
Diffraction angle (Rayleigh)	Resolvable angle $\theta = 1.22 \cdot \lambda / D$ (first dark ring of the Airy pattern, Rayleigh criterion).
Drag sail	Deployable surface that accelerates atmospheric decay.
Duty cycle	Fraction of orbit the payload is actively collecting.
E_b/N_0	Bit-energy to noise-spectral-density ratio.
Eccentricity	Orbit shape: 0 = circle, 1 = parabola.
EIRP	Effective Isotropic Radiated Power.

Emissivity (ε)	Fraction of black-body IR a surface emits.
EPS	Electrical Power System.
Free-space path loss (FSPL)	Friis-form expression for the power loss between isotropic antennas in free space. Positive-loss convention: L_FS = $20 \cdot \log_{10}(4\pi d/\lambda)$, in dB. Friis (gain) convention: $20 \cdot \log_{10}(\lambda/(4\pi d))$, which is just −L_FS. Both forms appear in the literature; the user-facing waterfall chart in Kendra shows the positive-loss form.
G/T	Ground-station antenna gain over system noise temperature.
Ground sample distance (GSD)	Strictly, the ground size of one detector pixel. Kendra does not know your detector, so the value it reports as the 'GSD floor' is the DIFFRACTION-LIMITED ground resolution (λ/D · h) — a best-case optical bound. True detector GSD is coarser once pixel pitch, MTF, smear and atmosphere are included.
Ground track	Path of the sub-satellite point across the ground.
Hohmann transfer	Two-burn manoeuvre between two coplanar circular orbits.
IADC	Inter-Agency Space Debris Coordination Committee.
Inclination	Orbit-plane tilt vs the equator.
Internal load	Internal dissipation in the spacecraft (W).
Isp	Specific impulse (s).
J2	Second zonal harmonic of the body's gravity field, drives nodal regression.
Launch mass	Wet mass + deployer.
Launch vehicle	The rocket. Sets the capacity check.
Learning curve	Cost reduction per doubling of quantity.
Link margin	Excess dB above the modulation's required E_b/N_0.
Mass ratio	m_initial / m_final.
Min elevation	Lowest angle a ground station accepts.
Modulation	How bits are encoded on the carrier.
Nodal regression	Westward drift of the ascending node from J2.
Operational orbit	The orbit the spacecraft does science on.
Payload mass	Dry mass of the instrument.
Perigee	Lowest point of an elliptical orbit.

Plane change	Manoeuvre that changes orbit inclination.
PocketQube	Smallest standardised satellite (50 mm cubes).
Pointing budget	Total angular error from all sources, RSS.
RAAN	Right Ascension of the Ascending Node.
Reaction wheel	Spinning flywheel that exchanges angular momentum to point the spacecraft.
Reset orbit	Simulation button — returns the satellite to the mission orbit.
Rocket equation	$\Delta v = Isp \cdot g_0 \cdot \ln(m\_initial/m\_final)$.
Slant range	Line-of-sight distance from satellite to ground point.
Slew rate	Angular speed of re-pointing (deg/s).
Solar flux	Incoming solar power per m^2 at the spacecraft.
Star tracker	Camera that identifies stars to determine attitude.
Station-keeping	Burns that maintain altitude against drag.
Sun-synchronous	Orbit whose plane precesses with the Sun.
Ground visibility footprint	Diameter of the ground access circle within which the satellite is visible above the minimum elevation angle (ground-station visibility, not an imaging-sensor swath).
System margin	Top-level dry-mass margin.
Target altitude	Post-Hohmann operational altitude.
Wet mass	Dry mass + propellant.

Appendix B — Quick reference card

One-page summary of the workflow. Keep this in front of you the first few times you use Kendra.

B.1 Order of operations

156. Start a mission (preset or blank) and name it.
157. Set the central body and orbit (altitude, inclination, design life).
158. Define the payload (aperture, power, mass, data rate).
159. Build the comms link(s).
160. Size the power subsystem.
161. Pass through thermal (first-cut).
162. Configure the ADCS sensors and actuators.
163. Pick the propulsion type and the de-orbit strategy.
164. Roll up the mass and pick the launch vehicle.
165. Glance at the cost estimate.
166. Verify every budget on the right pane is green.
167. Export to Excel.

B.2 If a budget is amber or red

Term	What it means
Mass over capacity	Reduce subsystem masses; pick a larger launch vehicle; reduce propellant by lowering ΔV margin or switching to higher Isp.
Power short	Raise cell efficiency or packing; accept more total array area; improve array pointing (sun-tracking drive); lower bus load. (Panel count only splits the required area — it does not add power.)
ΔV over budget	Reduce manoeuvres; use a higher-Isp propulsion; switch from active de-orbit to drag sail.
Link does not close	Raise TX power; bigger spacecraft antenna; bigger ground antenna; lower data rate; better modulation.
Data over capacity	Lower duty cycle; add ground stations; raise downlink rate.
Pointing miss	Tighter sensor (star tracker); finer actuators; reduce slew rate requirement.

Appendix C — Model assumptions & formulas

The principal public formulas, constants and model assumptions Kendra uses, in one place. This appendix documents the main equations behind every output; some component-library constants and lookup tables — the modulation E_b/N_0 table, the solar-cell and battery libraries, the ADCS component library, the atmospheric-density and orbital-decay tables, the launch-vehicle capacities and the status-colour thresholds — are maintained in the application and summarised here rather than listed exhaustively, so a few values are best read from the app itself. Kendra is a conceptual / pre-Phase-A trade-study tool; it is NOT a flight-verification tool, and the limits below tell you exactly where the simplifications are.

C.1 Universal constants

Term	What it means
Standard gravity g_0	9.80665 m/s² — the international standard value used in the rocket equation.
Speed of light c	299 792 458 m/s — used for wavelength = c/f in the link budgets.
Boltzmann constant k_B	1.380 649 × 10^{-23} J/K (−228.6 dBW/K/Hz). Sets the noise power density N_0 = k_B·T used in C/N_0 (with T supplied by the receiver G/T). The bandwidth B does NOT appear in C/N_0; it appears only in the wideband ratio C/N = C/(k_B·T·B).
Stefan-Boltzmann σ	5.670 374 419 × 10^{-8} W/(m²·K⁴). Used in the thermal balance.
Solar flux at 1 AU	1361 W/m². Scaled as 1/r² for other central bodies.
Earth IR (average)	237 W/m² — used for hot/cold case.
Earth Bond albedo	0.30 — used in the albedo absorbed term.

C.2 Central-body constants

From the SMAD reference spreadsheets and supplementary tables. Earth values are quoted exactly so that Kendra reproduces the reference results from SMAD Table 10-7, Fig 14-5, Fig 14-23.

Term	What it means
μ_Earth	398 600.4356 km³/s²
R_Earth (equatorial)	6378.1366 km
J2 (Earth)	0.001 082 635 9 (IERS 2003 / SMAD Table 10-14)
Sidereal day (Earth)	23.934 469 6 hours
Obliquity (Earth axial tilt)	23.4393°
Other bodies	Moon, Mars, Venus, Mercury, Jupiter and the Sun are implemented with their own μ, R, J2 and rotation period for ORBITAL MECHANICS. The power, thermal, atmospheric-lifetime and disposal models are Earth-calibrated (Earth albedo/IR,

	Earth's density table, ESA/FCC/IADC rules) and must not be used unchanged for other bodies.

C.3 Orbit derivations (astro.py)

Term	What it means
Period	$T = 2\pi \cdot \sqrt{a^3/\mu}$
Circular velocity	$v_{circ} = \sqrt{\mu/a}$
Ground-track speed (inertial)	$v_{ground} = v_{circ} \cdot R/(R+h)$. Sub-satellite point as seen from the inertial frame. Matches SMAD §10 'ground-track of orbit'.
Ground-track speed (Earth-rotating)	$v_{ground\_rot} \approx v_{ground} - \omega_{body} \cdot R \cdot \cos(i)$. Sub-satellite point as seen from the rotating-Earth frame. Matches SMAD Table 8-11. For Sun-centric orbits the rotation term is meaningless and the rotating-frame value is reported equal to the inertial value.
J2 nodal regression	$d\Omega/dt = -1.5 \cdot n \cdot J2 \cdot (R/a)^2 \cdot \cos(i) / (1 - e^2)^2$ · rad/s, converted to deg/day. Earth J2 = 0.0010826359 (IERS 2003; SMAD Table 10-14, Table 8-11).
Sun-sync inclination	Solves $d\Omega/dt = 2\pi / (365.2422 \cdot 86400)$ rad/s for $\cos(i)$
Eclipse fraction (β = 0)	$\rho/180°$, where $\sin(\rho) = R/(R+h)$
Eclipse fraction (general β)	$frac = (1/\pi) \cdot \arccos(\cos(\rho) / \cos(\beta))$; 0 if $\cos(\rho) \geq \cos(\beta)$
Coverage central angle (λ)	$\lambda = \pi/2 - \varepsilon - \eta$, where $\sin(\eta) = \sin(\rho) \cdot \cos(\varepsilon)$ (ε = min elevation)
Ground visibility footprint	$2 \cdot \lambda \cdot R$ — diameter of the ground access circle at the minimum elevation angle (ground-station visibility, not an imaging swath)
Slant range (max)	Law of sines: $slant = R \cdot \sin(\lambda)/\sin(\eta)$

C.4 Payload — diffraction (payload.py)

Term	What it means
Diffraction floor (SMAD)	$\theta = \lambda / D$, $GSD = \theta \cdot h$. Matches SMAD Table 17-5 exactly.
Rayleigh resolvable	$\theta = 1.22 \cdot \lambda / D$, $GSD = \theta \cdot h$. Two-point resolvability (Born & Wolf §8.5.2).
Validity	Optical and IR payloads only. Does NOT apply to SAR (range res = $c/(2 \cdot B_{signal})$, azimuth res = synthetic-aperture limited) or communications payloads.
Data / orbit	data_rate[Mbps] · (period[s] · duty_cycle) / 1000 (Gbit). NOTE: the period here is in SECONDS, not the minutes shown in the orbit panel.

C.5 Communications (comms.py)

Term	What it means
FSPL convention	Internally the Friis-form path gain is used: fspl_gain_db = $20 \cdot \log_{10}(\lambda / (4\pi \cdot d))$ (a NEGATIVE dB number). Equivalent to the customary positive-loss form L_FS = $+20 \cdot \log_{10}(4\pi \cdot d / \lambda)$. The waterfall chart in the UI shows the positive-loss form.
EIRP	$10 \cdot \log_{10}$(P_TX) + G_TX + line_loss_db (dBW)
Antenna gain (aperture)	G = $10 \cdot \log_{10}(\eta \cdot (\pi \cdot D / \lambda)^2)$ dBi, where η is efficiency. An override (sc_antenna_gain_dbi) lets you use a fixed gain for non-aperture antennas (whip, patch, helix). Matches SMAD Table 16web-3.
G/T	G_RX − $10 \cdot \log_{10}$(T_sys)
C/N_0	EIRP + fspl_gain_db + atmos + pointing + G/T − k_B
Eb/N_0	C/N_0 − $10 \cdot \log_{10}$(R_b · coding_overhead), where R_b is the information bit rate; the coding_overhead (≥1) is a conservative rate penalty, and the required Eb/N_0 already includes the scheme's coding gain — so coding is not double-counted
Margin	Eb/N_0 − required_EbN0(modulation) − required_margin

C.6 Power (power.py)

Term	What it means
Array sizing	P_sa = (P_e · T_e / X_e + P_d · T_d / X_d) / T_d, then scaled by (1 + design margin). X_e and X_d are battery-path and direct-path efficiencies.
EOL degradation	f_EOL = (1 − cell_degradation/yr) ^ design_life_years
EOL array output	P/m² = flux · cell_eff · inherent_deg · pointing_eff · f_EOL
Active cell area	A_active = P_sa / (P/m²)_EOL
Panel area	A_panel = A_active / packing_factor; per-panel = total/N_panels
Battery capacity	Total: C_batt [Wh] = P_e · (T_e / 3600) / (DoD · η_batt). Per parallel string: C_string = C_batt / N_strings. The strings split the fixed total capacity — they do not reduce it.
Notes	Bus-and-payload load are treated as continuous in this first-pass model. Mode-dependent profiles (eclipse vs payload-on vs comms-pass) are NOT modelled at this fidelity.

C.7 Thermal (thermal.py)

Term	What it means
Earth view factor	$VF = (R / (R + h))^2$
Solar absorbed	$Q\_solar = \alpha \cdot S \cdot A\_projected$, where S is solar flux
Albedo absorbed	$Q\_albedo = \alpha \cdot alb \cdot S \cdot A\_projected \cdot VF$
Earth IR absorbed	$Q\_IR = \varepsilon \cdot IR \cdot A\_surface \cdot VF$. First-order isothermal-node approximation: IR is applied over the TOTAL surface area, which tends to OVER-count (a rigorous model uses the Earth-facing projected area or a true spacecraft-to-Earth view factor). Treat the temperatures as a rough single-node estimate.
Internal dissipation	Q_int (user input)
Hot-case temperature	$T\_hot^4 = (Q\_solar + Q\_albedo + Q\_IR + Q\_int) / (\varepsilon \cdot \sigma \cdot A\_surface)$
Cold-case temperature	$T\_cold^4 = (Q\_IR + 0.4 \cdot Q\_int) / (\varepsilon \cdot \sigma \cdot A\_surface)$ (eclipse, reduced internal load)
Radiator capacity	$Q\_rad = \varepsilon \cdot \sigma \cdot A\_radiator \cdot (T\_allow^4 - T\_space^4)$, T_allow = 300 K, T_space = 2.7 K

C.8 ADCS (adcs.py)

Term	What it means
Inertia model	$I = (1/6) \cdot m \cdot L^2$ (cube approximation). Δ I taken as 0.3 · I for gravity-gradient torque.
Gravity-gradient torque	$T\_gg = 3 \cdot \mu / (2 \cdot a^3) \cdot \Delta I$
Solar-pressure torque	$T\_sp = (S/c) \cdot A\_face \cdot (1 + reflectivity\_factor) \cdot cp\_cg\_offset$
Aerodynamic torque	$T\_aero = 0.5 \cdot \rho(h) \cdot Cd \cdot A\_face \cdot v^2 \cdot cp\_cg\_offset$, Cd = 2.2
Atmospheric density	Shared atmospheric_density(h, mode) from propulsion.py — see C.10 for the table. ADCS uses the 'mean' column.
Magnetic torque	$T\_mag = m\_dipole \cdot B$, where $B = 2 \cdot (7.96 \cdot 10^{15})/a^3$ (Earth tilted dipole approximation)
Pointing knowledge	Minimum-variance (inverse-variance) fusion of the two best sensors: $\sigma = 1 / \sqrt{\Sigma 1/\sigma_i^2}$ — never worse than the best single sensor
Pointing error (RSS)	$\sqrt{knowledge^2 + alignment\_err^2 + thermal\_err^2}$ — RSS of the fused sensor knowledge with the (independent) alignment and thermal terms
Wheel momentum (cyclic)	$h\_needed = T\_sum \cdot period / 4$ — a CYCLIC quarter-orbit momentum-accumulation approximation. Valid for disturbances that reverse over an orbit; it

	is NOT a worst case for a constant/secular bias (residual dipole, steady aero or solar-pressure torque), which accumulates momentum until the next desaturation.
Slew torque (sizing aid)	t_slew = I · α, with α = slew_rate / 10 s — i.e. a representative profile that ramps to the commanded slew rate in ~10 s. A real slew budget also needs the slew angle, allowed time and the full acceleration/deceleration profile.

C.8.1 Scope of Kendra's pointing budget

Kendra's pointing-budget RSS is a deliberate three-term subset of the full SMAD Table 8-17 'Representative Mapping and Pointing Error Budgets'. The RSS structure (square root of the sum of squares of independent, zero-mean error sources) is mathematically correct; the SCOPE of error terms is reduced compared to a flight-design pointing budget.

What Kendra DOES include in the pointing RSS:

- Sensor measurement noise — minimum-variance (inverse-variance) fusion of the two best-performing sensors' 1σ errors (the optimal combination of redundant attitude measurements; never worse than the best single sensor).
- Sensor-to-bus alignment error (single scalar, deg).
- Thermal-deflection error (single scalar, deg).

What Kendra does NOT include (you must budget separately):

- Control-loop noise (closed-loop attitude tracking residual).
- Sensor bias drift between calibration cycles.
- Estimator latency (filter delay between measurement and command).
- Structural deflection under thermal cycling and dynamic loads (separate from the single 'thermal_err' scalar).
- Micro-vibration / jitter from reaction wheels, CMGs, cryocoolers.
- Actuator quantisation (wheel command resolution).
- Calibration-residual error (ground-to-orbit transfer of attitude frame definitions).
- Full inertia-tensor effects — Kendra uses the cubic-body approximation $I = (1/6) \cdot m \cdot L^2$ for one characteristic dimension, not the full 3×3 inertia tensor.

> **Tip:** For a flight pointing budget, build the full Table 8-17 RSS in a separate spreadsheet and treat Kendra's pointing RSS as one input (the 'fused-knowledge + alignment + thermal' term). The disturbance-torque values Kendra reports (gravity-gradient, solar-pressure, aero, magnetic) are still useful as actuator-sizing inputs and are calculated correctly from the SMAD §19 formulas.

C.9 Propulsion (propulsion.py)

Term	What it means

Rocket equation	Mp = M_dry · (exp(ΔV / (Isp · g_0)) − 1)
Mass ratio	m_initial / m_final = exp(ΔV / (Isp · g_0))
Hohmann transfer (two-burn)	Standard SMAD formulation; ΔV1 + ΔV2 with the cheaper combined burn at apogee when a plane change is requested.
Plane change (pure)	ΔV = 2 · v · sin(Δi/2), at the current orbital velocity v
Active de-orbit burn	ΔV = v_circ · (1 − √(2·r_perigee / (r_op + r_perigee))) — single burn at apogee that lowers perigee. NOT a controlled re-entry.
Station-keeping (auto)	ΔV/yr = 0.5 · ρ · v² · (1 yr) / BC, where ρ is from the shared density table at 'mean' solar activity
Station-keeping range	min/max are derived from the same table at 'min' (solar min, thinnest atmosphere) and 'max' (solar max, densest)
Lifetime	Interpolated against the SMAD-style decay-day table at a reference BC of 50 kg/m², scaled linearly with BC
Disposal screening	Estimated lifetime is compared against the threshold of the selected standard (ESA 5 yr, FCC 5 yr, IADC 25 yr, or Custom). Lifetime-only; not a full regulatory compliance test.

C.10 Atmospheric density table

Single source of truth used by propulsion (station-keeping, lifetime) AND ADCS (aero torque). Three columns capture the solar-cycle range (low / mean / high F10.7). Piecewise log-linear interpolation between altitudes; below 200 km clamped to the 200 km row, above 1000 km clamped to the 1000 km row. WARNING: real density rises steeply below 200 km, so the 200 km clamp UNDER-predicts drag, aero-torque and station-keeping for any sub-200 km segment — do not rely on Kendra below 200 km.

C.10.1 Model identity and known divergence from SMAD-NSME

Kendra's density model is a Jacchia-77 / NRL-MSISE-blended sampling biased toward elevated F10.7 (~150 sfu, solar-moderate-to-active conditions). This is deliberately MORE CONSERVATIVE than the table in SMAD-NSME Fig 10-17, which is built from US Standard Atmosphere 1976 with MSIS extensions at a solar-mean F10.7 of ~100 sfu. The two tables match closely below 250 km (ratio ≈ 1.0×), then diverge steadily with altitude: ≈1.7–2.4× across 300–500 km, ~2–3× around 400–600 km, rising to ~6× at 800 km and ~9× at 1000 km (see the table below). In short: roughly 1–9× depending on altitude.

Side-by-side at solar-mean conditions:

Term	What it means
h = 200 km	Kendra ρ_mean = 3.0e-10 · SMAD Fig 10-17 ρ_mean ≈ 2.9e-10 · ratio 1.0×

h = 300 km	Kendra ρ_mean = 4.0e-11 · SMAD Fig 10-17 ρ_mean ≈ 2.3e-11 · ratio 1.7×
h = 400 km	Kendra ρ_mean = 7.0e-12 · SMAD Fig 10-17 ρ_mean ≈ 3.3e-12 · ratio 2.1×
h = 500 km	Kendra ρ_mean = 1.5e-12 · SMAD Fig 10-17 ρ_mean ≈ 6.2e-13 · ratio 2.4×
h = 600 km	Kendra ρ_mean = 4.0e-13 · SMAD Fig 10-17 ρ_mean ≈ 1.4e-13 · ratio 2.9×
h = 800 km	Kendra ρ_mean = 7.0e-14 · SMAD Fig 10-17 ρ_mean ≈ 1.2e-14 · ratio 5.8×
h = 1000 km	Kendra ρ_mean = 2.5e-14 · SMAD Fig 10-17 ρ_mean ≈ 2.9e-15 · ratio ~9×

What this means in practice:

- Station-keeping ΔV/yr is higher in Kendra than under SMAD-NSME's solar-mean assumption — by the altitude-dependent ratio above (~2–3× around 400–600 km, growing to ~6–9× at 800–1000 km). Kendra is the more conservative side.
- Orbital lifetime estimates are correspondingly SHORTER in Kendra by the same altitude-dependent ratio.
- Aero-torque is correspondingly higher in Kendra by the same ratio.
- Kendra's solar-MIN column gives values close to SMAD-NSME's solar-MEAN column. If you want to reproduce SMAD-NSME numbers exactly, the rough equivalence is to interpret Kendra's 'min' column as the SMAD-NSME solar-mean baseline.

> **Tip:** This is a deliberate engineering choice, not a bug. The conservative side is the safer side for early trade studies: under-predicting decay risk or under-sizing station-keeping fuel is much worse than the reverse. If your reviewer specifically wants SMAD-NSME Fig 10-17 numbers, note the column-shift above.

C.10.2 Kendra density table (current shipping values)

Term	What it means
h = 200 km	ρ_min = 1.8e-10 · ρ_mean = 3.0e-10 · ρ_max = 4.5e-10 kg/m³
h = 300 km	ρ_min = 1.4e-11 · ρ_mean = 4.0e-11 · ρ_max = 1.4e-10 kg/m³
h = 400 km	ρ_min = 1.2e-12 · ρ_mean = 7.0e-12 · ρ_max = 4.0e-11 kg/m³
h = 500 km	ρ_min = 1.5e-13 · ρ_mean = 1.5e-12 · ρ_max = 1.5e-11 kg/m³
h = 600 km	ρ_min = 3.0e-14 · ρ_mean = 4.0e-13 · ρ_max = 5.0e-12 kg/m³
h = 700 km	ρ_min = 1.0e-14 · ρ_mean = 1.5e-13 · ρ_max = 2.0e-12 kg/m³
h = 800 km	ρ_min = 5.0e-15 · ρ_mean = 7.0e-14 · ρ_max = 9.0e-13 kg/m³
h = 900 km	ρ_min = 3.0e-15 · ρ_mean = 4.0e-14 · ρ_max = 5.0e-13 kg/m³

h = 1000 km	ρ_min = 2.0e-15 · ρ_mean = 2.5e-14 · ρ_max = 3.0e-13 kg/m³

C.11 Cost model (cost.py)

Term	What it means
Base year	FY2010 specific costs, rolled forward by inflation
Specific cost (bus)	$130 K / kg of bus dry mass (FY2010) — representative parametric value, not calibrated to a published CER
Specific cost (payload)	$220 K / kg of payload (FY2010) — representative parametric value, not calibrated to a published CER
Inflation rate	2.4 %/year ASSUMED flat escalation, applied as (1.024)^(fiscal_year − 2010) — a modelling assumption, not actual fiscal-year inflation indices
Complexity factor	User-set multiplier on T1 recurring cost (0.5–2.5 typical). CubeSats ≈ 0.7–1.0; complex SAR or interplanetary ≈ 1.5–2.0.
First-unit (T1) cost	T1 = bus_cost + payload_cost (specific costs · masses · complexity)
IA&T	0.14 · T1 (Integration, Assembly & Test)
Program-level	0.20 · T1
AGE	0.10 · T1 (Aerospace Ground Equipment)
Non-recurring	0.90 · T1 (rough development factor)
Recurring (multi-unit)	Wright learning curve: cost(k) = T1 · k^b where b = log(learning_curve) / log(2). Summed over units.
Scope of 'program cost'	Covers spacecraft non-recurring + recurring (bus + payload), IA&T, program-level and AGE. It does NOT include launch, operations, ground stations, software, licensing or reserves — budget those separately.
Validity	FIRST-ORDER ROM and a single point estimate (no uncertainty interval). The specific costs, the 2.4 % escalation and the percentage factors are representative parametric assumptions, not calibrated CERs. For a defensible estimate, use a bottoms-up Cost Estimating Relationship calibrated to your historical builds.

C.12 What Kendra explicitly does NOT model

Naming the limits openly so reviewers know exactly where Kendra's results stop being defensible:

- Controlled re-entry / targeted impact location. The 'Active de-orbit burn' option lowers perigee — it does NOT target an impact footprint.

- Component-level demisability / on-ground casualty risk. A real re-entry analysis (ESA DRAMA, NASA ORSAT, etc.) is always required separately.
- Cumulative collision probability against debris > 1 cm (part of ESA / FCC compliance — Kendra screens lifetime only).
- SAR resolution (range or azimuth) — payload model is OPTICAL / IR diffraction only.
- Mode-dependent power profiles (eclipse / pointing / payload-on / comms-pass) — bus and payload loads are treated continuously.
- Atmospheric drag time-of-flight, multi-pass decay or burn duration in the 3D simulation. The simulation is illustrative (badge in the title bar makes this explicit).
- Component-level pointing budget detail (CMG/RW saturation, structural dynamics, sensor bias drift) — Kendra fuses only the two best sensors (inverse-variance) with alignment and thermal terms.
- Propellant TANK volume, pressure, mass and packaging. The mass budget tracks propellant kg; tank feasibility must be checked separately, especially for cold-gas at 12U scale.
- Cost uncertainty interval — the ROM is a point estimate, not a distribution.

Appendix D — Revision history

What changed in each release of Kendra and of this manual. Anything that changed an output a serious user might quote is listed here.

Term	What it means
v1.0.0 — initial release	Kendra publicly available at kendra.avrtec.space. Full Mission Design + Subsystem + Output modules. SMAD-derived constants for Earth (μ, R, J2). Multi-body support (Moon, Mars, Venus, Mercury, Jupiter, Sun). FastAPI + React + Three.js stack.
v1.0.1 — beta pill	Added beta v1.0.1 indicator on the brand wordmark.
v1.0.2 — transfer, deorbit & sizing rewrite	Group sidebar; Hohmann transfer (combined with plane change where cheaper); solar + battery sizing (cell packing, EOL degradation, DoD); drag-derived station-keeping; solar-cycle lifetime range; Sun-eclipse fix; Kepler-anomaly animation; de-orbit phase in the 3D sim.
v1.0.3 — math & policy corrections	MAJOR: fixed ADCS atmospheric density (previously wrong by ~22 000× above 200 km — produced aero-torques 4 orders of magnitude too high; reaction-wheel momentum sizing was misleading). Now uses the same validated density table as propulsion. PAYLOAD: GSD is now reported under BOTH the SMAD Table 17-5 convention (λ/D, diffraction floor) AND the optics Rayleigh convention (1.22·λ/D), so neither user community is surprised. COMMS: documented the Friis-form FSPL sign convention; UI waterfall chart now shows positive loss. DISPOSAL: new selectable post-mission-lifetime standard with ESA Zero Debris (5 yr) as the default; FCC (5 yr) and IADC (25 yr, still the published international consortium guideline) and Custom also available. Renamed 'Disposal compliance' to 'Post-mission lifetime screening' to reflect that Kendra evaluates lifetime only, not full ESA/FCC/IADC compliance. TERMINOLOGY: 'Active controlled burn' renamed to 'Active de-orbit burn (perigee lowering)' — the spacecraft is NOT actively targeting an impact location. SIMULATION: now badged 'Illustrative animation — not an engineering propagator' in the title bar. MANUAL: AVRTEC-1 worked example is fully built from live Kendra outputs at build time (no hand-typed numbers); added model-assumptions appendix C and this revision-history appendix D.
v1.0.4 — SMAD-NSME cross-check + subsystem-math corrections (current)	J2 updated from the older IERS 1996 value (0.0010826267) to the IERS 2003 value (0.0010826359) used by SMAD-NSME Table 10-14 and Table 8-11 — sub-rounding change to outputs but exactly matches SMAD. ORBIT PANEL: now reports BOTH the inertial-frame ground-track speed ($v\_circ \cdot R/(R+h)$, Kendra's previous default) AND the Earth-rotating-frame ground-track speed ($v\_inertial - \omega\_body \cdot R \cdot \cos(i)$, matching SMAD Table 8-11). Manual: Appendix C.3 now distinguishes the two conventions. ATMOSPHERIC DENSITY: Appendix C.10 now explicitly names the Kendra model (Jacchia-77 / NRL-MSISE-blended at F10.7 ≈ 150 sfu) and discloses the divergence from SMAD-NSME Fig 10-17 (US Standard Atmosphere 1976 with MSIS at F10.7 ≈ 100 sfu) — Kendra is 2–6× more conservative at solar-mean conditions above 250 km, with a side-by-side table at

	200–1000 km. ADCS: new Appendix C.8.1 explicitly lists which pointing-budget terms Kendra includes (fused sensor knowledge, alignment, thermal) and which the user must budget separately against SMAD Table 8-17 (control-loop noise, sensor bias drift, estimator latency, structural deflection, micro-vibration/jitter, actuator quantisation, calibration residual, full inertia tensor). SUBSYSTEM-MATH CORRECTIONS: ADCS pointing knowledge now uses minimum-variance (inverse-variance) fusion of the best sensors instead of an RSS sum — an RSS made knowledge worse when a coarser second sensor was added, which is physically wrong for redundant attitude measurements. POWER: total battery capacity is no longer incorrectly divided by the number of parallel strings (the strings now only divide that fixed total into a per-string capacity). THERMAL: equilibrium temperature is explicitly that of an isothermal node radiating from the total surface area; the radiator-area input now drives a real heat-rejection-margin check (capacity vs internal dissipation) rather than being a dead input that was wrongly implied to set temperature. TERMINOLOGY/SCOPE: 'Swath width' renamed 'Ground visibility footprint' (the ground-station access diameter at the minimum elevation, not an imaging-sensor swath); GPS receiver flagged as a position/time aid, not an attitude sensor; the §14.9 propellant counterfactual now uses a green monopropellant (HAN, Isp ≈ 230 s) consistently instead of mislabelling it as hydrazine; added a circular/near-circular-orbit disclaimer to the orbit, eclipse and coverage outputs; softened the Appendix C reproducibility claim to 'principal public equations and assumptions', noting that some component-library constants and lookup tables are maintained in the application; corrected the FCC disposal date (adopted 2022, compliance required 2024).