Last updated: November 1, 2026

🗺️ Four-year roadmap · Year 4, Fall · 🧮 Built-in calculator

About this course

This free course has 10 units and 6 labs. Those are the real counts, not a longer syllabus cut short.

A check is one number or code result on a course page that a script recomputes before the page is published. The printed number and the recomputed number have to match.

> This is a free self-study course outline written by Saving Planets. It is not a university course, it carries no academic credit, and no school is involved.
>
> Its scope follows a one-semester senior spacecraft design course for aerospace engineers. It is modeled on the topics and depth of MIT 16.851 Satellite Engineering (free on MIT OpenCourseWare), using NASA's free Systems Engineering Handbook and Small Spacecraft Technology State of the Art report, which we link where they help. None of those authors, schools or agencies endorses this page.
>
> What we add: every unit ties to real work with a cited public source (NASA's Landsat 9, Europa Clipper and PACE missions and NASA's small-spacecraft technology survey), every number on the page is re-computed by a checking script before it goes live, and every lab has a free simulation or a spreadsheet.
>
> Work through it in order. Each unit has goals, key ideas, equations, step-by-step examples, practice with full answers, common mistakes, flashcards and a quiz. Your progress is saved only in this browser.

How this course helps save the planet

Earth-observing satellites are spacecraft design made useful: power, thermal, pointing and communications all have to work for years so scientists can track forests, water, crops and climate.

Good design also means long life and less waste in orbit. Each unit ends with a short, sourced section. Values that are not from a source are labeled as sample or textbook values.

For instructors

You can teach this course, or let a student work through it alone. It is free. Saving Planets does not give a grade or school credit.

- This page is the whole course: 10 units and 6 labs (AERO 430).
- Plan on 15 weeks, about 6 to 9 hours a week, including the lab weeks.
- Follow the 15-week schedule. Read the unit, do the practice on paper, then open the answer. In a lab week, do the lab or the home version.
- A check is one number or code result on the page that a script recomputes before we publish. The number you see and the recomputed number have to match.
- Use Print this page, or download the PDF study guide. The formula sheet is near the end.
- Ask: how does this unit help people and the planet? Each unit has a green box with a sourced fact.
- Copy the teacher guide template and write in your class name, the time you have, and the questions you will ask. Open the teacher guide template

Before you start

Prerequisites

- Orbital Mechanics: orbits, periods and Δv.
- Thermodynamics: heat transfer and radiation basics.
- Circuits: power, voltage and current.
- Flight Dynamics & Controls and Aerospace Structures: attitude control, stiffness and loads.

How to study

- Start every design from requirements, and keep a budget (mass, power, Δv, link) for every subsystem.
- Carry margins and say where they live.
- Track units: watts versus watt-hours, kelvin for radiation, decibels for links.
- Check every answer against a real mission’s order of magnitude.
- Sketch the spacecraft and its orbit before computing anything.
- Do every practice problem on paper before opening the answer, and retake the quizzes a few days later.

What you need

- A computer or tablet for the free PhET Blackbody Spectrum and Circuit Construction Kit simulations.
- Spreadsheet software (any free one works), or Python.
- NASA mission pages and the Small Spacecraft Technology report in a web browser.
- A calculator.

Suggested 15-week schedule

About 6 to 9 hours a week: reading, practice problems and, in lab weeks, the lab.

Week	Unit	Topics	Reading
1	Mission Requirements and Systems Engineering	Requirements and budgets; Lab A	NASA SE Handbook
2	Orbits and the Space Environment	Orbits and environment; Lab B	MIT 16.851
3	Power Generation: Solar Arrays	Solar arrays; Lab C	NASA SST SOA
4	Energy Storage and the Power Budget	Batteries and power budget; Lab D	NASA SST SOA
5	Thermal Control	Thermal control; Lab E	MIT 16.851
6	Structures, Mechanisms and Launch Loads	Structures and launch loads	MIT 16.851
7	Propulsion and the Delta-v Budget	Δv budgets; midterm practice	MIT 16.851
8	Attitude Determination and Control Subsystem	ADCS requirements	MIT 16.851
9	Attitude Determination and Control Subsystem	Sensors, actuators and momentum	NASA SST SOA
10	Communications and Data Handling	Link budgets	MIT 16.851
11	Communications and Data Handling	Data handling; Lab F	NASA Landsat 9
12	Reliability, Testing and End of Life	Reliability and redundancy	NASA SE Handbook
13	Reliability, Testing and End of Life	Testing and calibration	NASA Landsat 9
14	Reliability, Testing and End of Life	Operations and disposal	NASA SE Handbook
15	Reliability, Testing and End of Life	Review; final practice	MIT 16.851

Your progress

Tick units and labs as you finish them, and take the quizzes. Progress and quiz scores are saved only in this browser, never sent to us.

Units

Mission Requirements and Systems Engineering

Mission objectives, requirements, the project life cycle, trade studies, subsystem budgets, and design margins.

Learning objectives

By the end of this unit you can:

- Turn mission goals into measurable requirements.
- Build a mass budget with margin.
- Run a simple weighted trade study.
- Explain why margins shrink through a project.

Key concepts

- A mission starts with objectives; requirements make them measurable and verifiable (a number, a unit and a test).
- Projects move through phases from concept to operations, with reviews that check requirements are met.
- Every resource gets a budget: mass, power, Δv, data, pointing and cost, each with a margin.
- Early designs carry large margins (often 20–30%, textbook values) because estimates are uncertain; margins shrink as hardware matures.
- Trade studies score options against weighted criteria; the weights matter as much as the scores.

Key equations

$$m_{alloc} = m_{est}(1 + M)$$

`m_alloc=m_est(1+M)`

Mass with margin

$$S = \sum w_i s_i$$

`S= w_is_i`

Weighted trade score

$$\text{Margin} = \frac{\text{Capability} - \text{Need}}{\text{Need}}$$

`Margin=-NeedNeed`

Performance margin

$$\sum w_i = 1$$

`w_i=1`

Weights sum to one

Worked examples, step by step

Example 1.1 A dry-mass estimate is 800 kg. Allocate with a 20% margin (sample values).

1. 800 × 1.20.

Answer: 960 kg.

Example 1.2 NASA says Landsat 9 had to collect at least 400 scenes a day and collects 740. Find the margin.

1. (740 − 400)/400.

Answer: 85% above the requirement (740/400 = 1.85).

Example 1.3 Option A scores 8 (cost) and 6 (performance); B scores 5 and 9. Weights 0.4 and 0.6. Which wins?

1. A = 3.2 + 3.6 = 6.8.
2. B = 2.0 + 5.4 = 7.4.

Answer: B wins, 7.4 to 6.8.

Practice problems

Work each on paper first, then check.

1. Allocate 1200 kg at 25% margin.

   1500 kg.

2. If weights flip to 0.6/0.4, who wins?

   A: 7.2 vs B: 6.6.

3. What makes a requirement verifiable?

A measurable value and a test or analysis to check it.

4. Why carry margin?

   Estimates grow as designs mature.

Common misconceptions

Myth: Requirements are wishes.
Actually: They are measurable and verifiable.

Myth: Margins are waste.
Actually: They absorb growth and surprises.

Myth: Trade studies are objective.
Actually: The weights carry judgment.

Flashcards

Requirement

Measurable, verifiable need.

Budget

Allocation of a resource.

Margin

Reserve above estimate.

Trade study

Weighted comparison.

Life cycle

Phases from concept to disposal.

Verification

Proof a requirement is met.

Self-check quiz

1. 800 kg + 20%...

960 kg

820 kg

1000 kg

640 kg

960 kg. Multiply.

2. Landsat 9 scenes per day...

740

400

100

7400

740. NASA.

3. Trade winner...

B

A

tie

neither

B. 7.4 > 6.8.

4. Margins over time...

shrink

grow

vanish at start

are fixed

shrink. Maturity.

Try this quiz again

How this helps save the planet

NASA says Landsat 9's program requirements included collecting at least 400 scenes a day and a 5-year design life; Landsat 9 collects 740 scenes a day, almost double the minimum, and carries enough fuel to operate for at least 10 years.

Exceeding requirements like these extends a land record that, NASA notes, spans more than five decades and supports deforestation alerts, water-quality monitoring and crop reports.

On Saving Planets: Earth Observation · Solutions

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- NASA Systems Engineering Handbook (https://www.nasa.gov/reference/systems-engineering-handbook/): Free NASA handbook.
- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.

Watch the lecture

Lecture 21: Systems Engineering for Space Shuttle Payloads (https://ocw.mit.edu/courses/16-885j-aircraft-systems-engineering-fall-2005/resources/lecture-21/) (in English)

MIT 16.885J Aircraft Systems Engineering (Fall 2005), MIT OpenCourseWare. License: CC BY-NC-SA 4.0 (https://creativecommons.org/licenses/by-nc-sa/4.0/) · Terms of use (https://ocw.mit.edu/pages/privacy-and-terms-of-use/). Linked for free study only; Saving Planets is not affiliated with or endorsed by this university.

☐ **I finished this unit**

Orbits and the Space Environment

Choosing an orbit, period and speed, sun-synchronous and geostationary orbits, ground tracks and swaths, eclipse, vacuum, radiation and atomic oxygen.

Learning objectives

By the end of this unit you can:

- Compute orbital period and speed.
- Count orbits per day.
- Estimate eclipse duration in low orbit.
- List environment hazards by orbit.

Key concepts

- Period T = 2π√(a³/μ); circular speed v = √(μ/a).
- Sun-synchronous orbits are near-polar and precess once a year, so the satellite crosses the equator at the same local time each day.
- Low orbits pass through Earth’s shadow; the eclipse fraction for a circular orbit with the Sun in the orbit plane is about (2/2π)·asin(R_E/a).
- The space environment includes vacuum, extreme temperatures, radiation belts, atomic oxygen in low orbit and debris.
- Higher orbits see more of Earth but need bigger optics and antennas for the same resolution and data rate.

Key equations

$$T = 2\pi\sqrt{a^3/\mu}$$

T=2π^3/μ

Orbital period

$$v = \sqrt{\mu/a}$$

v=μ/a

Circular speed

$$f_e \approx \frac{\sin^{-1}(R_E/a)}{\pi}$$

Eclipse fraction (worst case)

$$N = \frac{86400}{T}$$

`N=86400/T`

Orbits per day

Worked examples, step by step

Example 2.1 Landsat 9 flies at 705 km. Find its period.

1. a = 6378.137 + 705 = 7083.1 km.
2. T = 2π√(7083.1³/398,600.4).

Answer: T = 98.9 min (NASA lists 99 min).

Example 2.2 Find orbits per day and speed.

1. 86,400/5932.7 s.
2. v = √(398,600.4/7083.1).

Answer: 14.56 orbits/day; 7.50 km/s.

Example 2.3 Estimate the worst-case eclipse.

1. asin(6378.1/7083.1) = 1.121 rad.
2. f = 1.121/π = 0.357.

Answer: About 35.3 min per orbit.

Practice problems

Work each on paper first, then check.

1. Why near-polar?

   To cover the whole globe.

2. Inclination of Landsat 9?

   98.2°.

3. Main low-orbit erosion hazard?

Atomic oxygen.

4. Does eclipse shrink at higher altitude?

   Yes, the fraction drops.

Common misconceptions

Myth: Space is cold, so spacecraft freeze.

Actually: Sunlit parts can overheat; balance matters.

Myth: Higher is always better.

Actually: Resolution and links suffer.

Myth: Sun-synchronous means always sunlit.

Actually: Only dawn–dusk versions avoid eclipse.

Flashcards

Period

$2\pi\sqrt{(a^3/\mu)}$.

Sun-synchronous

Same local crossing time.

Eclipse

Time in Earth’s shadow.

Swath

Ground width imaged.

Atomic oxygen

Erodes LEO surfaces.

Radiation belts

Trapped charged particles.

Self-check quiz

1. Landsat 9 period…

≈99 min

24 h

45 min

12 h

≈99 min. NASA.

2. Orbits per day...

≈14.5

1

100

3

≈14.5. 86,400/T.

3. Worst eclipse at 705 km...

≈35 min

0

60 min

5 min

≈35 min. Computed.

4. Sun-synchronous gives...

same local time

no eclipse

GEO view

zero drag

same local time. Precession.

Try this quiz again

How this helps save the planet

NASA lists Landsat 9 in a near-polar, sun-synchronous orbit at 705 km with a 98.2° inclination, a 99-minute period, about 14.5 orbits a day, a 185 km swath and an equatorial crossing near 10:12 a.m. local time.

With Landsat 8, it observes the same place every 8 days. Same-time-of-day lighting is what lets scientists compare images across decades.

On Saving Planets: Orbital Mechanics · Earth Observation

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.
- NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/): NASA mission page.

☐ **I finished this unit**

Power Generation: Solar Arrays

Solar flux and distance, cell efficiency, sun angle, beginning- and end-of-life power, array sizing and specific power.

Learning objectives

By the end of this unit you can:

- Compute array output per square meter.
- Apply the cosine and inverse-square laws.
- Size an array for a load.
- Compare cell technologies.

Key concepts

- Solar flux near Earth is about 1361 W/m² (textbook value) and falls with the inverse square of distance from the Sun.
- Power drops with the cosine of the angle between the array normal and the Sun.
- NASA's small-spacecraft survey reports multi-junction space cells at a nominal 30% efficiency (up to 34%), versus about 20% for single-junction silicon.
- Degradation from radiation, contamination and aging lowers end-of-life power, so arrays are sized for EOL.
- Specific power (W/kg) often governs feasibility; NASA notes solar-array missions cluster around 30 W/kg.

Key equations

$$P = S\eta A\cos\theta$$

`P=S Aθ`

Array power

$$S(r) = \frac{1361}{r^2}$$

`S(r)=(1361)/(r^2)`

Inverse square (r in AU)

$$A = \frac{P}{S\eta f_d}$$

`A=(P)/(S f_d)`

Array area

$$SP = \frac{P}{m}$$

SP=P/m

Specific power

Worked examples, step by step

Example 3.1 Find output per m² for 30% cells facing the Sun at 1 AU.

1. 1361 × 0.30.

Answer: 408.3 W/m².

Example 3.2 Find the area for 2 kW with a 0.85 degradation-and-packing factor (sample value).

1. 2000/(1361 × 0.30 × 0.85).

Answer: 5.76 m².

Example 3.3 Find solar flux at Jupiter (5.2 AU).

1. 1361/5.2².

Answer: 50.3 W/m², 27 times less.

Practice problems

Work each on paper first, then check.

1. Output per m² tilted 30°?

   353.6 W/m².

2. Flux at Mars (1.524 AU)?

   586 W/m².

3. Output per m² for 20% silicon?

272.2 W/m².

4. Array mass for 2 kW at 30 W/kg?

   66.7 kg.

Common misconceptions

Myth: Distance hardly matters.
Actually: Flux falls as 1/r².

Myth: BOL power is enough.
Actually: Size for end of life.

Myth: Efficiency is all that matters.
Actually: Mass and stowed volume matter too.

Flashcards

Solar flux

≈1361 W/m² at 1 AU.

Multi-junction cell

Stacked bandgaps, ~30%.

BOL/EOL

Beginning/end of life.

Cosine loss

P ∝ cos θ.

Inverse square

S ∝ 1/r².

Specific power

W/kg.

Self-check quiz

1. 30% at 1 AU per m²…

408 W

1361 W

136 W

30 W

408 W. Multiply.

2. Flux at Jupiter...

≈50 W/m²

1361

500

5

≈50 W/m². 1/r².

3. Nominal multi-junction η (NASA)...

30%

10%

50%

86%

30%. SOA report.

4. Tilt reduces power by...

cos θ

sin θ

θ²

nothing

cos θ. Cosine.

Try this quiz again

How this helps save the planet

NASA describes Europa Clipper as a solar-powered spacecraft that, with its solar arrays deployed, spans more than 100 feet (about 30 meters); it launched Oct. 14, 2024, and will travel 1.8 billion miles to reach Jupiter in April 2030.

At Jupiter, sunlight is about 27 times weaker than at Earth, which is why Clipper's arrays are so large: this unit's inverse-square law, at mission scale.

On Saving Planets: Solutions · Orbital Mechanics

Sources: NASA Science: Europa Clipper (https://science.nasa.gov/mission/europa-clipper/) · NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/)

Free learning resources

- NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/): Free NASA power chapter.
- PhET: Circuit Construction Kit: DC (https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc): Series and parallel strings.

☐ **I finished this unit**

Energy Storage and the Power Budget

Load lists, sunlight and eclipse energy balance, battery sizing with depth of discharge, specific energy, power management and distribution.

Learning objectives

By the end of this unit you can:

- Build a load list and orbit-average power.
- Size a battery for eclipse.
- Compute battery mass from specific energy.
- Explain depth-of-discharge limits.

Key concepts

- The power budget sums every load by mode; the array must power loads in sunlight and recharge the battery for eclipse.
- Battery energy = load × eclipse time ÷ allowed depth of discharge (DoD).
- Shallow DoD extends cycle life; low orbits see about 15 cycles a day, so DoD is often kept low (textbook guidance).
- NASA's survey reports commercial Li-ion cells at about 150–270 Wh/kg and 3.6 V average.
- Power management and distribution regulates bus voltage, switches loads and isolates faults.

Key equations

$$E = \frac{P_e t_e}{DoD}$$

`E=(P_et_e)/(DoD)`

Battery energy

$$m_b = \frac{E}{e_{sp}}$$

`m_b=_sp`

Battery mass

$$P_{avg} = \frac{P_d t_d + P_e t_e}{T}$$

`P_avg=(P_dt_d+P_et_e)/(T)`

Orbit-average load

$$Ah = \frac{Wh}{V}$$

`Ah=Wh/V`

Capacity

Worked examples, step by step

Example 4.1 A 500 W load must ride through the 35.3-minute eclipse from Unit 2. Find the energy used.

1. 500 × 35.28/60.

Answer: 294 Wh.

Example 4.2 Size the battery for 30% DoD (sample value).

1. 294/0.30.

Answer: 980 Wh.

Example 4.3 Find battery mass at 150 Wh/kg pack level.

1. 980/150.

Answer: 6.53 kg.

Practice problems

Work each on paper first, then check.

1. Capacity at 28 V?

   35 Ah.

2. Mass using 260 Wh/kg cells?

   3.77 kg (cells only).

3. Cycles per day at 14.56 orbits/day?

   About 14.6.

4. Why not 100% DoD?

   Cycle life collapses.

Common misconceptions

Myth: Watts and watt-hours are the same.

Actually: Power vs energy.

Myth: Deep discharge is fine.

Actually: It shortens life.

Myth: Cell energy = pack energy.

Actually: Packs add mass for structure and management.

Flashcards

Load list

Power per subsystem and mode.

DoD

Fraction of capacity used.

Specific energy

Wh/kg.

PMAD

Power management and distribution.

Eclipse

No solar power.

Orbit-average power

Time-weighted load.

Self-check quiz

1. Eclipse energy...

294 Wh

500 Wh

35 Wh

1000 Wh

294 Wh. P × t.

2. Battery at 30% DoD…

980 Wh

294 Wh

88 Wh

3000 Wh

980 Wh. Divide.

3. Li-ion cell voltage…

3.6 V

1.5 V

12 V

28 V

3.6 V. NASA.

4. Battery mass…

6.53 kg

65 kg

0.65 kg

1 kg

6.53 kg. 980/150.

Try this quiz again

How this helps save the planet

NASA's small-spacecraft technology survey lists 18650 lithium-ion cells with flight heritage on NASA missions, including LG Chem INR18650-MJ1 cells at 260 Wh/kg for NASA's PACE mission and LG Chem ICR18650 B3 cells at 191–205 Wh/kg for Europa Clipper.

PACE, launched in February 2024, measures phytoplankton, aerosols and clouds to help monitor ocean health, air quality and climate. Its batteries keep it working through every eclipse.

On Saving Planets: Oceans · Circuits

Sources: NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/) · NASA Science: PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) (https://science.nasa.gov/mission/pace/)

Free learning resources

- NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/): Free NASA power chapter.
- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.

☐ **I finished this unit**

Thermal Control

Radiation balance, absorptivity and emissivity, equilibrium temperature, radiator sizing, coatings, heaters and multilayer insulation.

Learning objectives

By the end of this unit you can:

- Compute an equilibrium temperature.
- Size a radiator.
- Choose coatings by α/ε.
- Explain heaters and insulation.

Key concepts

- In vacuum, heat leaves mainly by radiation: Q = εσAT⁴.
- Absorbed sunlight is αSA_proj; the ratio α/ε of a surface sets its equilibrium temperature.
- A black sphere at 1 AU with α = ε settles near (S/4σ)^¼ ≈ 278 K.
- Radiators reject waste heat; white paints and mirrors have low α/ε, staying cool in sunlight.
- Multilayer insulation blocks radiation; heaters keep batteries and propellant warm in eclipse.

Key equations

$$Q = \varepsilon \sigma A T^4$$

`Q=σ AT^4`

Radiated heat

$$T = \left(\frac{\alpha S}{4 \varepsilon \sigma} \right)^{1/4}$$

`T=((α S)/(4σ))^1/4`

Sphere equilibrium

$$A_r = \frac{Q}{\varepsilon \sigma T^4}$$

`A_r=(Q)/(σ T^4)`

Radiator area

$$Q_{abs} = \alpha S A_p$$

`Q_abs=α SA_p`

Absorbed sunlight

Worked examples, step by step

Example 5.1 Find the equilibrium temperature of a sphere at 1 AU with α = ε.

1. T = (1361/(4 × 5.6704 × 10⁻⁸))^¼.

Answer: T = 278.3 K (5 °C).

Example 5.2 Size a radiator to reject 500 W at 290 K with ε = 0.85 (ignoring absorbed sunlight).

1. A = 500/(0.85 × 5.6704 × 10⁻⁸ × 290⁴).

Answer: A = 1.47 m².

Example 5.3 How does equilibrium temperature scale with α/ε?

1. T ∝ (α/ε)^¼.

Answer: Doubling α/ε raises T by 2^¼ = 1.189.

Practice problems

Work each on paper first, then check.

1. T for α/ε = 2?

   331 K.

2. Radiator at 260 K for 500 W?

   2.27 m².

3. What does MLI do?

   Blocks radiative heat flow.

4. Why heaters in eclipse?

   To keep parts above minimum temperatures.

Common misconceptions

Myth: Space conducts heat away.

Actually: Vacuum: radiation dominates.

Myth: Black is always hot.

Actually: Depends on α/ε.

Myth: Thermal is an afterthought.

Actually: It drives layout and power.

Flashcards

Absorptivity α

Fraction of sunlight absorbed.

Emissivity ε

Radiating ability.

MLI

Multilayer insulation.

Radiator

Heat-rejecting surface.

Heater

Keeps parts warm.

σ

5.6704×10^{-8} W/(m²·K⁴).

Self-check quiz

1. Sphere at 1 AU...

278 K

373 K

200 K

0 K

278 K. Computed.

2. Q = ...

$\varepsilon\sigma AT^4$

$hA\Delta T$

$kA\Delta T/L$

$mc\Delta T$

$\varepsilon\sigma AT^4$. Radiation.

3. Radiator area example...

1.47 m^2

14.7 m^2

0.15 m^2

5 m^2

1.47 m^2. Computed.

4. Low α/ε surface...

stays cool

gets hot

no effect

glows

stays cool. Balance.

Try this quiz again

How this helps save the planet

NASA explains that Landsat 9's Thermal Infrared Sensor measures land surface temperature and contains a cryocooler radiator, an Earth shield, and a blackbody plus deep-space view for

calibration.

Thermal design is the instrument here: TIRS measures heat from Earth, which NASA notes helps track and manage water use, only because its own detectors are kept cold and stable.

On Saving Planets: Thermodynamics · Earth Observation

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- NASA Small Spacecraft Technology State of the Art: Thermal Control (https://www.nasa.gov/smallsat-institute/sst-soa/thermal-control/): Free NASA thermal chapter.
- PhET: Blackbody Spectrum (https://phet.colorado.edu/en/simulations/blackbody-spectrum): Thermal radiation.

- [ ] **I finished this unit**

Structures, Mechanisms and Launch Loads

Launch loads, quasi-static design loads, stiffness and natural frequency requirements, materials, deployables, and heritage buses.

Learning objectives

By the end of this unit you can:

- Compute a quasi-static launch load.
- Compute a natural frequency.
- Explain stiffness requirements.
- Weigh heritage versus new design.

Key concepts

- Launch subjects spacecraft to steady acceleration, vibration, acoustics and shock; design starts from quasi-static load factors (often several g, textbook values).
- Launch vehicles require the spacecraft's fundamental frequency to stay above a minimum so it does not couple with the rocket.
- For a simple spring-mass model, f = (1/2π)√(k/m): stiffness raises frequency, mass lowers it.
- Aluminum honeycomb and composites give stiffness for little mass; mechanisms deploy arrays, antennas and booms.
- Reusing a flight-proven bus (heritage) cuts risk and schedule.

Key equations

$$F = n\,m\,g_0$$

`F=n m g_0`

Quasi-static load

$$f = \frac{1}{2\pi}\sqrt{k/m}$$

`f=(1)/(2π)/m`

Natural frequency

$$\sigma = F/A$$

Stress

$$k = \frac{EA}{L}$$

k=EA/L

Axial stiffness

Worked examples, step by step

Example 6.1 Find the design load for a 1000 kg spacecraft at 6 g (sample values).

1. 6 × 1000 × 9.80665.

Answer: 58.8 kN.

Example 6.2 A 100 kg instrument on a mount of stiffness 10^6 N/m (sample values). Find f.

1. $(1/2\pi)\sqrt{(10^6/100)}$.

Answer: f = 15.9 Hz.

Example 6.3 How stiff must the mount be to double f?

1. $f \propto \sqrt{k}$.

Answer: 4×10^6 N/m (31.8 Hz).

Practice problems

Work each on paper first, then check.

1. f if mass doubles?

   11.3 Hz.

2. Load at 4 g for 500 kg?

   19.6 kN.

3. Why minimum frequency?

   Avoid coupling with launcher dynamics.

4. What is a heritage bus?

   A flight-proven spacecraft platform.

Common misconceptions

Myth: Strength is the only goal.
Actually: Stiffness often drives design.

Myth: Heavier is safer.
Actually: Mass lowers frequency and costs launch.

Myth: Deployables are simple.
Actually: They are common single points of failure.

Flashcards

Quasi-static load

Equivalent steady g.

Natural frequency

$(1/2\pi)\sqrt{(k/m)}$.

Honeycomb

Light stiff panel.

Deployable

Unfolds in orbit.

Heritage

Flight-proven design.

Bus

Spacecraft platform.

Self-check quiz

1. 6 g on 1000 kg...

58.8 kN

6 kN

9.8 kN

588 kN

58.8 kN. nmg.

2. f example…

15.9 Hz

100 Hz

1 Hz

159 Hz

15.9 Hz. Formula.

3. Double f needs k ×…

4

2

√2

8

4. f ∝ √k.

4. Heritage reduces…

risk

mass always

power

orbit

risk. Proven.

Try this quiz again

How this helps save the planet

NASA says Northrop Grumman designed and built the Landsat 9 spacecraft by adapting the LEOStar bus design used for Landsat 8, and integrated both instruments and ran satellite-level testing.

Reusing a proven bus is a design choice that reduces risk and helps keep the Landsat record continuous, which NASA notes is the longest continuous satellite record of Earth's land surface.

On Saving Planets: Aerospace Structures · Earth Observation

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.
- NASA Small Spacecraft Technology State of the Art (https://www.nasa.gov/smallsat-institute/sst-soa/): Free NASA technology survey.

☐ **I finished this unit**

Propulsion and the Delta-v Budget

Δv budgets for orbit insertion, station-keeping, attitude and disposal; the rocket equation for propellant mass; gravity assists; and propulsion choices.

Learning objectives

By the end of this unit you can:

- Build a Δv budget.
- Compute propellant mass from Δv.
- Compute Δv from propellant.
- Explain gravity assists.

Key concepts

- A Δv budget lists every maneuver: insertion, orbit maintenance, attitude control, collision avoidance and disposal, plus margin.
- Propellant needed: m_p = m_0(1 − e^(−Δv/v_e)).
- Monopropellant thrusters are simple; bipropellant gives higher Isp; electric gives very high Isp at low thrust.
- Gravity assists borrow momentum from a planet to change speed and direction without propellant.
- Leftover propellant can extend a mission past its design life.

Key equations

$$m_p = m_0 \left(1 - e^{-\Delta v / v_e}\right)$$

`m_p=m_0(1-e^-Δ v/v_e)`

Propellant mass

$$\Delta v = v_e \ln \frac{m_0}{m_f}$$

`Δ v=v_e(m_0)/(m_f)`

Rocket equation

$$v_e = I_{sp} g_0$$

`v_e=I_spg_0`

Exhaust velocity

$$\Delta v_{tot} = \sum \Delta v_i (1 + M)$$

`Δ v_tot=Δ v_i(1+M)`

Budget with margin

Worked examples, step by step

Example 7.1 A 1000 kg spacecraft needs 100 m/s with Isp 300 s (sample values). Find propellant.

1. v_e = 2942 m/s.
2. m_p = 1000(1 − e^(−100/2942)).

Answer: 33.4 kg.

Example 7.2 What Δv does 50 kg of propellant give?

1. 2942 ln(1000/950).

Answer: 150.9 m/s.

Example 7.3 Budget: 60 m/s insertion trim, 30 m/s station-keeping, 10 m/s disposal, 20% margin.

1. 100 × 1.2.

Answer: 120 m/s.

Practice problems

Work each on paper first, then check.

1. Propellant for 120 m/s?

   39.9 kg.

2. v_e for Isp 220 s?

   2157 m/s.

3. What does a gravity assist save?

   Propellant for the same Δv.

4. Why budget disposal Δv?

   To leave orbit responsibly.

Common misconceptions

Myth: Propellant scales linearly with Δv.

Actually: Exponentially.

Myth: Gravity assists are free energy.

Actually: Momentum is exchanged with the planet.

Myth: Disposal is optional.

Actually: It protects orbits for others.

Flashcards

Δv budget

Sum of maneuvers.

Station-keeping

Holding an orbit.

Monopropellant

Single propellant, simple.

Bipropellant

Fuel + oxidizer.

Gravity assist

Planetary flyby boost.

Disposal

End-of-life deorbit or graveyard.

Self-check quiz

1. m_p for 100 m/s...

33.4 kg

100 kg

3.3 kg

334 kg

33.4 kg. Formula.

2. Δv from 50 kg…

151 m/s

50 m/s

500 m/s

15 m/s

151 m/s. Rocket eq.

3. Budget with margin…

120 m/s

100 m/s

80 m/s

200 m/s

120 m/s. ×1.2.

4. Clipper’s Dec 2026 Earth pass is a…

gravity assist

landing

refuel

launch

gravity assist. NASA.

Try this quiz again

How this helps save the planet

NASA says Europa Clipper flew past Mars in 2025 and will swing by Earth again on Dec. 3, 2026, for a gravity assist that gives it a push for the rest of its trip to Jupiter, where it will make 49 close flybys of Europa.

Gravity assists stretch a fixed propellant load, the same goal this unit's Δv budget serves for Earth orbiters like Landsat 9, which NASA says carries fuel for at least 10 years.

On Saving Planets: Orbital Mechanics · Propulsion

Sources: NASA Science: Europa Clipper (https://science.nasa.gov/mission/europa-clipper/) · NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.
- NASA Small Spacecraft Technology State of the Art (https://www.nasa.gov/smallsat-institute/sst-soa/): Free NASA technology survey.

- [ ] **I finished this unit**

Attitude Determination and Control Subsystem

Pointing requirements from payloads, sensors and actuators, disturbance torques, momentum budgets, and pointing error on the ground.

Learning objectives

By the end of this unit you can:

- Derive a pointing requirement from ground resolution.
- Compute ground error from angle error.
- Build a momentum budget.
- Pick sensors and actuators.

Key concepts

- Payloads set pointing: an imager's pixel subtends an angle of (ground pixel)/(altitude).
- Ground error ≈ altitude × angle error (small angles).
- Sensors: star trackers, sun sensors, magnetometers, gyros; actuators: reaction wheels, magnetic torquers, thrusters.
- Disturbances (gravity gradient, drag, solar pressure, magnetic) build momentum H = τt that wheels must store.
- Momentum is dumped with magnetic torquers or thrusters before wheels saturate.

Key equations

$$\theta = \frac{x}{h}$$

Pixel angle

$$e = h\theta$$

Ground error

$$H = \tau t$$

`H=τ t`

Accumulated momentum

$$1'' = \frac{\pi}{648000}\,\mathrm{rad}$$

`1^=(π)/(648000) rad`

Worked examples, step by step

Example 8.1 Landsat 9 has 30 m pixels from 705 km. Find the angle per pixel.

1. 30/705,000 rad.

Answer: 4.26×10^{-5} rad = 8.78 arcsec.

Example 8.2 A 0.01° pointing error from 705 km shifts the image how far?

1. 705,000 × 0.0001745.

Answer: 123 m, about four pixels.

Example 8.3 A 10^{-5} N·m disturbance acts for a quarter of a 98.9-minute orbit (sample value). Find the momentum.

1. 10^{-5} × 1483 s.

Answer: 0.0148 N·m·s.

Practice problems

Work each on paper first, then check.

1. Angle for a 15 m pixel?

   4.39 arcsec.

2. Ground error for 0.001°?

   12.3 m.

3. Which sensor gives absolute attitude?

   A star tracker.

4. How are wheels unloaded in LEO?

   Magnetic torquers or thrusters.

Common misconceptions

Myth: Pointing knowledge equals control.

Actually: They are separate budgets.

Myth: Wheels can absorb momentum forever.

Actually: They saturate.

Myth: Small angles do not matter.

Actually: Altitude multiplies them.

Flashcards

Pointing accuracy

Control error.

Pointing knowledge

Measurement error.

Star tracker

Attitude from stars.

Magnetic torquer

Coil reacting with Earth’s field.

Gravity gradient

Tidal torque.

Momentum dumping

Unloading wheels.

Self-check quiz

1. Landsat pixel angle...

8.78"

1°

0.1"

60"

8.78". 30/705 km.

2. 0.01° at 705 km…

123 m

12 m

1.2 km

1 m

123 m. hθ.

3. H = …

τt

Iα

τ/t

mv

τt. Momentum.

4. Absolute attitude sensor…

star tracker

gyro

wheel

heater

star tracker. Stars.

Try this quiz again

How this helps save the planet

NASA lists Landsat 9's spatial resolution as 30 m for visible and shortwave infrared bands, 15 m panchromatic and 100 m thermal, from 705 km.

Holding a 30 m pixel steady from that height takes arcsecond-level control, the reason Landsat images line up across years for change detection.

On Saving Planets: Flight Dynamics & Controls · Earth Observation

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.
- NASA Small Spacecraft Technology State of the Art (https://www.nasa.gov/smallsat-institute/sst-soa/): Free NASA technology survey.

☐ **I finished this unit**

Communications and Data Handling

Data volume, downlink rates, the link budget in decibels, free-space path loss, antenna gain, and onboard computing and storage.

Learning objectives

By the end of this unit you can:

- Compute free-space path loss.
- Compute dish antenna gain.
- Build a simple link budget.
- Estimate daily data volume.

Key concepts

- Free-space path loss L = 20 $\log_{10}$(4πd/λ) dB grows with distance and frequency.
- Dish gain G = η(πD/λ)²; bigger dishes and higher frequencies give narrower, stronger beams.
- Link budget: received power = transmit power + gains − losses (all in dB); the margin over what the receiver needs must be positive.
- Data volume = images × bits per image; rate × contact time must exceed it.
- Command and data handling computers store data, run software and manage faults.

Key equations

$$L = 20 \log_{10} \frac{4\pi d}{\lambda}$$

`L=20_10(4π d)/()`

Free-space path loss

$$G = \eta \left(\frac{\pi D}{\lambda} \right)^2$$

`G=((π D)/())^2`

Dish gain

$$P_r = P_t + G_t + G_r - L$$

`P_r=P_t+G_t+G_r-L`

Link budget (dB)

$$\lambda = c/f$$

Wavelength

Worked examples, step by step

Example 9.1 Find the X-band (8.2 GHz) path loss at 2000 km (c = 3 × 10^8 m/s).

1. λ = 0.03659 m.
2. 20 $\log_{10}(4\pi \times 2 \times 10^6/0.03659)$.

Answer: L = 176.7 dB.

Example 9.2 Find the gain of a 3 m dish at 8.2 GHz with η = 0.55 (sample value).

1. 0.55 × $(\pi \times 3/0.03659)^2$.

Answer: G = 45.6 dBi.

Example 9.3 What happens to path loss if distance doubles?

1. +20 $\log_{10}$ 2.

Answer: +6.0 dB (182.8 dB at 4000 km).

Practice problems

Work each on paper first, then check.

1. Wavelength at 8.2 GHz?

   3.66 cm.

2. Gain change for a 6 m dish?

   +6.0 dB.

3. Landsat 9 scenes per day?

   About 740.

4. Bits per pixel for Landsat 9 OLI?

14.

Common misconceptions

Myth: Decibels add like watts.

Actually: dB add for products.

Myth: Higher frequency is always worse.

Actually: Loss rises but dish gain rises too.

Myth: Data volume is small.

Actually: It often drives ground-station design.

Flashcards

Path loss

Spreading loss in dB.

Antenna gain

Beam concentration.

Link margin

Received minus required.

X-band

≈8 GHz.

C&DH

Command and data handling.

Data volume

Bits per day.

Self-check quiz

1. Path loss 2000 km X-band...

176.7 dB

100 dB

50 dB

250 dB

176.7 dB. Formula.

2. 3 m dish gain…

45.6 dBi

10 dBi

90 dBi

3 dBi

45.6 dBi. Formula.

3. Double distance…

+6 dB loss

+3 dB

×2 dB

none

+6 dB loss. 20 log 2.

4. Link budget uses…

dB sums

products of watts only

volts

joules

dB sums. Log units.

Try this quiz again

How this helps save the planet

NASA says Europa Clipper carries nine science instruments plus a gravity experiment that uses its telecommunications system, and shows its 10-foot (3-meter) high-gain antenna installed in August

2023.

Closer to home, NASA reports Landsat 9 records 14-bit data and collects more than 700 scenes a day. Moving that much data to the ground every day is a communications design problem first.

On Saving Planets: Earth Observation · Circuits

Sources: NASA Science: Europa Clipper (https://science.nasa.gov/mission/europa-clipper/) · NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.
- NASA Small Spacecraft Technology State of the Art (https://www.nasa.gov/smallsat-institute/sst-soa/): Free NASA technology survey.

☐ **I finished this unit**

Reliability, Testing and End of Life

Failure rates and reliability, redundancy, environmental testing, calibration and verification, operations and responsible disposal.

Learning objectives

By the end of this unit you can:

- Compute reliability from a failure rate.
- Compute the benefit of redundancy.
- Describe environmental tests.
- Plan end-of-life disposal.

Key concepts

- With a constant failure rate λ, reliability R(t) = e^(−λt) and mean time between failures is 1/λ.
- Two units in parallel: R = 1 − (1 − R_1)²; redundancy trades mass and cost for reliability.
- “Test like you fly”: vibration, acoustic, shock, thermal-vacuum and electromagnetic tests before launch.
- Calibration keeps science data accurate over time; cross-calibration with other satellites ties records together.
- At end of life, spacecraft should be deorbited or moved to a disposal orbit to limit debris.

Key equations

$$R(t) = e^{-\lambda t}$$

```
R(t)=e^- t
```

Reliability

$$R_p = 1 - (1 - R)^2$$

```
R_p=1-(1-R)^2
```

Two in parallel

$$MTBF = 1/\lambda$$

```
MTBF=1/
```

Mean time between failures

$$R_s = \prod R_i$$

`R_s= R_i`

Series system

Worked examples, step by step

Example 10.1 A unit has $\lambda = 10^{-5}$ per hour (sample value). Find its 5-year reliability.

1. t = 43,800 h.
2. e^(−0.438).

Answer: R = 0.645.

Example 10.2 Add a redundant unit in parallel.

1. $1 - 0.355^2$.

Answer: R = 0.874.

Example 10.3 Find the MTBF.

1. $1/10^{-5}$ h.

Answer: 100,000 h = 11.4 years.

Practice problems

Work each on paper first, then check.

1. 10-year reliability of one unit?

   0.416.

2. Series system of 0.95 and 0.90?

   0.855.

3. Name a pre-launch environmental test.

   Thermal vacuum or vibration.

4. Why cross-calibrate?

   To keep records consistent across satellites.

Common misconceptions

Myth: Redundancy is free.

Actually: It costs mass, power and money.

Myth: Testing proves zero risk.

Actually: It reduces risk.

Myth: Disposal is someone else’s job.

Actually: It is designed in from the start.

Flashcards

Reliability

Probability of working.

Failure rate λ

Failures per hour.

Redundancy

Backup units.

Thermal vacuum test

Space conditions on the ground.

Calibration

Keeping measurements accurate.

Disposal

End-of-life deorbit.

Self-check quiz

1. 5-year R...

0.645

0.95

0.5

0.1

0.645. e^(−0.438).

2. Parallel pair…

0.874

0.645

0.416

1

0.874. 1 − 0.355^2.

3. MTBF…

100,000 h

10^{-5} h

1000 h

1 h

100,000 h. 1/λ.

4. Landsat underfly purpose…

cross-calibration

refuel

docking

disposal

cross-calibration. NASA.

Try this quiz again

How this helps save the planet

NASA reports that just after launch, Landsat 9 flew directly below Landsat 8 in a once-in-a-mission “underfly,” collecting 2,396 images from November 12–16, 2021, so calibration experts could compare

both satellites' measurements and ensure data continuity.

NASA notes that onboard calibration and redundancy help Landsat 9 collect accurate, reliable data for its mission life: reliability engineering in service of a planetary record.

On Saving Planets: Earth Observation · Solutions

Sources: NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Free learning resources

- NASA Systems Engineering Handbook (https://www.nasa.gov/reference/systems-engineering-handbook/): Free NASA handbook.
- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT lectures.

☐ **I finished this unit**

Problem Sets

These practice problems live inside each unit. Work on paper first, then open the answer.

1. Mission Requirements and Systems Engineering
   4 problems
2. Orbits and the Space Environment
   4 problems
3. Power Generation: Solar Arrays
   4 problems
4. Energy Storage and the Power Budget
   4 problems
5. Thermal Control
   4 problems
6. Structures, Mechanisms and Launch Loads
   4 problems
7. Propulsion and the Delta-v Budget
   4 problems
8. Attitude Determination and Control Subsystem
   4 problems
9. Communications and Data Handling
   4 problems
10. Reliability, Testing and End of Life
    4 problems

The lab (Spacecraft design lab)

The lab is the hands-on part of the course. Here it is free and for practice only, with no credit.

Every lab runs in a free simulation or a spreadsheet, so there are no physical hazards. Do not build, charge or modify battery packs for this course. Take screen breaks, sit with good posture, and keep cables out of walkways.

Safety reference: OSHA: Walking-working surfaces (slip, trip and fall hazards) (https://www.osha.gov/walking-working-surfaces)

Lab A: Mass and power budgets with margin

WEEK 1

Goal: Build a spreadsheet mass and power budget for a small Earth-observing satellite and apply margins.

$$m_{alloc} = m_{est}(1 + M)$$

```
m_alloc=m_est(1+M)
```

Allocation with margin

Procedure

1. List subsystems: payload, structure, power, thermal, ADCS, propulsion, comms, C&DH.
2. Enter sample mass estimates totaling 800 kg and power estimates totaling 500 W.
3. Apply 20% margin to each total.
4. Run the two-option weighted trade from Unit 1 and change the weights.

Data table

Budget	Estimate	With 20% margin
Dry mass	800 kg	960 kg
Power	500 W	600 W

Sample values.

Sample calculation

1. 800 × 1.2 = 960 kg.
2. 500 × 1.2 = 600 W.

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any spreadsheet works.

NASA Systems Engineering Handbook (https://www.nasa.gov/reference/systems-engineering-handbook/)

Planet link: NASA: Landsat 9 collects 740 scenes a day against a 400-scene requirement. NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

- [ ] **I completed this lab (wet or virtual)**

Lab B: Orbit period and eclipse calculator

WEEK 2

Goal: Compute period and worst-case eclipse for several low-orbit altitudes.

$$T = 2\pi\sqrt{a^3/\mu}$$

T=2π^3/μ

Orbital period

Procedure

1. Enter altitudes of 400, 705 and 1000 km.
2. Compute a, T and orbits per day.
3. Compute the eclipse fraction and minutes.
4. Compare 705 km with NASA's Landsat 9 values.

Data table

Altitude (km)	T (min)	Eclipse (min)
400	92.6	36.1
705	98.9	35.3
1000	105.1	34.9

Computed worst-case values (Sun in the orbit plane).

Sample calculation

1. T(400) = 2π√(6778.1³/398,600.4) = 92.6 min.
2. Eclipse(705) = 0.357 × 98.9 = 35.3 min.

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any spreadsheet works.

NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

Planet link: NASA lists Landsat 9 at 705 km with a 99-minute period. NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

- [ ] **I completed this lab (wet or virtual)**

Lab C: Solar cells in series and parallel

WEEK 3

Goal: Wire cells as batteries in PhET Circuit Construction Kit to see series and parallel strings, then size arrays across the solar system.

$$A = \frac{P}{S \eta f_d}$$

`A=(P)/(S f_d)`

Array area

Procedure

1. In PhET Circuit Construction Kit, connect sources in series and in parallel and note voltage and current.
2. In a spreadsheet, compute array area for 500 W with η = 0.30 and f_d = 0.85.
3. Repeat at 1, 1.524 and 5.2 AU.
4. Explain why outer-planet missions need huge arrays.

Data table

Distance (AU)	Area for 500 W (m²)
1	1.44
1.524	3.35
5.2	39.0

Computed sample values.

Sample calculation

1. 500/(1361 × 0.3 × 0.85) = 1.44 m².
2. 1.44 × 5.2² = 39.0 m².

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any browser and spreadsheet work.

PhET: Circuit Construction Kit: DC (https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc) · NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/)

Planet link: NASA: Europa Clipper's deployed arrays span more than 30 meters. NASA Science: Europa Clipper (https://science.nasa.gov/mission/europa-clipper/)

- [ ] **I completed this lab (wet or virtual)**

Lab D: Eclipse battery sizing

WEEK 4

Goal: Size batteries for different loads through a 35.3-minute eclipse.

$$E = \frac{P_e t_e}{DoD}$$

`E=(P_et_e)/(DoD)`

Battery energy

Procedure

1. Use the 705 km eclipse from Lab B.
2. Enter loads of 300, 500 and 800 W.
3. Compute battery energy at 30% DoD and mass at 150 Wh/kg.
4. Repeat with 20% DoD and discuss cycle life.

Data table

Load (W)	Battery (Wh)	Mass (kg)
300	588	3.92
500	980	6.53
800	1568	10.45

Computed sample values.

Sample calculation

1. 300 × 0.588 h/0.3 = 588 Wh.
2. 1568/150 = 10.45 kg.

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any spreadsheet works.

NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/)

Planet link: NASA lists 260 Wh/kg 18650 cells with heritage on its PACE mission. NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/)

- [ ] **I completed this lab (wet or virtual)**

Lab E: Radiation balance and radiator sizing

WEEK 5

Goal: Explore thermal radiation in PhET Blackbody Spectrum, then compute equilibrium temperatures and radiator areas.

$$T = \left(\frac{\alpha S}{4\varepsilon\sigma}\right)^{1/4}$$

T=((α S)/(4σ))^1/4

Sphere equilibrium

Procedure

1. In PhET Blackbody Spectrum, compare spectra at 250, 290 and 6000 K.
2. Compute sphere temperatures for α/ε = 0.5, 1 and 2.
3. Compute radiator area for 500 W at 250, 290 and 320 K with ε = 0.85.
4. Pick a radiator temperature and explain the trade.

Data table

Case	Result
α/ε = 0.5	234.0 K
α/ε = 1	278.3 K
α/ε = 2	331.0 K
Radiator at 250 K	2.66 m²
Radiator at 320 K	0.99 m²

Computed values.

Sample calculation

1. T = 278.3 × 0.5^¼ = 234.0 K.
2. A = 500/(0.85σ × 320⁴) = 0.99 m².

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any browser and spreadsheet work.

PhET: Blackbody Spectrum (https://phet.colorado.edu/en/simulations/blackbody-spectrum) · NASA Small Spacecraft Technology State of the Art: Thermal Control (https://www.nasa.gov/smallsat-institute/sst-soa/thermal-control/)

Planet link: NASA: Landsat 9's TIRS uses a cryocooler radiator and onboard blackbody. NASA Science: Landsat 9 (https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-overview/)

☐ **I completed this lab (wet or virtual)**

Lab F: Downlink link budget

WEEK 11

Goal: Build a decibel link budget and see how distance and antenna size change the margin.

$$L = 20 \log_{10} \frac{4\pi d}{\lambda}$$

`L=20_10(4π d)/()`

Free-space path loss

Procedure

1. Use f = 8.2 GHz and c = 3 × 10⁸ m/s.
2. Compute path loss at 1000, 2000 and 4000 km.
3. Add transmit power, both antenna gains and other losses.
4. Find the dish size that restores margin at 4000 km.

Data table

Distance (km)	Path loss (dB)
1000	170.7
2000	176.7
4000	182.8

Computed values.

Sample calculation

1. λ = 0.03659 m.
2. 20 $\log_{10}$(4π × 10⁶/0.03659) = 170.7 dB.

> **Safety**
>
> - Computer only.

Home or virtual alternative

- Any spreadsheet works.

MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/)

Planet link: NASA: Europa Clipper carries a 3-meter high-gain antenna. NASA Science: Europa Clipper (https://science.nasa.gov/mission/europa-clipper/)

☐ **I completed this lab (wet or virtual)**

Exam prep practice sets

Time yourself: about 10 minutes per problem. Then compare with the full solutions.

Midterm practice set (Units 1–5)

1. Allocate a 500 kg estimate with 30% margin.
    1. 500 × 1.3.

    Answer: 650 kg.

2. Find the period of a 550 km circular orbit.
    1. a = 6928.1 km.
    2. $T = 2\pi\sqrt{(a^3/\mu)}$.

    Answer: 95.6 min.

3. Array area for 1 kW at 1 AU, $\eta = 0.30$, $f_d = 0.85$?
    1. $1000/(1361 \times 0.3 \times 0.85)$.

    Answer: 2.88 m^2.

4. Battery for 400 W over 35 min at 25% DoD?
    1. $400 \times 35/60/0.25$.

    Answer: 933 Wh.

5. Radiator for 300 W at 300 K, $\varepsilon = 0.9$?
    1. $300/(0.9\sigma \times 300^4)$.

    Answer: 0.73 m^2.

Final practice set (Units 1–10)

1. Natural frequency for $k = 4 \times 10^5$ N/m, m = 40 kg?
    1. $(1/2\pi)\sqrt{(10^4)}$.

Answer: 15.9 Hz.

2. Propellant for 200 m/s on 800 kg at Isp 230 s?

    1. 800(1 − e^(−200/2255.5)).

    Answer: 67.9 kg.

3. Ground error for 0.005° from 600 km?

    1. 600,000 × 8.727 × 10⁻⁵.

    Answer: 52.4 m.

4. Path loss at 1500 km, 8.2 GHz?

    1. 20 log₁₀(4π × 1.5 × 10⁶/0.03659).

    Answer: 174.2 dB.

5. Reliability for λ = 2 × 10⁻⁶ /h over 7 years?

    1. e^(−0.1226).

    Answer: 0.885.

6. Parallel pair of 0.885 units?

    1. 1 − 0.115².

    Answer: 0.987.

Formula sheet

$$m_{alloc} = m_{est}(1+M),\ S = \sum w_i s_i$$

$$T = 2\pi\sqrt{a^3/\mu},\ v = \sqrt{\mu/a},\ f_e \approx \sin^{-1}(R_E/a)/\pi$$

$$P = S\eta A\cos\theta,\ S = 1361/r^2$$

$$E = P_e t_e / DoD,\ m_b = E/e_{sp}$$

$$Q = \varepsilon\sigma A T^4,\ T = (\alpha S/4\varepsilon\sigma)^{1/4}$$

$$F = nmg_0,\ f = \frac{1}{2\pi}\sqrt{k/m}$$

$$m_p = m_0(1 - e^{-\Delta v/v_e})$$

$$\theta = x/h,\ e = h\theta,\ H = \tau t$$

$$L = 20\log_{10}(4\pi d/\lambda),\ G = \eta(\pi D/\lambda)^2$$

$$R = e^{-\lambda t},\ R_p = 1-(1-R)^2$$

Constants

Constant	Value
Earth μ	398,600.4418 km^3/s^2
Earth radius (equatorial)	6378.137 km
Solar flux at 1 AU (textbook value)	1361 W/m^2
Stefan–Boltzmann constant	$\sigma = 5.670374419 \times 10^{-8}$ $W/(m^2 \cdot K^4)$
Speed of light	299,792,458 m/s (3×10^8 used in examples)
Standard gravity	$g_0 = 9.80665$ m/s^2

Source: NIST: CODATA value, Stefan–Boltzmann constant (https://physics.nist.gov/cgi-bin/cuu/Value?sigma)

Free texts and simulations

Use these free lectures, NASA references and simulations alongside the course.

- MIT OpenCourseWare 16.851 Satellite Engineering (Fall 2003) (https://ocw.mit.edu/courses/16-851-satellite-engineering-fall-2003/): Free MIT satellite engineering lectures.
- NASA Systems Engineering Handbook (https://www.nasa.gov/reference/systems-engineering-handbook/): Free NASA handbook.
- NASA Small Spacecraft Technology State of the Art (https://www.nasa.gov/smallsat-institute/sst-soa/): Free NASA technology survey.
- NASA Small Spacecraft Technology State of the Art: 3.0 Power (May 2026) (https://www.nasa.gov/smallsat-institute/sst-soa/power-subsystems/): Free NASA power chapter.
- PhET: Blackbody Spectrum (https://phet.colorado.edu/en/simulations/blackbody-spectrum): Thermal radiation interactively.
- PhET: Circuit Construction Kit: DC (https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc): Circuits interactively.

Glossary

ADCS
Attitude determination and control subsystem.

Antenna gain
Beam concentration relative to isotropic.

Bus
Spacecraft platform carrying the payload.

C&DH
Command and data handling.

Depth of discharge
Fraction of battery capacity used.

Eclipse
Time in a planet's shadow.

Emissivity
Ability to radiate heat.

End of life
Performance after degradation.

Gravity assist
Planetary flyby that changes velocity.

Heritage
Flight-proven design.

Link budget
Sum of gains and losses in a radio link.

Margin
Reserve above need.

Multilayer insulation
Thermal blanket that blocks radiation.

Path loss
Signal spreading loss.

Payload
Instruments the mission exists for.

Redundancy
Backup hardware.

Requirement
Measurable, verifiable need.

Solar flux
Sunlight power per area.

Specific power
Power per mass.

Sun-synchronous orbit
Orbit crossing at the same local time daily.

Self-assessment rubric

No grade or credit is given. Use this to judge honestly where you are in each unit.

Level	What it looks like
4 · Mastery	Starts from requirements, keeps consistent budgets with margins, checks units and orders of magnitude, and explains subsystem trades in plain words.
3 · Proficient	Solves the practice problems with occasional slips in units or margins.
2 · Developing	Follows worked examples but confuses power and energy or dB and linear values.
1 · Beginning	Plugs numbers into formulas without a requirement or budget; needs to revisit the unit.

Suggested weighting if you want a score

Part	Weight
Practice problems	20%
Labs	25%
Midterm practice set	25%
Final practice set	30%

Aim for level 3 or better in every unit before moving to the next course.

Related courses

- Flight Dynamics & Controls AERO 420
- Heat Transfer AERO 440
- Propulsion AERO 410
- All courses