Design a complete spacecraft: modes, tradeoffs, margins and system decisions

Essential answer

Design a complete spacecraft: modes, tradeoffs, margins and system decisions. The question to solve is: How do you choose between two architectures when neither is best everywhere? No subsystem can be maximised independently. More shielding adds mass; more power can require more radiator and battery; more redundancy adds mass and software; higher propulsion performance can add storage or thermal complexity. Systems engineering therefore compares architectures rather than isolated components. The rest of the course turns that idea into an auditable line of reasoning: explicit units, stated assumptions, reproducible calculations, order-of-magnitude checks and interpretation limits. A result is useful only when the reader can explain what it measures, where every input came from and which engineering decision it can support.

Reasoning map

1. 1 — The concrete scene
2. 2 — Essential words, explained before using them
3. 3 — See the architecture before calculating
4. 4 — Formulas, only when they answer a question
5. 5 — What units and margins mean

Functional configuration for a phase.

Assigned share of a resource.

Before calculating

Quantity:	Design a complete spacecraft: modes, tradeoffs, margins and system decisions
Check:	units + order of magnitude + assumptions
Decision:	state what the result actually supports

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Functional configuration for a phase.

Assigned share of a resource.

Possibility and consequence according to method.

Reserve for uncertainty or growth.

3 — See the architecture before calculating

List launch, cruise, emergency and arrival.

Keep multiple solutions alive long enough.

Compare mass, power, risk, maturity and maintainability.

A local choice moves other budgets.

4 — Formulas, only when they answer a question

How to read it : score equals sum of weight times rating

Structures a comparison but weights remain a choice to justify.

How to read it : reserve equals capability minus need

Positive mass reserve does not compensate negative power reserve.

5 — What units and margins mean

Criteria can have incompatible units; they only become addable after explicit normalisation in a decision method.

6 — Three concrete demonstrations, calculated step by step

A: mass 8/10, robustness 4/10. B: 6/10 and 8/10. Weights 40/60.

B wins with these weights.

8,000 kg with 15% reserve, +600 kg growth.

Two 400 W heaters, one nominally, both in emergency.

7 — Deepening: what the simplified diagram hides

Local optimisation must not violate system objective.

Promising technology can increase development risk.

Active reading

Sections:	3 — See the architecture before calculating ; 4 — Formulas, only when they answer a question
Verification:	A value is usable only with its unit and calculation boundary.
Exercise:	change one assumption and predict the direction of change before recalculating

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On long missions, diagnosis and repair can be worth mass.

Margins are consumed as design matures.

Identify early decisions that close options.

8 — Application to an Earth-Mars spacecraft

9 — Reference dossier: what a real project must still consider

No subsystem can be maximised independently. More shielding adds mass; more power can require more radiator and battery; more redundancy adds mass and software; higher propulsion performance can add storage or thermal complexity. Systems engineering therefore compares architectures rather than isolated components.

A high-level need such as safe crew return decomposes into functions and subsystem requirements. Each lower-level requirement should retain its reason for existence so the impact of mission changes can be traced across thermal, power, storage, maintenance and life support.

A high-performance technology can still be immature, difficult to manufacture or poorly tested in the relevant environment. Demonstrators and qualification campaigns reduce uncertainty before a technology becomes mission-critical. Useful innovation includes a credible path to qualification.

Early design contains high uncertainty, so projects keep reserve. As detail grows, some uncertainty falls while new needs appear. Tracking trend and remaining margin is more informative than one final number. Margin first protects against the unknown; it is not automatically free capacity for new features.

Short missions can tolerate some non-repairable equipment. Multi-year Mars infrastructure cannot apply that philosophy everywhere. Diagnostics, access, modularity, spares, documentation, training and local manufacturing may justify additional launch mass.

Some choices are easy to change; others lock many future interfaces. Habitat diameter, bus voltage, data standards or tank architecture may shape decades of hardware. Irreversible choices deserve early analysis, while replaceable details can stay open longer.

A spacecraft must survive launch, cruise, corrections, communications, anomalies, approach, safe mode and possibly return. Each scenario activates different functions and risks. Mode analysis, failure analysis and operational testing build a coherent system view, especially when several faults combine.

10 — Common traps and bad intuitions

Active reading

Sections:	8 — Application to an Earth-Mars spacecraft ; 9 — Reference dossier: what a real project must still consider
Verification:	A value is usable only with its unit and calculation boundary.
Exercise:	change one assumption and predict the direction of change before recalculating

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Treating a score as objective truth.

Using average instead of peak modes.

Designing the complete spacecraft means managing moving trade-offs

Architecture begins with mission phases and modes: launch, cruise, maneuver, science, faults, safe mode and end of life. Different subsystems and resources are active in each mode, so the vehicle is a time-varying network of dependencies rather than a simple mass sum.

Trade-offs carry second-order effects. More battery adds energy but also mass and thermal burden; more redundancy adds interfaces and software; lighter structure can increase vibration and qualification cost. Local optimization can damage the total mission.

Design maturity appears in margins and configuration. Early uncertainty demands larger reserves. As models and tests converge, margins are consumed or released. A late change is acceptable only if its consequences propagate through all budgets and evidence.

11 — Guided exercises

Question : What question comes before choosing hardware?

Question : Why is a nominal result insufficient?

12 — What to remember

Explain the topic in simple words before symbols.

Connect at least four interfaces with other subsystems.

Redo the three numerical examples without reasoning gaps.

13 — NASA sources for further study

NASA - 2026 State-of-the-Art: Complete Spacecraft Platforms

NASA - 2026 State-of-the-Art of Small Spacecraft Technology

NASA - 2026 State-of-the-Art: Integration, Launch, Deployment and Orbital Transport

Active reading

Sections:	Designing the complete spacecraft means managing moving trade-offs ; 11 — Guided exercises
Verification:	NASA Systems Engineering Handbook | NASA - 2026 State-of-the-Art: Complete Spacecraft Platforms | NASA - 2026 State-of-the-Art of Small Spacecraft Technology
Exercise:	change one assumption and predict the direction of change before recalculating