Integration: interfaces, budgets, verification and validation

Essential answer

Integration: interfaces, budgets, verification and validation. The question to solve is: Why do ten qualified units not automatically make a qualified spacecraft? Two boxes work separately but become incompatible together because of voltage, temperature or protocol differences. Integration creates new risks. 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

Two boxes work separately but become incompatible together because of voltage, temperature or protocol differences. Integration creates new risks.

Prove fitness for actual need.

Before calculating

Quantity:	Integration: interfaces, budgets, verification and validation
Check:	units + order of magnitude + assumptions
Decision:	state what the result actually supports

Integration: interfaces, budgets, verification and validation

2 — Essential words, explained before using them

Prove fitness for actual need.

Allocation of a limited resource.

3 — See the architecture before calculating

Write mechanical, electrical, thermal, data and software interfaces.

Unit → assembly → chain → vehicle.

Analysis, inspection, test or demonstration by requirement.

Evidence belongs to a specific version.

4 — Formulas, only when they answer a question

How to read it : margin equals capability minus need

Simple absolute margin; real convention must be stated.

How to read it : relative margin in percent

5 — What units and margins mean

Keep each budget unit: kg, W, K, N, bit/s, dimensions and protocols do not mix.

6 — Three concrete demonstrations, calculated step by step

Capability 1,000 W, need 850 W.

Box 120 W, interface 100 W.

Test passed in v3.2, logic changed in v3.3.

7 — Deepening: what the simplified diagram hides

Changes propagate to affected parties.

A neighbour can emit or suffer interference.

Active reading

Sections:	2 — Essential words, explained before using them ; 3 — See the architecture before calculating
Verification:	A value is usable only with its unit and calculation boundary.
Exercise:	change one assumption and predict the direction of change before recalculating

Integration: interfaces, budgets, verification and validation

Meeting a document is not always meeting actual use.

Make tests and sequences as representative as reasonable.

Understand cause before closing the problem.

8 — Application to an Earth-Mars spacecraft

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

Two units can work separately and fail when connected. Integration verifies mechanical, electrical, thermal, software, RF, fluid and operational interfaces. Interface Control Documents formalise parameters and ownership, but their value depends on remaining current as the design changes.

Mass, peak power, data rate and thermal predictions change as detail grows. Systems engineering tracks budgets and margins over time and defines when changes require approval and re-analysis by affected subsystems.

Verification asks whether the system meets its requirements. Validation asks whether those requirements and the resulting system actually satisfy the mission need. Both are necessary; a perfectly compliant system can still solve the wrong problem.

Testing should represent flight configuration and sequences as closely as practical, while flight should avoid untested modes. A complete Mars mission cannot be reproduced on Earth, so environmental tests, simulations, hardware benches and operational rehearsals are combined with explicit knowledge of what remains extrapolated.

Power converters, motors, radios and digital clocks can disturb other equipment through conducted or radiated noise. Cable routing, shielding, grounding and filters are integration issues, and some problems appear only in the complete configuration.

Test anomalies must be recorded, reproduced where possible, analysed and closed with rationale. Replacing a failed part without understanding the cause can hide a systemic problem. Traceability lets similar hardware and interfaces be checked.

Adding a module to a settlement requires compatibility with existing power, data, fluids, dimensions, software, safety and maintenance. Local interface standards, test benches, calibration references and configuration management become part of industrial autonomy.

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

Integration: interfaces, budgets, verification and validation

10 — Common traps and bad intuitions

Qualified components ≠ qualified system.

Integration is where correct subsystems can fail together

Testing power, computer, radio and mechanisms separately does not prove the integrated vehicle works. Integration exposes connector, voltage, protocol, timing, mechanical reference, software and procedure mismatches that isolated benches may hide.

System budgets must use consistent configurations and modes. Mass reserve consumed by one subsystem reduces total margin; additional power can enlarge batteries and radiators; a mechanical change can affect natural frequency and pointing. Configuration control is therefore an engineering function in its own right.

Verification asks whether a specified requirement has been met. Validation asks whether the implemented system actually satisfies the mission need. A perfectly verified requirement can still be the wrong requirement.

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: Integration, Launch, Deployment and Orbital Transport

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

Active reading

Sections:	10 — Common traps and bad intuitions ; Integration is where correct subsystems can fail together
Verification:	NASA - 2026 State-of-the-Art: Integration, Launch, Deployment and Orbital Transp | NASA Systems Engineering Handbook | NASA - 2026 State-of-the-Art: Complete Spacecraft Platforms
Exercise:	change one assumption and predict the direction of change before recalculating