Design an end-to-end Earth–Mars mission

Guiding question

Concrete → interfaces → measurement → calculation → failure → recovery.

Course map

Mission brief → System map → Data and assumptions → Governing relationship → Starting calculations

1 — Mission brief

Build the mission chain from departure injected mass to the reserves remaining after landing.
This capstone mission requires several modules at once. An answer is complete only when it closes physical budgets, describes sensors and actions, retains margin, handles a credible failure and explains what the crew must do. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

2 — System map

Start by drawing mass, energy, information and authority flows. An arrow without a unit or owner is incomplete. The map is then used to identify common dependencies and interfaces that can propagate failure. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».
The mission map must show at least four boundaries: Earth departure, interplanetary transit, Mars EDL and the first surface phase. For each boundary the student assigns mass, reserve, functional ownership and configuration state. The hard problem is not adding tonnes; it is identifying items that cross several boundaries, such as radiation shielding, contingency consumables, software, restart energy and spares. Margin retained at departure may be consumed by a decision made much later in the mission.

Equation - evidence - decision

m_total = m_structure + m_ergols + m_charge + m_reserves

Failure to test: Check air, water, thermal control, radiation, food, medicine and workload where relevant to this mission. The goal is to avoid a false “all good” technical calculation that forgets sleep time, suit donning or the need for a second crewmember during a critical operation. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

Design an end-to-end Earth–Mars mission

3 — Data and assumptions

The supplied numbers are training-scenario data. Copy them with units, add missing assumptions and separately mark values that come from NASA sources. Any value that changes the verdict requires sensitivity analysis. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

Assumptions must be ranked by maturity. An estimated structural mass, transit duration, water use or conversion efficiency do not carry the same confidence. The student separates imposed scenario data, sourced values, architecture choices and design margins, then runs at least one pessimistic case such as heavier shielding, lower available energy or degraded landing conditions. The mission verdict must remain explainable after the nominal assumption disappears.

4 — Governing relationship

The equation is only an entry point. It must be connected to a budget, an available measurement and a decision threshold. If units do not reduce correctly, stop before using a calculator. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

5 — Starting calculations

Budget masse 96 t - 34 t - 28 t - 12 t = 22 t margin plus other subsystems Interpret the result inside the global budget before making a decision.

Réserve énergie 180 kWh × 0,25 = 45 kWh reserve Interpret the result inside the global budget before making a decision.

Délai aller simple 18 min × 60 = 1 080 s Interpret the result inside the global budget before making a decision.

6 — Mass, power and time budget

Build three separate tables. The mass budget distinguishes structure, consumables, spares and margin. The energy budget separates instantaneous power from accumulated energy. The time budget includes operations, maintenance, rest and communications delay. Positive margin in one table does not automatically compensate for a deficit in another. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

Operational table

Phenomena / sections:	3 — Data and assumptions ; 4 — Governing relationship ; 5 — Starting calculations
Relationship to revisit:	m_total = m_structure + m_ergols + m_charge + m_reserves
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 3 — Data and assumptions ; 4 — Governing relationship ; 5 — Starting calculations. State one measured quantity, one margin and one possible decision.

Design an end-to-end Earth–Mars mission

The global budget is closed through interfaces rather than one grand sum. A mass increase may demand more propellant, change power needs, reduce spares or move an EDL threshold. The exercise therefore requires a consequence chain before accepting a change. The scenario's residual 22 tonnes may look comfortable, but it is not automatically free margin: uncounted subsystems, reserves and uncertainty still have claims on it.

7 — Navigation, communications and state knowledge

State which variables must be known locally, which can be reconstructed later by Earth, and what accuracy each decision requires. Radio delay means safing and initial diagnosis must be possible without waiting for Earth. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

State knowledge is treated as a budget just like mass. During transit and EDL, the crew or automation must know which quantities are essential for local decisions: remaining energy, attitude, position, pressure, leak rate, water inventory or computer state. Data that reaches Earth only after several minutes cannot be the only safety barrier. Each critical function therefore needs a measurement, a backup estimate and a local action threshold.

8 — Survival and human factors

Check air, water, thermal control, radiation, food, medicine and workload where relevant to this mission. The goal is to avoid a false “all good” technical calculation that forgets sleep time, suit donning or the need for a second crewmember during a critical operation. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

Survival cannot be added at the end of the architecture as an independent box. Trajectory, structural and mass choices constrain habitable volume, shielding, reserves and maintenance. The student must show what happens when one nominal function disappears for several hours: which resource becomes limiting, which degraded mode starts, how long remains and which tasks can be suspended without creating a second emergency.

Operational table

Phenomena / sections:	7 — Navigation, communications and state knowledge ; 8 — Survival and human factors
Relationship to revisit:	m_total = m_structure + m_ergols + m_charge + m_reserves
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 7 — Navigation, communications and state knowledge ; 8 — Survival and human factors. State one measured quantity, one margin and one possible decision.

Design an end-to-end Earth–Mars mission

9 — Mission-specific injected incident

Midway through design, radiation shielding grows by 4 t; the student must reopen the injection-mass budget, check energy margin and decide what can move to a precursor cargo flight. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

For AM-16.01, the answer must show which quantities in “Design an end-to-end Earth–Mars mission” are recomputed, which assumptions cease to be valid and which action remains reversible before consuming an irreversible reserve.

After radiation shielding increases by 4 tonnes, three broad responses exist: absorb the mass in genuine available margin, reduce another function, or change the architecture. The choice is not made by intuition. It is justified by reopened budgets, the risk introduced by removing protection or spares, and compatibility with EDL. Every option must retain a path back to a configuration that can be verified.

10 — Decision and justification

End with an explicit decision: continue, delay, reconfigure, abandon an activity or enter refuge mode. Cite the three quantities controlling that decision and the remaining margin. A conclusion without a numerical or operational criterion is an opinion, not an engineering decision. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

The final deliverable includes a one-page synthesis linking each major decision to evidence: calculation, source, test, measurement or assumption. The student also lists three decisions that should not be frozen until additional data exist. That list matters because a credible architecture is defined not only by what it decides, but also by what it explicitly knows it does not yet know.

Operational table

Phenomena / sections:	9 — Mission-specific injected incident ; ; 10 — Decision and justification
Relationship to revisit:	m_total = m_structure + m_ergols + m_charge + m_reserves
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 9 — Mission-specific injected incident ; ; 10 — Decision and justification. State one measured quantity, one margin and one possible decision.

Design an end-to-end Earth–Mars mission

11 — Required deliverables

12 — Assessment rubric

40%: calculation and unit consistency; 20%: interface treatment; 15%: margins and degraded mode; 15%: human factors and procedure; 10%: source quality and separation of data, assumptions and scenarios. For this mission, the criterion is applied explicitly to « Design an end-to-end Earth–Mars mission ».

13 — Reference sources

Topic-specific primary sources

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

NASA NTRS — Human Mars Entry, Descent, and Landing Architecture Study - https://ntrs.nasa.gov/citations/20160011571

NASA NTRS — Advanced Exploration Systems Life Support Systems Project Overview - https://ntrs.nasa.gov/citations/20210015025

NASA-STD-8729.1A — Reliability and Maintainability Standard - https://standards.nasa.gov/standard/NASA/NASA-STD-87291

Operational table

Phenomena / sections:	11 — Required deliverables ; 12 — Assessment rubric ; 13 — Reference sources
Relationship to revisit:	m_total = m_structure + m_ergols + m_charge + m_reserves
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 11 — Required deliverables ; 12 — Assessment rubric ; 13 — Reference sources. State one measured quantity, one margin and one possible decision.