Multiple failures: designing a habitat that still saves lives after several failures

Guiding question

Concrete → flows → sensors → calculation → failure → refuge.

Course map

The real phenomenon → Vocabulary and problem boundary → Course-specific system view → Mathematical relationship and reading the symbols → Worked calculations and interpretation

1 — The real phenomenon

Major accidents often arise from a chain: a leak consumes make-up gas, a power loss stops a processor, a fire makes a compartment unavailable, or a solar event coincides with maintenance. Resilience requires refuge space, minimum stocks, simplified vital functions, independent capability, load-shedding priorities and procedures that prevent the crew from worsening the situation. Survival mode must be designed before the emergency.
The guiding question is: What happens when two credible problems occur at the same time? Reasoning starts with the physical or operational function before introducing the mathematical relationship. The goal is not to accumulate terminology, but to know which quantity changes, why it changes and what becomes hazardous when it leaves its domain. For “Multiple failures: designing a habitat that still saves lives after several failures”, the first task here is therefore to identify the mechanism specific to this subject before searching for an equation or reference value.

2 — Vocabulary and problem boundary

In “Multiple failures: designing a habitat that still saves lives after several failures”, distinguish the phenomenon, available measurement, any command, the margin and the success criterion. The calculation boundary states what is included and excluded; without that boundary, a percentage, mass or time may be mathematically correct but wrong as an engineering conclusion. For “Multiple failures: designing a habitat that still saves lives after several failures”, the chosen boundary also states what would otherwise be double-counted or omitted from a mission budget.
partial pressures, ventilation flow, CO_2, O_2, humidity, temperature and trace contaminants
sensor drift, saturated sorbent, poorly ventilated zone or a loop that masks slow drift
closed-loop rig tests, controlled metabolic-load injections and recovery tests after a component loss

Equation - evidence - decision

$\text{jours\_survie} = \text{stock\_utilisable} / \text{consommation\_minimale}$; $P_{\text{parallèle}} = 1 - (1-p)^n$

Failure to test: The reference failure is not a vague “broken component.” For “Multiple failures: designing a habitat that still saves lives after several failures”, test in particular sensor drift, saturated sorbent, poorly ventilated zone or a loop that masks slow drift. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

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3 — Course-specific system view

This lesson does not reuse one generic picture for every subject. The system view follows cause → measured quantity → decision or physical response → limit for “Multiple failures: designing a habitat that still saves lives after several failures”. The English text remains fully equivalent while large translated illustrations are intentionally deferred until their dedicated artwork is supplied. For “Multiple failures: designing a habitat that still saves lives after several failures”, the system view must expose inputs, outputs, measured quantity and the consequence of drift without relying on a generic module diagram.

4 — Mathematical relationship and reading the symbols

Read aloud : survival days equal usable stock divided by minimum use; for truly independent identical elements, probability that at least one works equals one minus one minus p to the power n.

Before substituting numbers, write the unit of every term, state whether the relationship is a physical law, approximation or project indicator, and check dimensional consistency. This is especially important here because “Multiple failures: designing a habitat that still saves lives after several failures” combines quantities that do not all have the same evidence status. For “Multiple failures: designing a habitat that still saves lives after several failures”, this relationship is chosen because of the phenomenon under study; a different dominant quantity would require a different equation or model.

5 — Worked calculations and interpretation

240 L / 12 L/day = 20 days in this minimum-use scenario

$1 - (1-0.95)^2 = 0.9975$, only if independence is real

50 kW nominal → 18 kW survival: 32 kW reduction, or 64%

1. 1. Refuge water 240 L / 12 L/day = 20 days in this minimum-use scenario Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Multiple failures: designing a habitat that still saves lives after several failures”.

2. 2. Two independent 0.95 units $1 - (1-0.95)^2 = 0.9975$, only if independence is real Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Multiple failures: designing a habitat that still saves lives after several failures”.

3. 3. Load shedding 50 kW nominal → 18 kW survival: 32 kW reduction, or 64% Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Multiple failures: designing a habitat that still saves lives after several failures”.

Operational table

Phenomena / sections:	3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation
Relationship to revisit:	jours_survie = stock_utilisable / consommation_minimale ; $P\_parallèle = 1 - (1-p)^n$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation. State one measured quantity, one margin and one possible decision.

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6 — What the formula does not contain

The relationship “jours_survie = stock_utilisable / consommation_minimale ; $P\_parallèle = 1 - (1-p)^n$” does not by itself contain all of “Multiple failures: designing a habitat that still saves lives after several failures”. It does not automatically tell us whether a sensor is valid, a structure is aging, a resource is accessible, a command arrives in time or a secondary failure removes margin. The example 240 L / 12 L/day = 20 days in this minimum-use scenario therefore remains a local calculation rather than a complete architecture.

To make the model useful, explicitly add the quantities that dominate this subject: partial pressures, ventilation flow, CO_2, O_2, humidity, temperature and trace contaminants. We can then ask which variation truly changes the result, which is negligible and which forces an architectural change. For “Multiple failures: designing a habitat that still saves lives after several failures”, this model limitation states exactly what a correct calculation still cannot establish about the real system.

7 — Instrumentation, observability and data quality

For “Multiple failures: designing a habitat that still saves lives after several failures”, observability relies on partial pressures, ventilation flow, CO_2, O_2, humidity, temperature and trace contaminants. Each datum has a unit, acquisition rate, uncertainty, timestamp and validity domain. A value arriving without context can be more dangerous than no measurement because it creates unjustified confidence.

Consistency is checked with at least one independent piece of information when the function is critical. A trend, physical balance or second measurement principle helps distinguish a real system change from a drifting sensor. For “Multiple failures: designing a habitat that still saves lives after several failures”, the selected instrumentation must distinguish a real physical change from sensor drift or a bad state estimate.

8 — Phenomenon-specific failures and recovery

The reference failure is not a vague “broken component.” For “Multiple failures: designing a habitat that still saves lives after several failures”, test in particular sensor drift, saturated sorbent, poorly ventilated zone or a loop that masks slow drift. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

The degraded mode must be defined before failure: minimum function, allowable duration, consumed stock, crew action, abort condition and return-to-nominal criterion. That sequence is topic-specific and cannot be replaced by one universal paragraph about redundancy. For “Multiple failures: designing a habitat that still saves lives after several failures”, the degraded mode is defined around the minimum function

Operational table

Phenomena / sections:	6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery
Relationship to revisit:	jours_survie = stock_utilisable / consommation_minimale ; $P\_parallèle = 1 - (1-p)^n$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery. State one measured quantity, one margin and one possible decision.

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9 — NASA / reference case

The reference case is selected from ECLSS, NASA-STD-3001 or human-analog evidence according to the topic. The goal is not to copy the ISS onto Mars, but to identify what has been demonstrated, what is environment-dependent and what still requires qualification for a mission without rapid resupply.

The case is used only within what it actually demonstrates. Flight measurement, human-system standard, component test and architecture study are different kinds of evidence; the text therefore states what is observed, calculated, simulated or still prospective. For “Multiple failures: designing a habitat that still saves lives after several failures”, the cited NASA case is used as targeted evidence for this phenomenon and is never turned into one universal Mars architecture.

10 — Architecture trade

A good solution for “Multiple failures: designing a habitat that still saves lives after several failures” does not maximize one metric. Compare nominal performance, mass, energy, simplicity, maintenance, crew time, common dependencies and recoverability. An option that improves $1 - (1-0.95)^2 = 0.9975$, only if independence is real can still be rejected if it makes failure detection or repair much harder.

The trade is recorded together with its assumptions. If environment data, mass or mission cadence changes, we know which conclusions must be recomputed instead of silently preserving an obsolete choice. For “Multiple failures: designing a habitat that still saves lives after several failures”, the trade is evaluated against the interfaces actually touched by this subject rather than a generic list of desirable qualities.

11 — Demonstration, testing and success criteria

The evidence strategy for “Multiple failures: designing a habitat that still saves lives after several failures” combines closed-loop rig tests, controlled metabolic-load injections and recovery tests after a component loss. Every test records exact hardware, software, configuration, environment, tolerances and success criterion. A successful demonstration outside the mission domain does not replace qualification inside it.

Evidence grows by levels: analytical relationship, simulation, component, subsystem, integrated system, duration and failure. This hierarchy prevents one spectacular test from being presented as validation of the whole mission. For “Multiple failures: designing a habitat that still saves lives after several failures”, demonstration must reproduce the constraints that make this phenomenon difficult; a spectacular test outside the mission domain is insufficient.

12 — Decision exercise

Operational table

Phenomena / sections:	9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria
Relationship to revisit:	jours_survie = stock_utilisable / consommation_minimale ; $P\_parallèle = 1 - (1-p)^n$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria. State one measured quantity, one margin and one possible decision.

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Situation: revisit “Multiple failures: designing a habitat that still saves lives after several failures” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable.

Situation: revisit “Multiple failures: designing a habitat that still saves lives after several failures” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable. Expected answer: recompute the relationship, identify remaining margin, check whether observability is still adequate, and decide whether degraded operation remains acceptable. Multiplying by 1.2 is not enough if the variation also changes interfaces or limits.

13 — What to retain without over-generalizing

14 — Topic-specific primary sources

These references directly document the phenomenon, technology or human constraint addressed in this lesson. They do not by themselves define an official Mars architecture. For “Multiple failures: designing a habitat that still saves lives after several failures”, the bibliography is deliberately targeted to this page so that readers can trace each claim back to the relevant primary document.

Topic-specific primary sources

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

NASA Safety and Mission Assurance — Reliability and Maintainability - https://sma.nasa.gov/sma-disciplines/reliability-and-maintainability

NASA — Human Performance and Error, NASA-STD-3001 Vol. 2 - https://www.nasa.gov/reference/5-0-human-performance-and-error-vol-2/

NASA NTRS — Assumption Management in Complex Spaceflight - https://ntrs.nasa.gov/citations/20260004453

Operational table

Phenomena / sections:	13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources ; Topic-specific primary sources
Relationship to revisit:	jours_survie = stock_utilisable / consommation_minimale ; P_parallèle = 1 − $(1-p)^n$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources ; Topic-specific primary sources. State one measured quantity, one margin and one possible decision.