Reliability: understanding probability of success in a chain of systems

Guiding question

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

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

In a series chain, every required function must succeed. A simple approximation multiplies independent success probabilities, showing the cumulative effect of many elements. Real calculations require appropriate data, dependencies, mission profiles and common causes; this lesson teaches the logic.

The guiding question is: Why can several highly reliable components form a less reliable system? 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 “Reliability: understanding probability of success in a chain of systems”, 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 “Reliability: understanding probability of success in a chain of systems”, 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 “Reliability: understanding probability of success in a chain of systems”, the chosen boundary also states what would otherwise be double-counted or omitted from a mission budget.

failure rate, operating hours, margins, cycles, temperature, leaks, repair time and availability

common cause, slow drift, uncovered fatigue, consumed margin or a repair introducing a new defect

duration tests, reasoned accelerated cycling, FMEA/FMECA, injected faults and configuration tracking

Equation - evidence - decision

$R\_série = \Pi R_i$

Failure to test: The reference failure is not a vague “broken component.” For “Reliability: understanding probability of success in a chain of systems”, test in particular common cause, slow drift, uncovered fatigue, consumed margin or a repair introducing a new defect. 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 “Reliability: understanding probability of success in a chain of systems”. The English text remains fully equivalent while large translated illustrations are intentionally deferred until their dedicated artwork is supplied. For “Reliability: understanding probability of success in a chain of systems”, 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 : the reliability of an independent series chain is the product of element reliabilities.

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 “Reliability: understanding probability of success in a chain of systems” combines quantities that do not all have the same evidence status. For “Reliability: understanding probability of success in a chain of systems”, 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

$0.99 \times 0.98 = 0.9702 = 97.02\%$

$0.995^3 \approx 0.9851 = 98.51\%$

$1 - (1-0.9)^2 = 0.99 = 99\%$ if truly independent

Values such as R = 0.99, 0.98 or 0.995 only have meaning for a defined mission duration and profile. Without a time interval, environment and operating conditions, comparing success probabilities is incomplete.

1. 1. Two elements $0.99 \times 0.98 = 0.9702 = 97.02\%$ Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Reliability: understanding probability of success in a chain of systems”.
2. 2. Three elements $0.995^3 \approx 0.9851 = 98.51\%$ Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Reliability: understanding probability of success in a chain of systems”.
3. 3. Two ideal parallel paths $1 - (1-0.9)^2 = 0.99 = 99\%$ if truly independent Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Reliability: understanding

Operational table

Phenomena / sections:	3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation
Relationship to revisit:	$R\_série = \Pi R_i$
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.

Reliability: understanding probability of success in a chain of systems

6 — What the formula does not contain

The relationship “$R\_série = \Pi R_i$” does not by itself contain all of “Reliability: understanding probability of success in a chain of systems”. 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 $0.99 \times 0.98 = 0.9702 = 97.02\%$ therefore remains a local calculation rather than a complete architecture.

To make the model useful, explicitly add the quantities that dominate this subject: failure rate, operating hours, margins, cycles, temperature, leaks, repair time and availability. We can then ask which variation truly changes the result, which is negligible and which forces an architectural change. For “Reliability: understanding probability of success in a chain of systems”, this model limitation states exactly what a correct calculation still cannot establish about the real system.

7 — Instrumentation, observability and data quality

For “Reliability: understanding probability of success in a chain of systems”, observability relies on failure rate, operating hours, margins, cycles, temperature, leaks, repair time and availability. 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 “Reliability: understanding probability of success in a chain of systems”, 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 “Reliability: understanding probability of success in a chain of systems”, test in particular common cause, slow drift, uncovered fatigue, consumed margin or a repair introducing a new defect. 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 “Reliability: understanding probability of success in a chain of systems”, the degraded mode is defined around the minimum function specific to this subject, with an abort threshold and a return-to-nominal condition.

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:	$R\_série = \Pi R_i$
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

NASA material is used as an evidence dossier: requirements, reliability, maintainability, testing and configuration. The lesson never turns a generic failure rate into a universal truth; it shows how evidence is bounded to defined hardware, environment and duration.

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 “Reliability: understanding probability of success in a chain of systems”, 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 “Reliability: understanding probability of success in a chain of systems” does not maximize one metric. Compare nominal performance, mass, energy, simplicity, maintenance, crew time, common dependencies and recoverability. An option that improves $0.995^3 \approx 0.9851 = 98.51\%$ 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 “Reliability: understanding probability of success in a chain of systems”, 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 “Reliability: understanding probability of success in a chain of systems” combines duration tests, reasoned accelerated cycling, FMEA/FMECA, injected faults and configuration tracking. 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 “Reliability: understanding probability of success in a chain of systems”, 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:	$R\_série = \Pi R_i$
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.

Reliability: understanding probability of success in a chain of systems

Situation: revisit “Reliability: understanding probability of success in a chain of systems” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable.

Situation: revisit “Reliability: understanding probability of success in a chain of systems” 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 “Reliability: understanding probability of success in a chain of systems”, 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 — Addressing Reliability Analysis with FMEA and Reliability Block Diagrams - https://ntrs.nasa.gov/citations/20160001835

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

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

Operational table

Phenomena / sections:	13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources ; Topic-specific primary sources
Relationship to revisit:	$R\_série = \Pi R_i$
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.