

Mission Control, procedures and delayed operations

Turn technical architecture into an operable mission: flight rules, telemetry, procedures, simulation, handover and decision-making when Houston cannot answer in real time.

Before starting — Prerequisites: modules 00 to 28 are recommended depending on the topic. Every important symbol is defined at first use.

Mastery objectives

- explain quantities, units, assumptions and uncertainty
- repeat simple calculations without a black box
- identify interfaces, limits and degraded modes
- turn the result into an operational or architecture decision

1. Operations begin before launch

A safe mission does not invent procedures during an emergency. Teams define objectives, constraints, modes, abort criteria, flight rules and responsibilities before departure. Training then exposes those products to simulated failures.

Design and operations must interact early. An inaccessible valve, ambiguous display or system that cannot be isolated is an operational problem before it becomes a failure.

2. Telemetry: turn thousands of measurements into situation awareness

Telemetry matters only if it supports decisions. Controllers combine temperatures, pressures, currents, software states and events. Limits warn that a variable left the expected range, but an alarm is not a diagnosis.

Context matters: low pressure can be normal during venting and critical during a pressurized phase. Rules must combine measurement, mode, trend and consequence.

3. Procedures: state what to do and what to verify

A good procedure has a clear entry point, preconditions, actions, checks and exit criteria. It also identifies irreversible steps. Too much prose slows the crew; too little assumes perfect memory under stress.

On Mars, procedures must remain usable without immediate ground support. Critical steps benefit from short rationale for prohibitions so crews can adapt intelligently when an unanticipated case appears.

4. Flight rules: pre-decide difficult conflicts

A flight rule states in advance what happens when a condition occurs: continue, abort, isolate, return or wait. It prevents every crisis from beginning as an improvised policy debate.

Rules still need controlled exceptions when assumptions change. A Mars base requires clear governance for who may deviate, on what evidence and how the decision is recorded.

5. Integrated simulations and failure training

Simulation is not merely button training. It tests team behavior, interfaces, communications, procedures and support systems. A useful scenario injects failure plus ambiguity and incomplete information.

The goal is not to trick the crew. It is to discover before flight what is unclear, what takes too long and which dependencies remain hidden.

6. Handover and operational memory

Long missions run through teams and shifts. Handover should transmit state, open anomalies, work in progress, decisions, temporary constraints and upcoming deadlines. Without discipline, the same fault is diagnosed twice or an action is repeated.

On Mars, part of that memory must remain on site even if Earth communications fail: structured logs, event timelines and local procedure copies.

7. Decide with a twenty-minute one-way delay

With large delay, Earth mission control becomes more advisor, analyst and planner than instantaneous pilot. The crew needs defined local authority and a framework for safety decisions.

Messages to Earth should survive delay: current state, assumptions, options, action taken and the data needed for later analysis.

8. Worked example: when a procedure does not fit the available window

A critical sequence contains 12 steps averaging 35 s, four checks of 50 s and two mandatory waits of 90 s. Nominal duration is $12 \times 35 + 4 \times 50 + 2 \times 90 = 420 + 200 + 180 = 800$ s, or 13 min 20 s.

If the operational window is only 12 minutes, the procedure does not close. Redesign, automation or an earlier start is required; telling the crew to “go faster” is not engineering margin.

9. Decision-time budget: count the cost of clarification loops

On Earth, an ambiguous procedure can sometimes be rescued by a quick conversation. On Mars, every additional question consumes propagation time. Communications delay therefore becomes a quantity that belongs in procedure design just as mass or energy does.

Teaching assumption. Reuse a one-way delay $t_{\text{one}} = 12.5$ min. Minimum round-trip delay is $t_{\text{RT}} = 2 \times t_{\text{one}} = 25$ min. If a team needs four successive question-and-answer cycles to understand an anomaly, propagation alone consumes $4 \times 25 = 100$ min. No analysis time has yet been counted.

Why multiply by four? Each independent clarification requires another complete round trip. The result shows why a Mars procedure should carry more context in its first message: system state, timestamp, relevant measurements, last known safe action, prohibited limits and stop criteria. The more self-contained the initial package is, the fewer clarification loops the mission has to buy with time.

Degraded mode. A robust procedure also says what happens if Earth never answers: who has local authority, which functions can be isolated, what configuration is considered safe, and what evidence must be preserved for later analysis. Operational autonomy begins when the document remains usable without synchronous conversation.

Progressive exercise

Create a flight rule for partial cooling loss: entry conditions, loads to shed, recovery criteria, crew retreat threshold and information to transmit to Earth.

Reasoned correction

A defensible answer begins with thresholds explicitly labelled as exercise assumptions. For example, enter the rule when a cooling loop loses redundancy and a critical component remains outside its allowed temperature band for more than two control cycles. Shed science and comfort loads first, never ECLSS or emergency communications. Recovery requires temperature back inside the band, stable flow and no renewed alarm for a defined observation period. Crew retreat is triggered before an irreversible hardware limit is reached. The Earth message should include the timeline, temperatures, flows, commands executed, current configuration and remaining margin so delayed support can reason from the same state.

Mini-project

Write the concept of operations for one Mars day containing EVA, maintenance, science, rover recharge and communications. Inject a power failure halfway through and show how schedule, flight rules and local authority change.

Mission control when Earth cannot answer in time

Mars operations cannot copy low-Earth-orbit mission control. Radio commands and crew messages travel at the speed of light, but Earth and Mars are separated by a distance that changes continuously. The one-way delay therefore varies from minutes to more than twenty minutes, and the round trip can exceed the time available to stop a rapidly developing failure. Mission control remains valuable for planning, analysis and expertise, yet tactical authority must exist locally.

The practical design problem is to decide which decisions belong on Earth, which belong to the crew, and which may be delegated to onboard automation. That allocation must be written before the emergency. A vague instruction such as “contact mission control if uncertain” is useless when a pressure leak can become critical before a reply arrives. Procedures instead define thresholds, local stop rules, automatic safing actions, reporting requirements and the point at which Earth becomes an advisory rather than commanding node.

Delayed operations also change how information is packaged. A useful uplink is not a continuous conversation; it is a structured bundle containing intent, assumptions, constraints, time tags, priorities and branches. Downlink should preserve context so Earth can reconstruct what happened without forcing the crew to retell an entire shift. Good asynchronous operations turn communication delay from chaos into a manageable engineering condition.

Four ideas for commanding across interplanetary delay

One-way light time

One-way light time is the propagation delay from sender to receiver. It is not network congestion and cannot be removed by a faster processor or a better antenna. It sets the minimum delay for any information exchange between Earth and Mars.

Decision authority

Decision authority states who is permitted to make a particular class of operational decision under defined conditions. On Mars it must be explicit for nominal work, degraded modes and emergencies because Earth may be unable to participate synchronously.

Time-tagged command

A time-tagged command carries the time or event at which it should execute rather than relying only on the instant it is received. It can support carefully planned sequences but creates risk if vehicle state has changed since the sequence was built.

Asynchronous operations

Asynchronous operations are organized so useful work continues without immediate reply. Messages are complete enough to be understood later, decisions record their rationale, and teams exchange packages rather than depending on conversational back-and-forth.

Calculation laboratory

Formula 1 — one-way and round-trip light time

Canonical quantitative mini-lessons

This block is the module quantitative reference; exercise values are pedagogical and must be replaced by mission data before any real decision.

Procedure time margin

$$t_{\text{margin}} = t_{\text{window}} - t_{\text{proc}}$$

1 — Concrete question

What does “ $t_{\text{margin}} = t_{\text{window}} - t_{\text{proc}}$ ” compute in “Procedure time margin”?

2 — Intuition without symbols

The margin compares time available with time needed to execute the procedure correctly.

3 — Quantities

t_{margin} : time margin [min]; t_{window} : available window [min]; t_{proc} : procedure duration [min]

4 — Formula

$$t_{\text{margin}} = t_{\text{window}} - t_{\text{proc}}$$

5 — Read aloud

Read “ $t_{\text{margin}} = t_{\text{window}} - t_{\text{proc}}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{margin} : time margin [min]; t_{window} : available window [min]; t_{proc} : procedure duration [min]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

t_{margin} [min]; t_{window} [min]; t_{proc} [min]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Subtraction isolates a margin or difference between comparable states.

11 — Assumptions

Terms must share the same frame and unit.

12 — Independent check

Adding the margin back to the subtracted term should reconstruct the initial state.

13 — Numerical case

With $t_{\text{window}} = 30$ min, $t_{\text{proc}} = 22$ min: $t_{\text{margin}} = 30 - 22 = 8$ min.

14 — Why the calculation works

Subtraction isolates a margin or difference between comparable states.

15 — Verification

Adding the margin back to the subtracted term should reconstruct the initial state.

16 — Mental estimate

Comparing the two terms predicts the sign before calculation.

17 — Interpretation

A negative margin requires changing the procedure or sequence before the event.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result moves directly when either term changes.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $t_{\text{window}} = 20$ min, $t_{\text{proc}} = 18$ min: $t_{\text{margin}} = 20 - 18$?

Detailed guided correction — open after trying

With $t_{\text{window}} = 20$ min, $t_{\text{proc}} = 18$ min: $t_{\text{margin}} = 20 - 18 = 2$ min. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $t_{\text{window}} = 15$ min, $t_{\text{proc}} = 17$ min: $t_{\text{margin}} = 15 - 17$?

Autonomous correction — open after trying

With $t_{\text{window}} = 15$ min, $t_{\text{proc}} = 17$ min: $t_{\text{margin}} = 15 - 17 = -2$ min. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Delayed clarification loop

$$t_{\text{clarify}} = 2 \times t_{\text{ow}} + t_{\text{analysis}}$$

1 — Concrete question

What does “ $t_{\text{clarify}} = 2 \times t_{\text{ow}} + t_{\text{analysis}}$ ” compute in “Delayed clarification loop”?

2 — Intuition without symbols

A question sent to Earth consumes outbound delay, return delay and analysis time before producing a usable answer.

3 — Quantities

t_{clarify} : clarification-loop duration [min]; t_{ow} : one-way delay [min]; t_{analysis} : local analysis time [min]

4 — Formula

$$t_{\text{clarify}} = 2 \times t_{\text{ow}} + t_{\text{analysis}}$$

5 — Read aloud

Read “ $t_{\text{clarify}} = 2 \times t_{\text{ow}} + t_{\text{analysis}}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{clarify} : clarification-loop duration [min]; t_{ow} : one-way delay [min]; t_{analysis} : local analysis time [min]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

t_{clarify} [min]; t_{ow} [min]; t_{analysis} [min]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Addition combines delays or contributions that accumulate in the same operational chain.

11 — Assumptions

Contributions must use a common unit and the same system boundary.

12 — Independent check

Removing one term from the total should recover the sum of the others.

13 — Numerical case

With $t_{\text{ow}} = 20$ min, $t_{\text{analysis}} = 5$ min: $t_{\text{clarify}} = 2 \times 20 + 5 = 45$ min.

14 — Why the calculation works

Addition combines delays or contributions that accumulate in the same operational chain.

15 — Verification

Removing one term from the total should recover the sum of the others.

16 — Mental estimate

Adding dominant terms first gives a robust order of magnitude.

17 — Interpretation

Pre-delegate decisions whose window is shorter than this loop.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The total changes linearly with each term when the others stay fixed.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $t_{\text{ow}} = 8$ min, $t_{\text{analysis}} = 4$ min: $t_{\text{clarify}} = 2 \times 8 + 4$?

Detailed guided correction — open after trying

With $t_{\text{ow}} = 8$ min, $t_{\text{analysis}} = 4$ min: $t_{\text{clarify}} = 2 \times 8 + 4 = 20$ min. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $t_{\text{ow}} = 3$ min, $t_{\text{analysis}} = 2$ min: $t_{\text{clarify}} = 2 \times 3 + 2$?

Autonomous correction — open after trying

With $t_{ow} = 3$ min, $t_{analysis} = 2$ min: $t_{clarify} = 2 \times 3 + 2 = 8$ min. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Pre-delegate decisions whose window is shorter than this loop.

Telemetry volume

$$D_{tm} = R_{tm} \times t_{window}$$

1 — Concrete question

What does “ $D_{tm} = R_{tm} \times t_{window}$ ” compute in “Telemetry volume”?

2 — Intuition without symbols

Produced volume is telemetry rate sustained over the observation window.

3 — Quantities

D_{tm} : telemetry volume [Mb]; R_{tm} : telemetry rate [Mb/s]; t_{window} : duration [s]

4 — Formula

$$D_{tm} = R_{tm} \times t_{window}$$

5 — Read aloud

Read “ $D_{tm} = R_{tm} \times t_{window}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

D_{tm} : telemetry volume [Mb]; R_{tm} : telemetry rate [Mb/s]; t_{window} : duration [s]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

D_{tm} [Mb]; R_{tm} [Mb/s]; t_{window} [s]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Multiplication converts a rate, fraction or specific quantity into a total.

11 — Assumptions

Factors must belong to the same scenario and their units must combine correctly.

12 — Independent check

Dividing the result by a non-zero factor should recover the product of the others.

13 — Numerical case

With $R_{tm} = 2$ Mb/s, $t_{window} = 300$ s: $D_{tm} = 2 \times 300 = 600$ Mb.

14 — Why the calculation works

Multiplication converts a rate, fraction or specific quantity into a total.

15 — Verification

Dividing the result by a non-zero factor should recover the product of the others.

16 — Mental estimate

Estimating each factor separately quickly predicts product scale.

17 — Interpretation

Check storage and downlink before increasing parameter count or cadence.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

A relative change in one factor transfers directly to the product when the others stay fixed.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $R_{tm} = 5$ Mb/s, $t_{window} = 120$ s: $D_{tm} = 5 \times 120$?

Detailed guided correction — open after trying

With $R_{tm} = 5$ Mb/s, $t_{window} = 120$ s: $D_{tm} = 5 \times 120 = 600$ Mb. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $R_{tm} = 1.5$ Mb/s, $t_{window} = 600$ s: $D_{tm} = 1.5 \times 600$?

Autonomous correction — open after trying

With $R_{tm} = 1.5 \text{ Mb/s}$, $t_{window} = 600 \text{ s}$: $D_{tm} = 1.5 \times 600 = 900 \text{ Mb}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Check storage and downlink before increasing parameter count or cadence.

Procedural workload

$$H_{work} = n_{steps} \times t_{step}$$

1 — Concrete question

What does " $H_{work} = n_{steps} \times t_{step}$ " compute in "Procedural workload"?

2 — Intuition without symbols

Number of actions and their average duration give a first estimate of operator workload.

3 — Quantities

H_{work} : total workload [min]; n_{steps} : number of steps [step]; t_{step} : average time per step [min]

4 — Formula

$$H_{work} = n_{steps} \times t_{step}$$

5 — Read aloud

Read " $H_{work} = n_{steps} \times t_{step}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

H_{work} : total workload [min]; n_{steps} : number of steps [step]; t_{step} : average time per step [min]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

H_{work} [min]; n_{steps} [step]; t_{step} [min]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Multiplication converts a rate, fraction or specific quantity into a total.

11 — Assumptions

Factors must belong to the same scenario and their units must combine correctly.

12 — Independent check

Dividing the result by a non-zero factor should recover the product of the others.

13 — Numerical case

With $n_{steps} = 18 \text{ step}$, $t_{step} = 1.5 \text{ min}$: $H_{work} = 18 \times 1.5 = 27 \text{ min}$.

14 — Why the calculation works

Multiplication converts a rate, fraction or specific quantity into a total.

15 — Verification

Dividing the result by a non-zero factor should recover the product of the others.

16 — Mental estimate

Estimating each factor separately quickly predicts product scale.

17 — Interpretation

If workload approaches the total window, simplify or redistribute tasks before operations.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

A relative change in one factor transfers directly to the product when the others stay fixed.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $n_{steps} = 30 \text{ step}$, $t_{step} = 0.8 \text{ min}$: $H_{work} = 30 \times 0.8$?

Detailed guided correction — open after trying

With $n_steps = 30$ step, $t_step = 0.8$ min: $H_work = 30 \times 0.8 = 24$ min. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $n_steps = 12$ step, $t_step = 2$ min: $H_work = 12 \times 2$?

Autonomous correction — open after trying

With $n_steps = 12$ step, $t_step = 2$ min: $H_work = 12 \times 2 = 24$ min. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

If workload approaches the total window, simplify or redistribute tasks before operations.

Readiness ratio

$R_ready = n_ready / n_required$

1 — Concrete question

What does " $R_ready = n_ready / n_required$ " compute in "Readiness ratio"?

2 — Intuition without symbols

Readiness compares items actually ready with those required by the mission configuration.

3 — Quantities

R_ready : readiness ratio [sans dimension]; n_ready : ready items [item]; $n_required$: required items [item]

4 — Formula

$R_ready = n_ready / n_required$

5 — Read aloud

Read " $R_ready = n_ready / n_required$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

R_ready : readiness ratio [sans dimension]; n_ready : ready items [item]; $n_required$: required items [item]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

R_ready [sans dimension]; n_ready [item]; $n_required$ [item]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Division relates a quantity to a coherent capacity, duration or reference.

11 — Assumptions

Numerator and denominator must describe the same scenario and the denominator must remain positive.

12 — Independent check

Multiplying the result by the denominator should reconstruct the numerator.

13 — Numerical case

With $n_ready = 18$ item, $n_required = 20$ item: $R_ready = 18 / 20 = 0.9$.

14 — Why the calculation works

Division relates a quantity to a coherent capacity, duration or reference.

15 — Verification

Multiplying the result by the denominator should reconstruct the numerator.

16 — Mental estimate

Comparing numerator and denominator scales predicts the result.

17 — Interpretation

Do not cross a critical gate when required items remain unready without explicit waiver.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result rises with the numerator and falls as the denominator rises.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $n_ready = 25$ item, $n_required = 25$ item: $R_ready = 25 / 25$?

Detailed guided correction — open after trying

With $n_{\text{ready}} = 25$ item, $n_{\text{required}} = 25$ item: $R_{\text{ready}} = 25 / 25 = 1$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $n_{\text{ready}} = 14$ item, $n_{\text{required}} = 16$ item: $R_{\text{ready}} = 14 / 16$?

Autonomous correction — open after trying

With $n_{\text{ready}} = 14$ item, $n_{\text{required}} = 16$ item: $R_{\text{ready}} = 14 / 16 = 0.875$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Do not cross a critical gate when required items remain unready without explicit waiver.

Handover completeness

$C_{\text{handover}} = n_{\text{confirmed}} / n_{\text{items}}$

1 — Concrete question

What does " $C_{\text{handover}} = n_{\text{confirmed}} / n_{\text{items}}$ " compute in "Handover completeness"?

2 — Intuition without symbols

A reliable handover verifies that critical items were explicitly received and understood.

3 — Quantities

C_{handover} : handover completeness [sans dimension]; $n_{\text{confirmed}}$: confirmed items [item]; n_{items} : items to hand over [item]

4 — Formula

$C_{\text{handover}} = n_{\text{confirmed}} / n_{\text{items}}$

5 — Read aloud

Read " $C_{\text{handover}} = n_{\text{confirmed}} / n_{\text{items}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

C_{handover} : handover completeness [sans dimension]; $n_{\text{confirmed}}$: confirmed items [item]; n_{items} : items to hand over [item]

7 — Pronunciation

Say subscripts, powers, parentheses and Greek letters explicitly so the relation can be reconstructed without seeing the page.

8 — Units

C_{handover} [sans dimension]; $n_{\text{confirmed}}$ [item]; n_{items} [item]

9 — Convention

Keep the same frame, time basis, system boundary and sign convention throughout the substitution.

10 — Why this operation

Division relates a quantity to a coherent capacity, duration or reference.

11 — Assumptions

Numerator and denominator must describe the same scenario and the denominator must remain positive.

12 — Independent check

Multiplying the result by the denominator should reconstruct the numerator.

13 — Numerical case

With $n_{\text{confirmed}} = 28$ item, $n_{\text{items}} = 30$ item: $C_{\text{handover}} = 28 / 30 = 0.9333$.

14 — Why the calculation works

Division relates a quantity to a coherent capacity, duration or reference.

15 — Verification

Multiplying the result by the denominator should reconstruct the numerator.

16 — Mental estimate

Comparing numerator and denominator scales predicts the result.

17 — Interpretation

Resolve handover gaps before the outgoing team becomes unavailable.

18 — What the result does not prove

The calculation proves neither that inputs are exact nor that the model remains valid outside the declared scenario; both require separate evidence.

19 — Sensitivity

The result rises with the numerator and falls as the denominator rises.

20 — Guided and autonomous exercises

Guided exercise. Recalculate this scenario: With $n_{\text{confirmed}} = 20$ item, $n_{\text{items}} = 20$ item: $C_{\text{handover}} = 20 / 20$?

Detailed guided correction — open after trying

With $n_{\text{confirmed}} = 20$ item, $n_{\text{items}} = 20$ item: $C_{\text{handover}} = 20 / 20 = 1$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $n_{\text{confirmed}} = 15$ item, $n_{\text{items}} = 18$ item: $C_{\text{handover}} = 15 / 18$?

Autonomous correction — open after trying

With $n_{\text{confirmed}} = 15$ item, $n_{\text{items}} = 18$ item: $C_{\text{handover}} = 15 / 18 = 0.8333$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Resolve handover gaps before the outgoing team becomes unavailable.

Starting question

What is the minimum communication delay imposed purely by the Earth–Mars distance?

Read aloud

Say: “one-way time equals distance divided by the speed of light; round-trip time is twice the one-way time.”

Symbols, pronunciation and meaning

d is path distance and c is the speed of light in vacuum. t_{RT} is the earliest possible send-and-receive interval before processing delays.

Units

Use matching units. With distance in kilometres and $c \approx 299,792$ km/s, time emerges in seconds and can be converted to minutes.

Origin and status of values

Distance must come from ephemeris or a declared training scenario. The speed of light is a physical constant; routing and processing delays are additional.

Why this operation

Division converts distance into propagation time because speed equals distance divided by time. Doubling gives the return path under the same simplified distance.

Substitution and calculation

For $d = 225,000,000$ km: $t = 225,000,000 / 299,792 \approx 750.5$ s ≈ 12.5 min. Round trip ≈ 25.0 min.

Calculator entry

Enter $225000000 \div 299792$, then divide by 60 for minutes. Double the result for a simplified round-trip estimate.

Mental estimate

Light crosses 18 million km per minute, so 225 million km should require a little over twelve minutes. The result matches that scale.

Independent check

Multiply 750.5 s by 299,792 km/s; the product returns approximately 225 million km.

Physical or operational interpretation

A 25-minute round trip means a crew cannot wait for Earth to authorize actions that must occur in seconds or a few minutes.

Plain-English translation

The earliest reply to a question sent now arrives roughly twenty-five minutes later in this example, before human analysis time is added.

Variation / sensitivity

At a larger separation the delay rises linearly with distance. Operational authority and onboard autonomy therefore need to tolerate the whole mission range.

Limit / assumption

Real signals may use relays and the Earth–Mars distance changes during the exchange. The formula is a first-order propagation model, not a network schedule.

Formula 2 — command queue completion time

Starting question

How long will a sequence of equally spaced commands take to complete once its first command starts?

Read aloud

Read: “completion time equals start time plus command count times the command spacing.”

Symbols, pronunciation and meaning

N is the number of scheduled intervals represented by the sequence and Δt is the spacing between command events.

Units

If Δt is in minutes, the added duration is in minutes. Keep mission elapsed time and Earth clock time distinct.

Origin and status of values

Command count and spacing come from the reviewed timeline. This simple model assumes equal spacing; real sequences often use event-dependent waits.

Why this operation

Repeated equal intervals add linearly. Multiplication is a compact way to sum the same spacing many times.

Substitution and calculation

If a ten-step sequence uses 3 min spacing after a start at MET 120 min, the simple end estimate is $120 + 10 \times 3 = \text{MET } 150 \text{ min}$.

Calculator entry

Type $120 + 10 \times 3$. Check whether your sequence definition uses ten intervals or nine gaps between ten discrete commands.

Mental estimate

Ten intervals of three minutes add about half an hour, so an end near MET 150 min is expected.

Independent check

Subtract the start time from the result: $150 - 120 = 30 \text{ min}$, which equals $10 \times 3 \text{ min}$.

Physical or operational interpretation

Timeline arithmetic matters because communication windows, thermal constraints and crew tasks can conflict with a command sequence even when each command is valid alone.

Plain-English translation

The command train occupies about thirty minutes after its start under the declared convention.

Variation / sensitivity

Increasing spacing to 5 min would extend the same ten intervals to 50 min, potentially crossing an operational constraint.

Limit / assumption

This model ignores conditional branches, acknowledgements, execution latency and events that can pause or abort the sequence.

Mission reasoning: build operations that survive missing conversation

Write intent, not only button presses

Earth should send the reason behind a plan, the constraints that matter and acceptable alternatives. If the exact action becomes impossible after the message leaves Earth, a crew that understands intent can still choose a safe equivalent. A command list without intent can turn obsolete during the light-time delay.

Define local stop rules

A stop rule is a condition that halts an activity without waiting for discussion: unexpected pressure loss, suit parameter outside limit, loss of a required navigation source or another declared hazard. Stop rules reduce cognitive debate under stress and make authority visible before the mission.

Preserve state in every handover

An asynchronous handover should state current configuration, open anomalies, resources, assumptions, commands already queued, work in progress and decisions expected next. Without that state, Earth may analyse an obsolete configuration and return technically correct advice for a situation that no longer exists.

Separate telemetry from interpretation

Raw telemetry tells Earth what sensors reported; an operations note tells Earth what the crew believes is happening. Both are needed. If interpretation is transmitted as though it were fact, analysts may miss alternative diagnoses. If only raw data are sent, Earth can spend precious hours reconstructing context the crew already knows.

Treat command authorization as configuration control

A time-tagged sequence is a controlled product. Its software version, assumptions, expiry condition and applicable vehicle configuration should be known. If the system changes after review, the sequence may become invalid even if every individual command remains syntactically correct.

Delayed-operations exercises — decide before the reply arrives

Exercise A — Pressure anomaly authority

A habitat pressure trend reaches a predeclared emergency threshold. Earth is twelve light-minutes away. Who should authorize isolation?

Reveal the reasoned solution

The local crew or automation should act according to the approved emergency rule. Earth cannot be in the immediate control loop. Mission control should receive the event, support diagnosis and help with recovery planning after the local safing action. The authority allocation must exist before the anomaly.

Exercise B — Round-trip estimate

At a scenario distance of 180 million km, estimate one-way light time using 300,000 km/s for a mental calculation.

Reveal the reasoned solution

$180,000,000 / 300,000 = 600 \text{ s} = 10 \text{ min}$ one way. A simplified round trip is about 20 min before people read, analyse and compose a response. The approximation is adequate for operational intuition.

Exercise C — Obsolete uplink

Earth sends a rover route. During propagation the crew closes one corridor because of dust and visibility. What information in the uplink would help the crew adapt safely?

Reveal the reasoned solution

The uplink should include route intent, required destination, hazards to avoid, energy reserve, timing constraints and acceptable alternatives. Then the crew can choose a different path while preserving the mission objective rather than blindly following coordinates that were valid when sent.

Exercise D — Time-tag risk

A command sequence will open a valve at a future time. Name two reasons to cancel it before execution.

Reveal the reasoned solution

Cancel if the vehicle configuration no longer matches the reviewed assumptions or if a prerequisite sensor/state is not satisfied. Time tagging does not make a stale command safe; it only schedules execution. Robust sequences include inhibits, state checks or explicit expiry.

Exercise E — Handover quality

Rewrite a weak handover that says only “pump problem, investigating” into the categories of information Earth needs.

Reveal the reasoned solution

A useful handover identifies the affected pump, time of onset, measured symptoms, configuration, actions already taken, current safe mode, resource impact, leading hypotheses, evidence still needed and the decision the crew expects next. That turns a vague message into an analysable operational state.

Exercise F — Reply-cycle cost

A weak message requires two clarification cycles while one-way light time is 11 minutes. Ignoring human analysis time, how much extra round-trip delay do those clarifications create?

Reveal the reasoned solution

One round trip is about 22 minutes. Two unnecessary clarification cycles add about 44 minutes before a useful answer can return. This is why first-contact packages should include configuration, evidence, constraints and the specific decision required.

Interactive beginner glossary

The vocabulary below separates physical communication delay, operational authority and the records needed to coordinate two teams that cannot converse in real time.

- one-way light time — The minimum propagation time for a signal to travel once between two locations at the speed of light.
- round-trip light time — The propagation time for a signal to go to the remote end and for a reply signal to return, before human processing.
- latency — Delay between an initiating event and the corresponding information, command or response becoming available at another point.
- asynchronous operations — Work organized so each side can continue productively without an immediate conversational reply from the other side.
- mission control — The ground organization that plans, monitors, analyses and supports mission execution using defined roles and procedures.
- flight rule — A preapproved operational rule that defines a required action, limit, authority or response for a known class of situation.
- procedure — A controlled sequence of actions and checks used to perform a task consistently and safely.
- checklist — A concise list used to confirm critical items or actions without reproducing the full explanation contained in a procedure.
- stop rule — A condition that requires an activity to halt immediately or enter a safer state without waiting for further discussion.
- decision authority — The assigned right and responsibility to make a defined class of operational decision.
- telemetry — Measurements and status information sent from a spacecraft, habitat, suit, rover or other system to operators.
- telecommand — A command transmitted to a remote system for execution.
- uplink — Communication sent from a controlling or supporting node toward a spacecraft, habitat or remote operational system.
- downlink — Communication sent from the remote system toward Earth or another receiving operations node.
- command load — A reviewed set of commands packaged for transmission or scheduled execution.
- time tag — A recorded time associated with an event or command, often used to order data or schedule future execution.
- mission elapsed time — A clock referenced to a defined mission event rather than to a civil time zone.
- event marker — A recorded indication that a significant operational event occurred, used to align data, logs and later analysis.
- anomaly — Observed behaviour or data that differ from the expected condition and therefore require assessment.
- contingency — A foreseeable off-nominal situation for which alternative actions or resources have been prepared.
- safing — Automatic or commanded transition toward a configuration intended to reduce immediate hazard and preserve recoverability.
- degraded mode — A configuration in which the system continues a limited set of functions after loss or restriction of normal capability.
- operational intent — The purpose and constraints behind a planned action, allowing a remote team to choose an equivalent action when details change.
- handover — Structured transfer of current operational state, open work, risks and responsibilities between people, shifts or control nodes.
- shift log — A chronological operational record of events, decisions, anomalies, commands and relevant observations during a work period.
- configuration state — The actual set of active modes, hardware, software versions, connections and settings that define how the system is currently arranged.
- expiry condition — A condition after which a plan, command load or authorization must no longer be considered valid.
- inhibit — A deliberate condition that prevents an action from executing until stated safety or configuration criteria are satisfied.
- acknowledgement — A message confirming that information or a command was received; it does not necessarily prove successful execution.
- decision log — A record of what was decided, by whom, from which evidence and assumptions, so later teams can reconstruct the reasoning.

Operational depth: designing the Earth–Mars team as one delayed system

Use two planning horizons

Earth is well suited to long-horizon planning, model updates, specialist consultation and next-sol preparation. Mars is better positioned for immediate execution and tactical adaptation. Procedures should exploit that difference rather than pretend both nodes operate on the same clock.

Package questions so Earth can answer once

A weak question generates a chain of clarifications, each costing another light-time cycle. A strong request states the observed data, current configuration, actions already tried, constraints, decision deadline and exactly what support is requested. This can save hours during a complex anomaly.

Record uncertainty explicitly

Operational messages should distinguish measured facts, interpretations and hypotheses. “Tank pressure fell 8 kPa” is a measurement; “valve leakage is suspected” is a hypothesis. Keeping those categories separate reduces confirmation bias across delayed teams.

Protect command queues from stale state

Queued commands should be revalidated against current state before execution when practical. A sequence prepared on Earth may arrive after the crew has changed a valve lineup, software mode or power allocation. State-aware inhibits and expiry rules are therefore central to safe delayed control.

Train loss of Earth support

Simulations should include periods in which mission control is intentionally unavailable. The goal is not to prove that Earth is unnecessary; it is to expose decisions for which local procedures, expertise or tools are inadequate. Those gaps can then be corrected before Mars.

Measure handover effectiveness

A handover is successful when the receiving team can predict what should happen next and identify the open risks without asking the outgoing team to reconstruct the story. Exercises can test this by removing the author and asking a fresh team to continue from the written package alone.

Design the message around the next decision

A delayed message is most useful when it is written around the next decision rather than around everything the sender knows. The package should state what changed, what remains safe, what deadline exists, which options are still available and what evidence would discriminate between them. This structure helps the receiving team return one useful answer instead of a list of questions. It also creates a durable record: when a later shift reviews the anomaly, the sequence of decisions is visible rather than buried inside conversational fragments.

Plan communication outages as a normal degraded mode

Mars infrastructure will occasionally lose a relay, antenna, power channel or network service. The operations concept should therefore include a state in which Earth support is temporarily unavailable even though the habitat remains healthy. During that state, crews continue only the activities for which local authority, knowledge and contingency margin are sufficient. High-risk work can be paused, queued commands can be inhibited, and non-urgent science can continue. This turns a communications loss from an improvisation into a rehearsed degraded mode.

Review delayed decisions against the information that actually existed

Post-shift review should judge a decision from the telemetry, procedures and constraints available at the time, not from hindsight after Earth has reconstructed the full event. This matters because delayed teams routinely act with incomplete information. A fair review asks whether the crew identified uncertainty, followed the correct authority boundary, protected safety margins and left a usable record for the next decision. When Earth later discovers that another option would have been better, the lesson should update procedures or training rather than simply blame the local decision. That distinction encourages crews to report uncertainty honestly and gives the mission a way to improve its delayed-control architecture over time.

Preserve communication margin

Not every available contact period should be filled with low-priority data. Reserving bandwidth and operator attention for anomalies gives the mission room to transmit high-value telemetry, images and decision packages when the unexpected occurs.

Operational review checklist

- Calculate the current one-way and round-trip communication delay for the operating scenario.
- Assign decision authority before an anomaly, not during it.
- Write local stop rules for hazards whose consequences evolve faster than Earth can reply.
- Include intent, constraints and expiry conditions in delayed command packages.
- Distinguish measured telemetry from crew interpretation and hypotheses.
- Time-tag events consistently so Earth and Mars can reconstruct the same chronology.
- Revalidate queued commands after configuration changes.
- Use structured handovers that include open anomalies, resources and pending decisions.
- Practise periods of lost or unusable Earth support.
- Review decisions afterward so procedures and authority boundaries improve from experience.

Primary sources and pathways

- [NASA JSC — Spaceflight Operations](#)
- [NASA JSC — Crew & Operations Training](#)
- [NASA JSC — Program Management & Execution](#)

FR ↔ EN parity matrix

Procedure time margin	Marge temporelle de procédure
Delayed clarification loop	Boucle de clarification différée
Telemetry volume	Volume de télémesure
Procedural workload	Charge de travail procédurale
Readiness ratio	Ratio de préparation
Handover completeness	Complétude de passation