

Emergency medicine and clinical autonomy for Mars

Prepare for cases in which evacuation is impossible: triage, limited diagnostics, pharmacy, procedures, medical decisions and the interface between human health and habitat systems.

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. Evacuation is no longer an immediate option

In low Earth orbit, return to Earth can sometimes be part of contingency planning. On Mars it is not an immediate response. The mission therefore needs medical autonomy consistent with duration, crew size and risk.

That does not mean turning every astronaut into a surgeon. The architecture must define what can be stabilized, which procedures require training, which decisions can wait for a remote physician and which conditions truly exceed available capability.

2. Triage: treat first what threatens life or function

Triage prioritizes by threat to life, time sensitivity and available resources. Major bleeding, airway obstruction or decompression require immediate action. Stable pain can wait for more complete assessment.

On Mars, triage also has mission consequences: using an entire medical oxygen reserve for an uncertain case may endanger the rest of the crew. Such dilemmas should be studied before flight rather than improvised under pressure.

3. Diagnosis with limited tools

Diagnosis combines history, examination, vital signs and available tools such as ultrasound, simple laboratory tests, ECG and limited imaging. Telemedicine helps, but delay means the crew must gather useful data before asking for advice.

Decision support should expose uncertainty and never hide the need for clinical examination. Automation can guide a sequence; it cannot guarantee a diagnosis.

4. Pharmacy and shelf life

A Mars pharmacy must track indication, dose, contraindications, interactions and stability over time. Medicines have storage requirements and may degrade during a long mission.

Medical logistics should therefore trace lots and substitutions. A mature base might make some simple consumables locally, while complex pharmaceuticals remain a major logistics dependency.

5. Invasive procedures, infection and sterility

The more invasive a procedure, the more it depends on asepsis, training and follow-up. Wounds and interventions create infection risk in a closed habitat. Water, waste, microbiome and ventilation become medical interfaces.

The medical bay must therefore integrate cleaning, isolation, sterile storage, lighting, power and biological-waste handling.

6. Behavioral health, fatigue and decision-making

Behavioral health directly affects safety. Fatigue, conflict, isolation and sleep loss alter attention, memory and judgment. A cognitive error can trigger a technical accident as surely as a broken component.

Operations should protect sleep, track workload and provide confidential support. Command also needs criteria for temporarily removing a crewmember from a critical task.

7. Medicine and engineering need shared situational data

CO₂ exposure may look like a human problem while the root cause is ECLSS. A burn can reveal an electrical fault. Dehydration can come from EVA scheduling or suit performance. Medical analysis therefore needs access to relevant system data.

At the same time, personal medical privacy matters. Architecture should separate what operations needs for safety from the private clinical record.

8. Worked example: autonomy of a medical oxygen reserve

A base has a 24 L medical-oxygen cylinder at 200 bar. Approximate equivalent volume at 1 bar is $24 \times 200 = 4,800$ L, ignoring non-ideal gas effects. At 6 L/min therapeutic flow, theoretical duration is $4,800/6 = 800$ min, or 13 h 20 min.

That is an upper bound. Residual pressure, regulator performance, leakage and simultaneous needs reduce real autonomy. Prescribed flow therefore becomes a logistics decision as well as a clinical one.

9. Clinical autonomy: reason about stock without confusing inventory with treatment

An isolated mission must know how long a diagnostic stock can support planned activity, but this calculation prescribes no medical action. It is a logistics problem: available units, average consumption rate, margin for degraded periods and time until resupply.

Teaching assumption. A stock contains $N = 72$ diagnostic cartridges. Crew size is $n = 4$ and the planning assumption is $r = 0.12$ cartridge per person per day on average. Group consumption is $C = n \times r = 4 \times 0.12 = \mathbf{0.48 \text{ cartridge/day}}$. Nominal endurance is $A = N / C = 72 / 0.48 = \mathbf{150 \text{ days}}$.

If an incident phase temporarily doubles average use, $C_{\text{degraded}} = 0.96$ cartridge/day and $A_{\text{degraded}} = 72 / 0.96 = \mathbf{75 \text{ days}}$. The same stock therefore loses half its endurance when demand doubles. This simple relationship explains why a Mars base must monitor real consumption rather than a nominal expiry date alone.

Model limit. Real medicine does not consume items at a constant rate and needs depend on events. A complete engineering assessment distinguishes routine use, emergency reserve, non-substitutable items, shelf life, storage conditions, and the ability to manufacture or substitute some consumables locally. The calculation helps frame the logistics problem; it does not determine care.

Progressive exercise

A mission carries three identical medical kits. One emergency consumes 40% of one kit and another consumes 70% of a second. Compute total remaining fraction assuming kits are equivalent, then explain why the arithmetic is insufficient if the consumed items are different.

Reasoned correction

Three kits initially represent 3 units of capacity. The emergencies consume $0.4 + 0.7 = 1.1$ kit-equivalents, leaving 1.9 units, or $1.9 / 3 \approx 63.3\%$ of nominal capacity if every item is perfectly interchangeable. That assumption is exactly where the arithmetic becomes misleading. Two emergencies may consume the same drug, IV bag, sterile device or unique size, leaving plenty of total mass but zero of one critical consumable. Operational inventory must therefore be tracked by item, clinical indication, expiry and substitution options rather than by a single percentage of whole-kit capacity.

Mini-project

Design medical autonomy for a six-person, 500-day Mars base: cross-training, equipment, pharmacy, telemedicine, isolation, sterility, inventory, emergency procedures, privacy and mission-reassessment criteria.

Clinical autonomy when evacuation is not an option

A medical emergency on Mars must be managed with the people, equipment and medicines already present. A return to Earth cannot function as an ambulance response, and communication delay prevents a remote physician from directing every minute of care. The habitat therefore needs a layered medical capability: trained crew, clear emergency procedures, monitoring, diagnostic tools, treatment supplies and a way to obtain delayed specialist support without making the patient wait for each individual decision.

Clinical autonomy does not mean that every crew member becomes a surgeon. It means the mission defines which conditions can be recognized and stabilized locally, which interventions require a specifically trained medical officer, and which cases may consume scarce resources for days or weeks. The equipment list must be tied to credible scenarios rather than to a catalogue of attractive devices. A diagnostic capability is useful only if the crew can act on its result.

Medical planning is also a logistics discipline. Drugs expire, sterile supplies are consumed, oxygen and fluids have finite stock, and a prolonged casualty may remove both the patient and a caregiver from normal work. Every serious event therefore has a clinical dimension and a mission-resource dimension. The best plan makes those consequences visible before the emergency.

Four clinical ideas that matter especially far from Earth

Triage

Triage is prioritization when needs compete for limited people, time or resources. In a Mars habitat it can apply not only to multiple casualties but also to a single complex patient whose treatment competes with environmental emergencies or crew survival tasks.

Stabilization

Stabilization means controlling immediate threats to life and preventing rapid deterioration before a complete diagnosis is available. Airway, breathing, circulation, major bleeding and environmental exposure are examples of priorities that can outrank diagnostic certainty.

Clinical autonomy

Clinical autonomy is the ability to make and execute appropriate medical decisions locally within the mission's declared competence, equipment and protocols. It includes knowing when delayed Earth consultation is useful and when waiting would be unsafe.

Medical contingency reserve

A medical contingency reserve is stock protected for plausible high-consequence events rather than consumed routinely. It may include oxygen, fluids, medications, sterile materials or diagnostic capacity whose depletion changes the mission risk posture.

Calculation laboratory

Formula 1 — oxygen supply duration for a declared flow

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.

Oxygen-reserve endurance

$$t_{\text{oxygen}} = V_{\text{stock}} / q_{\text{day}}$$

1 — Concrete question

What does “ $t_{\text{oxygen}} = V_{\text{stock}} / q_{\text{day}}$ ” compute in “Oxygen-reserve endurance”?

2 — Intuition without symbols

A medical reserve becomes operationally useful only when divided by expected daily consumption.

3 — Quantities

t_{oxygen} : endurance [d]; V_{stock} : available volume [L]; q_{day} : daily consumption [L/d]

4 — Formula

$$t_{\text{oxygen}} = V_{\text{stock}} / q_{\text{day}}$$

5 — Read aloud

Read “ $t_{\text{oxygen}} = V_{\text{stock}} / q_{\text{day}}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{oxygen} : endurance [d]; V_{stock} : available volume [L]; q_{day} : daily consumption [L/d]

7 — Pronunciation

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

8 — Units

t_{oxygen} [d]; V_{stock} [L]; q_{day} [L/d]

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 $V_{\text{stock}} = 1200$ L, $q_{\text{day}} = 80$ L/d: $t_{\text{oxygen}} = 1200 / 80 = 15$ day.

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

Keep margin for clinical variability, losses and incidents rather than planning to zero.

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 $V_{\text{stock}} = 600 \text{ L}$, $q_{\text{day}} = 50 \text{ L/d}$: $t_{\text{oxygen}} = 600 / 50$?

Detailed guided correction — open after trying

With $V_{\text{stock}} = 600 \text{ L}$, $q_{\text{day}} = 50 \text{ L/d}$: $t_{\text{oxygen}} = 600 / 50 = 12 \text{ day}$. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $V_{\text{stock}} = 2000 \text{ L}$, $q_{\text{day}} = 100 \text{ L/d}$: $t_{\text{oxygen}} = 2000 / 100$?

Autonomous correction — open after trying

With $V_{\text{stock}} = 2000 \text{ L}$, $q_{\text{day}} = 100 \text{ L/d}$: $t_{\text{oxygen}} = 2000 / 100 = 20 \text{ day}$. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Keep margin for clinical variability, losses and incidents rather than planning to zero.

Dose-stock endurance

$$t_{\text{med}} = N_{\text{doses}} / (d_{\text{daily}} \times N_{\text{patients}})$$

1 — Concrete question

What does " $t_{\text{med}} = N_{\text{doses}} / (d_{\text{daily}} \times N_{\text{patients}})$ " compute in "Dose-stock endurance"?

2 — Intuition without symbols

Stock must be divided by the combined consumption of patients actually treated.

3 — Quantities

t_{med} : stock endurance [d]; N_{doses} : available doses [dose]; d_{daily} : doses per patient per day [dose/(patient·d)]; N_{patients} : simultaneous patients [patient]

4 — Formula

$$t_{\text{med}} = N_{\text{doses}} / (d_{\text{daily}} \times N_{\text{patients}})$$

5 — Read aloud

Read " $t_{\text{med}} = N_{\text{doses}} / (d_{\text{daily}} \times N_{\text{patients}})$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{med} : stock endurance [d]; N_{doses} : available doses [dose]; d_{daily} : doses per patient per day [dose/(patient·d)]; N_{patients} : simultaneous patients [patient]

7 — Pronunciation

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

8 — Units

t_{med} [d]; N_{doses} [dose]; d_{daily} [dose/(patient·d)]; N_{patients} [patient]

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 $N_doses = 120$ dose, $d_daily = 2$ dose/(patient·d), $N_patients = 3$ patient: $t_med = 120 / (2 \times 3) = 20$ day.

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

Trigger resupply or substitution before endurance falls below realistic backup delay.

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 $N_doses = 90$ dose, $d_daily = 3$ dose/(patient·d), $N_patients = 2$ patient: $t_med = 90 / (3 \times 2)$?

Detailed guided correction — open after trying

With $N_doses = 90$ dose, $d_daily = 3$ dose/(patient·d), $N_patients = 2$ patient: $t_med = 90 / (3 \times 2) = 15$ day. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $N_doses = 200$ dose, $d_daily = 1$ dose/(patient·d), $N_patients = 4$ patient: $t_med = 200 / (1 \times 4)$?

Autonomous correction — open after trying

With $N_doses = 200$ dose, $d_daily = 1$ dose/(patient·d), $N_patients = 4$ patient: $t_med = 200 / (1 \times 4) = 50$ day. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Trigger resupply or substitution before endurance falls below realistic backup delay.

Total fluid requirement

$$V_fluid = q_patient \times N_patients \times t_days$$

1 — Concrete question

What does “ $V_fluid = q_patient \times N_patients \times t_days$ ” compute in “Total fluid requirement”?

2 — Intuition without symbols

An individual requirement becomes a logistics requirement when multiplied by patient count and duration.

3 — Quantities

V_fluid : total required volume [L]; $q_patient$: per-patient daily need [L/(patient·jour)]; $N_patients$: number of patients [patient]; t_days : care duration [d]

4 — Formula

$$V_fluid = q_patient \times N_patients \times t_days$$

5 — Read aloud

Read “ $V_fluid = q_patient \times N_patients \times t_days$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

V_fluid : total required volume [L]; $q_patient$: per-patient daily need [L/(patient·jour)]; $N_patients$: number of patients [patient]; t_days : care duration [d]

7 — Pronunciation

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

8 — Units

V_fluid [L]; $q_patient$ [L/(patient·jour)]; $N_patients$ [patient]; t_days [d]

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 $q_patient = 2.5$ L/(patient·jour), $N_patients = 4$ patient, $t_days = 3$ d: $V_fluid = 2.5 \times 4 \times 3 = 30$ L.

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

Verify available stock covers the peak scenario rather than only historical average.

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 $q_patient = 1.8$ L/(patient·jour), $N_patients = 6$ patient, $t_days = 2$ d: $V_fluid = 1.8 \times 6 \times 2$?

Detailed guided correction — open after trying

With $q_patient = 1.8$ L/(patient·jour), $N_patients = 6$ patient, $t_days = 2$ d: $V_fluid = 1.8 \times 6 \times 2 = 21.6$ L. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $q_patient = 3$ L/(patient·jour), $N_patients = 2$ patient, $t_days = 5$ d: $V_fluid = 3 \times 2 \times 5$?

Autonomous correction — open after trying

With $q_patient = 3$ L/(patient·jour), $N_patients = 2$ patient, $t_days = 5$ d: $V_fluid = 3 \times 2 \times 5 = 30$ L. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Verify available stock covers the peak scenario rather than only historical average.

Consumable-stock endurance

$t_shelf = N_units / q_use_day$

1 — Concrete question

What does “ $t_shelf = N_units / q_use_day$ ” compute in “Consumable-stock endurance”?

2 — Intuition without symbols

Unit count indicates endurance only after comparison with usage rate.

3 — Quantities

t_{shelf} : consumable endurance [d]; N_{units} : available units [unit]; $q_{\text{use_day}}$: daily usage [unité/jour]

4 — Formula

$$t_{\text{shelf}} = N_{\text{units}} / q_{\text{use_day}}$$

5 — Read aloud

Read " $t_{\text{shelf}} = N_{\text{units}} / q_{\text{use_day}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{shelf} : consumable endurance [d]; N_{units} : available units [unit]; $q_{\text{use_day}}$: daily usage [unité/jour]

7 — Pronunciation

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

8 — Units

t_{shelf} [d]; N_{units} [unit]; $q_{\text{use_day}}$ [unité/jour]

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 $N_{\text{units}} = 300$ unit, $q_{\text{use_day}} = 12$ unité/jour: $t_{\text{shelf}} = 300 / 12 = 25$ day.

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

Review usage rate when endurance drops below the next realistic production or resupply opportunity.

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 $N_{\text{units}} = 150$ unit, $q_{\text{use_day}} = 10$ unité/jour: $t_{\text{shelf}} = 150 / 10$?

Detailed guided correction — open after trying

With $N_{\text{units}} = 150$ unit, $q_{\text{use_day}} = 10$ unité/jour: $t_{\text{shelf}} = 150 / 10 = 15$ day. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $N_{\text{units}} = 480$ unit, $q_{\text{use_day}} = 16$ unité/jour: $t_{\text{shelf}} = 480 / 16$?

Autonomous correction — open after trying

With $N_{\text{units}} = 480$ unit, $q_{\text{use_day}} = 16$ unité/jour: $t_{\text{shelf}} = 480 / 16 = 30$ day. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

Review usage rate when endurance drops below the next realistic production or resupply opportunity.

Sterilization capacity

$$C_{\text{sterile}} = n_{\text{cycles}} \times n_{\text{items_cycle}}$$

1 — Concrete question

What does “ $C_{\text{sterile}} = n_{\text{cycles}} \times n_{\text{items_cycle}}$ ” compute in “Sterilization capacity”?

2 — Intuition without symbols

Daily capacity depends on achievable cycles and safe load per cycle.

3 — Quantities

C_{sterile} : total capacity [instrument]; n_{cycles} : available cycles [cycle]; $n_{\text{items_cycle}}$: items per cycle [instrument/cycle]

4 — Formula

$$C_{\text{sterile}} = n_{\text{cycles}} \times n_{\text{items_cycle}}$$

5 — Read aloud

Read “ $C_{\text{sterile}} = n_{\text{cycles}} \times n_{\text{items_cycle}}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

C_{sterile} : total capacity [instrument]; n_{cycles} : available cycles [cycle]; $n_{\text{items_cycle}}$: items per cycle [instrument/cycle]

7 — Pronunciation

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

8 — Units

C_{sterile} [instrument]; n_{cycles} [cycle]; $n_{\text{items_cycle}}$ [instrument/cycle]

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 $n_{\text{cycles}} = 6$ cycle, $n_{\text{items_cycle}} = 12$ instrument/cycle: $C_{\text{sterile}} = 6 \times 12 = 72$ instrument.

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 demand exceeds capacity, prioritize or add sterilization capability before the procedure.

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 $n_{\text{cycles}} = 4$ cycle, $n_{\text{items_cycle}} = 20$ instrument/cycle: $C_{\text{sterile}} = 4 \times 20$?

Detailed guided correction — open after trying

With $n_{\text{cycles}} = 4$ cycle, $n_{\text{items_cycle}} = 20$ instrument/cycle: $C_{\text{sterile}} = 4 \times 20 = 80$ instrument. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With $n_{\text{cycles}} = 10$ cycle, $n_{\text{items_cycle}} = 8$ instrument/cycle: $C_{\text{sterile}} = 10 \times 8$?

Autonomous correction — open after trying

With $n_{\text{cycles}} = 10$ cycle, $n_{\text{items_cycle}} = 8$ instrument/cycle: $C_{\text{sterile}} = 10 \times 8 = 80$ instrument. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

If demand exceeds capacity, prioritize or add sterilization capability before the procedure.

Medical reserve margin

$M_{\text{med}} = \text{stock} - \text{demand}$

1 — Concrete question

What does “ $M_{\text{med}} = \text{stock} - \text{demand}$ ” compute in “Medical reserve margin”?

2 — Intuition without symbols

The margin measures what remains after covering a defined clinical scenario.

3 — Quantities

M_{med} : reserve margin [unit]; stock: available stock [unit]; demand: scenario demand [unit]

4 — Formula

$M_{\text{med}} = \text{stock} - \text{demand}$

5 — Read aloud

Read “ $M_{\text{med}} = \text{stock} - \text{demand}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

M_{med} : reserve margin [unit]; stock: available stock [unit]; demand: scenario demand [unit]

7 — Pronunciation

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

8 — Units

M_{med} [unit]; stock [unit]; demand [unit]

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 stock = 120 unit, demand = 90 unit: $M_{\text{med}} = 120 - 90 = 30$ unit.

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 means the scenario is not medically supportable without mitigation.

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 stock = 50 unit, demand = 55 unit: $M_{med} = 50 - 55$?

Detailed guided correction — open after trying

With stock = 50 unit, demand = 55 unit: $M_{med} = 50 - 55 = -5$ unit. The decision must then be checked against the module margins and assumptions.

Autonomous exercise. Recalculate this scenario: With stock = 300 unit, demand = 240 unit: $M_{med} = 300 - 240$?

Autonomous correction — open after trying

With stock = 300 unit, demand = 240 unit: $M_{med} = 300 - 240 = 60$ unit. The decision must then be checked against the module margins and assumptions.

21 — Mission decision

A negative margin means the scenario is not medically supportable without mitigation.

Starting question

For how long can a known usable oxygen quantity support a declared continuous flow?

Read aloud

Say: “duration equals usable volume divided by flow rate.”

Symbols, pronunciation and meaning

V_{usable} is the usable oxygen volume expressed at the same reference conditions as the flow; Q is volumetric flow.

Units

If volume is in litres and flow in litres per minute, time emerges in minutes and can be converted to hours.

Origin and status of values

Use mission inventory data and the actual device flow setting. Compressed-gas cylinder markings require correct conversion to usable gas volume.

Why this operation

Flow is volume per unit time, so dividing available volume by the consumption rate gives time to depletion.

Substitution and calculation

For 1,200 L usable oxygen at 4 L/min: $1,200 / 4 = 300 \text{ min} = 5 \text{ h}$.

Calculator entry

Enter $1200 \div 4$, then divide the minutes by 60. Record the assumptions beside the result.

Mental estimate

Four litres each minute uses 240 L each hour. Five hours would therefore use about 1,200 L, matching the calculation.

Independent check

Multiply 4 L/min by 300 min; recovering 1,200 L checks the arithmetic.

Physical or operational interpretation

The duration is a logistics warning: if the patient may need oxygen longer than five hours, the crew must change flow, source or treatment plan before depletion.

Plain-English translation

At the stated flow, this supply lasts about five hours, not “all day.”

Variation / sensitivity

Reducing flow to 3 L/min would extend the same quantity to about 6.7 h, but clinical requirements—not inventory alone—determine whether that is acceptable.

Limit / assumption

Real systems include regulator losses, reserve pressure, changing clinical flow and other oxygen demands. The simple quotient is an initial planning estimate.

Formula 2 — remaining stock after repeated treatment doses

Starting question

How many treatment units remain after a defined number of identical emergency uses?

Read aloud

Read: “remaining stock equals initial stock minus number of events times units used per event.”

Symbols, pronunciation and meaning

N_{initial} is starting inventory, n is event count, and $N_{\text{per event}}$ is the units consumed by one scenario.

Units

All N quantities are counts of the same item. The result is a count and cannot fall below zero without indicating shortage.

Origin and status of values

Starting stock comes from controlled inventory. Per-event use should come from a scenario, protocol or training assumption, not an undocumented guess.

Why this operation

Multiplication gives total consumed stock across identical events; subtraction shows what remains available for future care.

Substitution and calculation

With 24 sterile kits and three events consuming four kits each: $\text{used} = 3 \times 4 = 12$; $\text{remaining} = 24 - 12 = 12$ kits.

Calculator entry

Type $24 - (3 \times 4)$. Parentheses make the consumption calculation explicit.

Mental estimate

Three groups of four use half of twenty-four, so roughly twelve should remain.

Independent check

Add consumed and remaining stock: $12 + 12 = 24$, recovering the starting inventory.

Physical or operational interpretation

The result can trigger a change in medical readiness even when the current patient is stable, because half the contingency capacity has been consumed.

Plain-English translation

After three such events, twelve of the original twenty-four kits remain.

Variation / sensitivity

If each event used five kits instead of four, only nine would remain. Small scenario assumptions can materially change reserve life.

Limit / assumption

Real events are not identical and some items are shared across kits. Inventory planning should model specific consumables rather than rely only on kit counts.

Mission reasoning: connect medicine to the habitat and crew system

Stabilize before seeking diagnostic elegance

In a time-critical emergency, the crew first controls immediately reversible threats using the approved capability. Delayed consultation can improve diagnosis and longer-term management, but it should not postpone actions already authorized for a rapidly deteriorating patient. Procedures must distinguish these phases clearly.

Design diagnostics around decisions

An ultrasound device or laboratory analyser has value only if operators can acquire reliable data and know how the result changes treatment. Training, probe handling, quality checks, consumables and interpretation support are part of the diagnostic system. A sophisticated device without those elements can create false confidence.

Protect crew from cross-contamination

Medical care can produce blood, aerosols, contaminated waste and cleaning chemicals inside a closed habitat. Isolation, ventilation state, personal protective equipment and waste routing therefore connect clinical response to environmental control. The patient can be stabilized while the habitat is made less safe unless those interfaces are planned.

Track treatment as a mission resource

A prolonged illness changes duty rosters, food and water needs, medicine stock and fatigue for caregivers. Mission leadership should receive a resource forecast that respects medical privacy while still showing operational impact. Medical autonomy is stronger when it can explain what the rest of the settlement must protect.

Prepare for degraded medical capability

The medical officer may be the casualty. Equipment may fail during the same event that causes injury. Cross-training, simplified emergency protocols, redundant monitoring and accessible reference material therefore matter. A medical system that works only when every specialist and device is available is not resilient enough for Mars.

Clinical-autonomy exercises — manage the patient and the mission resources

Exercise A — Oxygen duration

A patient requires a declared 5 L/min oxygen flow and the usable supply allocated to the event is 1,500 L. Estimate duration.

Reveal the reasoned solution

$1,500 / 5 = 300 \text{ min} = 5 \text{ h}$. The crew should not interpret this as a treatment recommendation; it is an inventory-duration calculation. Operationally, five hours is the point before which a replenishment or revised plan must be secured if oxygen remains clinically necessary.

Exercise B — Delayed consultation

A crew member has a stable but unclear condition. Earth specialist advice will return in about thirty minutes. Which information should be sent in the first package?

Reveal the reasoned solution

Send the timeline, symptoms, relevant history, measured vital signs, examination findings within crew capability, diagnostic results, treatment already given, allergies, current stability, available equipment and the specific questions requiring specialist input. A complete first package avoids wasting another light-time cycle on basic clarification.

Exercise C — Sterile-stock depletion

The habitat has 30 sterile dressing packs. A prolonged wound-management scenario consumes two per day for six days. How much remains?

Reveal the reasoned solution

Consumption is $2 \times 6 = 12$ packs. Remaining stock is $30 - 12 = 18$. The medical team should also ask whether eighteen packs still satisfy the reserve required for unrelated emergencies.

Exercise D — Medical officer unavailable

The designated physician is incapacitated. Identify three design measures that reduce the resulting capability loss.

Reveal the reasoned solution

Cross-train at least one backup in emergency skills, provide stepwise protocols and decision support usable by non-specialists, and ensure critical equipment can be operated by more than one crew member. Delayed Earth consultation adds support but cannot replace immediate local stabilization.

Exercise E — Isolation interface

A patient may have an infectious illness. Explain why the response cannot be written only as a medical procedure.

Reveal the reasoned solution

Isolation changes airflow, room use, cleaning, waste handling, crew movement and possibly protective-equipment consumption. The medical procedure therefore needs interfaces with ECLSS, habitat zoning, logistics and leadership. Otherwise one department can unknowingly defeat another department's controls.

Exercise F — Consumable reserve

A treatment scenario uses three sterile units per day for four days. The habitat has 25 units and policy requires keeping ten untouched for another emergency. Is the scenario supportable from this stock?

Reveal the reasoned solution

The scenario consumes $3 \times 4 = 12$ units, leaving 13. Because the protected reserve is ten, the stock can support the stated scenario with three units of margin. The mission should still verify whether other concurrent uses draw from the same inventory.

Interactive beginner glossary

These definitions are deliberately operational: they explain the terms a non-specialist Mars crew must understand when following a medical response plan and reporting to delayed support on Earth.

- triage — Prioritization of patients or medical needs when available time, people or treatment resources cannot satisfy everything simultaneously.
- stabilization — Immediate care aimed at controlling life-threatening deterioration and creating time for fuller diagnosis and treatment.
- airway — The passage through which air moves to and from the lungs; loss of a usable airway is an immediate emergency.
- ventilation — Movement of air into and out of the lungs; it is distinct from circulation of blood and from habitat ventilation.
- circulation — Movement of blood through the body to transport oxygen, nutrients and heat and to remove metabolic products.
- vital signs — Basic physiological measurements such as heart rate, blood pressure, respiratory rate, oxygen saturation and temperature.
- oxygen saturation — An estimate of the proportion of haemoglobin carrying oxygen, commonly measured non-invasively by pulse oximetry.
- pulse oximeter — A sensor that estimates arterial oxygen saturation and pulse using light transmitted or reflected through tissue.
- ultrasound — Diagnostic imaging using high-frequency sound waves, useful because compact systems can image many soft-tissue structures without ionizing radiation.
- sterile — Prepared to be free of viable microorganisms under a defined sterilization process and handling condition.
- aseptic technique — Practices intended to prevent contamination of a vulnerable site, sterile equipment or a medical procedure.
- analgesia — Reduction of pain without necessarily causing unconsciousness.
- sedation — Use of medication to reduce awareness, anxiety or responsiveness; depth and monitoring requirements vary.
- allergy — An immune reaction to a substance that can range from mild symptoms to life-threatening systemic response.
- anaphylaxis — A severe, rapidly developing allergic reaction that can compromise airway, breathing or circulation.
- dehydration — A state in which body water deficit becomes clinically significant, potentially affecting circulation, temperature control and performance.
- intravenous access — A route into a vein used for fluids or medication when clinically indicated and within crew capability.
- diagnostic uncertainty — The condition in which available evidence supports more than one plausible explanation and the diagnosis is not yet resolved.
- differential diagnosis — A structured list of plausible conditions considered to explain a patient's findings.
- clinical protocol — A controlled decision and action framework for managing a defined medical situation.
- clinical autonomy — Local capability to assess and manage medical problems within declared competence without depending on immediate Earth direction.

- medical officer — A crew role carrying defined medical responsibilities; the exact qualification and authority must be specified by the mission.
- telemedicine — Remote medical support delivered through transmitted information, images, measurements and communication rather than physical co-location.
- medical contingency reserve — Protected stock or capacity retained for high-consequence medical events rather than routine consumption.
- pharmacy inventory — Controlled record of medicines, concentrations, quantities, expiry dates, storage conditions and dispensing status.
- expiry date — A date after which a manufacturer or authority no longer guarantees the declared quality under specified storage conditions.
- cross-contamination — Transfer of biological or chemical contamination from one person, surface, tool or zone to another.
- isolation — Separation measures used to reduce transmission or exposure between a patient, crew and habitat environment.
- caregiver fatigue — Performance degradation in personnel providing prolonged care, which can increase error risk and must be managed operationally.
- medical debrief — Structured review after an event to capture clinical, equipment, training and logistics lessons while respecting appropriate confidentiality.

Operational depth: building a medical system that can keep functioning

Train for recognition, not memorized diagnosis

Non-specialist crew should be able to recognize dangerous patterns, take reliable measurements and start approved stabilization steps. Training that depends on remembering rare disease names is less robust than training that recognizes airway compromise, shock, neurological change, severe bleeding or environmental injury.

Keep equipment interoperable

Medical devices consume power, data storage, disinfectants, sensors and sometimes proprietary consumables. Standard connectors, common batteries where appropriate and controlled spares reduce the chance that an otherwise functional instrument becomes unusable because one small accessory is missing.

Use Earth expertise strategically

Delayed specialists are excellent for reviewing imaging, laboratory trends, treatment options and uncertain diagnoses. They are less suitable for second-by-second direction during an unstable emergency. The communication plan should match each medical task to the latency it can tolerate.

Manage medication as both therapy and inventory

A medicine plan must consider dose form, storage, expiry, interactions, substitutions and the number of scenarios the stock can support. A drug cabinet can appear well supplied while lacking the one formulation or delivery route needed by an emergency protocol.

Protect privacy without hiding operational impact

Health information should not be broadcast unnecessarily, yet mission planners may need to know that a crew member cannot perform EVA or that a caregiver is unavailable. Procedures should define the minimum operational information required for staffing and risk decisions.

Debrief near misses as aggressively as injuries

A delayed diagnosis, difficult equipment setup or almost-missed allergy can reveal a system weakness even when the patient recovers. Capturing these lessons improves training, stock and procedure design before a future event has worse consequences.

Operational review checklist

- Identify which emergencies require immediate local action before Earth can reply.
- Cross-train backup crew for essential stabilization tasks.
- Link each diagnostic device to an actionable decision and an operator training plan.
- Calculate duration of finite oxygen, fluids and other critical consumables for credible scenarios.
- Track expiry, storage condition and remaining quantity of medical stock.
- Integrate isolation, waste and cleaning procedures with habitat environmental control.
- Prepare structured telemedicine packages that reduce clarification cycles.
- Plan duty coverage when both patient and caregiver are removed from normal work.
- Keep emergency protocols usable if the designated medical specialist is incapacitated.
- Debrief equipment, logistics and decision failures after every significant medical event.

Primary sources and pathways

The medical sources listed here are the operational and human-system standards bridge for this autonomy module. NASA Medical Operations and NASA-STD-3001 provide the requirements and practice context; the lesson does not replace flight-surgeon judgement or mission-specific clinical protocols.

- [NASA — Medical Operations, NASA-STD-3001](#)
- [NASA — Spaceflight Human-System Standard Volume 1](#)
- [NASA — Human Spaceflight Standards](#)

FR ↔ EN parity matrix

Oxygen-reserve endurance	Autonomie d'une réserve d'oxygène
Dose-stock endurance	Autonomie d'un stock de doses
Total fluid requirement	Besoin total de fluide
Consumable-stock endurance	Autonomie d'un consommable
Sterilization capacity	Capacité de stérilisation
Medical reserve margin	Marge de réserve médicale