

Human factors, EVA & space medicine

A crewed mission does not simply add passengers to a robotic vehicle. The human body imposes atmosphere, temperature, sleep, food, exercise, radiation protection and medical care. Crew also adds extraordinary diagnostic and improvisational capability, but that capability declines with fatigue, stress, illness or poor interfaces. Human systems engineering therefore seeks robust performance rather than assuming heroic, infallible people.

Before you start — Prerequisites: modules 01 to 09 recommended. Every important symbol is defined again at first use.

Mastery objectives

- explain concepts with units and assumptions
- redo a simple calculation by hand before using a tool
- identify at least one failure mode or model limitation
- connect the discipline to a complete Mars architecture

1. Human performance and physiological limits

Performance varies with sleep, circadian rhythm, workload, stress, nutrition and health. A procedure designed for a rested operator may become dangerous after a long overnight anomaly. Systems should reduce reliance on memory, provide clear cues and preserve recovery time. Fatigue is a system risk, not a moral failure of the crew.

Human-performance check. When assessing human performance, separate physiological limits from task design. Record sleep opportunity, workload duration, environmental stressors and the performance measure that would trigger a schedule or staffing change.

Approfondissement — Human performance: fatigue is a system variable

A tired crew does not suddenly lose all skill. People become slower, omit more steps and handle simultaneous signals less reliably. That makes fatigue dangerous because degradation can remain subtle until a bad moment. Workload can be tracked through task duration, interruptions, procedure complexity and sleep adequacy, but no single metric replaces observed performance.

On Mars, schedules should be designed as resource budgets. A six-hour EVA does not consume only six hours: preparation, suit donning, depressurization, egress, return, repressurization, suit maintenance and debrief all use time and attention. If an emergency occurs immediately afterward, the system must assume a crew that is already depleted. Human margin should therefore be protected like electrical or thermal margin, not routinely consumed during nominal operations.

2. Human factors and interface design

Human factors connects physiology, cognition and task design to operational safety. An alarm must be perceivable, understandable and prioritized. Too many simultaneous alarms become noise; critical information hidden on a secondary display delays diagnosis. Design considers anthropometry, gloves, visibility, lighting, maintenance access and procedural compatibility. The interface is part of the safety system.

Human-machine interface check. Review an interface by asking what the operator must perceive, decide and do under nominal and emergency conditions. Controls, displays and alarms should make the correct action easier than the dangerous one, especially under fatigue.

3. Space medicine and increasing autonomy

Far from Earth, a crew cannot assume rapid evacuation. Diagnostic capability, medicines, emergency procedures, telemedicine, consumables and cross-trained skills must be defined. Required autonomy depends on communication delay and return time. A durable settlement needs more than a first-aid kit; it needs a healthcare chain.

Medical-autonomy rule. Build medical autonomy around time-to-treatment and capability gaps. Identify which conditions need immediate local diagnosis or intervention because Earth consultation cannot arrive before the clinical decision must be made.

Approfondissement — Operational medicine: making decisions when evacuation is not available

On Earth, a medical team can stabilize a patient and transfer them to a higher level of care. On Mars, the higher level may not exist. Medical design has to begin with actual capability: diagnostics, drugs, imaging, limited surgery, dentistry, rehabilitation and isolation. Treatment decisions also interact with the remaining stock and risk to the rest of the crew.

Triage changes when rapid evacuation is impossible. A serious EVA injury may require two rescuers, interrupt critical work and consume irreplaceable medical supplies. Procedures therefore have to connect medicine, operations, resources and command. Prevention remains the strongest control: ergonomic design, training, load limits, fall protection, fatigue monitoring and authority to stop work before schedule pressure turns an avoidable incident into a medical emergency.

4. EVA: turn a human into a mobile autonomous system

Extravehicular activity combines a pressurized suit, oxygen, CO₂ removal, thermal control, communications, power, mobility and procedures. Every minute outside consumes resources and exposes the crew to hazards. Mars adds dust, terrain, distance and airlock management. An EVA is therefore a complete mission nested inside the main mission.

EVA reserve rule. Plan an EVA from consumables backward: oxygen, carbon-dioxide removal, battery, thermal capacity and crew time all need explicit reserves. Add a credible return path before assigning productive surface tasks.

Approfondissement — EVA budget: time, oxygen, carbon dioxide removal, cooling and energy must all close

An extravehicular activity has several simultaneous budgets. Maximum duration depends on oxygen, carbon-dioxide removal, cooling, battery energy and emergency reserve. If a battery stores energy $E = 3.0$ kWh and average power is $P = 0.42$ kW, the theoretical energy-limited time is $t = E \div P = 3.0 \div 0.42 \approx 7.14$ h. Here E is energy, P power and t time. That does not mean the EVA may last 7.14 h; another consumable may become limiting first.

The operational plan therefore uses the tightest constraint and keeps reserve. It must also cover a slower-than-planned return caused by injury, rover failure, an unavailable airlock or low visibility. Emergency reserve is not part of the nominal work budget. A base that repeatedly spends its EVA oxygen reserve to gain thirty minutes of productivity has already turned a survival margin into operational debt.

5. Spacesuits, airlocks and contamination

A spacesuit maintains pressure and gas composition while allowing movement. The airlock manages pressure transitions, equipment and contamination. Martian dust creates problems for seals, filters, abrasion and habitat entry. Architectures can reduce dust transfer through intermediate zones, cleaning procedures and material choices.

Dust-contamination rule. Treat the suit and airlock as one contamination-control system. Map where dust can enter seals, bearings, filters and habitat volumes, then define inspection and cleaning steps before the contamination becomes a maintenance failure.

6. Robotics as a crew partner

Robots, manipulators and rovers can prepare sites, move loads or inspect areas before human exposure. The question is not 'human or robot' but how to allocate tasks according to strength, precision, judgement, delay and risk. A good interface lets crew supervise multiple systems without becoming the bottleneck for every operation.

Robot-partnership rule. Assign robots tasks that reduce exposure or repetitive workload, but define what the crew does when perception, communications or manipulation fail. A robot partnership is robust only when degraded modes preserve crew safety.

7. Nominal procedures, emergencies and abort criteria

A nominal procedure explains how to succeed; an emergency procedure must also explain when to stop. Fire, depressurization, toxicity, medical crisis or power loss need explicit priorities. Immediate actions should be simple and trained. Later actions can use checklists, diagnosis and ground support.

Emergency-procedure rule. For every emergency procedure, state the trigger, immediate safe action, decision point and abort threshold. Crew should not have to invent criteria while simultaneously managing pressure loss, injury or vehicle instability.

8. Training, simulation and repetition

Operational skill grows through realistic repetition. Simulators, mock-ups, integrated scenarios and constrained training let crews learn from errors without losing the vehicle. Injected failures force teams to practise communication, authority and recovery. Training must cover rare transitions, not only frequent nominal operation.

Simulation-training rule. Use simulation to rehearse rare combinations, not only nominal checklists. Vary timing, sensor failures and crew availability so training tests diagnosis, communication and recovery rather than memorised button sequences.

9. Team, leadership and delayed communications

A Mars crew cannot wait for Earth approval for every decision. Roles, delegation and authority limits must be prepared. Leadership can shift with the situation: a specialist may hold technical authority during a fault and return it later. Handover effectiveness and operational logs become essential when decisions unfold over days.

Delayed-team authority rule. Design delayed-team operations with explicit authority boundaries. Decide in advance which choices the Mars crew can make autonomously, what must be reported to Earth, and how leadership transfers during medical or operational overload.

Worked example step by step

Workload has no single formula: track available time, critical tasks, interruptions, sleep and margin. Scheduling people at 100% capacity creates a fragile architecture.

The work method is always the same: state what every symbol represents, convert all units into a coherent system, perform the operation, then translate the result into a sentence. Finally perform an order-of-magnitude check. If the answer changes by a factor of one thousand because millimetres were treated as metres, the conversion must be visible in the calculation.

Progressive exercise

1. Choose a simple case and list every input with units.
2. Compute the nominal result without margin.
3. Vary the most uncertain parameter by $\pm 20\%$ and compare.
4. Inject one credible failure and explain which indicator detects it.
5. Decide whether the system continues, degrades or stops.

Detailed solution — reasoning and decision

Reasoned solution

A good solution is not only the final number. It shows conversions, why the equation applies, sensitivity and the resulting decision. If different plausible assumptions lead to the same operational decision, the design is relatively robust to that uncertainty. If a small variation reverses the decision, the parameter becomes a priority for measurement or margin.

Validation mini-project

Build a two-to-four-page engineering note applying this course to one Mars subsystem. Include need, assumptions, functional sketch, hand calculation, second calculation or simulation, uncertainties, injected failure, decision criteria and three primary references. The goal is a chain of evidence that another reader can reproduce.

Common errors to detect

- mixing units or frames without explicit conversion;
- presenting calculated values as measured data;
- ignoring a model's validity range;
- confusing numerical precision with physical accuracy;
- sizing only the nominal case with no margin or degraded mode.

Primary sources and pathways

- NASA — Crew & Operations Training
- NASA-STD-3001 — Crew Health

Human-operations foundations and mission reasoning

This English human-factors module matches the French teaching intent by connecting physiology, workload and communication to concrete EVA and crew decisions, with answers kept out of the questions.

Four concepts to master first

human factor

Definition. A human factor is a physiological, cognitive or organisational characteristic that changes real-world performance.

Mission example. Fatigue, display design, stress and team communication can turn a technically correct procedure into a risky operation.

Pitfall. Do not treat the operator as a perfectly repeatable component with unlimited attention.

Mental check. Ask how the same task changes after sleep loss, alarm load, gloves, time pressure or reduced visibility.

Evidence

Use timed task trials, error logs, workload ratings and observations from suited or otherwise representative operators under mission-like conditions.

Decision use

If users cannot perform the task reliably, redesign the interface, procedure or staffing plan rather than blaming the operator.

EVA

Definition. EVA means extravehicular activity: work outside the main pressurised volume using a suit or mobile system that provides pressure, oxygen, thermal control and communications.

Mission example. A solar-array inspection on Mars adds dust, partial gravity, tools, navigation, reserve time and airlock return constraints.

Pitfall. Do not reduce EVA planning to suit oxygen duration alone.

Mental check. Verify the complete timeline from prebreathe and egress through the latest safe return and repressurisation.

Evidence

Use suit telemetry, consumable margins, task-duration records and airlock-return timing from rehearsal or representative EVA operations.

Decision use

If reserve or return criteria are threatened, shorten the task, change the route or terminate the EVA before the latest-safe-return point.

workload

Definition. Workload combines task quantity, difficulty, time pressure, interruptions and the mental or physical resources demanded from a person or team.

Mission example. Two individually simple alarms can become unsafe when they arrive during a difficult EVA manoeuvre.

Pitfall. A schedule at 100% theoretical utilisation has no capacity for diagnosis, recovery or unexpected work.

Mental check. Compare required task-hours with genuinely available crew-hours and preserve explicit contingency margin.

Evidence

Use task timelines, crew-hour accounting, interruption logs and workload assessments for the actual duty period being planned.

Decision use

Excess workload requires reprioritising tasks, adding crew support or protecting rest instead of hiding the shortfall in an optimistic schedule.

deconditioning

Definition. Deconditioning is the loss or alteration of physiological capability after prolonged exposure to microgravity, isolation or reduced activity.

Mission example. Cardiovascular and muscle changes can reduce the ability to stand, carry loads or perform an emergency EVA after landing.

Pitfall. Do not assume a medically healthy astronaut retains the same operational capacity throughout a mission.

Mental check. Track trends in strength, aerobic performance, balance and recovery rather than relying on one preflight baseline.

Evidence

Use repeated strength, cardiovascular and functional performance measurements rather than a single snapshot taken in isolation.

Decision use

A degrading trend can trigger countermeasure changes, medical review or tighter EVA limits even while one measurement remains inside a nominal range.

Calculation laboratory

Use every quantitative relation here as an operational check: identify whether it concerns time margin, crew-hours or physiological capacity, keep the units explicit, and interpret the result for crew safety.

Canonical quantitative mini-lessons

This block is the module quantitative reference; exercise values are pedagogical and must not be confused with mission data.

Activity time margin

$$t_{\text{margin}} = t_{\text{available}} - t_{\text{task}}$$

1 — Concrete question

What does “ $t_{\text{margin}} = t_{\text{available}} - t_{\text{task}}$ ” compute in “Activity time margin”?

2 — Intuition without symbols

Time margin is the time left to absorb slowdown, diagnosis or an early return.

3 — Quantities

t_{margin} : time margin; $t_{\text{available}}$: available safe window; t_{task} : nominal task duration

4 — Formula

$$t_{\text{margin}} = t_{\text{available}} - t_{\text{task}}$$

5 — Read aloud

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

6 — Symbols and meaning

t_margin: time margin; t_available: available safe window; t_task: nominal task duration

7 — Pronunciation

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

8 — Units

all terms in the same time 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 change between two quantities expressed on the same basis.

11 — Assumptions

Both terms must use the same frame, unit and system boundary.

12 — Unit check

all terms in the same time unit Verify that dimensional reduction reaches the unit of the requested output.

13 — Numerical case

With t_available=68 min and t_task=52 min, t_margin=16 min.

14 — Why the calculation works

Subtraction isolates a margin or change between two quantities expressed on the same basis.

15 — Independent check

Adding the difference back to the subtracted term must recover the initial term.

16 — Mental estimate

Comparing the two terms is enough to predict the sign and scale of the difference.

17 — Interpretation

A small margin is not necessarily acceptable when return or airlock closure requires protected reserve.

18 — What the result does not prove

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

19 — Sensitivity

Increasing the first term raises the result; increasing the second lowers it with unit slope.

20 — Guided and autonomous exercises

Guided exercise. t_available=90 min and t_task=70 min.

Detailed guided correction — open after trying

t_available=90 min and t_task=70 min. t_margin=20 min.

Autonomous exercise. t_available=45 min and t_task=40 min.

Autonomous correction — open after trying

t_available=45 min and t_task=40 min. t_margin=5 min.

21 — Mission decision

Define an abort threshold before EVA and do not consume return reserve.

Crew workload utilisation

$U_work = H_tasks / H_available$

1 — Concrete question

What does “ $U_work = H_tasks / H_available$ ” compute in “Crew workload utilisation”?

2 — Intuition without symbols

A crew must retain capacity for errors, care, recovery and anomalies rather than merely filling all available hours.

3 — Quantities

U_work: fraction of capacity used; H_tasks: task hours; H_available: usable hours

4 — Formula

$U_work = H_tasks / H_available$

5 — Read aloud

Read " $U_{\text{work}} = H_{\text{tasks}} / H_{\text{available}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

U_{work} : fraction of capacity used; H_{tasks} : task hours; $H_{\text{available}}$: usable hours

7 — Pronunciation

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

8 — Units

U_{work} dimensionless; hours over the same period

9 — Convention

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

10 — Why this operation

Division compares one quantity with a homogeneous reference and produces a proportion indicator.

11 — Assumptions

Both quantities must belong to the same scope and time period.

12 — Unit check

U_{work} dimensionless; hours over the same period Verify that dimensional reduction reaches the unit of the requested output.

13 — Numerical case

With $H_{\text{tasks}}=60$ h and $H_{\text{available}}=72$ h, $U_{\text{work}}\approx 0.8333=83.33\%$.

14 — Why the calculation works

Division compares one quantity with a homogeneous reference and produces a proportion indicator.

15 — Independent check

Multiplying the result by the denominator must recover the numerator.

16 — Mental estimate

Before calculating, compare numerator and denominator mentally to predict whether the result should be below, near or above one.

17 — Interpretation

Two schedules with the same global utilisation can differ greatly when one specialty is saturated.

18 — What the result does not prove

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

19 — Sensitivity

The result rises with the numerator and falls with the denominator, all else equal.

20 — Guided and autonomous exercises

Guided exercise. $H_{\text{tasks}}=48$ h and $H_{\text{available}}=64$ h.

Detailed guided correction — open after trying

$H_{\text{tasks}}=48$ h and $H_{\text{available}}=64$ h. $U_{\text{work}}=0.75=75\%$.

Autonomous exercise. $H_{\text{tasks}}=35$ h and $H_{\text{available}}=50$ h.

Autonomous correction — open after trying

$H_{\text{tasks}}=35$ h and $H_{\text{available}}=50$ h. $U_{\text{work}}=0.70=70\%$.

21 — Mission decision

Also analyse load by critical role and recovery after EVA or emergencies.

Oxygen endurance

$$t_{\text{O}_2} = m_{\text{O}_2} / q_{\text{O}_2}$$

1 — Concrete question

What does " $t_{\text{O}_2} = m_{\text{O}_2} / q_{\text{O}_2}$ " compute in "Oxygen endurance"?

2 — Intuition without symbols

A breathing stock becomes endurance when divided by the consumption rate in the same scenario.

3 — Quantities

t_{O2} : endurance; m_{O2} : usable oxygen mass; q_{O2} : average mass consumption rate

4 — Formula

$$t_{O2} = m_{O2} / q_{O2}$$

5 — Read aloud

Read " $t_{O2} = m_{O2} / q_{O2}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

t_{O2} : endurance; m_{O2} : usable oxygen mass; q_{O2} : average mass consumption rate

7 — Pronunciation

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

8 — Units

t_{O2} in time; m_{O2} in kg; q_{O2} in kg per time unit

9 — Convention

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

10 — Why this operation

Division compares one quantity with a homogeneous reference and produces a proportion indicator.

11 — Assumptions

Both quantities must belong to the same scope and time period.

12 — Unit check

t_{O2} in time; m_{O2} in kg; q_{O2} in kg per time unit. Verify that dimensional reduction reaches the unit of the requested output.

13 — Numerical case

With $m_{O2}=1.2$ kg and $q_{O2}=0.10$ kg/h, $t_{O2}=12$ h.

14 — Why the calculation works

Division compares one quantity with a homogeneous reference and produces a proportion indicator.

15 — Independent check

Multiplying the result by the denominator must recover the numerator.

16 — Mental estimate

Before calculating, compare numerator and denominator mentally to predict whether the result should be below, near or above one.

17 — Interpretation

Consumption varies with metabolism, work, leakage and suit mode; nominal endurance must not be consumed to zero.

18 — What the result does not prove

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

19 — Sensitivity

The result rises with the numerator and falls with the denominator, all else equal.

20 — Guided and autonomous exercises

Guided exercise. $m_{O2}=0.9$ kg and $q_{O2}=0.075$ kg/h.

Detailed guided correction — open after trying

$m_{O2}=0.9$ kg and $q_{O2}=0.075$ kg/h. $t_{O2}=12$ h.

Autonomous exercise. $m_{O2}=1.5$ kg and $q_{O2}=0.125$ kg/h.

Autonomous correction — open after trying

$m_{O2}=1.5$ kg and $q_{O2}=0.125$ kg/h. $t_{O2}=12$ h.

21 — Mission decision

Keep a return reserve and use the worst credible flow for abort decisions.

Metabolic energy over an EVA

$$E_{\text{met}} = P_{\text{met}} \times t_{\text{eva}}$$

- 1 — Concrete question
What does “ $E_{\text{met}} = P_{\text{met}} \times t_{\text{eva}}$ ” compute in “Metabolic energy over an EVA”?
- 2 — Intuition without symbols
Accumulated thermal and physiological load depends on average metabolic power and time spent working.
- 3 — Quantities
 E_{met} : metabolic energy; P_{met} : average metabolic power; t_{eva} : EVA duration
- 4 — Formula
 $E_{\text{met}} = P_{\text{met}} \times t_{\text{eva}}$
- 5 — Read aloud
Read “ $E_{\text{met}} = P_{\text{met}} \times t_{\text{eva}}$ ” by naming every operation, subscript and grouping explicitly.
- 6 — Symbols and meaning
 E_{met} : metabolic energy; P_{met} : average metabolic power; t_{eva} : EVA duration
- 7 — Pronunciation
Say subscripts, powers, Greek letters and parentheses explicitly so the relation can be reconstructed without seeing the page.
- 8 — Units
 E_{met} in Wh when P_{met} is W and t_{eva} is h
- 9 — Convention
Keep the same frame, time basis, system boundary and sign convention throughout the substitution.
- 10 — Why this operation
Multiplication converts a rate or specific quantity into a total over the chosen interval or population.
- 11 — Assumptions
Factors must describe the same scenario and their units must be compatible.
- 12 — Unit check
 E_{met} in Wh when P_{met} is W and t_{eva} is h Verify that dimensional reduction reaches the unit of the requested output.
- 13 — Numerical case
With $P_{\text{met}}=350$ W and $t_{\text{eva}}=4$ h, $E_{\text{met}}=1,400$ Wh=1.4 kWh.
- 14 — Why the calculation works
Multiplication converts a rate or specific quantity into a total over the chosen interval or population.
- 15 — Independent check
Dividing the result by any non-zero factor must recover the other factor.
- 16 — Mental estimate
Estimating each factor separately predicts the order of magnitude of the product.
- 17 — Interpretation
An energy average does not replace analysis of exertion peaks, cooling and individual limits.
- 18 — What the result does not prove
The calculation proves neither that the inputs are correct nor that the model remains valid outside the declared scenario; those questions require separate evidence.
- 19 — Sensitivity
With independent factors, a relative change in one factor transfers directly to the product.
- 20 — Guided and autonomous exercises
Guided exercise. $P_{\text{met}}=300$ W and $t_{\text{eva}}=5$ h.

Detailed guided correction — open after trying

$P_{\text{met}}=300$ W and $t_{\text{eva}}=5$ h. $E_{\text{met}}=1,500$ Wh.

Autonomous exercise. $P_{\text{met}}=450$ W and $t_{\text{eva}}=2.5$ h.

Autonomous correction — open after trying

$P_{\text{met}}=450$ W and $t_{\text{eva}}=2.5$ h. $E_{\text{met}}=1,125$ Wh.

- 21 — Mission decision
Size cooling and procedures using qualified metabolic loads, not a convenient average.

CO2 mass produced during an EVA

$$m_{\text{CO2}} = q_{\text{CO2}} \times t_{\text{eva}}$$

1 — Concrete question

What does " $m_{\text{CO2}} = q_{\text{CO2}} \times t_{\text{eva}}$ " compute in "CO2 mass produced during an EVA"?

2 — Intuition without symbols

Accumulated carbon-dioxide production drives the removal capacity required during the EVA.

3 — Quantities

m_{CO2} : CO2 mass produced; q_{CO2} : average production mass flow; t_{eva} : EVA duration

4 — Formula

$$m_{\text{CO2}} = q_{\text{CO2}} \times t_{\text{eva}}$$

5 — Read aloud

Read " $m_{\text{CO2}} = q_{\text{CO2}} \times t_{\text{eva}}$ " by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

m_{CO2} : CO2 mass produced; q_{CO2} : average production mass flow; t_{eva} : EVA duration

7 — Pronunciation

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

8 — Units

m_{CO2} in kg; q_{CO2} in kg/h; t_{eva} in h

9 — Convention

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

10 — Why this operation

Multiplication converts a rate or specific quantity into a total over the chosen interval or population.

11 — Assumptions

Factors must describe the same scenario and their units must be compatible.

12 — Unit check

m_{CO2} in kg; q_{CO2} in kg/h; t_{eva} in h Verify that dimensional reduction reaches the unit of the requested output.

13 — Numerical case

With $q_{\text{CO2}}=0.09$ kg/h and $t_{\text{eva}}=6$ h, $m_{\text{CO2}}=0.54$ kg.

14 — Why the calculation works

Multiplication converts a rate or specific quantity into a total over the chosen interval or population.

15 — Independent check

Dividing the result by any non-zero factor must recover the other factor.

16 — Mental estimate

Estimating each factor separately predicts the order of magnitude of the product.

17 — Interpretation

Instantaneous production varies with workload; scrubbing capacity must also handle peaks.

18 — What the result does not prove

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

19 — Sensitivity

With independent factors, a relative change in one factor transfers directly to the product.

20 — Guided and autonomous exercises

Guided exercise. $q_{\text{CO2}}=0.08$ kg/h and $t_{\text{eva}}=5$ h.

Detailed guided correction — open after trying

$q_{\text{CO2}}=0.08$ kg/h and $t_{\text{eva}}=5$ h. $m_{\text{CO2}}=0.40$ kg.

Autonomous exercise. $q_{\text{CO2}}=0.12$ kg/h and $t_{\text{eva}}=3$ h.

Autonomous correction — open after trying

$q_{\text{CO2}}=0.12$ kg/h and $t_{\text{eva}}=3$ h. $m_{\text{CO2}}=0.36$ kg.

21 — Mission decision

Keep scrubbing margin and monitor CO2 partial pressure in real time.

Accumulated dose at constant dose rate

$$D = \text{dose_rate} \times t_{\text{exposure}}$$

1 — Concrete question

What does “ $D = \text{dose_rate} \times t_{\text{exposure}}$ ” compute in “Accumulated dose at constant dose rate”?

2 — Intuition without symbols

At constant dose rate, accumulated dose grows directly with time spent in the environment.

3 — Quantities

D: accumulated dose; dose_rate: average dose rate; t_exposure: exposure duration

4 — Formula

$$D = \text{dose_rate} \times t_{\text{exposure}}$$

5 — Read aloud

Read “ $D = \text{dose_rate} \times t_{\text{exposure}}$ ” by naming every operation, subscript and grouping explicitly.

6 — Symbols and meaning

D: accumulated dose; dose_rate: average dose rate; t_exposure: exposure duration

7 — Pronunciation

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

8 — Units

D in dose units; dose_rate in dose per time; t_exposure in time

9 — Convention

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

10 — Why this operation

Multiplication converts a rate or specific quantity into a total over the chosen interval or population.

11 — Assumptions

Factors must describe the same scenario and their units must be compatible.

12 — Unit check

D in dose units; dose_rate in dose per time; t_exposure in time. Verify that dimensional reduction reaches the unit of the requested output.

13 — Numerical case

With dose_rate=0.5 mSv/h and t_exposure=6 h, D=3.0 mSv.

14 — Why the calculation works

Multiplication converts a rate or specific quantity into a total over the chosen interval or population.

15 — Independent check

Dividing the result by any non-zero factor must recover the other factor.

16 — Mental estimate

Estimating each factor separately predicts the order of magnitude of the product.

17 — Interpretation

Dose rate may vary with shielding, geometry and solar events; the real time integral must then replace the simple product.

18 — What the result does not prove

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

19 — Sensitivity

With independent factors, a relative change in one factor transfers directly to the product.

20 — Guided and autonomous exercises

Guided exercise. dose_rate=0.2 mSv/h and t_exposure=10 h.

Detailed guided correction — open after trying

dose_rate=0.2 mSv/h and t_exposure=10 h. D=2.0 mSv.

Autonomous exercise. dose_rate=1.2 mSv/h and t_exposure=2 h.

Autonomous correction — open after trying

dose_rate=1.2 mSv/h and t_exposure=2 h. D=2.4 mSv.

21 — Mission decision

Mission reasoning

Designing for the human operator

Mars operations last too long for heroics to substitute for design. Controls must be reachable with gloves, alarms must support prioritisation, procedures must be usable under stress, and roles must remain understandable during degraded modes. Human-factors engineering therefore begins before hardware freeze. Mock-ups, timed walkthroughs and error-observation studies expose hazards that a purely technical simulation can miss.

EVA as a coupled survival system

An EVA timeline couples suit resources, thermal balance, communications, navigation, tool handling, dust exposure, physiological effort and rescue capability. A long task can be safe in benign terrain yet unacceptable when the return route crosses a slope or when a dust event reduces visibility. Planning therefore uses latest-safe-return points and abort triggers rather than one optimistic duration. The crew must know what condition changes a mission from continue to return.

Medical autonomy and delayed support

On Mars, medical decisions cannot depend on real-time terrestrial specialists. Communication delay forces the crew to stabilise, diagnose and treat with local skills, equipment and consumables. Training should focus on time-critical patterns, differential diagnosis, procedure support and knowing when uncertainty is itself a hazard. Medical stocks must be linked to mission duration, shelf life and realistic case frequency.

CRM and workload protection

Crew resource management makes information flow explicit. Challenge-and-response, closed-loop communication and cross-checking reduce silent misunderstandings. Workload protection matters just as much: the team needs protected sleep, handover time, maintenance reserve and recovery after high-stress events. A plan that appears efficient because every hour is assigned can fail the first time an alarm, injury or delayed repair consumes the missing margin.

Crew-operations practice — work the scenario first, then open its solution

Exercise A — Human-factor redesign

A checklist is technically correct but requires reading small text while wearing pressurised gloves during an alarm. Propose three redesigns and explain which error each one reduces.

Detailed correction — Exercise A

Increase legibility and grouping, move time-critical steps to large unambiguous cues, and use confirmation states or physical differentiation for controls. These changes reduce visual search, memory load and selection errors. The specific design should be tested with suited users under representative lighting and workload.

Evaluate the checklist while wearing the suit, under alarm lighting and time pressure; legibility that works at a desk is not evidence that the EVA interface is usable.

Exercise B — EVA return reserve

An EVA plan leaves 16 minutes of time margin before the latest safe return. A tool problem adds 9 minutes and a navigation detour is estimated at 5 minutes. Decide whether the original task can continue.

Detailed correction — Exercise B

The remaining nominal margin is only $16 - 9 - 5 = 2$ minutes before accounting for uncertainty. Continuing the original scope is therefore fragile. A disciplined decision is to stop discretionary work, begin return or switch to an abort profile according to the prebriefed threshold.

Subtract the tool delay and detour from the original 16-minute margin, then compare the remaining reserve with the declared latest-safe-return rule before deciding whether the task can continue.

Exercise C — Workload calculation

A four-person crew has 72 usable crew-hours in a planning day after protected activities. Assigned work totals 60 task-hours. Calculate workload and interpret the result.

Detailed correction — Exercise C

$60/72 = 0.833$, about 83.3%. The number looks feasible but leaves only 12 crew-hours across the team for disturbance and recovery. Whether that is acceptable depends on task concurrency, specialist bottlenecks and the consequence of deferral.

Keep clock time separate from cumulative crew-hours: 72 available crew-hours minus 60 assigned task-hours leaves 12 crew-hours of labor capacity, not twelve extra hours in the day.

Exercise D — Deconditioning trend

An astronaut's repeated functional test shows a gradual decline while a single medical snapshot remains within normal limits. Which evidence should operations use for planning a strenuous EVA?

Detailed correction — Exercise D

Use the trend plus task-specific performance, not the isolated "normal" snapshot alone. Operational planning should consider the direction and rate of change, recovery after exercise, orthostatic tolerance and the margin required for emergency work.

Treat the downward functional trend as evidence requiring investigation even if one snapshot remains inside a reference range; trend, symptoms and operational consequence must be considered together.

Exercise E — Crew communication

During a depressurisation response, one crewmember calls out a valve command but receives no acknowledgement. What should happen before assuming the action is complete?

Detailed correction — Exercise E

Use closed-loop communication: the receiver repeats or acknowledges the command, executes it, and reports completion or inability. If no acknowledgement occurs, the commander treats the action as unconfirmed and re-establishes communication rather than silently assuming success.

Require the receiver to acknowledge and repeat the critical valve instruction before action continues; silence breaks the communication loop and must be treated as unresolved.

Interactive beginner glossary

Use the interactive vocabulary to connect human limitations with design choices. A definition is useful only if it clarifies how crew behavior, equipment or procedures should change.

- **human factor** — A human factor is a physiological, cognitive or organizational characteristic that affects how people perform a task and how safely they interact with equipment and procedures.
- **ergonomics** — Ergonomics adapts tools, controls, displays, workspaces and tasks to human capabilities and limitations so work can be performed safely, efficiently and with fewer errors.
- **cognition** — Cognition includes perception, attention, memory, reasoning and decision-making. Space operations must account for the fact that these resources are limited and degrade under stress or fatigue.
- **fatigue** — Human fatigue is a reduction in alertness, reaction speed and decision-making performance caused by insufficient sleep, long duty periods, circadian disruption or sustained workload.
- **workload** — Workload is the demand placed on a person by the number, difficulty and timing of tasks relative to available attention, time and physical capacity.
- **situational awareness** — Situational awareness is understanding what is happening now, why it matters and what is likely to happen next. It depends on accurate perception, comprehension and projection.
- **EVA** — Extravehicular activity (EVA) is work performed outside a pressurized vehicle or habitat while the astronaut depends on a spacesuit and portable life-support system.
- **airlock** — An airlock is a pressure-controlled chamber that allows people or equipment to pass between a pressurized habitat and the external environment while limiting atmosphere loss and contamination.
- **pressure suit** — A pressure suit is an individual life-support garment that maintains body pressure and breathable atmosphere while also providing thermal, mobility and environmental protection.
- **life support** — Life support maintains conditions required for survival, including oxygen supply, carbon-dioxide removal, pressure, temperature, humidity and often water management.

- oxygen reserve — An oxygen reserve is the quantity deliberately kept unused during nominal operations so breathing support remains available during delays, leaks or an emergency return.
- thermal control — Thermal control keeps equipment and crew within acceptable temperature limits by managing heat generation, transport, insulation, storage and rejection.
- crew resource management — Crew resource management is the structured use of communication, leadership, cross-checking and shared decision-making to reduce human error and use the whole crew's capabilities.
- closed-loop communication — Closed-loop communication requires a message to be sent, acknowledged and confirmed so the sender knows that the correct instruction or information was actually received and understood.
- deconditioning — Deconditioning is the loss of physiological capacity that develops during reduced gravity or inactivity, affecting muscles, bones, cardiovascular function and tolerance to later physical stress.
- microgravity — Microgravity is a condition of continuous free fall in which apparent weight is very small even though gravity still acts. It drives major changes in fluids, muscles, bones and orientation.
- partial gravity — Partial gravity is surface gravity lower than Earth's but greater than microgravity. Mars is about 0.38 g, so long-term adaptation may differ from both Earth and orbital flight.
- exercise countermeasure — An exercise countermeasure is a planned physical-training method used to limit losses in muscle, bone and cardiovascular capacity during reduced-gravity missions.
- orthostatic tolerance — Orthostatic tolerance is the body's ability to maintain adequate blood pressure and brain perfusion when upright against gravity, especially after prolonged exposure to microgravity.
- medical autonomy — Medical autonomy is the crew's ability to assess and treat illness or injury without immediate specialist support from Earth, using onboard skills, equipment, drugs and decision protocols.
- triage — Triage prioritizes patients when medical resources are limited by comparing urgency, likely benefit and resource demand rather than simply treating people in arrival order.
- diagnosis — Diagnosis is the reasoned identification of the most likely condition from symptoms, signs, measurements and tests while considering alternative explanations and uncertainty.
- contingency — A contingency is a preplanned response to a credible off-nominal event, including triggers, responsibilities, protected resources and criteria for recovery or escalation.
- abort trigger — An abort trigger is a predefined condition that requires abandoning the current objective and moving to a safer plan before remaining margins become unacceptable.
- latest safe return — The latest safe return is the last time at which an EVA crew can start returning and still reach a protected location within the declared consumable, thermal and operational reserves.
- crew-hour — A crew-hour is one person working for one hour. It measures cumulative labor capacity, so two people working for three hours provide six crew-hours even though only three clock hours pass.

Operational depth: from calculation to mission decision

Human reliability is contextual

Performance is not a fixed personal trait. The same trained crewmember can behave differently after poor sleep, during a suit leak, while managing multiple alarms or when communication with Earth is unavailable. Human-factors work therefore models context: posture, gloves, visibility, noise, time pressure, workload, team composition and the reversibility of an error. Training should reproduce the difficult context rather than merely teaching the nominal procedure in a classroom. The strongest design reduces the number of critical actions that depend on perfect memory at the worst possible moment.

EVA planning around abortability

A good EVA plan is built backward from safe return. Every worksite has an expected travel time, a latest departure time, consumable reserves and conditions that trigger immediate return. The plan also includes what happens if the primary route is blocked or one astronaut becomes less mobile. This approach makes margin visible. Instead of asking only whether the planned work fits inside suit duration, the team asks how much reserve remains after realistic navigation error, slower movement, tool handling, decontamination and airlock recovery.

Medical capability as a system

Medical autonomy is a chain rather than a cabinet of supplies. It includes trained people, diagnostic tools, pharmaceuticals, procedural guidance, sterile capability, communications, record keeping and the ability to continue care when the patient is also a mission specialist. A treatment that consumes the only critical drug or immobilises the only power-system expert creates

operational consequences outside medicine. Medical planning should therefore connect likely conditions with inventory, shelf life, cross-training and mission staffing rather than treating health as an isolated service.

Workload and simultaneous demand

Crew-hour arithmetic can hide concurrency. Four hours of work split across four people may fit on paper, yet still be impossible if all four tasks require the same surgeon, EVA-certified operator or workstation at the same time. Schedules therefore need resource identity as well as total hours. Peaks matter too: alarms, handovers and maintenance can coincide. Operations teams use protected margin, task deferral rules and role substitution to prevent one local overload from becoming a system-level emergency.

Recovery after high-stress events

After a fire, medical emergency or difficult EVA, the mission should not immediately return to a fully loaded schedule. High cognitive demand leaves fatigue, unresolved uncertainty and maintenance follow-up. A recovery plan includes debrief, equipment inspection, medical checks, sleep opportunity and a review of temporary workarounds. This is not lost productivity. It is a way to prevent the second failure that often follows when a team carries hidden damage and fatigue into the next nominal task.

Final mission assurance note

Mars crew scheduling also needs recovery capacity at the team level. A person can be medically fit and still be the wrong resource for an operation after a difficult EVA, night alarm or emotionally demanding event. Commanders should maintain cross-training so essential functions do not depend on one exhausted specialist. Handover effectiveness is another hidden human factor: incomplete transfer of temporary workarounds, medication, equipment restrictions or deferred maintenance can create the next incident. A robust daily plan therefore protects briefings and cross-checks even when the mission feels behind schedule.

Mission integration note

Crew autonomy also depends on role clarity during degraded operations. In nominal work, specialists may own their domains, but emergencies can erase those boundaries. A medical event during EVA may force one person to coordinate rescue, another to prepare the airlock and another to protect habitat systems. Roles should therefore have primary and backup owners, explicit transfer conditions and rehearsed communication phrases. This reduces hesitation when the normal chain of command is overloaded. It also reveals training gaps long before a real emergency makes them visible. Human-factors reviews should include these cross-role transitions, because many incidents emerge not from one difficult task but from two reasonable tasks colliding at the same time.

Additional operational assurance

Long missions also require explicit fatigue governance. Fatigue cannot be managed only by telling individuals to speak up when tired, because social pressure and mission urgency can discourage self-reporting. The schedule should contain objective protections: minimum sleep opportunities, limits on extended duty, recovery after night alarms and rules for postponing nonessential EVA or maintenance. Commanders can combine subjective fatigue ratings with reaction-time tests, recent workload and observed errors. The aim is not to create a medical label for ordinary tiredness, but to keep degraded performance from becoming normalised. A crew that repeatedly “borrows” from sleep to recover schedule will eventually pay that debt during a task where precision matters most.

Last readiness check

Operational planning should also preserve a reserve of trained attention. A schedule can have spare crew-hours and still fail if the only person qualified for a critical task is already committed elsewhere. Cross-training, backup roles and explicit priority rules convert aggregate time margin into usable resilience.

Operational review checklist

Before accepting a human-operations result, distinguish clock time from crew-hours, measured performance from assumptions, and nominal capacity from protected reserve. Then state the crew decision the calculation supports.

Prepare for degraded human performance as deliberately as for hardware faults: consider lost communication, fatigue, suit limitations, delayed return or reduced medical support, and define a safe response before margins disappear.

- www.nasa.gov — institutional documentation
- [Space Academy](#) — full pathway

FR ↔ EN parity matrix

EN	FR
Activity time margin	Marge temporelle d'activité
Crew workload utilisation	Charge de travail équipage
Oxygen endurance	Autonomie d'oxygène
Metabolic energy over an EVA	Énergie métabolique sur une EVA
CO2 mass produced during an EVA	Masse de CO ₂ produite pendant une EVA
Accumulated dose at constant dose rate	Dose cumulée à débit constant