Land a heavy payload: trade a 20–30 tonne EDL system

Guiding question

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

Course map

Mission brief → System map → Data and assumptions → Governing relationship → Starting calculations

1 — Mission brief

Compare arrival energy, braking, terminal propulsion and dispersion without inventing one universal NASA architecture. This capstone mission requires several modules at once. An answer is complete only when it closes physical budgets, describes sensors and actions, retains margin, handles a credible failure and explains what the crew must do. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

2 — System map

Start by drawing mass, energy, information and authority flows. An arrow without a unit or owner is incomplete. The map is then used to identify common dependencies and interfaces that can propagate failure. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».
Heavy Mars EDL is a chain for dissipating energy and reducing uncertainty. The mission map separates energy removed by the atmosphere, handled by thermal protection, and finally cancelled by propulsion. A 20–30 tonne architecture is therefore not judged only by thrust; it must also accommodate atmospheric dispersion, ignition timing, navigation and plume-surface interaction.

Equation - evidence - decision

$E_k = 1/2\, m v^2$

Failure to test: Check air, water, thermal control, radiation, food, medicine and workload where relevant to this mission. The goal is to avoid a false “all good” technical calculation that forgets sleep time, suit donning or the need for a second crewmember during a critical operation. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

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3 — Data and assumptions

The supplied numbers are training-scenario data. Copy them with units, add missing assumptions and separately mark values that come from NASA sources. Any value that changes the verdict requires sensitivity analysis. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

Atmospheric assumptions must be bounded by a range rather than a single value. A density shift changes deceleration, heating and the point at which propulsion becomes effective. The student builds at least two limiting cases and identifies the onboard measurement used to determine which trajectory is actually occurring. The architecture must remain controllable when reality does not match the nominal ground model exactly.

4 — Governing relationship

The equation is only an entry point. It must be connected to a budget, an available measurement and a decision threshold. If units do not reduce correctly, stop before using a calculator. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

5 — Starting calculations

Énergie 25 t à 5,4 km/s $0{,}5 \times 25\,000 \times 5\,400^2 = 364{,}5$ GJ Interpret the result inside the global budget before making a decision.

Rapport de masse 25 000 kg ÷ 1 025 kg ≈ 24,4 fois la masse du rover Perseverance Interpret the result inside the global budget before making a decision.

Réserve ergols 8 000 kg × 0,12 = 960 kg reserve scénario Interpret the result inside the global budget before making a decision.

6 — Mass, power and time budget

Operational table

Phenomena / sections:	3 — Data and assumptions ; 4 — Governing relationship ; 5 — Starting calculations
Relationship to revisit:	$E_k = 1/2\, m v^2$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 3 — Data and assumptions ; 4 — Governing relationship ; 5 — Starting calculations. State one measured quantity, one margin and one possible decision.

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Build three separate tables. The mass budget distinguishes structure, consumables, spares and margin. The energy budget separates instantaneous power from accumulated energy. The time budget includes operations, maintenance, rest and communications delay. Positive margin in one table does not automatically compensate for a deficit in another. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

Kinetic-energy calculation gives a useful scale but does not select an architecture. The student next allocates responsibilities to thermal protection, possible lift, propulsion, landing gear and propellant reserve. A divert margin and a terminal-descent margin are identified separately; neither should be confused with propellant theoretically left after a perfect nominal profile.

7 — Navigation, communications and state knowledge

State which variables must be known locally, which can be reconstructed later by Earth, and what accuracy each decision requires. Radio delay means safing and initial diagnosis must be possible without waiting for Earth. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

State knowledge is critical during the final minutes. Altitude, vertical and horizontal velocity, attitude, position relative to safe terrain and engine state must be available locally at a rate compatible with decisions. The student describes cross-checking among inertial navigation, radar and terrain-relative navigation, including the response when one sensor becomes inconsistent with the others.

8 — Survival and human factors

Check air, water, thermal control, radiation, food, medicine and workload where relevant to this mission. The goal is to avoid a false “all good” technical calculation that forgets sleep time, suit donning or the need for a second crewmember during a critical operation. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

For a crewed vehicle, success does not end at touchdown. The lander must remain stable, powered, atmospherically safe and capable of supporting a safe egress. The scenario therefore reserves resources for post-landing diagnosis, communications, thermal stabilization, leak checks and preparation of the route to the habitat. A trajectory that is optimal in flight but leaves no operational reserve may be a poor trade.

Operational table

Phenomena / sections:	7 — Navigation, communications and state knowledge ; 8 — Survival and human factors
Relationship to revisit:	$E_k = 1/2\ m\ v^2$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 7 — Navigation, communications and state knowledge ; 8 — Survival and human factors. State one measured quantity, one margin and one possible decision.

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9 — Mission-specific injected incident

During descent, estimated atmospheric density departs from the model and increases dispersion; braking margin and the criterion for entering powered descent must be reassessed. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

For AM-16.04, the answer must show which quantities in “Land a heavy payload: trade a 20–30 tonne EDL system” are recomputed, which assumptions cease to be valid and which action remains reversible before consuming an irreversible reserve.

When estimated atmospheric density diverges during descent, the student identifies the variables that actually change the decision: velocity at retropropulsion start, remaining altitude, propellant reserve and accessible landing ellipse. A threshold for switching to a conservative profile or alternate site is defined. The answer must be conditional logic, not simply 'add margin' without saying where it is used.

10 — Decision and justification

End with an explicit decision: continue, delay, reconfigure, abandon an activity or enter refuge mode. Cite the three quantities controlling that decision and the remaining margin. A conclusion without a numerical or operational criterion is an opinion, not an engineering decision. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

The final deliverable compares at least two architectures under the same criteria: mass, energy dissipation, guidance complexity, failure modes, sensing requirements, divert capability and vehicle state after landing. The goal is not to declare one universal solution, but to explain why an option may be preferable for a given payload, site and technology maturity.

Operational table

Phenomena / sections:	9 — Mission-specific injected incident ; ; 10 — Decision and justification
Relationship to revisit:	$E_k = 1/2\ m\ v^2$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 9 — Mission-specific injected incident ; ; 10 — Decision and justification. State one measured quantity, one margin and one possible decision.

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11 — Required deliverables

12 — Assessment rubric

40%: calculation and unit consistency; 20%: interface treatment; 15%: margins and degraded mode; 15%: human factors and procedure; 10%: source quality and separation of data, assumptions and scenarios. For this mission, the criterion is applied explicitly to « Land a heavy payload: trade a 20–30 tonne EDL system ».

13 — Reference sources

Topic-specific primary sources

NASA NTRS — Human Mars Entry, Descent, and Landing Architecture Study - https://ntrs.nasa.gov/citations/20160011571

NASA NTRS — Advancing Supersonic Retropropulsion Using Mars-Relevant Flight Data - https://ntrs.nasa.gov/citations/20170008725

NASA NTRS — ASPIRE Parachute Modeling and Flight Comparison - https://ntrs.nasa.gov/citations/20200002925

NASA NTRS — Mars 2020 Terrain-Relative Navigation Performance - https://ntrs.nasa.gov/citations/20230007014

Operational table

Phenomena / sections:	11 — Required deliverables ; 12 — Assessment rubric ; 13 — Reference sources
Relationship to revisit:	$E_k = 1/2\ m\ v^2$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 11 — Required deliverables ; 12 — Assessment rubric ; 13 — Reference sources. State one measured quantity, one margin and one possible decision.