Terrain-relative navigation: recognising Mars to correct position

Guiding question

Concrete → vocabulary → diagram → calculation → limits → mission.

Course map

The real phenomenon → Vocabulary and problem boundary → Course-specific system view → Mathematical relationship and reading the symbols → Worked calculations and interpretation

1 — The real phenomenon

Terrain-relative navigation compares descent images with an onboard map or expected landmarks. It produces a position correction that can be fused with inertial navigation. Perseverance demonstrated this logic through Terrain-Relative Navigation and the Lander Vision System. For a future vehicle the principle remains useful, but altitudes, sensors, maps and margins are architecture-dependent.
The guiding question is: How can a camera help a lander know where it really is? Reasoning starts with the physical or operational function before introducing the mathematical relationship. The goal is not to accumulate terminology, but to know which quantity changes, why it changes and what becomes hazardous when it leaves its domain. For “Terrain-relative navigation: recognising Mars to correct position”, the first task here is therefore to identify the mechanism specific to this subject before searching for an equation or reference value.

2 — Vocabulary and problem boundary

In “Terrain-relative navigation: recognising Mars to correct position”, distinguish the phenomenon, available measurement, any command, the margin and the success criterion. The calculation boundary states what is included and excluded; without that boundary, a percentage, mass or time may be mathematically correct but wrong as an engineering conclusion. For “Terrain-relative navigation: recognising Mars to correct position”, the chosen boundary also states what would otherwise be double-counted or omitted from a mission budget.
descent imagery, estimated position, correlation quality, reference map and distance to the safe target
low-feature terrain, a misregistered map, adverse lighting or an incorrect correlation solution
image replay, synthetic scenes, field campaigns and localization-error measurement against known truth

Equation - evidence - decision

$e = \sqrt{\Delta x^2 + \Delta y^2}$; échelle = distance / pixels

Failure to test: The reference failure is not a vague “broken component.” For “Terrain-relative navigation: recognising Mars to correct position”, test in particular low-feature terrain, a misregistered map, adverse lighting or an incorrect correlation solution. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

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3 — Course-specific system view

This lesson does not reuse one generic picture for every subject. The system view follows cause → measured quantity → decision or physical response → limit for “Terrain-relative navigation: recognising Mars to correct position”. The English text remains fully equivalent while large translated illustrations are intentionally deferred until their dedicated artwork is supplied. For “Terrain-relative navigation: recognising Mars to correct position”, the system view must expose inputs, outputs, measured quantity and the consequence of drift without relying on a generic module diagram.

4 — Mathematical relationship and reading the symbols

Read aloud : error e is the square root of delta x squared plus delta y squared; scale relates real distance to pixels.

Before substituting numbers, write the unit of every term, state whether the relationship is a physical law, approximation or project indicator, and check dimensional consistency. This is especially important here because “Terrain-relative navigation: recognising Mars to correct position” combines quantities that do not all have the same evidence status. For “Terrain-relative navigation: recognising Mars to correct position”, this relationship is chosen because of the phenomenon under study; a different dominant quantity would require a different equation or model.

5 — Worked calculations and interpretation

250 m / 1,000 pixels = 0.25 m/pixel

20 m/s for 25 s → about 500 m if lateral speed could be maintained

1. 1. Map error $\sqrt{30^2+40^2} = 50$ m Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Terrain-relative navigation: recognising Mars to correct position”.
2. 2. Image scale 250 m / 1,000 pixels = 0.25 m/pixel Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Terrain-relative navigation: recognising Mars to correct position”.
3. 3. Teaching divert capability 20 m/s for 25 s → about 500 m if lateral speed could be maintained Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Terrain-relative navigation: recognising Mars to correct position”.

6 — What the formula does not contain

The relationship “$e = \sqrt{\Delta x^2 + \Delta y^2}$; échelle = distance / pixels” does not by itself contain all of “Terrain-relative navigation: recognising Mars to correct position”. It does not automatically tell us

Operational table

Phenomena / sections:	3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation
Relationship to revisit:	$e = \sqrt{\Delta x^2 + \Delta y^2}$; échelle = distance / pixels
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation. State one measured quantity, one margin and one possible decision.

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To make the model useful, explicitly add the quantities that dominate this subject: descent imagery, estimated position, correlation quality, reference map and distance to the safe target. We can then ask which variation truly changes the result, which is negligible and which forces an architectural change. For “Terrain-relative navigation: recognising Mars to correct position”, this model limitation states exactly what a correct calculation still cannot establish about the real system.

7 — Instrumentation, observability and data quality

For “Terrain-relative navigation: recognising Mars to correct position”, observability relies on descent imagery, estimated position, correlation quality, reference map and distance to the safe target. Each datum has a unit, acquisition rate, uncertainty, timestamp and validity domain. A value arriving without context can be more dangerous than no measurement because it creates unjustified confidence.

Consistency is checked with at least one independent piece of information when the function is critical. A trend, physical balance or second measurement principle helps distinguish a real system change from a drifting sensor. For “Terrain-relative navigation: recognising Mars to correct position”, the selected instrumentation must distinguish a real physical change from sensor drift or a bad state estimate.

8 — Phenomenon-specific failures and recovery

The reference failure is not a vague “broken component.” For “Terrain-relative navigation: recognising Mars to correct position”, test in particular low-feature terrain, a misregistered map, adverse lighting or an incorrect correlation solution. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

The degraded mode must be defined before failure: minimum function, allowable duration, consumed stock, crew action, abort condition and return-to-nominal criterion. That sequence is topic-specific and cannot be replaced by one universal paragraph about redundancy. For “Terrain-relative navigation: recognising Mars to correct position”, the degraded mode is defined around the minimum function specific to this subject, with an abort threshold and a return-to-nominal condition.

9 — NASA / reference case

Mars 2020 flight results make this lesson quantitative: NASA’s published TRN performance analysis reports a localization requirement of about 60 m, a pre-landing estimate of about 33 m and a final measured distance of about 5 m from the selected target. These numbers describe different stages and metrics and must not be collapsed into one generic “TRN accuracy.”

Operational table

Phenomena / sections:	7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery ; 9 — NASA / reference case
Relationship to revisit:	$e = \sqrt{\Delta x^2 + \Delta y^2}$; échelle = distance / pixels
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery ; 9 — NASA / reference case. State one measured quantity, one margin and one possible decision.

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The case is used only within what it actually demonstrates. Flight measurement, human-system standard, component test and architecture study are different kinds of evidence; the text therefore states what is observed, calculated, simulated or still prospective. For “Terrain-relative navigation: recognising Mars to correct position”, the cited NASA case is used as targeted evidence for this phenomenon and is never turned into one universal Mars architecture.

10 — Architecture trade

A good solution for “Terrain-relative navigation: recognising Mars to correct position” does not maximize one metric. Compare nominal performance, mass, energy, simplicity, maintenance, crew time, common dependencies and recoverability. An option that improves 250 m / 1,000 pixels = 0.25 m/pixel can still be rejected if it makes failure detection or repair much harder.

The trade is recorded together with its assumptions. If environment data, mass or mission cadence changes, we know which conclusions must be recomputed instead of silently preserving an obsolete choice. For “Terrain-relative navigation: recognising Mars to correct position”, the trade is evaluated against the interfaces actually touched by this subject rather than a generic list of desirable qualities.

11 — Demonstration, testing and success criteria

The evidence strategy for “Terrain-relative navigation: recognising Mars to correct position” combines image replay, synthetic scenes, field campaigns and localization-error measurement against known truth. Every test records exact hardware, software, configuration, environment, tolerances and success criterion. A successful demonstration outside the mission domain does not replace qualification inside it.

Evidence grows by levels: analytical relationship, simulation, component, subsystem, integrated system, duration and failure. This hierarchy prevents one spectacular test from being presented as validation of the whole mission. For “Terrain-relative navigation: recognising Mars to correct position”, demonstration must reproduce the constraints that make this phenomenon difficult; a spectacular test outside the mission domain is insufficient.

12 — Decision exercise

Situation: revisit “Terrain-relative navigation: recognising Mars to correct position” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable.

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Operational table

Phenomena / sections:	10 — Architecture trade ; 11 — Demonstration, testing and success criteria ; 12 — Decision exercise
Relationship to revisit:	$e = \sqrt{(\Delta x^2 + \Delta y^2)}$; échelle = distance / pixels
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 10 — Architecture trade ; 11 — Demonstration, testing and success criteria ; 12 — Decision exercise. State one measured quantity, one margin and one possible decision.

Terrain-relative navigation: recognising Mars to correct position

13 — What to retain without over-generalizing

14 — Topic-specific primary sources

These references directly document the phenomenon, technology or human constraint addressed in this lesson. They do not by themselves define an official Mars architecture. For "Terrain-relative navigation: recognising Mars to correct position", the bibliography is deliberately targeted to this page so that readers can trace each claim back to the relevant primary document.

Topic-specific primary sources

NASA NTRS — The Lander Vision System for Mars 2020 EDL - https://ntrs.nasa.gov/citations/20190025658

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

NASA NTRS — The Mars 2020 Perseverance Navigation Filter - https://ntrs.nasa.gov/citations/20230005661

Operational table

Phenomena / sections:	13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources ; Topic-specific primary sources
Relationship to revisit:	$e = \sqrt{\Delta x^2 + \Delta y^2}$; échelle = distance / pixels
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources ; Topic-specific primary sources. State one measured quantity, one margin and one possible decision.