Radar, altimetry and velocimetry: knowing where you are before the ground

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

Terminal navigation fuses several sensors: inertial measurement, radar, sometimes lidar, camera and terrain models. Radar altimetry measures round-trip time or modulated frequency; Doppler radar can estimate relative velocity. Measurements have bias, noise, blind zones and geometric limitations. Safety comes from fusion, consistency checks and detection of impossible measurements.
The guiding question is: How does a lander estimate altitude and velocity when a few seconds of error can be fatal? 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, the chosen boundary also states what would otherwise be double-counted or omitted from a mission budget.
altitude, vertical and horizontal velocity, measurement quality, bias and cross-sensor consistency
common bias, ambiguous ground return, loss of lock or data fusion accepting a bad measurement
sensor rigs, recorded data, representative terrain, hardware-in-the-loop campaigns and comparison with independent truth

Equation - evidence - decision

$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f /(2 f_0)$

Failure to test: The reference failure is not a vague “broken component.” For “Radar, altimetry and velocimetry: knowing where you are before the ground”, test in particular common bias, ambiguous ground return, loss of lock or data fusion accepting a bad measurement. Diagnosis asks which symptoms appear first, which are only consequences and which action preserves the most options.

Radar, altimetry and velocimetry: knowing where you are before the ground

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 “Radar, altimetry and velocimetry: knowing where you are before the ground”. The English text remains fully equivalent while large translated illustrations are intentionally deferred until their dedicated artwork is supplied. For “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 : distance d equals light speed c times round-trip time delta t divided by two; radial velocity is approximately related to Doppler frequency shift.

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 “Radar, altimetry and velocimetry: knowing where you are before the ground” combines quantities that do not all have the same evidence status. For “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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

$\Delta t = 2\times10{,}000/299{,}792{,}458 \approx 66.7\ \mu s$

$v \approx 299{,}792{,}458\times160{,}000/(2\times24\times10^9) \approx 999.3$ m/s

A 5 m error over 1,000 m is 0.5%

1. 1. Echo at 10 km $\Delta t = 2\times10{,}000/299{,}792{,}458 \approx 66.7\ \mu s$ Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Radar, altimetry and velocimetry: knowing where you are before the ground”.
2. 2. Teaching Doppler at 24 GHz $v \approx 299{,}792{,}458\times160{,}000/(2\times24\times10^9) \approx 999.3$ m/s Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Radar, altimetry and velocimetry: knowing where you are before the ground”.
3. 3. Relative error A 5 m error over 1,000 m is 0.5% Interpretation: this result is used only after comparison with units, margin and the scenario boundary for “Radar, altimetry and velocimetry: knowing where you are before the ground”.

Operational table

Phenomena / sections:	3 — Course-specific system view ; 4 — Mathematical relationship and reading the symbols ; 5 — Worked calculations and interpretation
Relationship to revisit:	$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f /(2 f_0)$
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.

Radar, altimetry and velocimetry: knowing where you are before the ground

6 — What the formula does not contain

The relationship “$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f /(2 f_0)$” does not by itself contain all of “Radar, altimetry and velocimetry: knowing where you are before the ground”. It does not automatically tell us whether a sensor is valid, a structure is aging, a resource is accessible, a command arrives in time or a secondary failure removes margin. The example $\Delta t = 2 \times 10{,}000/299{,}792{,}458 \approx 66.7$ µs therefore remains a local calculation rather than a complete architecture.

To make the model useful, explicitly add the quantities that dominate this subject: altitude, vertical and horizontal velocity, measurement quality, bias and cross-sensor consistency. We can then ask which variation truly changes the result, which is negligible and which forces an architectural change. For “Radar, altimetry and velocimetry: knowing where you are before the ground”, this model limitation states exactly what a correct calculation still cannot establish about the real system.

7 — Instrumentation, observability and data quality

For “Radar, altimetry and velocimetry: knowing where you are before the ground”, observability relies on altitude, vertical and horizontal velocity, measurement quality, bias and cross-sensor consistency. 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, test in particular common bias, ambiguous ground return, loss of lock or data fusion accepting a bad measurement. 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, the degraded mode is defined around the minimum function specific to this subject, with an abort threshold and a return-to-nominal condition.

Operational table

Phenomena / sections:	6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery
Relationship to revisit:	$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f /(2 f_0)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 6 — What the formula does not contain ; 7 — Instrumentation, observability and data quality ; 8 — Phenomenon-specific failures and recovery. State one measured quantity, one margin and one possible decision.

Radar, altimetry and velocimetry: knowing where you are before the ground

9 — NASA / reference case

Descent systems must distinguish altitude, velocity and attitude. A radar or lidar measurement matters only if geometry, validity, timing and integration in the navigation filter are controlled; one number is not yet a navigation state.

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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 “Radar, altimetry and velocimetry: knowing where you are before the ground” does not maximize one metric. Compare nominal performance, mass, energy, simplicity, maintenance, crew time, common dependencies and recoverability. An option that improves $v \approx 299{,}792{,}458 \times 160{,}000/(2 \times 24 \times 10^9) \approx 999.3$ m/s 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 “Radar, altimetry and velocimetry: knowing where you are before the ground” combines sensor rigs, recorded data, representative terrain, hardware-in-the-loop campaigns and comparison with independent 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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, demonstration must reproduce the constraints that make this phenomenon difficult; a spectacular test outside the mission domain is insufficient.

Operational table

Phenomena / sections:	9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria
Relationship to revisit:	$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f /(2 f_0)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 9 — NASA / reference case ; 10 — Architecture trade ; 11 — Demonstration, testing and success criteria. State one measured quantity, one margin and one possible decision.

Radar, altimetry and velocimetry: knowing where you are before the ground

12 — Decision exercise

Situation: revisit “Radar, altimetry and velocimetry: knowing where you are before the ground” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable.

Situation: revisit “Radar, altimetry and velocimetry: knowing where you are before the ground” with a 20% increase in the most penalizing quantity from the first worked example while one measurement or backup path is unavailable. Expected answer: recompute the relationship, identify remaining margin, check whether observability is still adequate, and decide whether degraded operation remains acceptable. Multiplying by 1.2 is not enough if the variation also changes interfaces or limits.

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 “Radar, altimetry and velocimetry: knowing where you are before the ground”, 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 Mars 2020 Perseverance Navigation Filter - https://ntrs.nasa.gov/citations/20230005661

NASA NTRS — Precision Landing & Hazard Avoidance - https://ntrs.nasa.gov/citations/20170001719

NASA NTRS — Assessment of the Mars 2020 Entry, Descent, and Landing Flight Mechanics Simulation - https://ntrs.nasa.gov/citations/20210024480

Operational table

Phenomena / sections:	12 — Decision exercise ; 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources
Relationship to revisit:	$d = c \times \Delta t / 2$; $v_r \approx c \times \Delta f / (2 f_0)$
Expected decision:	measure → compare with margin → choose nominal, degraded or stop

Check before continuing

Explain without rereading: 12 — Decision exercise ; 13 — What to retain without over-generalizing ; 14 — Topic-specific primary sources. State one measured quantity, one margin and one possible decision.