AM-08.01 · SPACE ACADEMY

AM-08.01 — Space navigation: reference trajectory, orbit determination and correction

How do we actually know where a spacecraft is millions of kilometres away?

Course compass

Space navigation: reference trajectory, orbit determination and correction. The lesson starts from a concrete situation, defines every term and symbol, then introduces formulas and mission use.

Open educational resource: this lesson explains principles for beginners. It does not replace mission design, operational ephemerides, procedures, testing or agency validation.

1 — Build a mental picture before using a formula

A planned trajectory is only useful if the mission can estimate where the spacecraft really is, compare that estimate with the plan and correct when needed. NASA describes deep-space navigation in terms of a reference trajectory, orbit determination and flight-path control.

Question to ask: How do we actually know where a spacecraft is millions of kilometres away?

2 — Essential vocabulary before going further

None of these words should remain mysterious. Read them once now, then return to them as the lesson progresses.

- **reference trajectory** — planned route and state versus time.
- **orbit determination** — estimating position and velocity from observations.
- **state** — position plus velocity at an instant.
- **residual** — difference between measurement and model prediction.
- **propagation** — predicting future state using dynamics.

3 — Understand the mechanism step by step

1 — Predict

Build the reference trajectory.

2 — Measure

Use radio, optical, inertial or other observations.

3 — Estimate

Combine noisy observations and a dynamics model to estimate the most likely state and uncertainty.

4 — Correct

Propagate the estimate, compare with the target and design a maneuver if required.

4 — The formula, only now

```
state x = [position, velocity]
```

How to read it: x denotes a state vector grouping several numbers. In three dimensions, position and velocity commonly contribute six components, plus uncertainty information.

Detailed calculation

In a very short straight-line teaching example, 2 m/s for 10 s gives 20 m displacement. Real navigation propagates gravity and other forces.

> **Learning rule:** if you can obtain the number but cannot explain why the operation is legitimate, the reasoning is not yet mastered.

5 — What the units tell you

A physical equation is more than numbers. Units identify the kind of result and provide a consistency check. At every division, multiplication or square root, track what happens to the units; this catches many errors before checking the numerical value.

6 — Three concrete demonstrations

Example 1 — Position is not enough

The same position with different velocity produces different future trajectories.

Example 2 — Residual

A 20-microsecond difference between predicted and measured round-trip radio time carries information about range.

Example 3 — Updated solution

More tracking data can shrink uncertainty and alter a planned correction maneuver.

7 — Why this matters for a Mars mission

Navigation links orbital mechanics, communications and spacecraft control, enabling precise Mars entry or orbit insertion targeting.

In a real mission, operational value comes from the chain: measure, estimate, calculate, check margins, execute, then measure again. A formula by itself does not fly a spacecraft.

8 — Common traps and misleading intuitions

- treating position as exact.
- forgetting velocity.
- confusing a sensor reading with the final state estimate.
- assuming either model or measurement can work alone.

9 — What I should be able to explain at the end

- explain the idea in ordinary words
- read and pronounce the important symbols
- repeat at least one calculation without hidden steps

- identify what the simplified model assumes and does not prove

10 — Guided exercises and answers

1. **Restate:** explain the lesson's main term aloud without a formula; define any technical word immediately.
2. **Units:** repeat the main calculation and verify the final units represent the quantity being sought.
3. **Variation:** change one input by 10%, predict the direction of the effect before recalculating, then check your intuition.
4. **Model limit:** name two real effects the teaching model does not fully include.

> **Expected answer style:** name the physical object, preserve units, justify each operation and distinguish a teaching estimate from an operational navigation solution.

11 — NASA / JPL sources for further study

These are primary institutional sources used to check concepts and orders of magnitude. They are more technical than this introductory lesson.

- NASA Science — Basics of Space Flight, Navigation