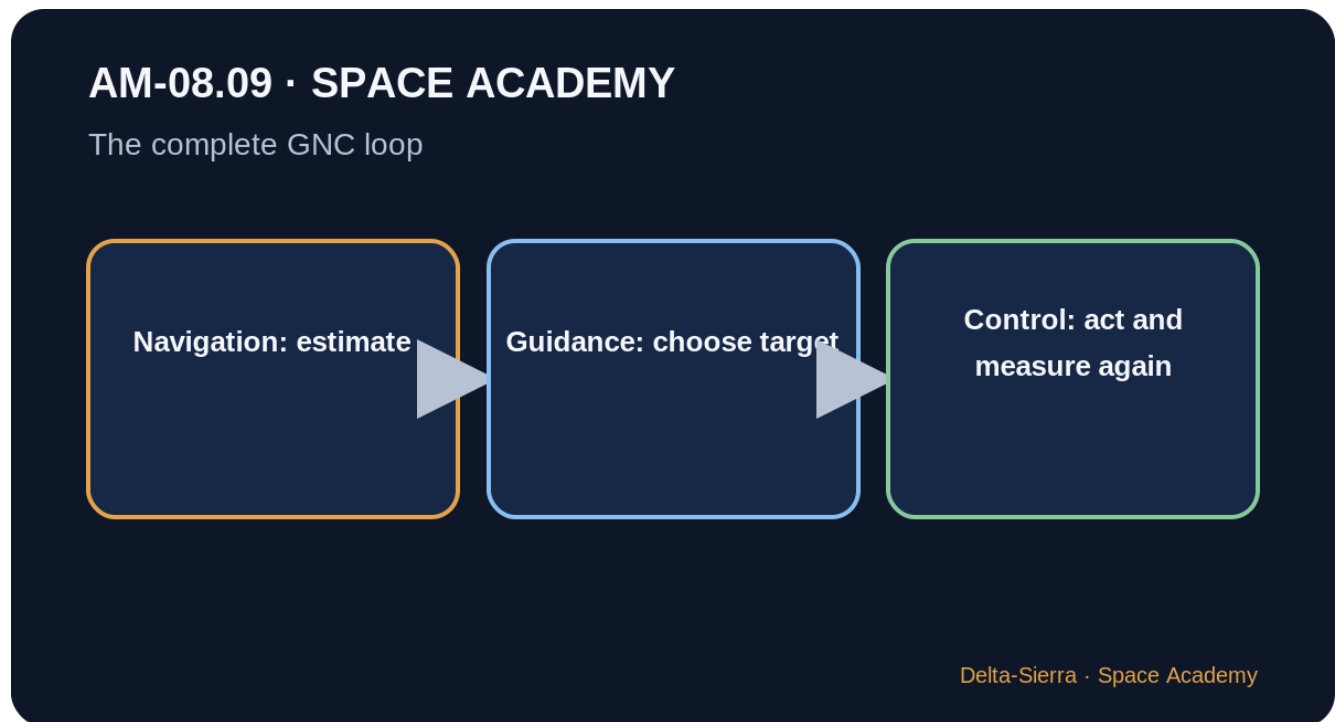


AM-08.09 — GNC: the complete loop that observes, decides and acts

What is the difference between guidance, navigation, and control, and how do the three functions cooperate many times per second?



Observe, estimate, compare, command, then observe again: the loop continues throughout the mission.

1 - Understand the scene

A Mars lander descends toward the surface. It has a desired trajectory, but disturbances, model errors, and dispersions push it away. The system must repeatedly answer: where am I? where should I be? what correction should I command? did the actuators have the expected effect?

These questions correspond to GNC: Guidance, Navigation and Control. Navigation estimates the state; guidance constructs the desired path or command; control converts the error between actual and desired state into actuator commands.

2 - Essential vocabulary

Guidance - Function determining where the vehicle should go or what attitude it should target.

Navigation - Function estimating where the vehicle is, how it moves, and how it is oriented.

Control - Function computing the action required to reduce error between command and estimated state.

State - Minimal set of variables needed by the model: position, velocity, attitude, angular rate, etc.

Setpoint / command - Desired value such as angle, velocity, trajectory, altitude, or other target.

Feedback loop - Architecture where the result of an action is measured again and fed back into the next command.

3 - Step-by-step mechanism

1. Measure and estimate

Radio tracking, IMU, stars, cameras, or altimeters produce observations. An estimator combines them into a consistent state with uncertainty.

2. Compare with mission need

Guidance supplies a desired trajectory or attitude. The system computes an error: for example 2° too far right or 15 m/s too fast.

3. Command then verify

The controller turns error into wheel, engine, aerodynamic, or thruster commands. The vehicle responds; new measurements arrive; the loop repeats. Stability depends on proper delays, gains, models, and limits.

4 - Formulas and reading

$$e = \text{consigne} - \text{mesure}$$

"e equals command minus measurement." e is the control error.

Subtract the estimated value from the target to determine correction direction and magnitude.

$$u = K_p \times e$$

"u equals K p times e." u is a command and Kp a simple proportional gain.

In a basic proportional controller, twice the error gives twice the command. Real systems add limits, dynamics, and other terms.

5 - Units and checks

A GNC loop can involve metres, m/s, degrees, rad/s, newtons, and newton-metres. Units must be consistent with the gain converting an error into a command. A control gain is therefore not always an arbitrary dimensionless number.

Before using a gain, ask: 'what unit enters the controller, and what unit must leave it?' This catches many modeling mistakes.

6 - Three demonstrations

Example 1 — Proportional pointing

An antenna is 4° right of target. Convention: error is negative. $K_p = 0.5$ command unit per degree.

$$e = 0 - 4 = -4^\circ$$

$$u = 0.5 \times (-4)$$

$$u = -2 \text{ command units}$$

Conclusion: The command acts to reduce error if sign conventions are consistent.

Example 2 — Velocity guidance

Estimated vertical velocity is -65 m/s and command is -50 m/s.

$$e = -50 - (-65)$$

$$e = +15 \text{ m/s}$$

Conclusion: The vehicle is descending 15 m/s faster than desired; control must reduce descent rate.

Example 3 — Bad sensor

Two sensors agree while a third suddenly jumps from 2° to 80°.

plausibility check

isolate suspect measurement

continue in degraded mode if possible

Conclusion: A robust loop must not turn every received measurement directly into a motor command.

7 - Deepening

Stability

Too little gain can make correction slow; too much gain combined with delay and vehicle inertia can cause oscillation or instability. Tuning a loop is a dynamics problem.

Actuator saturation

The controller may request more than a motor, wheel, or valve can deliver. Software must know these limits and prevent impossible commands from corrupting estimation or integrators.

FDIR and degraded modes

Fault Detection, Isolation and Recovery means detecting a fault, identifying its likely source, and reconfiguring the system. A distant mission often must do this before Earth can respond.

Autonomous guidance

Guidance can be a fixed command or an algorithm continuously recomputing a trajectory, avoiding hazards, or selecting a landing target compatible with the actual state.

8 - Why this matters for Mars

Mars entry, descent, and landing compresses all GNC functions into minutes: rapid estimation, target guidance, attitude and velocity control, and fault detection.

A Mars base will also use GNC loops in drones, rovers, cranes, pressurized vehicles, and docking systems. Understanding the generic loop helps explain many different machines.

9 - Common traps

- Using “guidance” as a synonym for all navigation.
- Connecting a sensor directly to an actuator with no estimation or checks.
- Ignoring loop delay.
- Choosing gain without considering units and dynamics.
- Assuming the loop stays stable when an actuator saturates or a sensor fails.

10 - Guided exercises

Question: Command 10° , measurement 12° . What error $e = \text{command} - \text{measurement}$?

Answer: $10 - 12 = -2^\circ$.

Question: With $K_p = 0.4 \text{ command}/^\circ$, what proportional command?

Answer: $u = 0.4 \times (-2) = -0.8 \text{ command unit}$.

Question: Why should navigation and control remain conceptually distinct?

Answer: Navigation estimates reality from sensors; control decides how to act. Mixing them hides error sources and complicates safety.

11 - What you should explain

- Clearly distinguish guidance, navigation, and control.
- Describe sensor $\rightarrow$ estimation $\rightarrow$ command $\rightarrow$ controller $\rightarrow$ actuator $\rightarrow$ vehicle $\rightarrow$ sensor feedback.
- Compute simple error and proportional command.
- Explain saturation, delay, and stability in ordinary language.

- Describe the role of FDIR in an autonomous mission.

12 - NASA / JPL sources

NASA - State-of-the-Art of Small Spacecraft Technology, Guidance Navigation and Control
<https://www.nasa.gov/smallsat-institute/sst-soa/guidance-navigation-and-control/>

Free educational resource: this lesson explains the principles for beginners. It does not replace operational mission design, flight models, procedures, testing, or agency validation.