



ILS (*I*nstrument *L*anding *S*ystem)



• Ultimate Guide

- By IDEO-LAB & Lockheed LLC
- September 2026
- Version 1.2
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Ultimate Guide

By **IDEO-LAB**



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ILS — Instrument Landing System

ILS — How an Airplane Finds the Runway

≡ A simple guide for everyone ≡



 **Localizer:**
keeps the aircraft
lined up with the runway

 **Glide Slope:**
keeps the descent
path correct
3°

Cockpit instruments show
whether the aircraft is
left/right or high/low



ILS antennas
send guidance
signals



Result:
a precise and
safer landing,
even in poor visibility

ILS — Instrument Landing System

A Simple Introduction for Everyone

The **Instrument Landing System (ILS)** is a radio-navigation system that helps an aircraft approach and land on a runway accurately, especially when visibility is poor because of **fog, rain, clouds, or darkness**.

Its purpose is simple: **guide the aircraft toward the runway in the correct horizontal and vertical position**.

An ILS mainly uses two radio guidance signals. The **Localizer (LOC)** provides **left/right guidance** and tells the aircraft whether it is aligned with the runway centerline. The **Glide Slope (G/S)** provides **up/down guidance** and helps the aircraft follow the correct descent path, usually close to **3 degrees**.

A simple way to imagine it is this:

Localizer = "Am I left or right of the runway?"

Glide Slope = "Am I too high or too low?"

When both signals are centered, the aircraft is following the correct approach path toward the runway.

Many ILS installations are also associated with **DME (Distance Measuring Equipment)**, which gives the crew an indication of distance from a defined ground reference. Approach lights and runway lighting then help the pilots make the final transition from instrument guidance to visual landing.

Inside the aircraft, dedicated navigation receivers process the ILS radio signals. The information is displayed on the pilots' flight instruments, such as the **Primary Flight Display (PFD)**. The pilots can follow the guidance manually, or the **Flight Director and Autopilot** can use it to control the aircraft automatically.

Modern aircraft may even perform an **automatic landing (Autoland)** when the aircraft, airport, crew, and operating conditions are certified for it.

Safety is a fundamental part of ILS design. Ground equipment continuously monitors the quality of the signals, and many systems use **redundant transmitters, receivers, power supplies, computers, and autopilot channels**. If unreliable guidance is detected, the system is designed to warn the crew, downgrade the available capability, or remove the faulty signal from service.

The key idea

ILS does not need to calculate the aircraft's exact geographical position like GPS does. Instead, it continuously answers two very simple questions:

How far am I from the runway centerline?

How far am I from the correct descent path?

By continuously reducing these two errors toward zero, the aircraft is guided toward a **stable, precise and safe landing path**.

ILS = Lateral Guidance + Vertical Guidance + Continuous Monitoring = Precision Approach

ILS : A SHORT HISTORY REMINDER

ILS: The Backbone of Precision Landings in Modern Air Traffic

At major international hubs, where airliners touch down every minute, adverse weather could easily paralyze the entire network. This is where the **ILS (Instrument Landing System)** plays its most critical role. By providing pinpoint guidance along both the runway centerline and the ideal glide path, the ILS enables safe landings day or night, even when visibility drops close to zero. Without it, maintaining the high-density flow and operational reliability of modern air traffic would be impossible.

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ILS: (Instrument Landing System)

ILS Ground Equipment

H-D TRAFFIC FLOW



Visibility: Category III



IDEO-LAB

A Brief History and Major Milestones of the ILS

- **1930s – The Pioneers:** Early experiments with radio-guided approaches began in the United States, led by the National Bureau of Standards. In 1938, the first scheduled passenger flight landed using a predecessor of the modern ILS in Pittsburgh.
- **1947 – ICAO Standardization:** Following World War II, the newly formed International Civil Aviation Organization (ICAO) established the ILS as the global standard for precision approach systems. The system relies on two key radio beams: the Localizer (lateral guidance) and the Glide Path (vertical guidance).
- **1960s – The Autoland Era:** The advent of commercial jetliners (such as the Caravelle and Hawker Siddeley Trident) brought huge improvements in system reliability and redundancy. On November 4, 1968, Air France achieved the first fully automatic ILS landing in scheduled passenger service under low-visibility conditions at Paris-Orly.
- **Evolution of ILS Categories (CAT I to CAT III):**
 - **CAT I:** Standard precision approach down to a decision height of 200 ft (60 m).
 - **CAT II:** Precision approach down to 100 ft (30 m).
 - **CAT IIIa/b/c:** Enables fully automatic landings with runway visual ranges (RVR) down to near-zero or zero visibility, relying on multi-channel autopilot architectures and highly directional ground transmitters.
- **Signal Refinement & Digital Integration:** Over the decades, ground antenna arrays evolved from basic dipole designs to advanced multi-element directional arrays, drastically reducing signal bends caused by terrain and physical obstacles. Modern digital monitoring systems instantly detect and correct signal anomalies to maintain category integrity.

A Brief History of the ILS

From early radio guidance to CAT III autoland



1

2

3

4

5



1930s — Early Pioneers

First radio-guided approach experiments in the U.S.



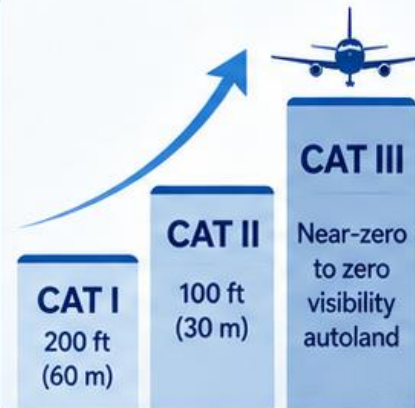
1947 — ICAO Standardization

ILS established as the global precision-approach standard.



1968 — Autoland Era

Air France performs the first fully automatic passenger landing at Paris-Orly.



CAT I to CAT III

Approach capability evolves from decision-height guidance to near-zero visibility autoland.



Modern Digital ILS

Digital monitoring and refined antenna arrays improve accuracy and integrity.



Core idea: better guidance, greater redundancy, lower visibility limits.



ILS : THE KEY CONCEPT

Why ILS is elegant: it continuously drives lateral and vertical error toward zero

ILS does NOT
mainly tell you



Latitude X /
Longitude Y /
Altitude Z

LOCALIZER
(LOC)

Vertical guidance
plane aligned with
runway centerline

GLIDE SLOPE
(G/S)

Inclined guidance
plane for the
required descent

DME
4.2 NM

LOC error
(lateral)

G/S error
(vertical)



Reduce both errors toward zero
→ converge to the final approach path



ILS continuously answers
two precise questions

1



How far are you
from the runway
centerline
guidance plane?

2



How far are you
from the required
descent
guidance plane?



FUNDAMENTAL ENGINEERING IDEA



LOC =
lateral error



G/S =
vertical error



DME =
distance reference



PFD =
pilot monitoring



FD/AP =
guidance
and control



Ground monitoring =
signal integrity

ILS : SIMULATOR A320 AND 737



This type rating course concerns both airline pilots and individual trainees.

This course has been approved by the French Civil Aviation Authority (DGAC).

Objectives

This course is provided on a full flight simulator and enables the trainees to be familiarized with aircraft systems, check list procedures, under normal and abnormal conditions.

Contents and duration

This training course lasts 7 weeks and includes:

- Computer-based training and cockpit trainer sessions for basic technical knowledge and familiarization with aircraft operating procedures,
- Full Flight Simulator training (33,5 hours) to practice aircraft operating normal & abnormal procedures,
- Base training on Air France aircraft during which the trainee performs 7 touch-and-go (take-offs, approaches, touch-and-go and landings).

Requirements

- CPL and valid IFR,
- Theoretical ATPL,
- Completed MCC,
- 70 hours experience as Captain,
- Valid Class 1 Medical Certificate,
- Logbook's last 3 pages.

Entry level assessment

A close-up photograph of a white rectangular sign with black text. The text reads "AIRFRANCE" in a large, bold, sans-serif font, followed by "FLIGHT TRAINING" in a slightly smaller font. Below this, separated by a thin horizontal line, is "A320 FULL FLIGHT SIMULATOR". The sign is tilted slightly to the right.









THE TEAM AND AUTHORS





Target me
properly

I.L.S

OK...
So ILS is...
LOC ?
No.... GS ?
Or both ?!?

AP1 ?
AP2 ?
A/THR ?

WHEN SHIRA DISCOVERS
THE ILS... ☺

We're
really on
the runway ?!

BIP !

Bip !

BIP !



A320 — APPROACH MODE
(and still a little bit of panic)



ILS :
NOT AS EASY
AS IT LOOKS ! ;)

ILS MAIN SHORT LIST

ILS APPROACH – ACTIVATION & USE SEQUENCE (SUMMARY)

GOAL: Intercept, capture and follow the ILS using the autopilot while monitoring continuously.

1 PREPARE THE APPROACH

- Select arrival and ILS approach in the FMC.
- Verify runway, frequency, course, minima (DA/DH), altitudes.
- Review the approach chart.



2 TUNE THE RADIOS

- Tune the ILS frequency on NAV radios (both if required).
- Verify LOC frequency is correct (108.10-111.95 MHz).
- Glide slope (GS) is automatically paired.



3 IDENTIFY THE ILS

- Verify proper station identification (Morse code or ID display).
- Do not arm APP until the ILS is correctly identified.



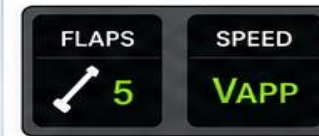
4 SET COURSE & MINIMUMS

- Enter the published FINAL APP CRS (front course) in the CRS selector (both sides if required).
- Set BARO/RADIO minimums on the MCP.



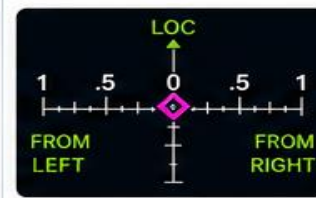
5 PREPARE THE AIRCRAFT

- Configure the aircraft: Flaps (usually 5 before LOC), speed, autobrake, etc.
- Complete approach checklist.
- Ensure you have approach clearance.



6 INTERCEPT THE LOCALIZER

- Fly an intercept heading.
- Check LOC & GS indications on the PFD.
- Move the LOC diamond toward center.



7 ARM APP

- Press APP.
- Check the FMA: VOR/LOC ARM and G/S ARM (as applicable).
- Aircraft is ready to capture LOC then GS.



8 CAPTURE LOCALIZER

- LOC is centered.
- FMA changes from VOR/LOC ARM to VOR/LOC (ACT).
- Aircraft is on the ILS lateral path.



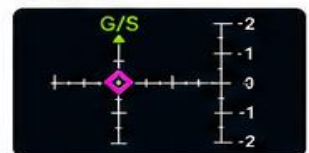
9 SYNC HEADING TO FINAL CRS

- Once established on LOC, set heading bug to final approach course.
- Verify the heading follows correctly.



10 MONITOR GLIDE SLOPE

- GS diamond descends toward center.
- Continue configuration: Gear Down, Flaps Full, Vref, Checklists.
- Prepare missed approach altitude.



11 CAPTURE GLIDE SLOPE

- GS is centered.
- FMA changes to G/S (ACT).
- Aircraft descends on the glide path.



12 SET MISSED APPROACH ALTITUDE

- Display the published missed approach altitude in the ALT window after GS capture (per SOP).
- Announce "Go-around altitude set".



13 CROSS-CHECK & MONITOR

- Cross-check at FAF: altitude on profile.
- Continuous monitoring: LOC, GS, FMA, speed, configuration, altitude, distance (DME).
- Keep the approach stabilized.



14 MINIMA – DECISION

- At DA/DH: check required visual references.
- If adequate and approach is stabilized: LAND.
- If not adequate or not stabilized: GO-AROUND.

LAND
(REFERENCES OK)

GO-AROUND
(NOT STABILIZED / NO REF)

CONTINUOUS MONITORING THROUGHOUT THE APPROACH

FMA (FLIGHT MODES)

- Which mode is armed?
- Which mode is captured?
- What is the aircraft being commanded to do?

VOR/LOC G/S ALT A/T

LOC (LATERAL)

- Diamond centered
- Small deviation
- ILS axis maintained



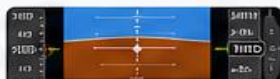
G/S (VERTICAL)

- Diamond centered
- Small deviation
- Descent path followed



ALTITUDE & V/S

- On profile
- Controlled vertical speed



SPEED & CONFIG

- Vapp +10 / -5 (typ.)
- Correct configuration
- Checklists complete



DISTANCE (DME)

- Distance / altitude consistent
- Check fixes and approach waypoints



KEY REMINDER

MCP = What the pilot selects.

FMA = What the autoflight does.

PFD (RAW DATA) = What the aircraft is actually doing.

⚠ If at any time the approach is not stabilized or the indications are inconsistent: → **GO-AROUND** according to SOP.



AGENDA

- 0. How It Works
- 1. System Architecture & Ground Layout
- 2. The Glide Path (GP / GS) - Vertical Guidance
- 3. Physical Principle: Modulation Depth Difference (DDM)
- 4. Core Ground and Airborne Components
- 5. Redundancy & Safety Features
- 6. ILS Operational Categories
- 7. ILS Approach inside an Airbus A320
- 8. Targeting Russian Airports
- 9. Microsoft Simulator 2020/2024
- 10 Weaknesses of an ILS — Single Points of Failure (SPF)
- 11. ALTERNATIVES TO ILS IN CASE OF FAILURE

0. How It Works

How It Works

The ILS uses ground-based transmitters to send radio signals that define a precise three-dimensional approach path:

- **Localizer (108-112 MHz)** — Provides horizontal guidance (left/right alignment with the runway centerline)
- **Glide Slope (UHF, paired with localizer frequency)** — Provides vertical guidance (descent angle, typically 3°)
- **Marker Beacons or DME** — Provide distance information from the runway threshold

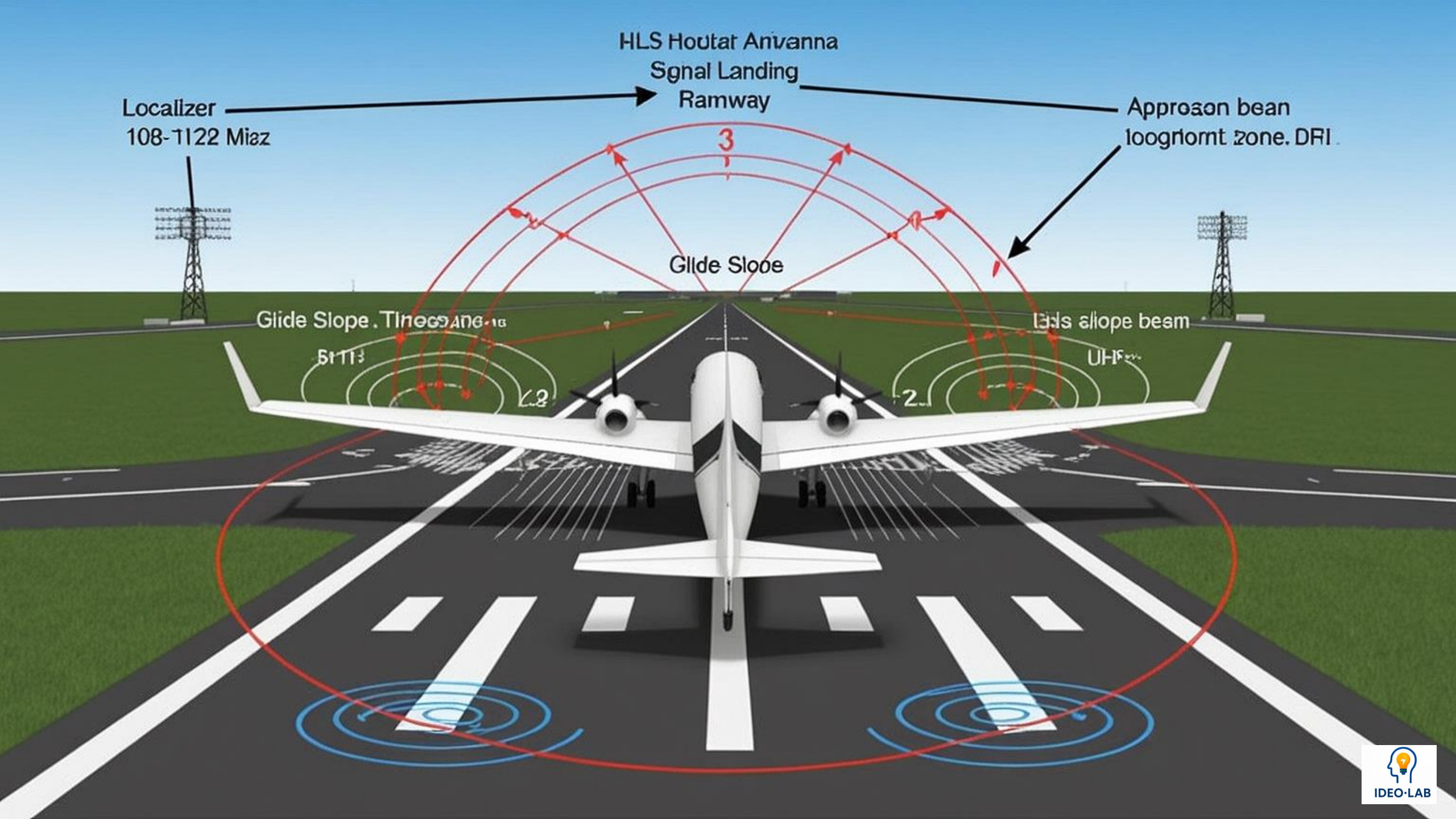
Aircraft Equipment

Onboard, the aircraft has:

- ILS receivers to interpret the signals
- Course deviation indicators (CDI) or integrated flight displays showing lateral and vertical deviation
- Autopilot and flight director systems can couple to the ILS for automated approaches

Approach Categories

- **CAT I** — Decision height 200 ft, visibility $\geq 550\text{m}$ (autopilot not required)
- **CAT II** — Decision height 100 ft, visibility $\geq 300\text{m}$ (requires autopilot/autoland)
- **CAT III** — Decision height $< 100\text{ ft}$ or no decision height, visibility $< 200\text{m}$ (full autoland capability)





1. Global Ground Architecture & Protection Zones

ILS (Instrument Landing System)

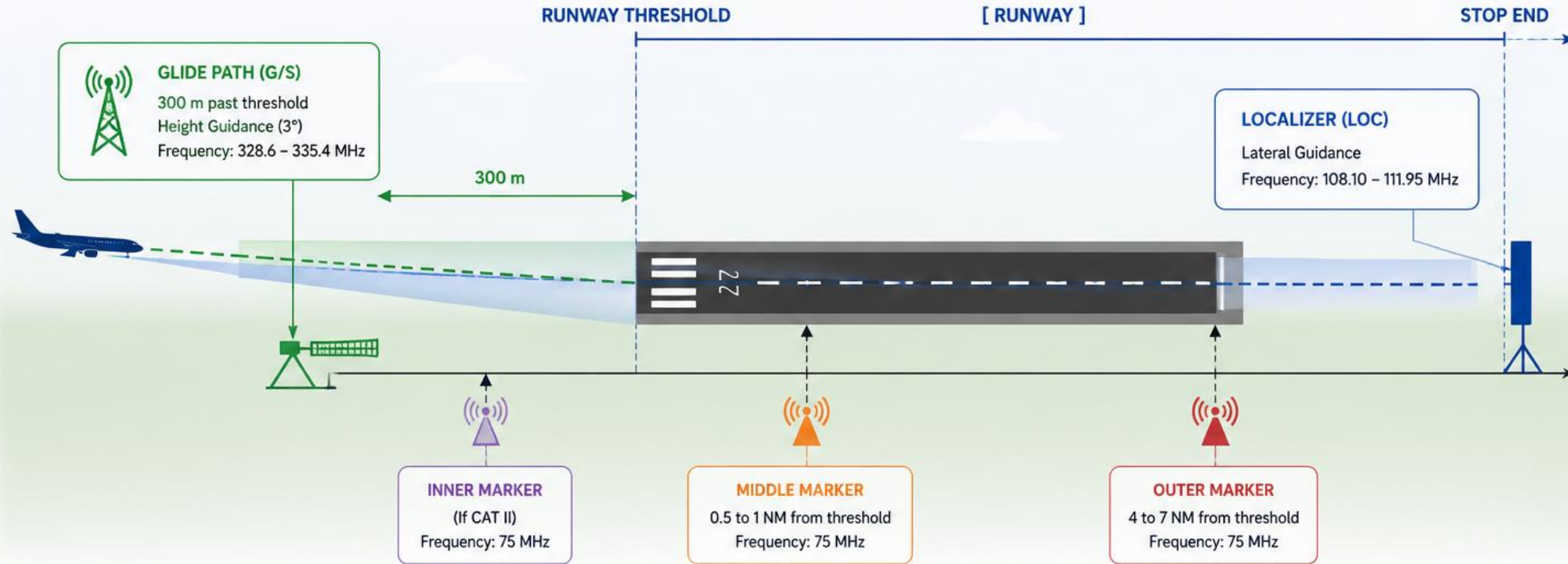


An ILS (Instrument Landing System) is a standardized ICAO ground-based radionavigation system that provides aircraft with ultra-precise lateral and vertical guidance during instrument approaches and landings.

KEY FUNCTIONS

- Glide Path (G/S):** Provides vertical guidance (typically 3° descent path)
- Localizer (LOC):** Provides lateral guidance (runway centerline)

SYSTEM ARCHITECTURE & GROUND LAYOUT



HOW IT WORKS



The **Glide Path (G/S)** provides the aircraft with vertical guidance along a ~3° descent path toward the runway.



The **Localizer (LOC)** provides lateral guidance to keep the aircraft on the extended runway centerline.

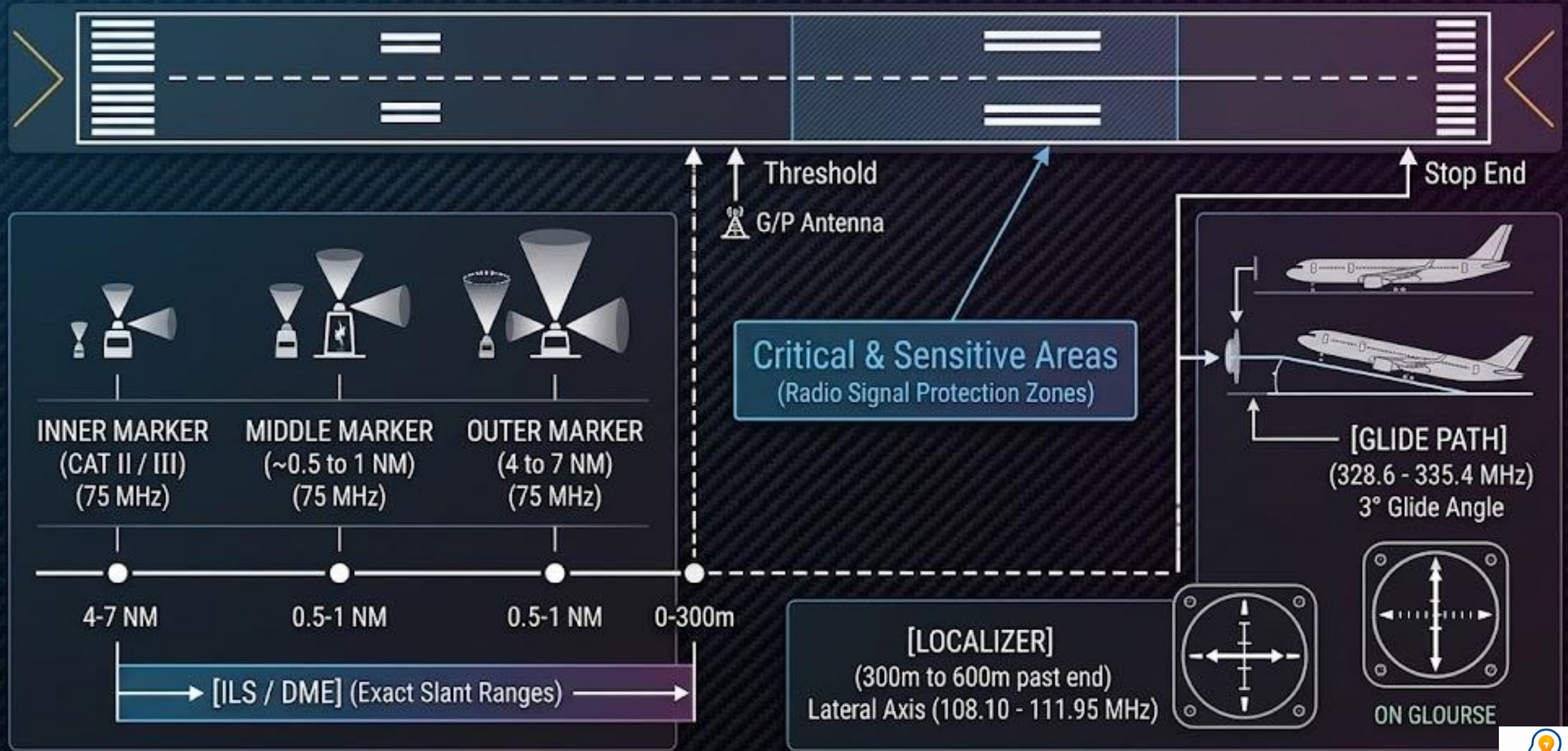


Marker beacons provide distance information to the aircraft during the approach.

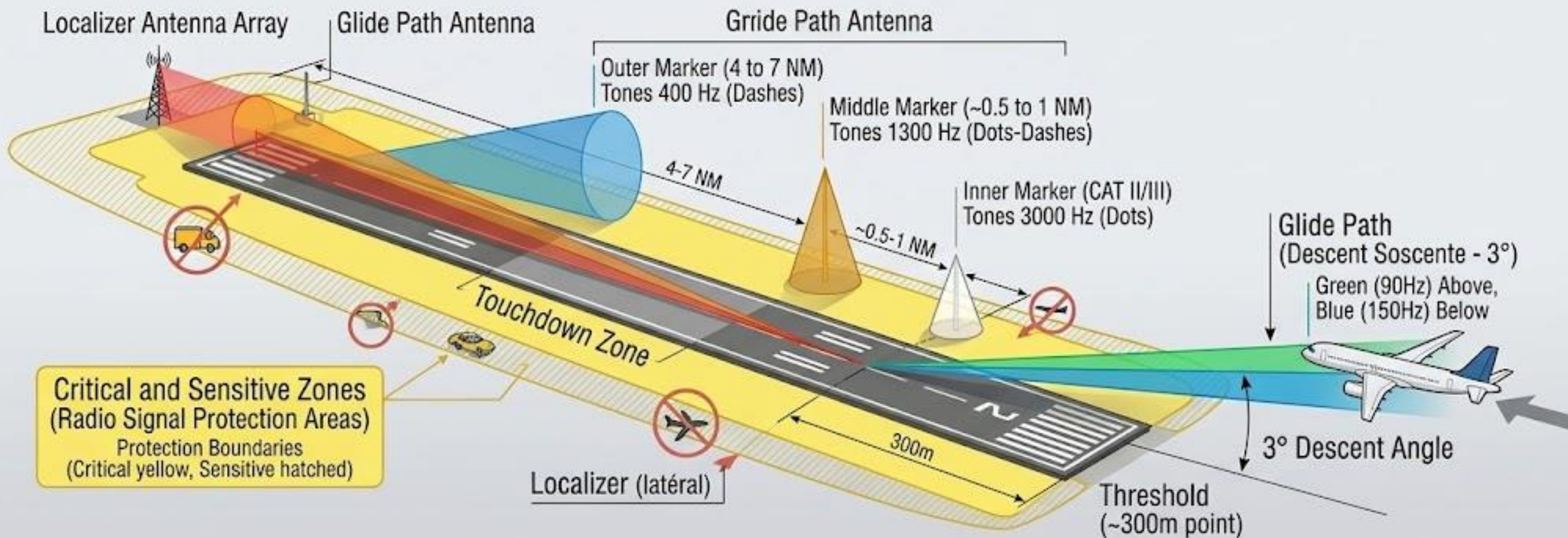


RESULT: The combination of Glide Path, Localizer, and Marker beacons enables safe, precise, and reliable instrument approaches and landings.

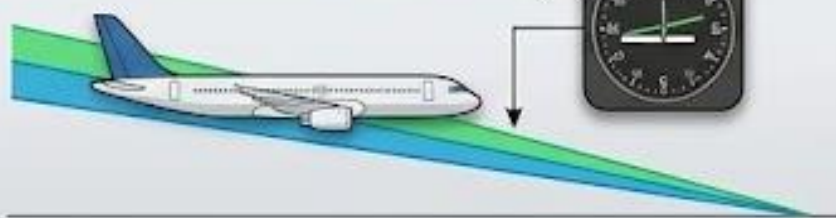
[SYSTEM TECHNICAL SPECIFICATIONS: ILS]



BASIC ILS OPERATION



Vertical Cross-Section: Glide Path (3°)

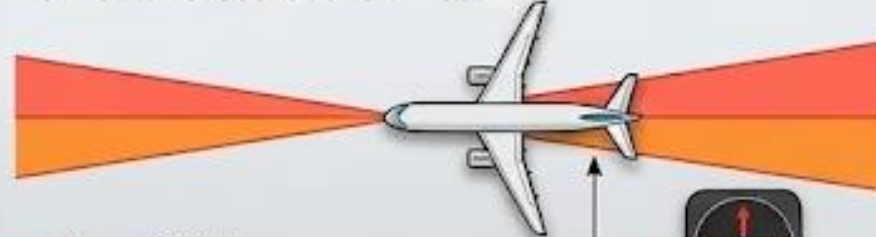


Indicateur de Pente



Green (90Hz)
Slope Indicator

Horizontal Cross-Section: Localizer



Green (90Hz)
Blue (150Hz)

Axicateur d'Axe



Red (90Hz)
Orange (150Hz)

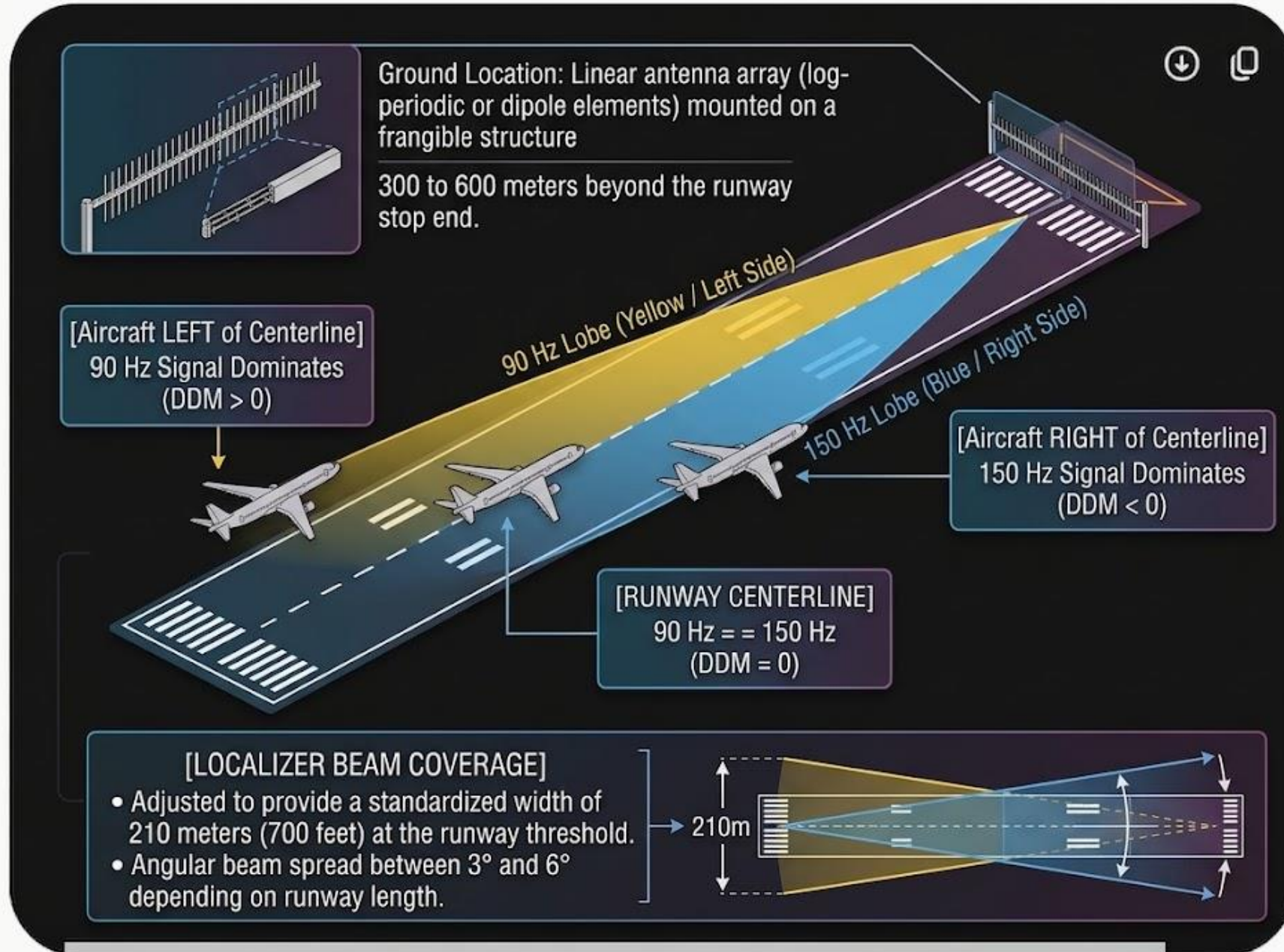
Global Ground Architecture & Protection Zones

The physical placement of every ground component strictly adheres to radio wave propagation principles and obstacle clearance requirements to prevent collisions and signal degradation.

Global Ground Architecture & Protection Zones

- 1. The Localizer (LLZ / LOC): Lateral Guidance
- 2. The Glide Path (GP / GS): Vertical Guidance
- 3. Distance Fixes: Markers vs. DME
- 4. Signal Protection Zones (Critical & Sensitive Areas)

1. The Localizer (LLZ / LOC): Lateral Guidance



The Localizer (LLZ / LOC) - Lateral Guidance

- Chapter 1: Introduction to the Localizer
- Chapter 2: The Ground Station - Physical Installation
- Chapter 3: Safety and Antenna Structure
- Chapter 4: Beam Coverage and Operational Specifications

Chapter 1: Introduction to the Localizer

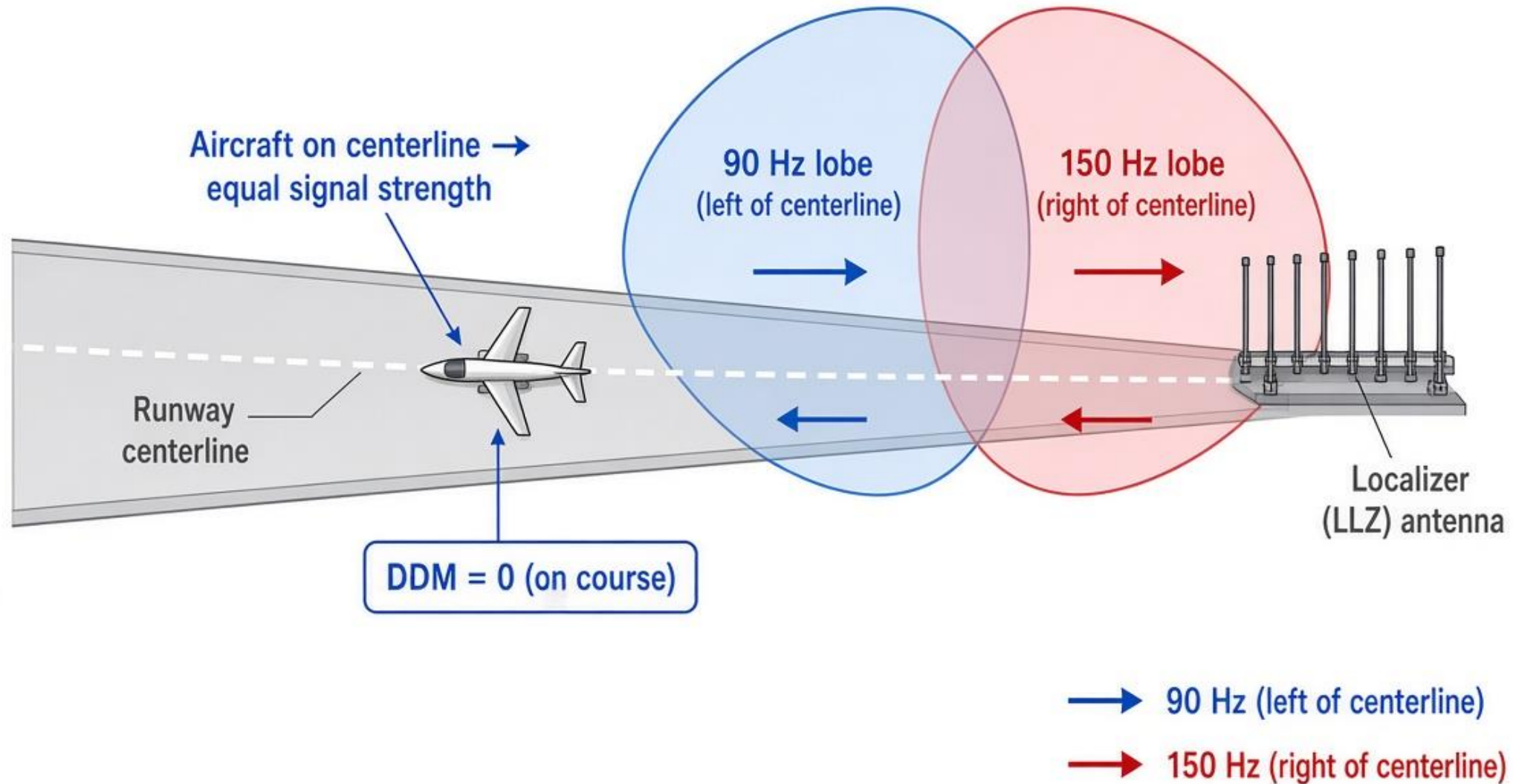
1.1 Core Function and System Context

The Localizer (LLZ or LOC) is a foundational component of the aviation Instrument Landing System (ILS). Its primary and non-negotiable purpose is to provide highly precise, real-time **lateral guidance** to pilots during the critical approach and landing phases.

While the ILS as a whole is a two-dimensional guidance system, the Localizer specifically ensures that the aircraft is aligned horizontally with the exact centerline of the intended runway, regardless of prevailing weather and visibility. This function is independent of the other component, the Glide Path (GP or GS), which handles the vertical, or altitude, guidance.

Key Definition: The Localizer is an VHF (Very High Frequency) radio transmitter that generates two signal lobes. One lobe (90 Hz) is biased to the left of the centerline, and the other (150 Hz) is biased to the right. When the aircraft receives equal signal strength from both lobes, it is on the precise centerline. This state is defined as 'DDM=0' (Difference in Depth of Modulation is zero).

Instrument Landing System (ILS) Localizer (LLZ/LOC)



Chapter 2: The Ground Station - Physical Installation

2.1 Strategic Ground Location

The physical placement of the Localizer ground equipment is critical for optimal system performance and safety.

2.1.1 Location Specification

- **Primary Location:** The Localizer antenna array is universally positioned beyond the far end of the runway, specifically centered on the extended runway centerline.
- **Distance Factor:** This is the key detailed measurement. The antennas are physically mounted **300 to 600 meters** (approximately 1000 to 2000 feet) **beyond the runway stop end.**

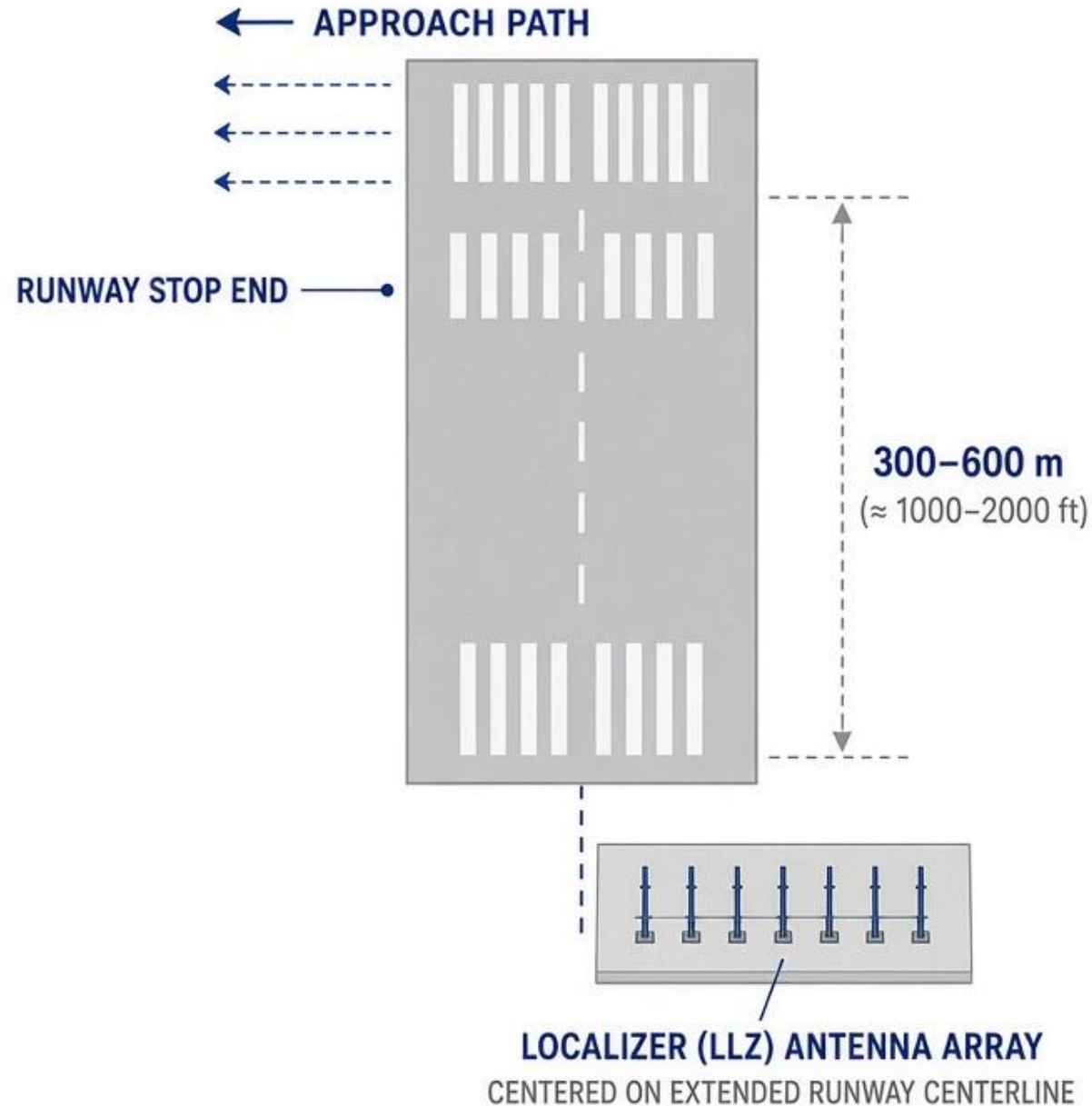
2.1.2 Technical Rationale for Location

The 300 to 600-meter distance is carefully calculated for two reasons:

1. **Far-Field Stability:** Radio frequency signals need a certain distance to form their intended stable radiation pattern (the dual-lobe signal). By placing the array far from the touchdown zone, the signals stabilized and provided a clean, precise guiding beam in the critical approach area.
2. **Obstruction Clearance:** Radio signals can be warped or reflected by nearby physical objects. Placing the antenna far beyond the runway places it in an area where physical obstructions (like other airport buildings or terrain features) can be minimized or managed, further improving the signal-in-space quality.

ILS LOCALIZER (LLZ) GROUND STATION INSTALLATION

TOP-DOWN VIEW



FAR-FIELD STABILITY

distance allows the dual-lobe radiation pattern to fully form and stabilize



OBSTRUCTION CLEARANCE

placement minimizes signal reflections from buildings and terrain







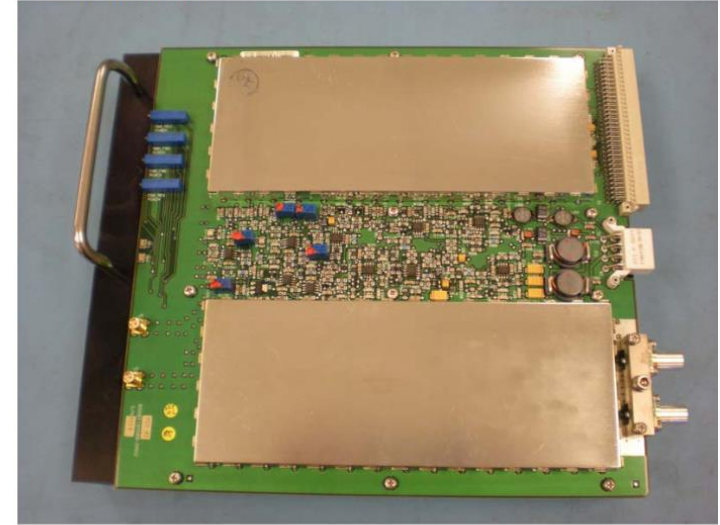


Localizer Station & MotherBoards (LLZ)

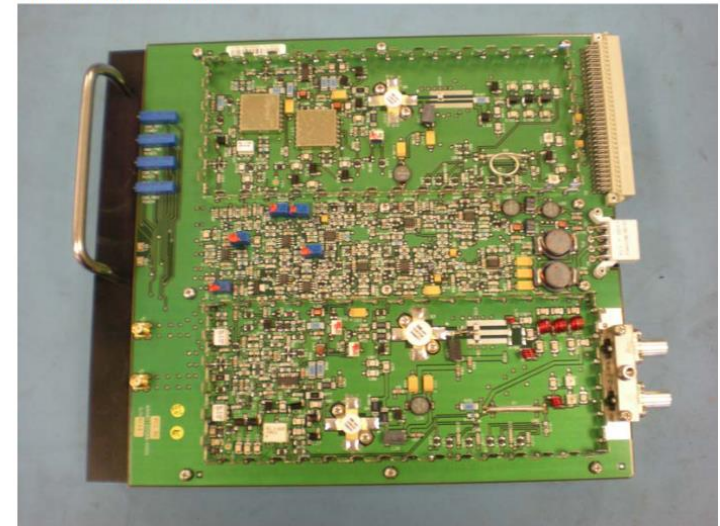
LOC Card Racks



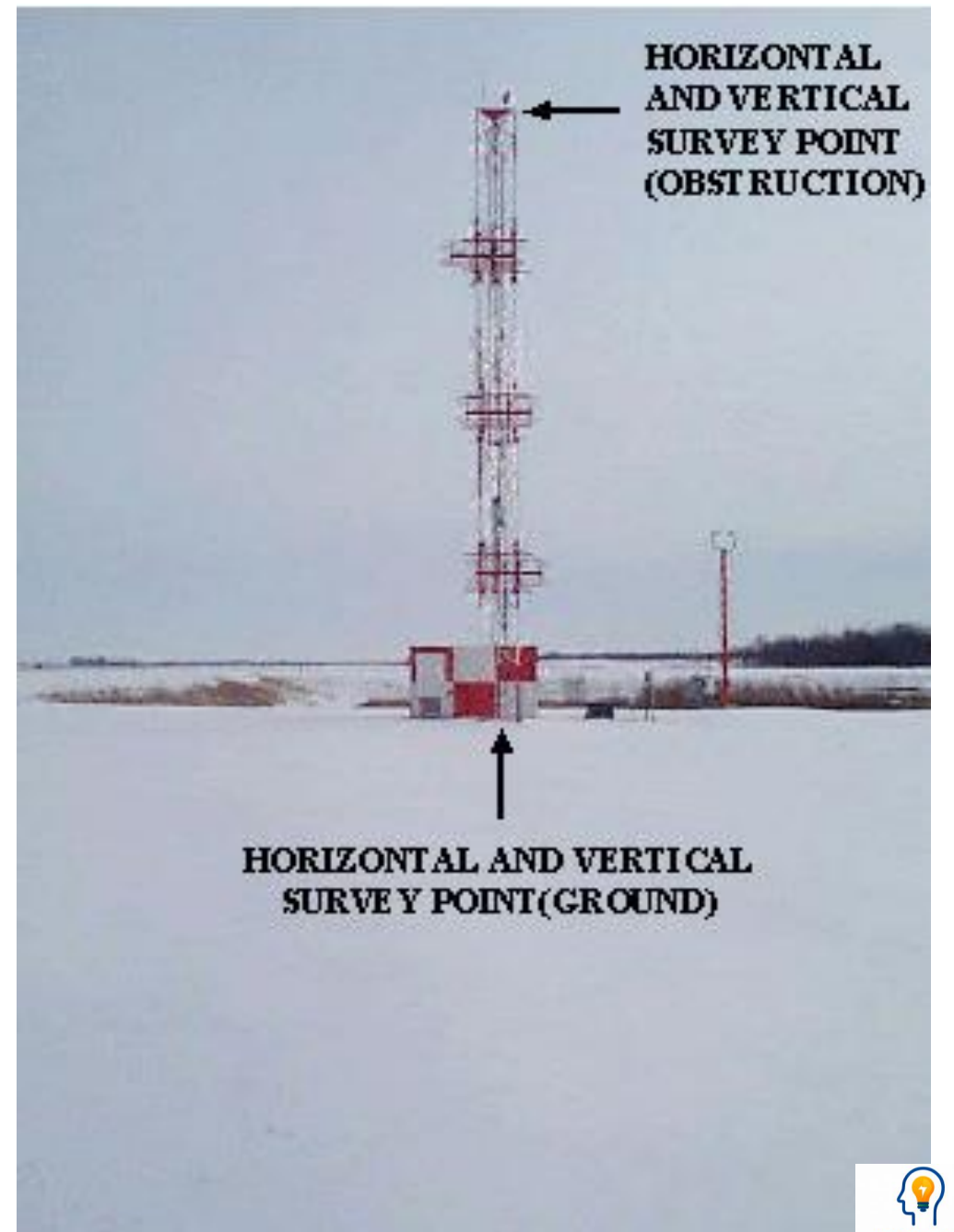
LOC PA with Shields



LOC PA without Shields



GLIDE SLOPE (GP)



Chapter 3: Safety and Antenna Structure

3.1 Advanced Frangible Mounts

Airport equipment must be designed for safety, and the Localizer array is no exception. This chapter explains the "why" and "how" of its mounting.

3.1.1 Frangibility as a Safety Principle

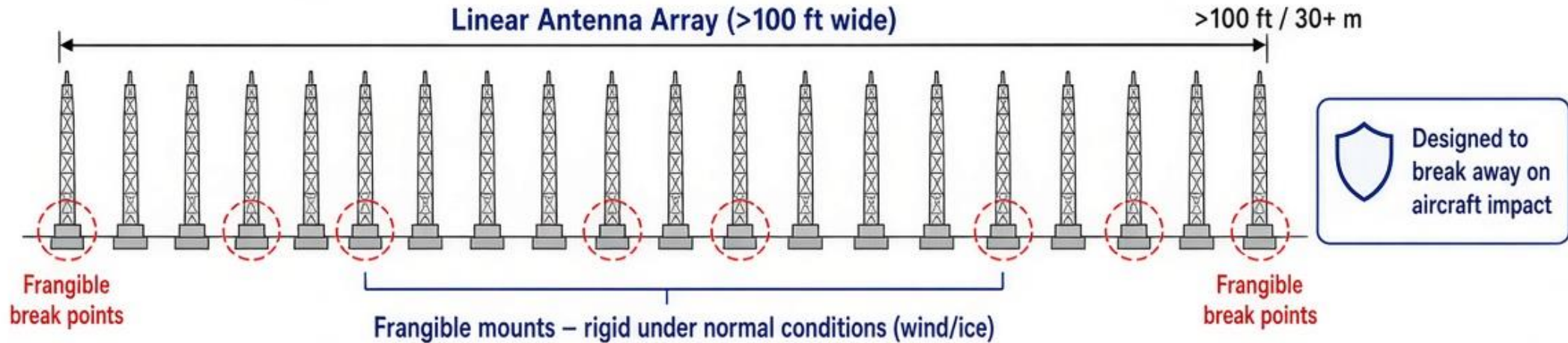
The antenna array, being located near the runway centerline, must never be a hard, catastrophic obstruction. Its mounts are engineered with a specific failure mode.

3.1.2 Detailed Component Construction

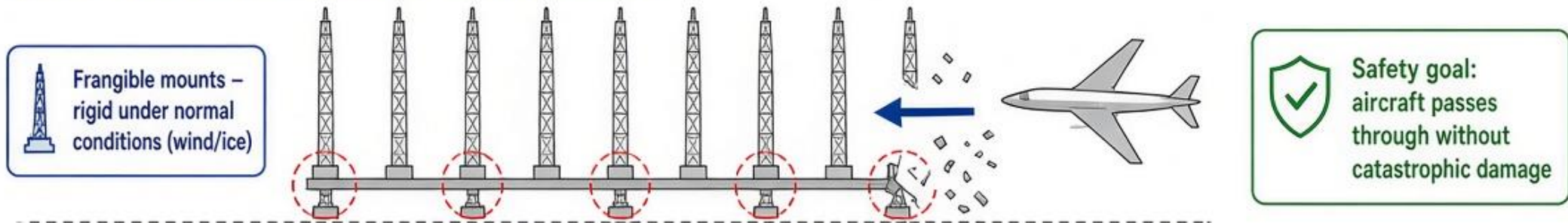
- **Linear Antenna Array:** The array itself is a large-scale structure, typically over 100 feet wide, composed of multiple highly directional antenna elements (such as log-periodic or dipole elements).
- **Frangible Structure:** The structural support system that holds this massive array is **frangible**. This means it is designed to hold the array rigidly under all normal weather conditions (even high wind and ice), but to break away and disintegrate upon impact with a moving aircraft.
 - Specific techniques, such as brittle failure-mode components and engineered fracture points, are used. The primary concern is that an overrunning or departing aircraft will pass through the structure without catastrophic damage, rather than impacting a solid object. The massive nature of the 300-600 meter distance provides a crucial safety margin.

ILS Localizer – Frangible Antenna Structure (Chapter 3)

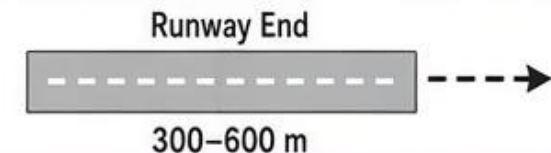
1 TOP VIEW (PLAN VIEW)



2 SIDE VIEW (AIRCRAFT OVERRUN SCENARIO)



Located **300–600 m** beyond runway end for additional safety margin



Chapter 4: Beam Coverage and Operational Specifications

4.1 System Coverage Architecture

The Localizer beam is not a simple, non-varying signal cone; it is precisely shaped to provide guidance from the earliest stage of intercepting the ILS path down to the runway surface.

4.1.1 Signal Interception Zones

- **Standard Interception:** Pilots typically intercept the Localizer centerline between 15 and 20 nautical miles from the threshold, when the signal is well-formed.
- **Detailed Coverage Area:** To facilitate interception, the standard ICAO specification provides guidance in sectors:
 - **Main Sector:** Full guidance is available within **+/- 10 degrees** of the centerline to a distance of 18 NM.
 - **Side Sectors:** Less-precise, directional-only guidance is available within **+/- 35 degrees** out to 10 NM.

4.2 Standardized Boundary at Threshold

This is a key detailed and specific measurement that standardizes the operational feel of all ILS approaches.

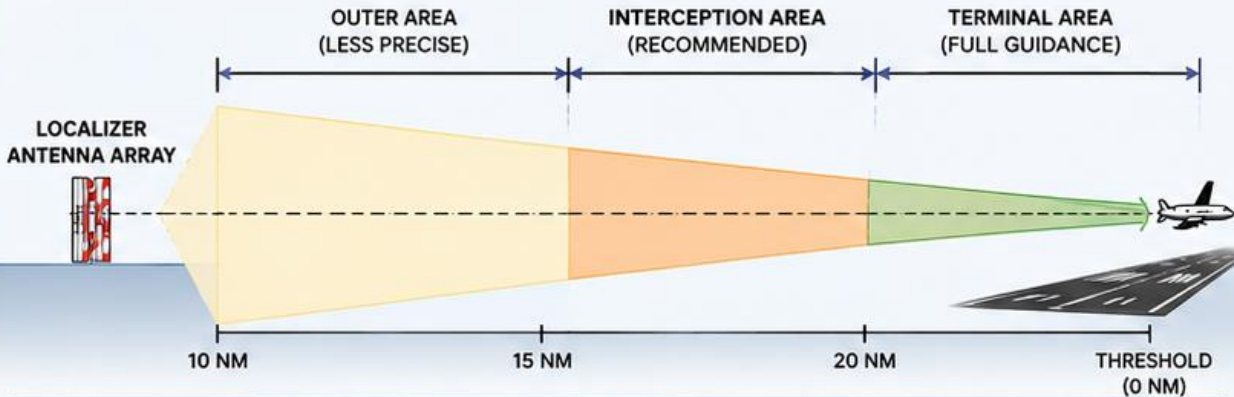
4.2.1 Core Measurement

- **Constraint:** To provide consistent and predictable steering response for all aircraft, the width of the Localizer course (the area where full-scale indicator deflection occurs) is standardized.
- **Specification:** The coverage is physically adjusted and tailored (via the antenna array and power distribution) to provide a constant width at the most critical operational point: the runway **threshold**. This width is standardized at a precise **210 meters (approximately 700 feet)**.

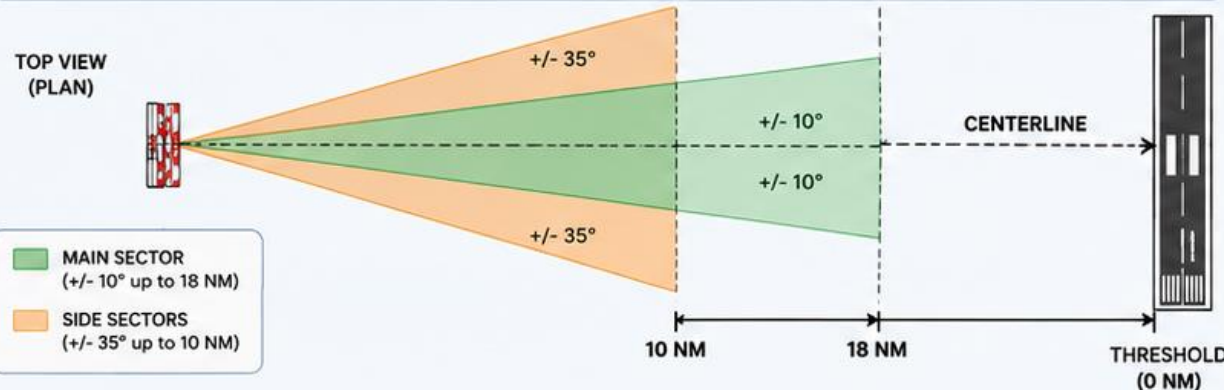
Chapter 4: Beam Coverage and Operational Specifications (ILS Localizer)

4.1 SYSTEM COVERAGE ARCHITECTURE

The Localizer beam is precisely shaped to provide guidance from the earliest stage of intercepting the ILS path down to the runway surface.



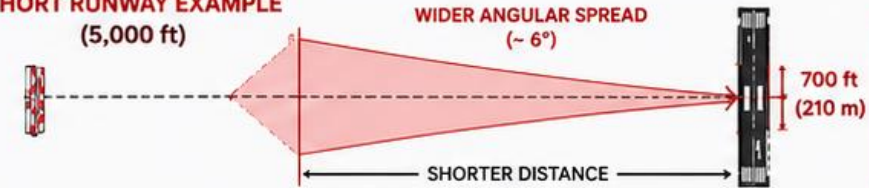
4.1.1 SIGNAL INTERCEPTION ZONES



4.2 FUNCTIONAL PURPOSE

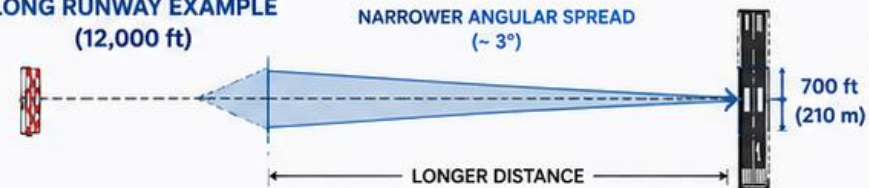
This 210-meter constraint is the most operationally significant. By preattent a 700-foot wide course only at the threshold, the physical angular spread must be varied.

SHORT RUNWAY EXAMPLE (5,000 ft)



- A short runway requires a wider angular beam spread (e.g. $\sim 6^\circ$) from the far end to achieve 700 ft at the threshold.

LONG RUNWAY EXAMPLE (12,000 ft)



- A very long runway requires a narrower angular beam spread (e.g. $\sim 3^\circ$) to ensure the course does not widen beyond 700 ft at the threshold.



This precise adjustment ensures the sensitivity of the Localizer needle on the pilot's indicator remains functionally consistent across runways of any length. A small change in lateral deviation results in a proportional and predictable needle movement, which is critical for precise flight management and automated landing systems.

4.2 STANDARDIZED BOUNDARY AT THRESHOLD

This is a key detailed and specific measurement that standardizes the operational feel of all ILS approaches.

4.2.1 CORE MEASUREMENT



CONSTRAINT

To provide consistent and predictable steering response for all aircraft, the width of the Localizer course (the area where full-scale indicator deflection occurs) is standardized.



SPECIFICATION

The coverage is physically adjusted and tailored (via the antenna array and power distribution) to provide a constant width at the most critical operational point: the runway threshold.

KEY STANDARD

210 METERS
(APPROX. 700 FEET)

Constant course width
at the runway threshold



SUMMARY: The Localizer beam is engineered to provide precise lateral guidance. Its angular spread is dynamically adjusted based on runway length so that its width at the threshold is always a constant 210 meters (700 feet), ensuring a standard and reliable pilot experience for all ILS approaches.



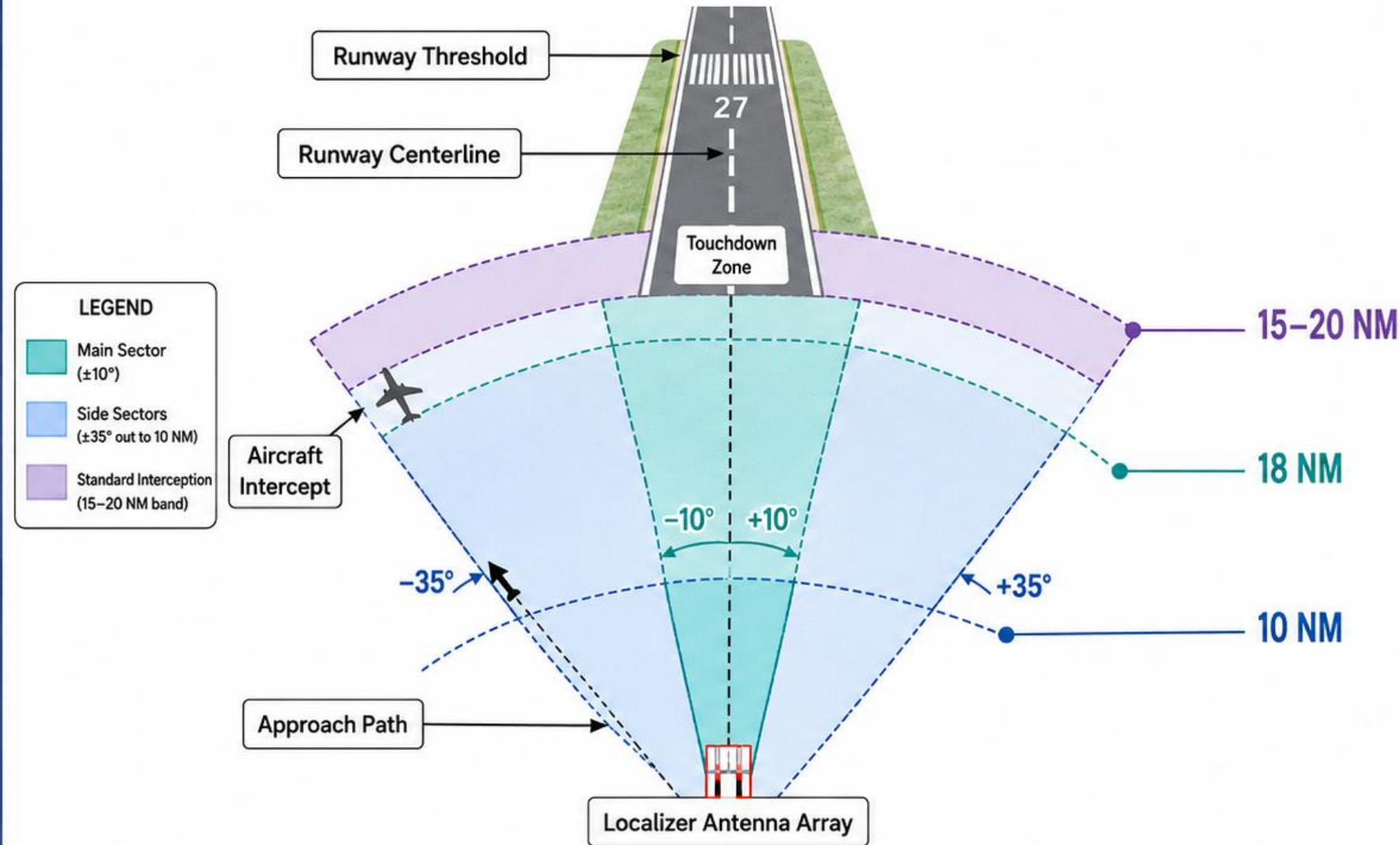
4.2.2 Functional Purpose

This 210-meter constraint is the most operationally significant. By creating a 700-foot wide course only at the threshold, the physical angular spread must be varied.

- A short runway of, say, 5,000 feet, would require a wider angular beam spread (perhaps 6°) from the far end to achieve a 700-foot width at the nearer threshold.
- A very long runway of 12,000 feet, where the threshold is much farther from the antennas, would require a narrower, tighter angular beam spread (perhaps 3°) to ensure the course does not widen beyond the standard 700 feet at the threshold.
 - This precise adjustment ensures the sensitivity of the Localizer needle on the pilot's indicator remains functionally consistent across runways of any length. A small change in lateral deviation results in a proportional and predictable needle movement, which is critical for precise flight management and automated landing systems.

Chapter 4: Beam Coverage and Operational Specifications

4.1 System Coverage Architecture — ILS Localizer



Operational Coverage Summary



1. Standard Interception

Pilots typically intercept the Localizer centerline between 15 and 20 nautical miles from the threshold, when the signal is well formed.



2. Main Sector

Full guidance is available within ±10° of the centerline to a distance of 18 NM.



3. Side Sectors

Less-precise, directional-only guidance is available within ±35° out to 10 NM.



The localizer beam is precisely shaped to guide aircraft from early interception of the ILS path down to the runway surface.



2. The Glide Path (GP / GS) - Vertical Guidance

AGENDA GLIDE SLOPE

- Chapter 1: Introduction to the Glide Path
- Chapter 2: Ground Installation & Antenna Geometry
- Chapter 3: Signal Modulation and Dual-Lobe Physics
- Chapter 4: Descent Gradient and Angle Specifications
- Chapter 5: Operational Safety Features & False Signals

Chapter 1: Introduction to the Glide Path

1.1 Core Function and System Context

The Glide Path (GP), often referred to as the Glide Slope (GS), is the vertical component of the Instrument Landing System (ILS). Its objective is to provide precise **vertical guidance** to the pilot, ensuring a smooth, controlled descent toward the runway touchdown zone.

While the Localizer (LLZ) aligns the aircraft horizontally with the runway centerline, the Glide Path establishes the correct angle of approach to maintain terrain clearance and achieve a safe touchdown point.

Key Definition: The Glide Path operates in the Ultra High Frequency (UHF) spectrum between **328.6 MHz and 335.4 MHz**. It projects a dual-lobe signal into space:

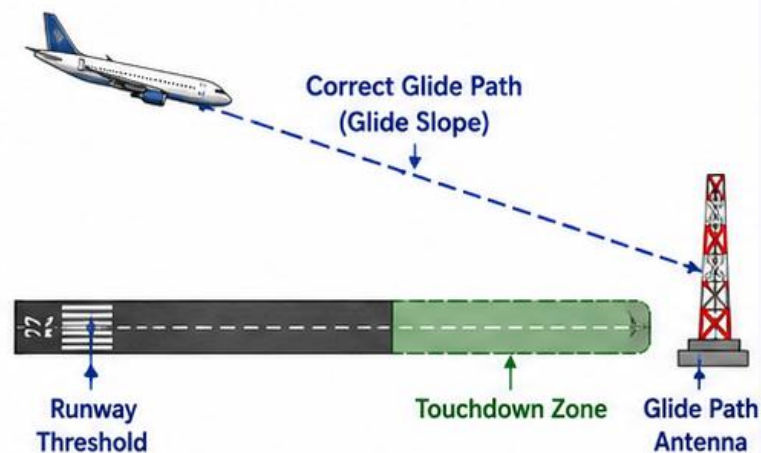
- **Upper Lobe (90 Hz):** Dominates above the optimal glide angle.
- **Lower Lobe (150 Hz):** Dominates below the optimal glide angle.
- **On-Glide-Path (DDM = 0):** The aircraft receives an equal intensity of both 90 Hz and 150 Hz signals, indicating the pilot is on the correct descent path.

Chapter 1: Introduction to the Glide Path

1.1 Core Function and System Context

1. GLIDE PATH FUNCTION

- The Glide Path (GP), also referred to as Glide Slope (GS), is the vertical component of the Instrument Landing System (ILS).
- It provides precise vertical guidance to the pilot.
- It ensures a smooth, controlled descent toward the runway touchdown zone.



2. ROLE WITHIN THE ILS

LOCALIZER (LLZ) Horizontal Alignment



GLIDE PATH (GP) Vertical Guidance



While the Localizer aligns the aircraft horizontally with the runway centerline, the Glide Path establishes the correct angle of approach to maintain terrain clearance and achieve a safe touchdown point.

3. UHF OPERATING BAND



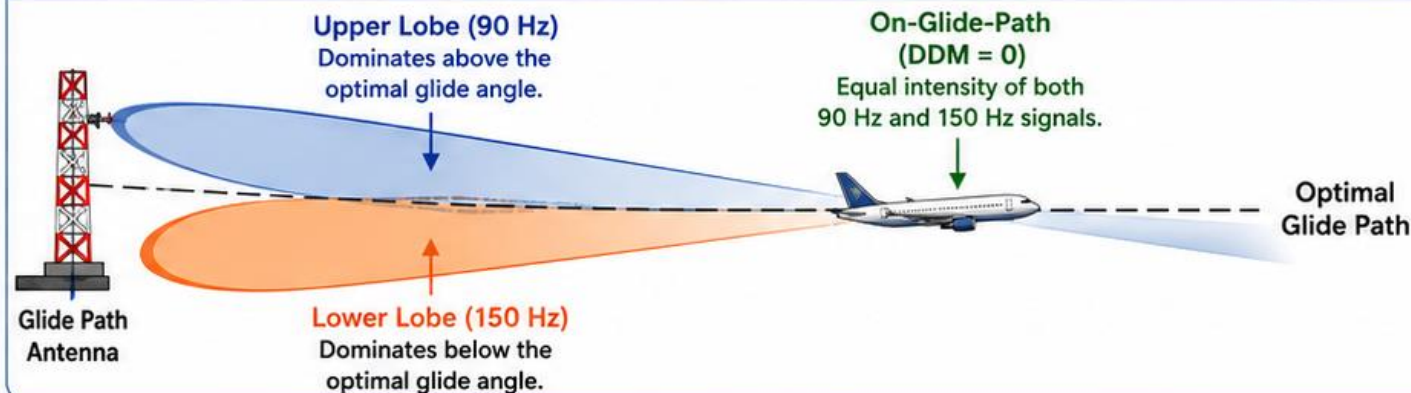
Glide Path operates in the
Ultra High Frequency (UHF) spectrum

328.6 MHz to 335.4 MHz



UHF Band

4. DUAL-LOBE GUIDANCE



SUMMARY:

The Glide Path is the ILS vertical guidance element. Operating in the UHF band, it uses two signal lobes—90 Hz above and 150 Hz below—to guide aircraft onto the correct descent path. When both signals are equal (DDM = 0), the aircraft is on the proper glide path.

Chapter 2: Ground Installation & Antenna Geometry

2.1 Physical Location and Dimensions

The Glide Path antenna mast is located within the airport perimeter adjacent to the runway, specifically positioned relative to the landing threshold.

2.1.1 Location Specifications

- **Mast Height:** The antenna array is mounted on a vertical mast typically **10 to 15 meters (33 to 50 feet)** tall.
- **Lateral Offset:** It is offset laterally by approximately **120 meters (400 feet)** from the runway centerline to clear the primary runway strip safety area.
- **Longitudinal Distance:** It is installed approximately **300 meters (1,000 feet)** past the landing threshold, directly aiming at the touchdown zone.

2.1.2 Technical Rationale for Placement

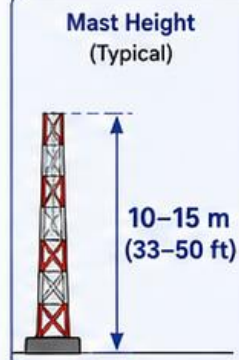
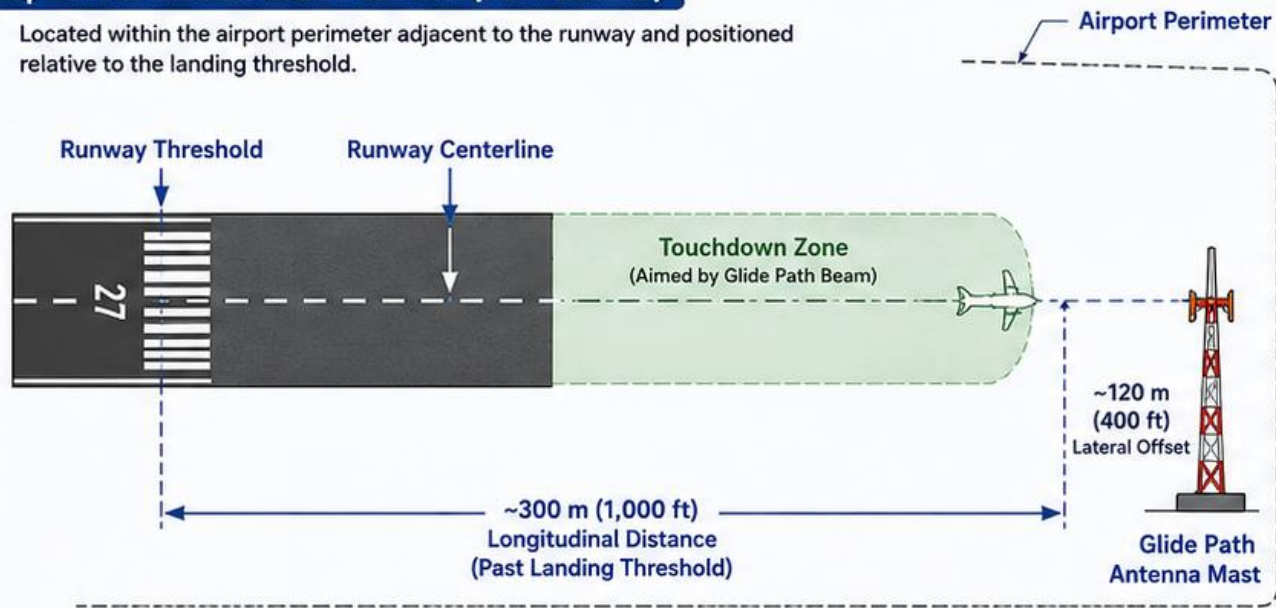
- **Touchdown Zone Alignment:** Positioning the mast ~300 m down the runway ensures that following the beam brings the aircraft over the runway threshold with an adequate wheel clearance (Threshold Crossing Height, or TCH, typically 50 feet) before touchdown.
- **Ground Reflection Principles:** Most conventional Glide Path systems (such as null-glide or image-type arrays) rely on signal reflection off the ground in front of the antenna to form the lower lobe. This requires a smooth, flat ground plane in front of the mast, known as the ILS ground reflection area.

Chapter 2: Ground Installation & Antenna Geometry

2.1 Physical Location and Dimensions — Glide Path Antenna

INSTALLATION GEOMETRY (PLAN VIEW)

Located within the airport perimeter adjacent to the runway and positioned relative to the landing threshold.

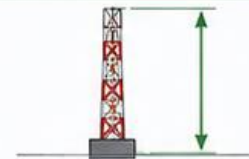


2. LOCATION SPECIFICATIONS

Key dimensional requirements for Glide Path antenna placement.



Mast Height
10–15 m
(33–50 ft)



Lateral Offset
~120 m (400 ft)
from runway
centerline

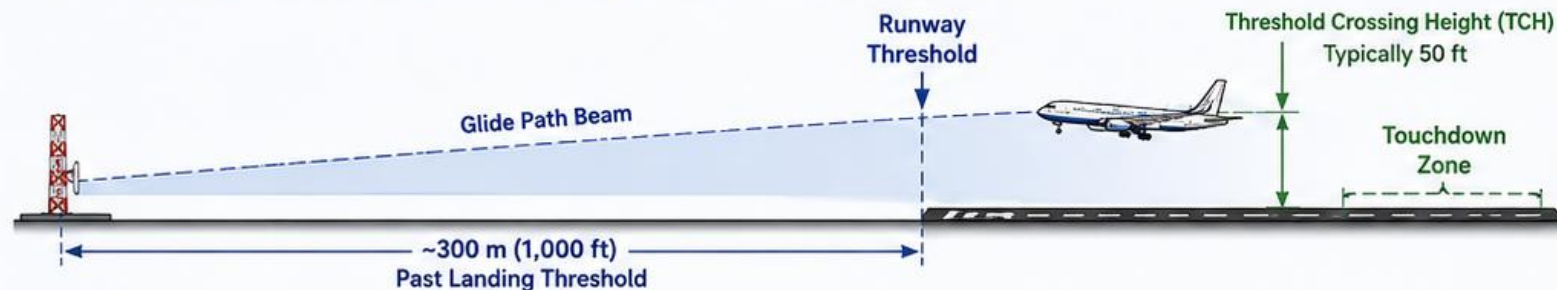


Longitudinal Distance
~300 m (1,000 ft)
past the landing
threshold



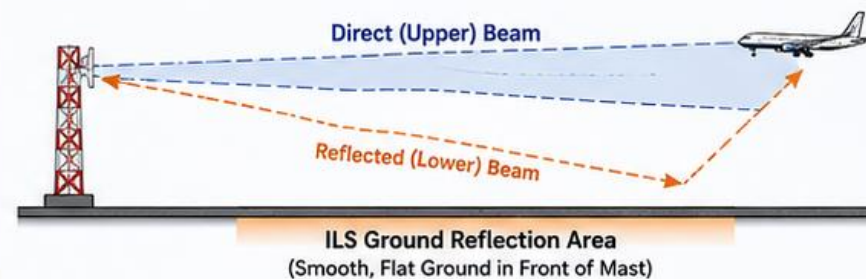
TECHNICAL RATIONALE FOR PLACEMENT — TOUCHDOWN ZONE ALIGNMENT

Positioning the mast ~300 m down the runway ensures the glide path beam is aimed so that following it brings the aircraft over the runway threshold with adequate wheel clearance before touchdown.



4. GROUND REFLECTION PRINCIPLES

Conventional Glide Path systems rely on signal reflection off the ground in front of the antenna to form the lower lobe of the vertical guidance beam.



SUMMARY: The Glide Path antenna is carefully positioned in height, offset, and distance so the approach beam provides stable vertical guidance, proper threshold crossing height, and reliable touchdown zone alignment.



Proper Height
10–15 m
(33–50 ft)



Correct Offset
~120 m
(400 ft)



Right Distance
~300 m
(1,000 ft)

Chapter 3: Signal Modulation and Dual-Lobe Physics

3.1 Overlapping Radio Frequency Lobes

The vertical guidance beam is created by intersecting two overlapping UHF directional patterns radiating from the mast.

3.1.1 90 Hz Lobe (Above Path)

- **Frequency Modulation:** Amplitude modulated at **90 Hz**.
- **Position:** Formed higher in the vertical plane.
- **Cockpit Indication:** If the aircraft flies above the glide path, the receiver detects a predominant 90 Hz signal. The cockpit glide slope indicator needle points **downward**, commanding the pilot (or autopilot) to pitch down to intercept the path.

3.1.2 150 Hz Lobe (Below Path)

- **Frequency Modulation:** Amplitude modulated at **150 Hz**.
- **Position:** Formed lower in the vertical plane, closer to the ground.
- **Cockpit Indication:** If the aircraft drops below the glide path, the 150 Hz signal dominates. The cockpit needle points **upward**, warning the pilot to decrease the descent rate or go around.

3.1.3 Difference in Depth of Modulation (DDM)

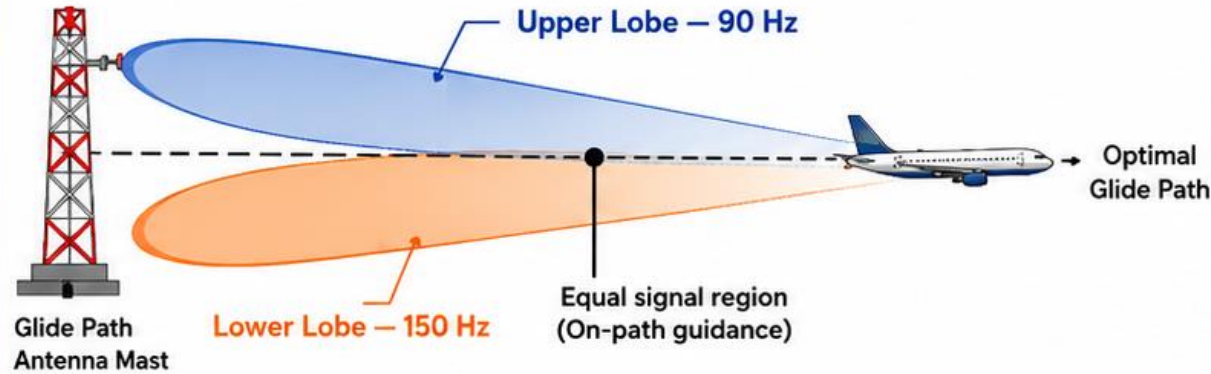
- **DDM > 0:** Aircraft is above the path (90 Hz > 150 Hz).
- **DDM < 0:** Aircraft is below the path (150 Hz > 90 Hz).
- **DDM = 0:** On-path trajectory where both modulations are equal.

Chapter 3: Signal Modulation and Dual-Lobe Physics

3.1 Overlapping Radio Frequency Lobes

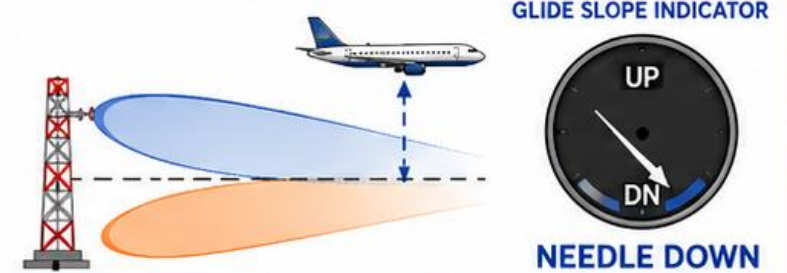
The vertical guidance beam is created by intersecting two overlapping UHF directional patterns radiating from the mast.

1. OVERLAPPING RF LOBES



2. 90 HZ LOBE (ABOVE PATH)

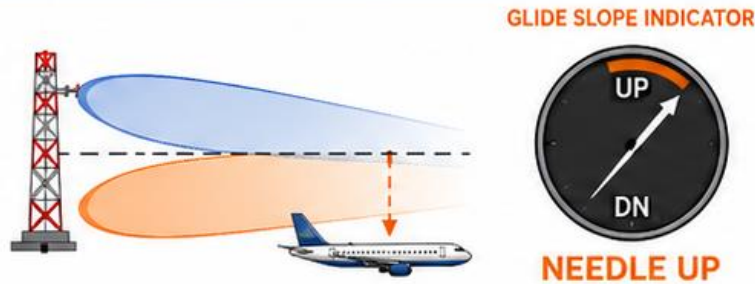
- **Frequency modulation:** amplitude modulated at 90 Hz.
- **Position:** formed higher in the vertical plane.



i If the aircraft flies **above** the glide path, the receiver detects a predominant 90 Hz signal. The cockpit glide slope needle points **downward**, commanding the pilot or autopilot to pitch down to intercept the path.

3. 150 HZ LOBE (BELOW PATH)

- **Frequency modulation:** amplitude modulated at 150 Hz.
- **Position:** formed lower in the vertical plane, closer to the ground.



i If the aircraft drops below the glide path, the 150 Hz signal dominates. The cockpit needle points **upward**, warning the pilot to decrease the descent rate or go around.

4. COCKPIT RESPONSE SUMMARY

Aircraft Position	Signal Relationship	Glide Slope Indicator	Pilot / Autopilot Response
Above glide path	90 Hz dominant		Needle down Pitch down / intercept
On glide path	Balanced signals		Centered needle Maintain approach
Below glide path	150 Hz dominant		Needle up Reduce descent rate / go around

✓ SUMMARY: Glide path guidance is produced by two overlapping lobes: 90 Hz above and 150 Hz below. Their balance determines whether the aircraft is above, on, or below the correct descent path.

Chapter 4: Descent Gradient and Angle Specifications

4.1 Standard 3.0° Glide Angle

The standard reference slope for an ILS Glide Path is **3.0°**, which balances terrain clearance, aircraft pitch attitude, and passenger comfort.

4.1.1 Gradient & Rate of Descent Metrics

- **Descent Gradient:** A 3.0° slope yields a descent gradient of approximately **5.2%** or **300 feet per nautical mile (NM)**.
- **Calculating Rate of Descent (ROD):** Pilots use a standard rule of thumb to estimate the required rate of descent in feet per minute (fpm) based on groundspeed (GS):

$$\text{Rate of Descent (fpm)} \approx \text{Groundspeed (knots)} \times 5$$

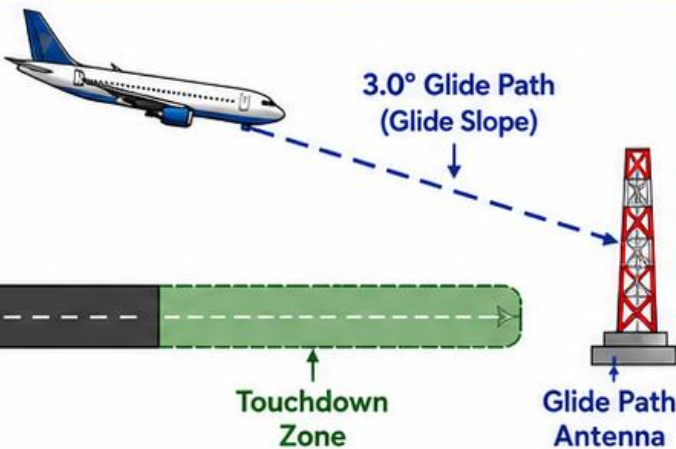
Groundspeed (kt)	Approximate Rate of Descent (fpm)
100 kt	500 fpm
120 kt	600 fpm
140 kt	700 fpm
160 kt	800 fpm

Chapter 4: Descent Gradient and Angle Specifications

4.1 Standard 3.0° Glide Angle

1. STANDARD 3.0° GLIDE ANGLE

The standard reference slope for an ILS Glide Path is **3.0°**, which balances terrain clearance, aircraft pitch attitude, and passenger comfort.



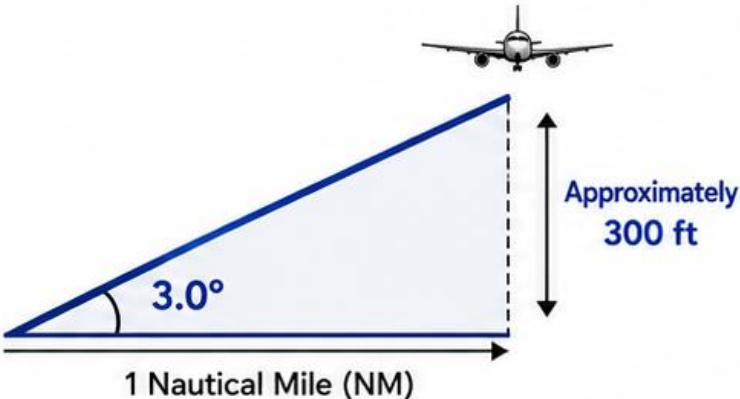
2. GRADIENT METRICS



Descent Gradient:
approximately **5.2%**



Approximately
300 feet per nautical mile (NM)



3. CALCULATING RATE OF DESCENT (ROD)



Rate of Descent (fpm) $\approx$ Groundspeed (kt) $\times$ 5

Pilots use this standard rule of thumb to estimate the required rate of descent in feet per minute (fpm) based on the aircraft's groundspeed (GS) in knots.

4. QUICK REFERENCE TABLE

Groundspeed (kt)	Approximate Rate of Descent (fpm)
100 kt	500 fpm
120 kt	600 fpm
140 kt	700 fpm
160 kt	800 fpm

SUMMARY



A 3.0° ILS glide path provides a standard and predictable descent profile.

- Descent Gradient: approximately **5.2%**
- Approximately **300 feet per nautical mile (NM)**
- Pilots estimate the required descent rate using:

Rate of Descent (fpm) $\approx$ Groundspeed (kt) $\times$ 5



Chapter 5: Operational Safety Features & False Signals

5.1 False Glide Slopes

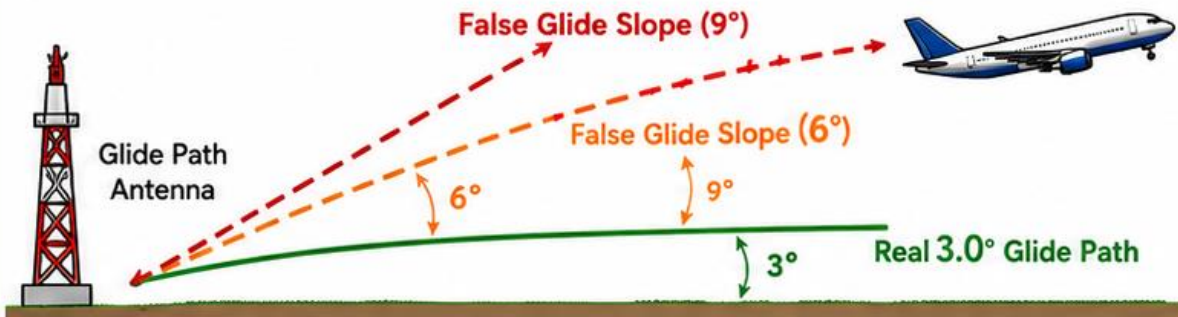
Due to signal reflections from the ground and antenna geometry, high-angle harmonic lobes (false glide paths) can form above the real 3.0° beam.

- **Characteristics:** False paths typically occur at multiples of the standard angle (e.g., 6° or 9°).
- **Signal Inversion:** False paths often exhibit reversed command signals (e.g., flying higher causes the needle to command pitch up).
- **Operational Defense:** Pilots intercept the Glide Path from **below** at a published altitude to ensure they lock onto the primary 3.0° slope and avoid false high-angle lobes.

Chapter 5: Operational Safety Features & False Signals

5.1 False Glide Slopes

1. TRUE VS FALSE GLIDE SLOPES



High-angle harmonic lobes can form above the real beam.

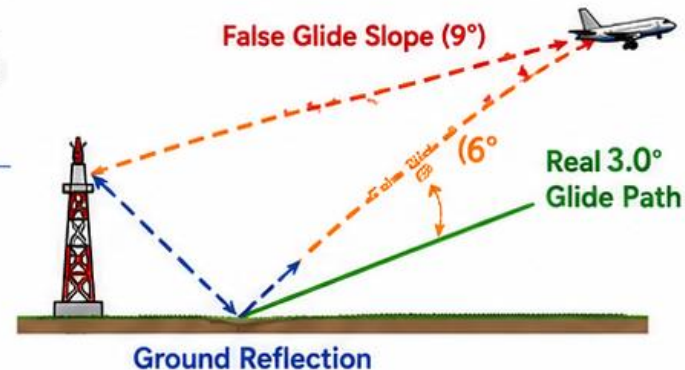
2. KEY CHARACTERISTICS

6°
9°

False paths typically occur at multiples of the standard angle (e.g. 6° or 9°).



They result from ground reflections and antenna geometry.



3. SIGNAL INVERSION / COCKPIT EFFECT



False paths can produce reversed command signals.



Example: flying higher may command **pitch up** instead of normal correction logic.

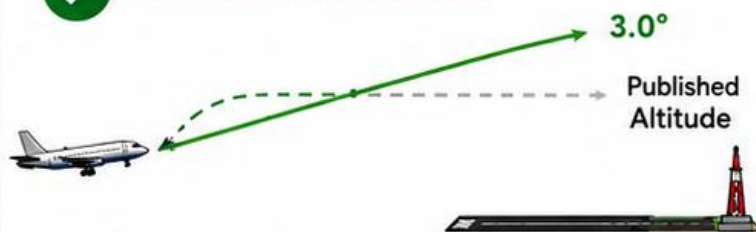


Misleading indications can lead to unstable approaches.

4. OPERATIONAL DEFENSE



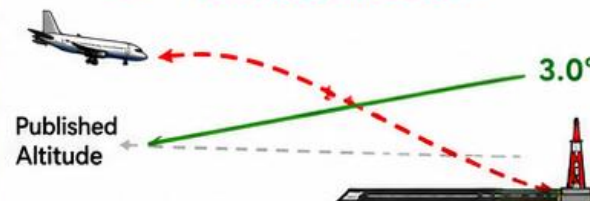
INTERCEPT FROM BELOW



Pilots intercept the glide path from below at a published altitude to ensure capture of the primary 3.0° beam and avoid false high-angle lobes.



HIGH INTERCEPT
NOT RECOMMENDED



Intercepting from above increases the risk of capturing a false 6° or 9° lobe.

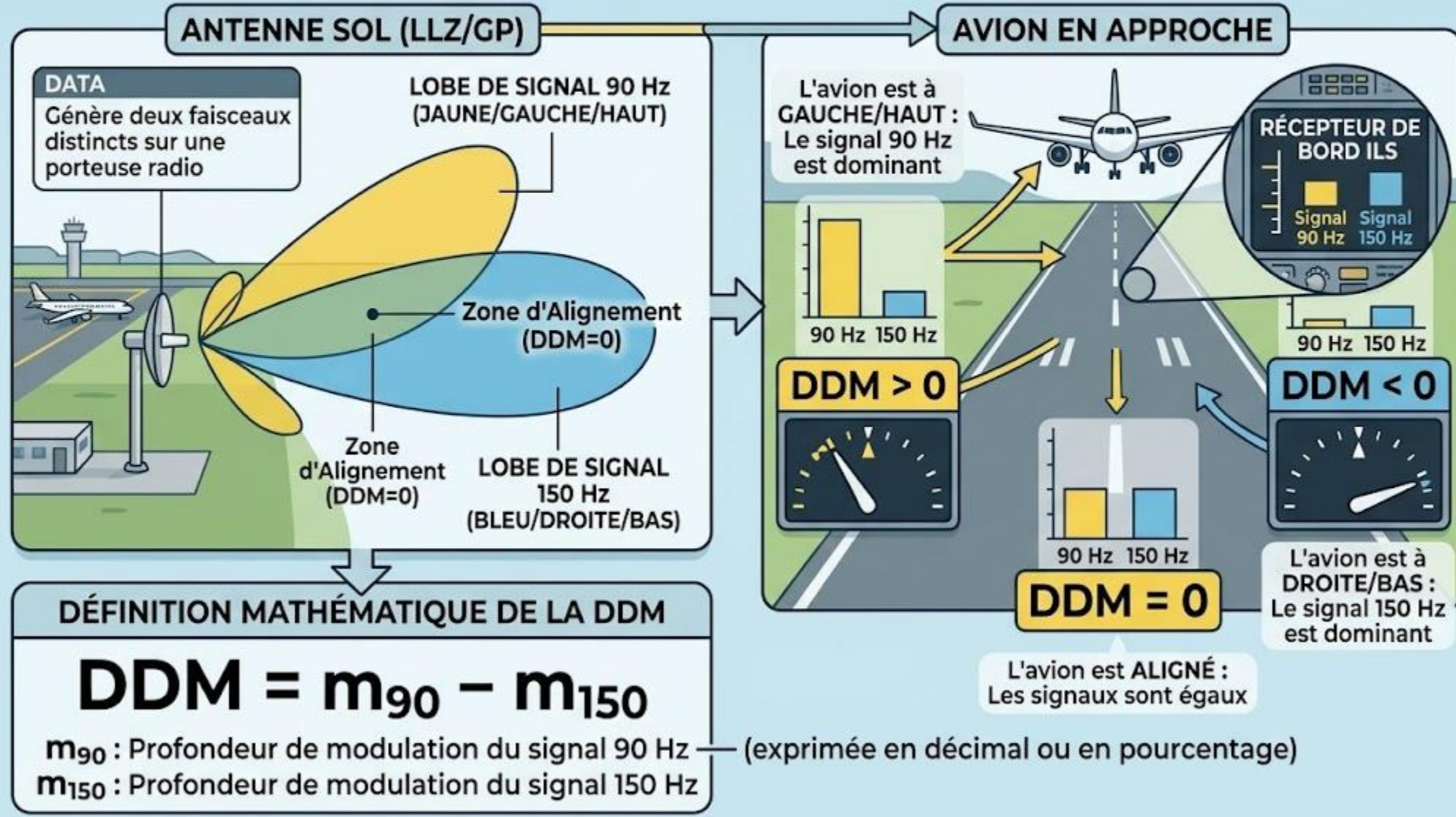


SUMMARY: False glide slopes are spurious high-angle lobes above the real 3.0° glide path. Recognizing their behavior and intercepting the glide path from below helps ensure capture of the true beam and avoid misleading indications.

3. Physical Principle: Modulation Depth Difference (DDM)

Concept Fondamental de la DDM (Différence de Profondeur de Modulation)

Chapitre 1.1 : Principe de Base et Définition



Chapter 1: Fundamental Concept of DDM

1.1 Core Principle and Definition

The **Difference in Depth of Modulation (DDM)** is the core physical parameter used by both the Localizer (LLZ) and Glide Path (GP) ground stations to transmit precise spatial positioning data to an approaching aircraft.

Instead of transmitting phase-shift data or raw distance measurements, the ILS relies on comparing the relative percentage depths of two distinct low-frequency audio tones modulated onto a single Radio Frequency (RF) carrier wave:

- **90 Hz Tone:** Represents upper (vertical) or left (horizontal) positioning.
- **150 Hz Tone:** Represents lower (vertical) or right (horizontal) positioning.

Mathematical Definition:

$$\text{DDM} = m_{90} - m_{150}$$

Where m_{90} is the depth of modulation of the 90 Hz signal (expressed as a decimal or percentage) and m_{150} is the depth of modulation of the 150 Hz signal.

CHAPTER 1: FUNDAMENTAL CONCEPT OF DDM

1.1 CORE PRINCIPLE AND DEFINITION

$$\text{DDM} = m_{90} - m_{150}$$

CORE PRINCIPLE AND DEFINITION

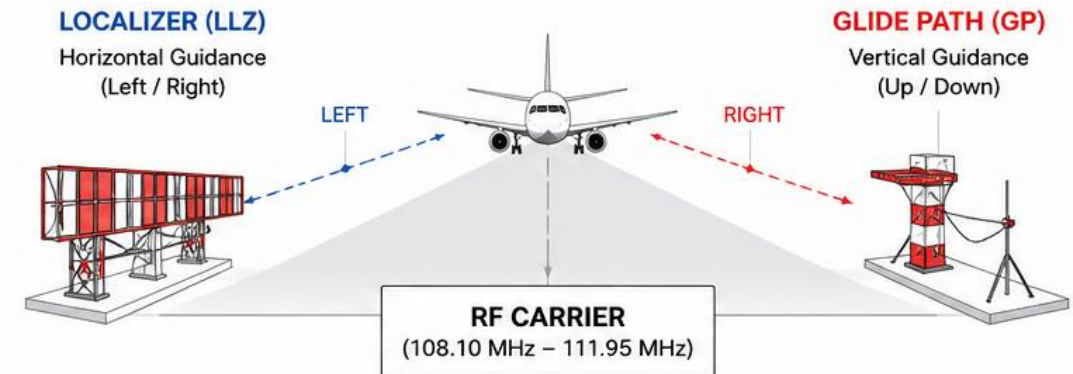
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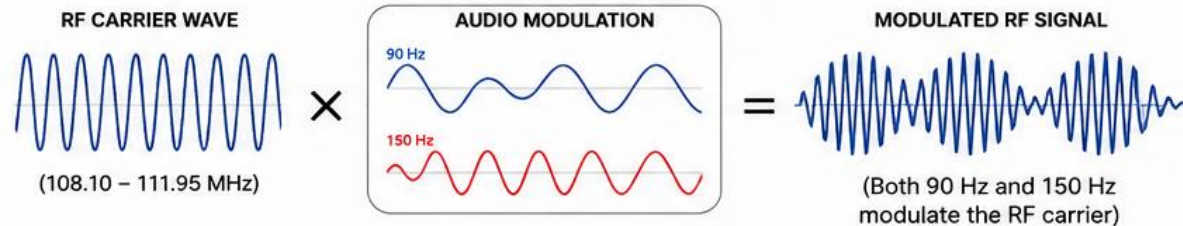
90 Hz Tone: Represents upper (vertical) or left (horizontal) positioning.

150 Hz Tone: Represents lower (vertical) or right (horizontal) positioning.

HOW ILS TRANSMITS POSITION INFORMATION



DDM: COMPARING THE DEPTHS OF TWO MODULATING TONES



MATHEMATICAL DEFINITION

$$\text{DDM} = m_{90} - m_{150}$$

Where:

m_{90} is the depth of modulation of the 90 Hz signal (expressed as a decimal or percentage)

m_{150} is the depth of modulation of the 150 Hz signal (expressed as a decimal or percentage)

MEANING OF DDM VALUES

✓ **ON COURSE (CENTERLINE)**

$$m_{90} = m_{150} \rightarrow \text{DDM} = 0$$



Aircraft is on the centerline (LLZ or GP path)

← **LEFT / ABOVE (DDM POSITIVE)**

$$m_{90} > m_{150} \rightarrow \text{DDM} > 0$$



Aircraft is left of centerline (LLZ) or above glide path (GP)

→ **RIGHT / BELOW (DDM NEGATIVE)**

$$m_{90} < m_{150} \rightarrow \text{DDM} < 0$$



Aircraft is right of centerline (LLZ) or below glide path (GP)

EXAMPLES

POSITION	m_{90} (DEPTH)	m_{150} (DEPTH)	DDM ($m_{90} - m_{150}$)	INTERPRETATION
Left / Above	0.70 (70%)	0.30 (30%)	+0.40	Left of course / Above glide path
On Course	0.50 (50%)	0.50 (50%)	0.00	On centerline / On glide path
Right / Below	0.30 (30%)	0.70 (70%)	-0.40	Right of course / Below glide path



Key Idea: DDM is not a raw measurement of distance or phase — it is a comparison of modulation depths between 90 Hz and 150 Hz signals that encodes the aircraft's relative position with respect to the ILS reference path.

Chapter 2: How DDM Translates to Spatial Coordinates

2.1 The Two Modulated Lobes

Ground antennas emit two distinct radiation patterns in space:

1. **Carrier plus Sidebands (CSB):** Contains the RF carrier frequency amplitude-modulated equally by both 90 Hz and 150 Hz tones.
2. **Sidebands Only (SBO):** Contains only the modulation sideband frequencies without the main RF carrier. The phasing of the SBO signal creates destructive interference on one side of the axis and constructive interference on the other.

2.2 Signal Conditions Across the Guidance Axis

- **On-Course / On-Glide-Slope Line ($DDM = 0$):**
At the exact extended runway centerline (or 3.0° glide angle), the aircraft receives equal amplitudes of both the 90 Hz and 150 Hz modulations ($m_{90} = m_{150} = 20\%$ for LLZ, or 40% for GP). The difference is exactly zero, causing the cockpit indicator needle to center perfectly.
- **Left / Above Deviation ($DDM > 0$):**
When the aircraft strays to the left of the runway centerline or above the glide slope, the receiver detects a higher percentage of the 90 Hz modulation ($m_{90} > m_{150}$). The resulting positive DDM value commands a rightward or downward correction.
- **Right / Below Deviation ($DDM < 0$):**
When the aircraft strays to the right of the centerline or below the glide slope, the 150 Hz modulation dominates ($m_{150} > m_{90}$). The resulting negative DDM value commands a leftward or upward correction.

CHAPTER 2: HOW DDM TRANSLATES TO SPATIAL COORDINATES

2.1 The Two Modulated Lobes • 2.2 Signal Conditions Across the Guidance Axis

DDM = m_{90} - m_{150}

1 THE TWO MODULATED LOBES

Carrier plus Sidebands (CSB)

Contains the RF carrier amplitude-modulated equally by both 90 Hz and 150 Hz tones.

RF CARRIER (108.10 – 111.95 MHz)

MODULATION TONES

90 Hz

150 Hz

Sidebands Only (SBO)

Contains only the modulation sidebands, without the main RF carrier.

Phasing of the SBO signal creates:

DESTRUCTIVE INTERFERENCE

CONSTRUCTIVE INTERFERENCE

Null on one side

Lobe on the other side

GUIDANCE AXIS

2 HOW POSITION IS DETERMINED ACROSS THE GUIDANCE AXIS

LEFT / ABOVE DEVIATION

DDM > 0

$m_{90} > m_{150}$

More 90 Hz modulation

ON-COURSE / ON-GLIDE-SLOPE LINE

DDM = 0

$m_{90} = m_{150}$

Equal 90 Hz and 150 Hz modulation

RIGHT / BELOW DEVIATION

DDM < 0

$m_{150} > m_{90}$

More 150 Hz modulation

GUIDANCE AXIS (CENTERLINE / ON-GLIDE-SLOPE)

CORRECTION COMMAND:

Rightward (LLZ) or Downward (GP)

CORRECTION COMMAND:

No correction (Stay centered)

CORRECTION COMMAND:

Leftward (LLZ) or Upward (GP)

3 COCKPIT INTERPRETATION

On-course / On-glide-slope (DDM = 0)

Indicator centered

Stay centered

Left / Above Deviation (DDM > 0)

Positive DDM

Commands rightward (LLZ) or downward (GP) correction

Right / Below Deviation (DDM < 0)

Negative DDM

Commands leftward (LLZ) or upward (GP) correction

MODULATION DEPTHS

m_{90} = depth of 90 Hz modulation (percentage)

m_{150} = depth of 150 Hz modulation (percentage)

Depth is measured relative to the RF carrier amplitude at the receiver.

5 SUMMARY

DDM translates radio modulation balance into spatial guidance.

Equal 90 Hz and 150 Hz modulation gives **DDM = 0** on the reference path.

More 90 Hz yields a **positive DDM** (left of localizer or above glide path).

More 150 Hz yields a **negative DDM** (right of localizer or below glide path).

Chapter 3: DDM Value Standards and Sensitivity

3.1 Standardized DDM Values

The International Civil Aviation Organization (ICAO) standardizes the relationship between physical deviation and DDM output values to ensure consistent cockpit needle sensitivity across all ILS installations worldwide.

System Component	Full Scale Deflection (Fly-Left / Fly-Up)	Centerline / On-Path	Full Scale De (Fly-Right / F
Localizer (LLZ)	DDM = +0.155	DDM = 0.000	DDM = -
Glide Path (GP)	DDM = +0.175	DDM = 0.000	DDM = -

...

3.2 Linear Sector

Within the core sector around the course line, the relationship between angular displacement (in degrees) and DDM is strictly linear:

- **Course Line Sensitivity:** The receiver converts small changes in DDM into microamperes (μA) of current fed to the indicator or flight guidance system.
- **Full-Scale Deflection Current:** Typically, a current of $150\ \mu\text{A}$ represents full-scale deflection on a standard analog Course Deviation Indicator (CDI).

CHAPTER 3: DDM VALUE STANDARDS AND SENSITIVITY

3.1 Standardized DDM Values • 3.2 Linear Sector

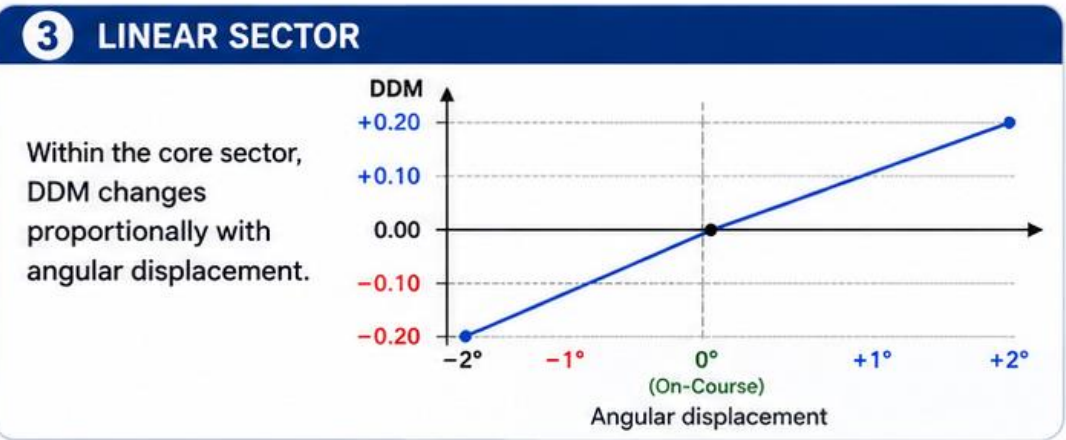
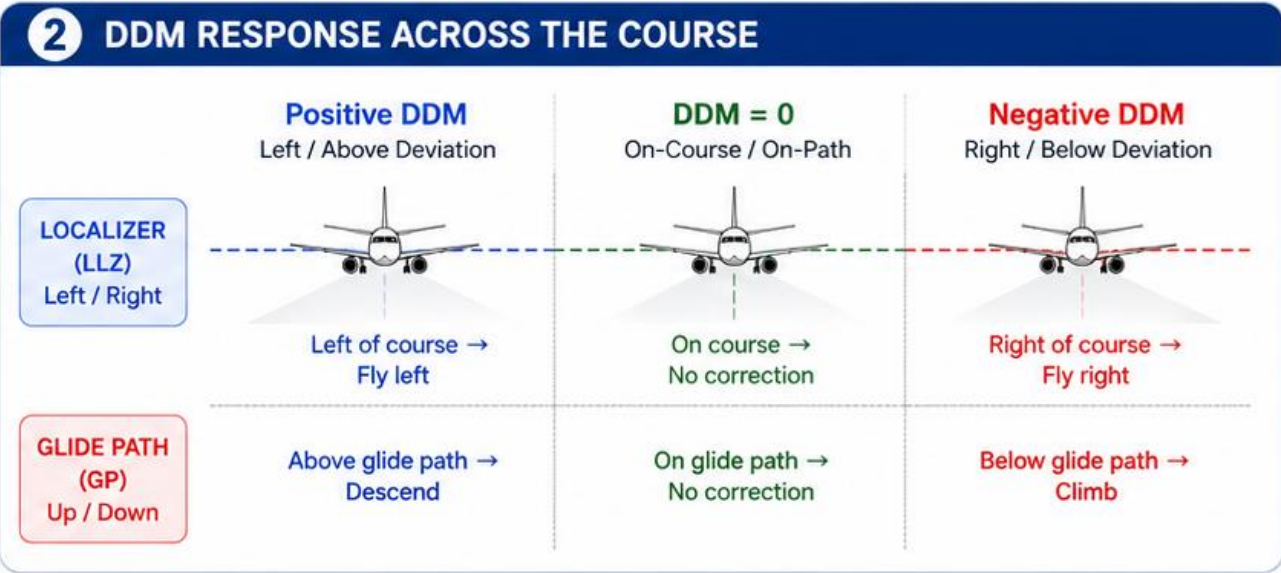
DDM = m_{90} - m_{150}

1 STANDARDIZED DDM VALUES

System Component	Full Scale Deflection (Fly-Left / Fly-Up)	Centerline On-Path	Full Scale Deflection (Fly-Right / Fly-Down)
 Localizer (LLZ)	+0.155	0.000	-0.155
 Glide Path (GP)	+0.175	0.000	-0.175

i

ICAO standardizes DDM response so cockpit sensitivity remains consistent across ILS installations worldwide.



4 COCKPIT SENSITIVITY

**Course Line Sensitivity**
Small changes in DDM are converted into microamperes (μA) of current fed to the indicator or flight guidance system.

**Full-Scale Deflection Current**
Typically, a current of 150 μA corresponds to full-scale deflection on a standard analog CDI.



0.000 DDM (On-Course)

+ Full Scale (DDM Positive)

- Full Scale (DDM Negative)

5 QUICK REFERENCE SUMMARY

 LLZ FULL SCALE ± 0.155 DDM	 GP FULL SCALE ± 0.175 DDM	 ON-COURSE / ON-PATH 0.000 DDM	 FULL-SCALE INDICATOR CURRENT $\approx 150 \mu A$	 LINEAR SECTOR Proportional response
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Chapter 4: Airborne Signal Processing & Calibration

4.1 On-Board Processing

1. **RF Demodulation:** The aircraft ILS receiver receives the combined VHF/UHF signal and strips away the main radio carrier wave.
2. **Bandpass Filtering:** The signal is split into two parallel channels via active audio filters: one tuned strictly to **90 Hz** and the other to **150 Hz**.
3. **Rectification & Comparison:** Both signal levels are rectified into Direct Current (DC) voltages. A differential amplifier subtracts the 150 Hz DC level from the 90 Hz DC level.
4. **Indicator Driving:** The output DC current directly drives the CDI needles or modern Electronic Flight Instrument System (EFIS) crosshair displays.

4.2 System Monitoring and Safety Bounds

Ground-based monitoring units continuously measure the local field DDM values. If environmental factors (e.g., snow build-up, metallic reflections from ground vehicles) cause the DDM at the reference points to shift beyond tight limits (typically a shift of ± 0.015 DDM on localizer), the ground station automatically switches to a standby transmitter or shuts down to prevent corrupt guidance.

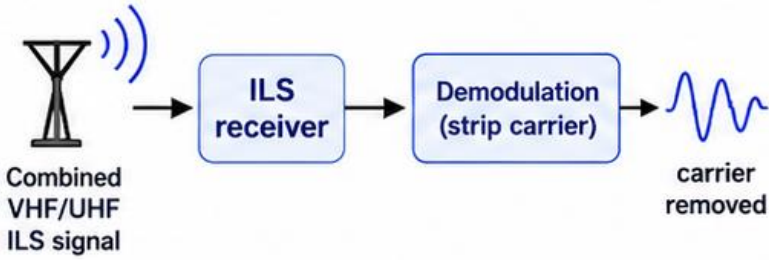
Chapter 4: Airborne Signal Processing & Calibration

4.1 On-Board Processing • 4.2 System Monitoring and Safety Bounds

DDM = m_{90} - m_{150}

1

RF DEMODULATION



Combined VHF/UHF ILS signal

ILS receiver

Demodulation (strip carrier)

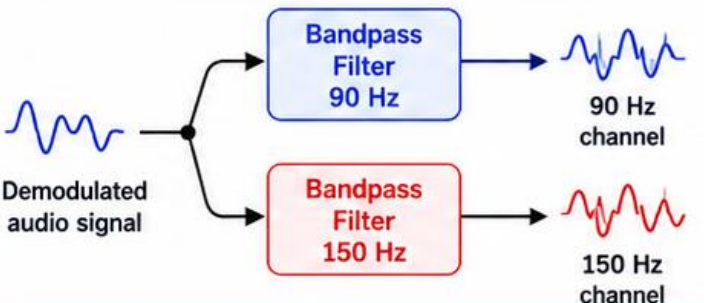
carrier removed

i

The airborne ILS receiver receives the combined signal and removes the main radio carrier wave.

2

BANDPASS FILTERING



Demodulated audio signal

Bandpass Filter 90 Hz

90 Hz channel

Bandpass Filter 150 Hz

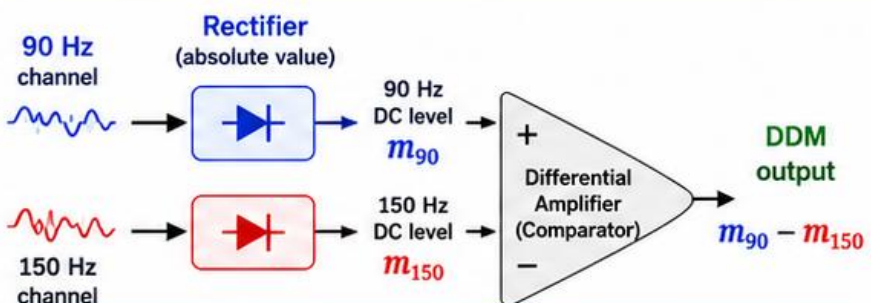
150 Hz channel

i

Active filters separate the signal into two channels tuned to 90 Hz and 150 Hz.

3

RECTIFICATION & COMPARISON



90 Hz channel

Rectifier (absolute value)

90 Hz DC level m_{90}

150 Hz channel

150 Hz DC level m_{150}

Differential Amplifier (Comparator)

DDM output $m_{90} - m_{150}$

i

Both channels are rectified into DC voltages; a differential amplifier compares them to produce DDM.

4

INDICATOR DRIVING



DDM output (DC current)

$m_{90} - m_{150}$

Classic CDI

Modern EFIS / PFD

CDI / EFIS display

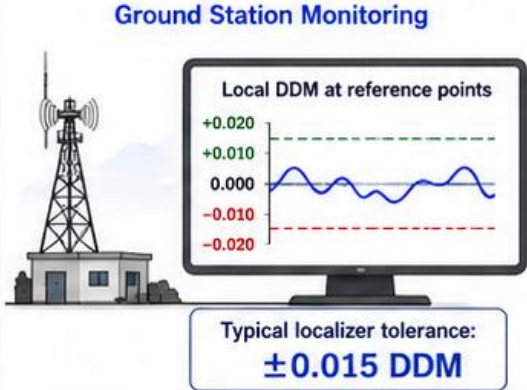
CDI / EFIS display

i

The DC output drives the course/glide indicators shown to the pilots.

5

SYSTEM MONITORING & SAFETY BOUNDS



Ground Station Monitoring

Local DDM at reference points

Typical localizer tolerance: ± 0.015 DDM

Environmental Factors That Can Disturb DDM

 Snow build-up on antennas

 Ground vehicles causing metallic reflections

 Terrain or other reflective interference

Within limits ($\leq \pm 0.015$ DDM)

 Normal transmission

Out of limits ($> \pm 0.015$ DDM)

 Switch to standby transmitter or shut down

i

If field DDM shifts beyond tight limits, the station protects the approach by changing to standby or shutting down.



Airborne processing convertt the received ILS modulation into cockpit guidance, while ground monitoring continuously checks DDM integrity to prevent misleading signals.

4. Core Ground and Airborne Components of an ILS

Core Ground and Airborne Components of an ILS

An Instrument Landing System (ILS) is not a single piece of equipment. It is a complete precision-approach architecture built around ground-based radio transmitters, airborne receivers and cockpit displays, supplemented by distance information, visual aids, monitoring systems and, on suitably equipped aircraft, automatic-flight systems.

Its fundamental purpose is to provide the aircraft with two independent guidance references during the final approach:

- **Lateral guidance** — **Localizer (LOC)**: keeps the aircraft aligned with the runway centerline.
- **Vertical guidance** — **Glide Slope (G/S)**: keeps the aircraft on the required descent path toward the runway.

LOCALIZER (Lateral Guidance)

Runway Centerline

GLIDE SLOPE (Vertical Guidance)

3° Descent Path

ILS INDICATOR



APPROACH LIGHTS

ALSF-2



OUTER MARKER OM
DME 5.2 NM

MIDDLE MARKER MM
DME 1.2 NM

INNER MARKER IM
DME 0.3 NM

Beacon

Distance (DME)

TOUCHDOWN ZONE

RUNWAY EDGE LIGHTS

CENTERLINE LIGHTS

TDZ LIGHTS

36



Glideslope Antenna



ILS Critical Area



ILS ILS



AGENDA CORE GROUND - 1

- 1. Overall ILS Architecture
- 2. The Localizer — Lateral Guidance
- 3. Localizer Indication in the Cockpit
- 4. The Glide Slope — Vertical Guidance
- 5. Glide-Slope Signal Principle
- 6. The ILS Is Therefore a 3-D Guidance System
- 7. DME — Distance Information
- 8. Marker Beacons — The Historical Distance Component
- 9. Ground Monitoring Equipment
- 10. Critical and Sensitive Areas

AGENDA CORE GROUND - 2

- 11. Airborne ILS Antennas
- 12. Airborne Navigation Receivers
- 13. Primary Flight Display — The Pilot's Main ILS Interface
- 14. Flight Mode Annunciator — FMA
- 15. Flight Director
- 16. Autopilot and ILS Coupling
- 17. Dual-Channel and Autoland Capability
- 18. Approach Lighting — Transition from Instruments to Visual Flight
- 19. The Complete ILS Chain
- 20. The Key Concept

1. Overall ILS Architecture

An operational ILS can be divided into three major groups:

Ground segment

LOCALIZER + GLIDE SLOPE + DME/MARKERS + MONITORING

Airborne segment

ILS RECEIVERS + ANTENNAS + AVIONICS + PFD/ND + FLIGHT DIRECTOR/AUTOPILOT

Visual segment

APPROACH LIGHTS + RUNWAY LIGHTING + VISUAL REFERENCES

The ground installation generates the guidance signals. The aircraft receives and processes them. The flight instruments then transform the radio information into lateral and vertical deviations that can be interpreted by the pilots, Flight Director and automatic-flight system.

Overall ILS Architecture

Three segments working together during an ILS approach



The ground installation transmits ILS guidance, the aircraft converts it into lateral and vertical deviations, and the visual environment supports final landing.

2. The Localizer — Lateral Guidance

The **Localizer**, normally abbreviated **LOC**, provides the horizontal or lateral component of the ILS.

Its antenna array is normally installed beyond the departure end of the runway, approximately aligned with the extended runway centerline.

The objective is straightforward:

Is the aircraft LEFT or RIGHT of the desired final approach path?

The LOC operates in the **108.10–111.95 MHz VHF band**, using specific channel assignments reserved for ILS localizer operation.

How the Localizer works

The transmitted signal contains two principal amplitude-modulated components:

90 Hz and 150 Hz.

The airborne receiver compares their modulation depths.

Conceptually:

90 Hz predominance ← CENTERLINE → 150 Hz predominance

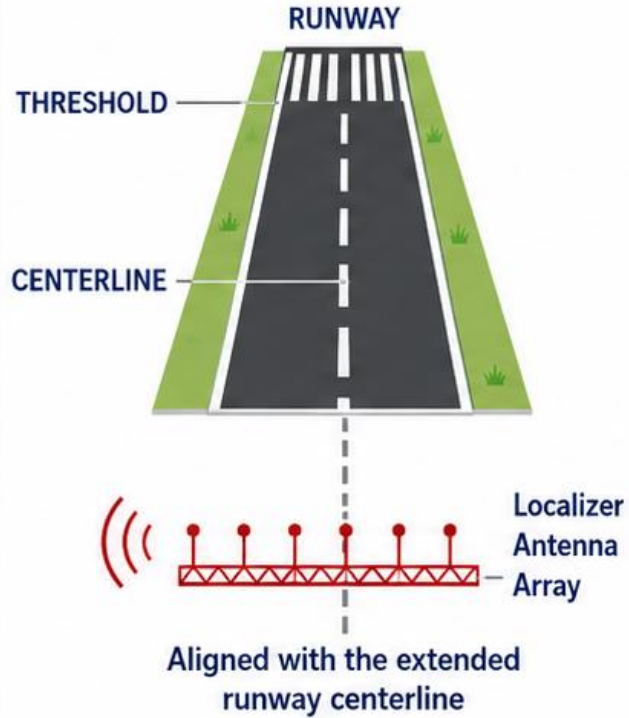
On the centerline, the modulation components are balanced.

The receiver calculates the **Difference in Depth of Modulation (DDM)**. The sign and magnitude of that difference provide lateral displacement information.

The Localizer — Lateral Guidance

How the LOC provides left/right guidance during an ILS approach

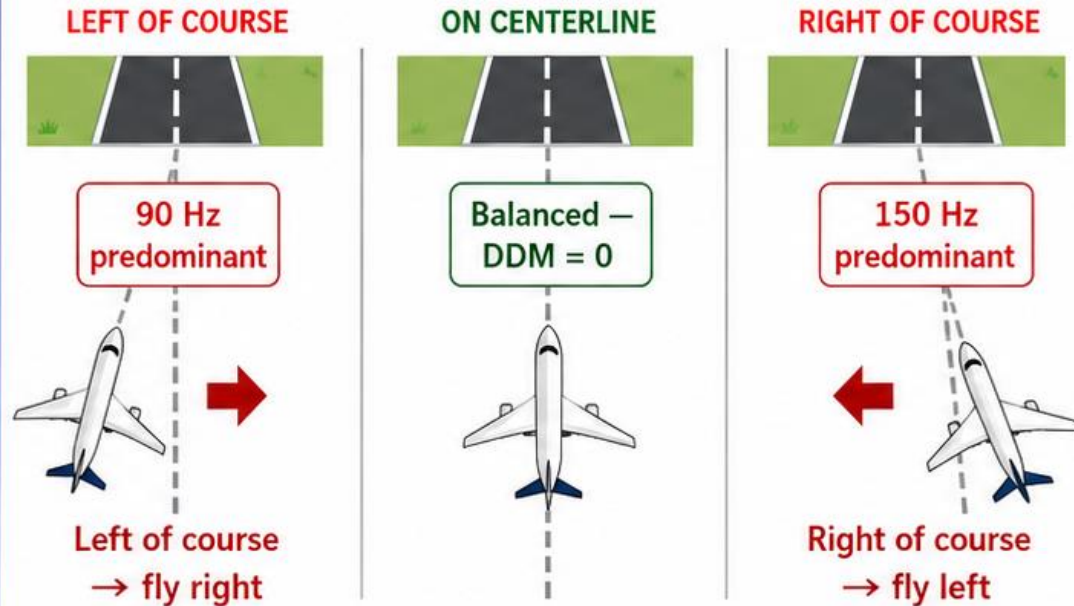
1 Location and Role



Provides the lateral (horizontal) component of the ILS.

2 How the Localizer Works

The receiver compares two modulation components:
90 Hz and 150 Hz.



90 Hz predominance ← CENTERLINE → 150 Hz predominance

3 Key Technical Points



VHF band:
108.10–111.95 MHz



Two AM tones:
90 Hz and 150 Hz



Receiver compares
modulation depths



DDM indicates
lateral displacement

3. Localizer Indication in the Cockpit

The processed LOC signal is displayed on the pilot's flight instruments.

On a modern Boeing 737, the pilot primarily monitors it on the **Primary Flight Display (PFD)**.

The lateral deviation indication shows whether the aircraft is displaced from the localizer centerline.

During interception, the indication progressively moves toward the center.

When centered:

LOC deviation $\approx 0 \rightarrow$ aircraft approximately aligned with the localizer course.

But the pilot must not simply watch the deviation symbol.

The complete monitoring loop is:

LOC signal $\rightarrow$ receiver $\rightarrow$ avionics $\rightarrow$ PFD $\rightarrow$ Flight Director/Autopilot $\rightarrow$ aircraft response $\rightarrow$ LOC signal again

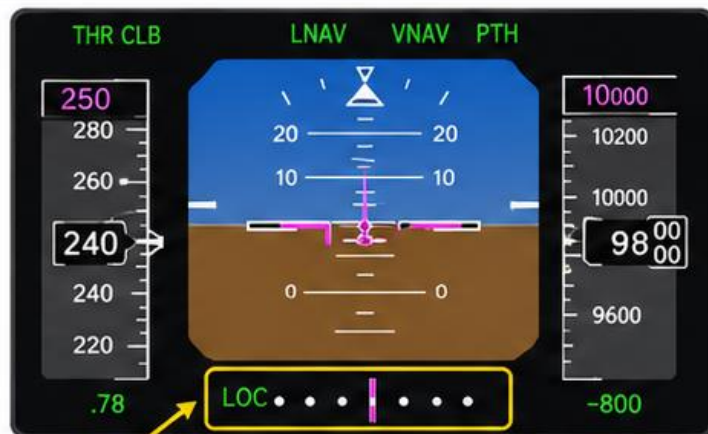
It is therefore a continuously closed guidance loop.



3. Localizer Indication in the Cockpit

How the processed LOC signal is displayed and monitored on the Boeing 737 Primary Flight Display (PFD)

1 Where the pilot monitors it

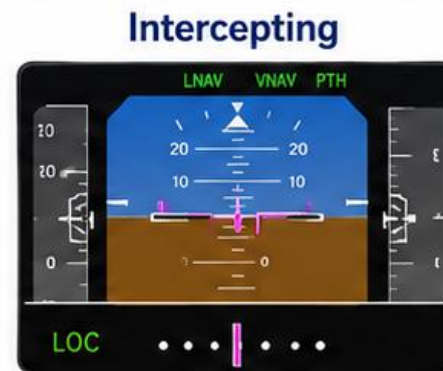


On a modern Boeing 737, the pilot primarily monitors the Localizer on the PFD.

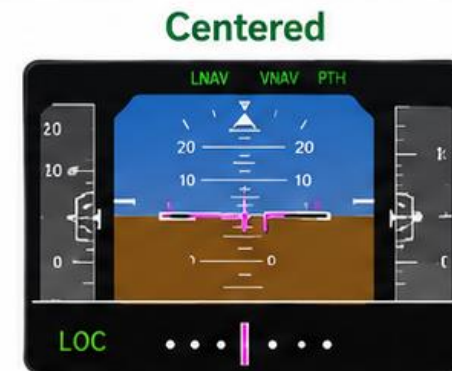
2 What the LOC indication means



Aircraft displaced from centerline

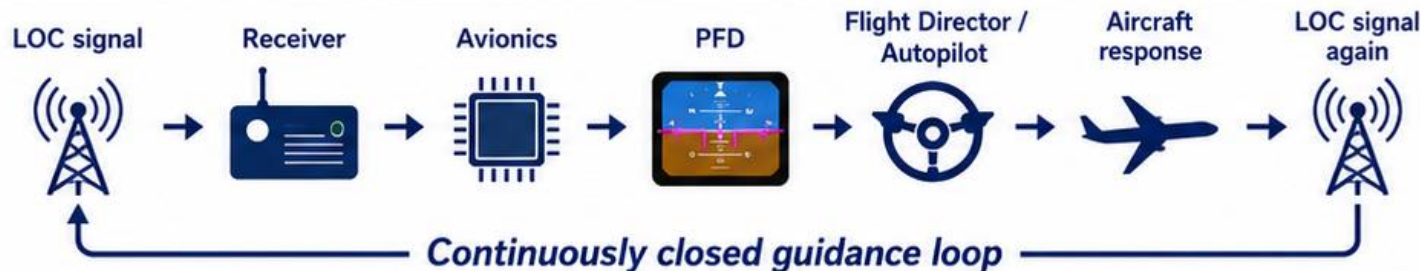


During interception, the indication progressively moves toward the center



✓ LOC deviation $\approx 0 \rightarrow$ aircraft approximately aligned with the localizer course

3 Closed guidance loop



4 Pilot monitoring concept



The pilot monitors lateral deviation on the PFD.



The indication shows whether the aircraft is left or right of the localizer centerline.



The pilot must not watch only the deviation symbol — the full guidance loop matters.



The Localizer indication on the PFD is part of a *continuous guidance loop* that helps the crew keep the aircraft aligned with the runway centerline.



4. The Glide Slope — Vertical Guidance

The second fundamental component is the **Glide Slope**, commonly abbreviated **G/S** or sometimes **GS**.

Its purpose is to answer another question:

Is the aircraft ABOVE or BELOW the required descent path?

The glide-slope antenna installation is located alongside the runway, near the touchdown end of the approach environment.

Unlike the Localizer, which establishes a vertical plane aligned with the runway, the glide slope creates an inclined guidance surface.

For a conventional installation, the nominal descent angle is commonly around:

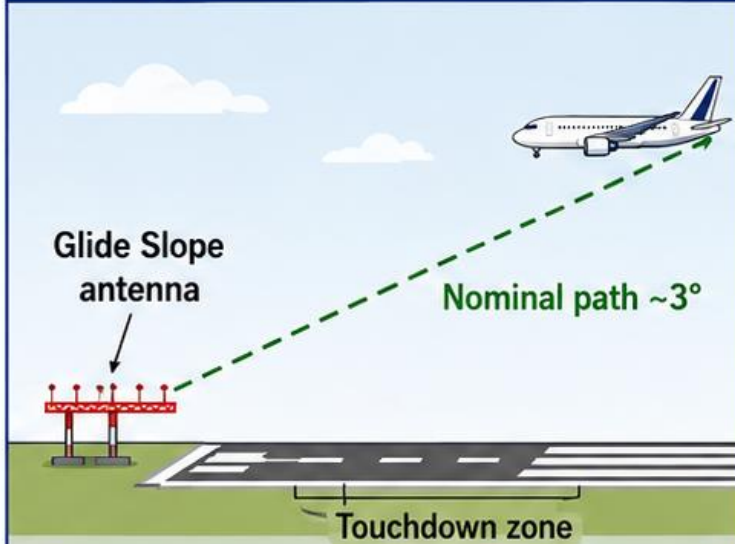
3°

but the published procedure for the specific runway is authoritative.

4. The Glide Slope — Vertical Guidance

How the G/S provides above/below guidance during an ILS approach

1 Location and Role

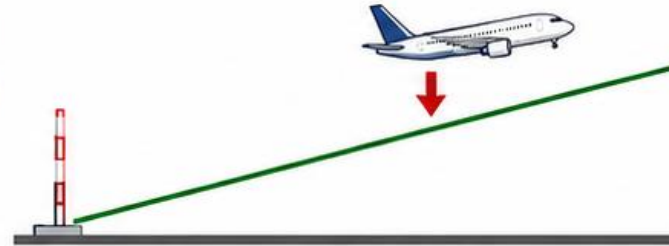


i Provides the vertical component of the ILS.

? Answers the question: Is the aircraft **ABOVE** or **BELOW** the required descent path?

2 How the Glide Slope Works

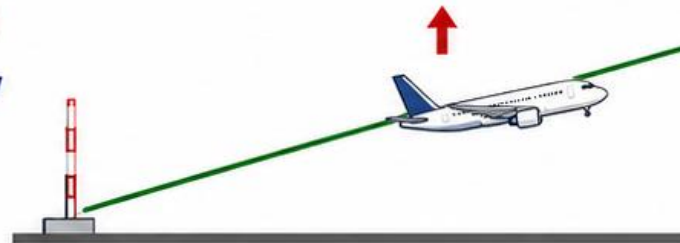
ABOVE PATH
Aircraft above glide slope
→ descend



ON GLIDE SLOPE
Centered / on path



BELOW PATH
Aircraft below glide slope
→ climb



3 Key Technical Points



Purpose:
vertical guidance



Antenna location:
alongside runway
near touchdown end



Guidance surface:
inclined plane



Typical nominal descent angle: 3°



The published procedure for the specific runway is authoritative.



The Glide Slope creates an inclined vertical guidance path, typically about 3° , helping the aircraft stay on the correct descent profile during final approach.

5. Glide-Slope Signal Principle

The G/S uses the same fundamental 90 Hz / 150 Hz comparison principle, although it operates in a different radio-frequency band: approximately 329.15–335.00 MHz UHF.

The localizer and glide-slope frequencies are paired by standardized channelization. Selecting the published ILS localizer frequency therefore causes the appropriate airborne equipment to use the associated glide-slope channel.

The receiver determines vertical displacement from the balance between the modulation components.

Conceptually:

Above glide path

↑

G/S CENTER

↓

Below glide path

When the aircraft reaches the correct geometric descent path, the glide-slope deviation indication becomes centered.

The aircraft is then simultaneously trying to satisfy two conditions:

LOC centered + G/S centered

5. Glide-Slope Signal Principle

How the G/S signal provides vertical guidance during an ILS approach

1 Core Principle



Same comparison principle as the localizer:



UHF Operating Band
329.15–335.00 MHz



Localizer and glide-slope frequencies are paired by standardized channelization.



Selecting the published ILS localizer frequency automatically pairs the associated glide-slope channel.

2 Vertical Guidance Logic

ABOVE GLIDE PATH

90 Hz predominant
→ descend



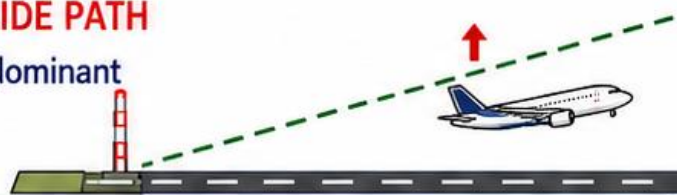
ON GLIDE PATH

90 Hz = 150 Hz
→ centered



BELOW GLIDE PATH

150 Hz predominant
→ climb



G/S antenna
(near runway
threshold)

Nominal glide path
(typically ~3°)

Runway

3 What the Receiver/Display Does



The receiver determines vertical displacement from the balance between the **90 Hz** and **150 Hz** modulation components.



When the aircraft reaches the correct geometric descent path, the glide-slope deviation indication becomes centered.



Objective during approach:

LOC centered + G/S centered



The glide slope uses the 90 Hz / 150 Hz comparison principle to show whether the aircraft is above, on, or below the correct descent path.

6. The ILS Is Therefore a 3-D Guidance System

One useful way of visualizing the architecture is to imagine two electromagnetic surfaces.

The **Localizer** creates a vertical guidance plane:

LEFT | RUNWAY CENTERLINE | RIGHT

The **Glide Slope** creates an inclined guidance plane:

HIGH / CORRECT DESCENT PATH / LOW

Their intersection produces the desired approach trajectory:

FINAL APPROACH COURSE + DESCENT PATH = ILS APPROACH PATH

The aircraft continually measures its displacement from both references.

This is why an ILS can provide extremely precise guidance without calculating the aircraft's geographical position in the way GNSS does.

It is fundamentally a **relative radio-navigation system**.

6. THE ILS IS THEREFORE A 3-D GUIDANCE SYSTEM



The ILS guides the aircraft in 3 dimensions by using two electromagnetic reference surfaces.



LOCALIZER (LATERAL)

Creates a vertical guidance plane aligned with the runway centerline.

LEFT | RUNWAY CENTERLINE | RIGHT



GLIDE SLOPE (VERTICAL)

Creates an inclined guidance plane (typically $\sim 3^\circ$) for the descent path.

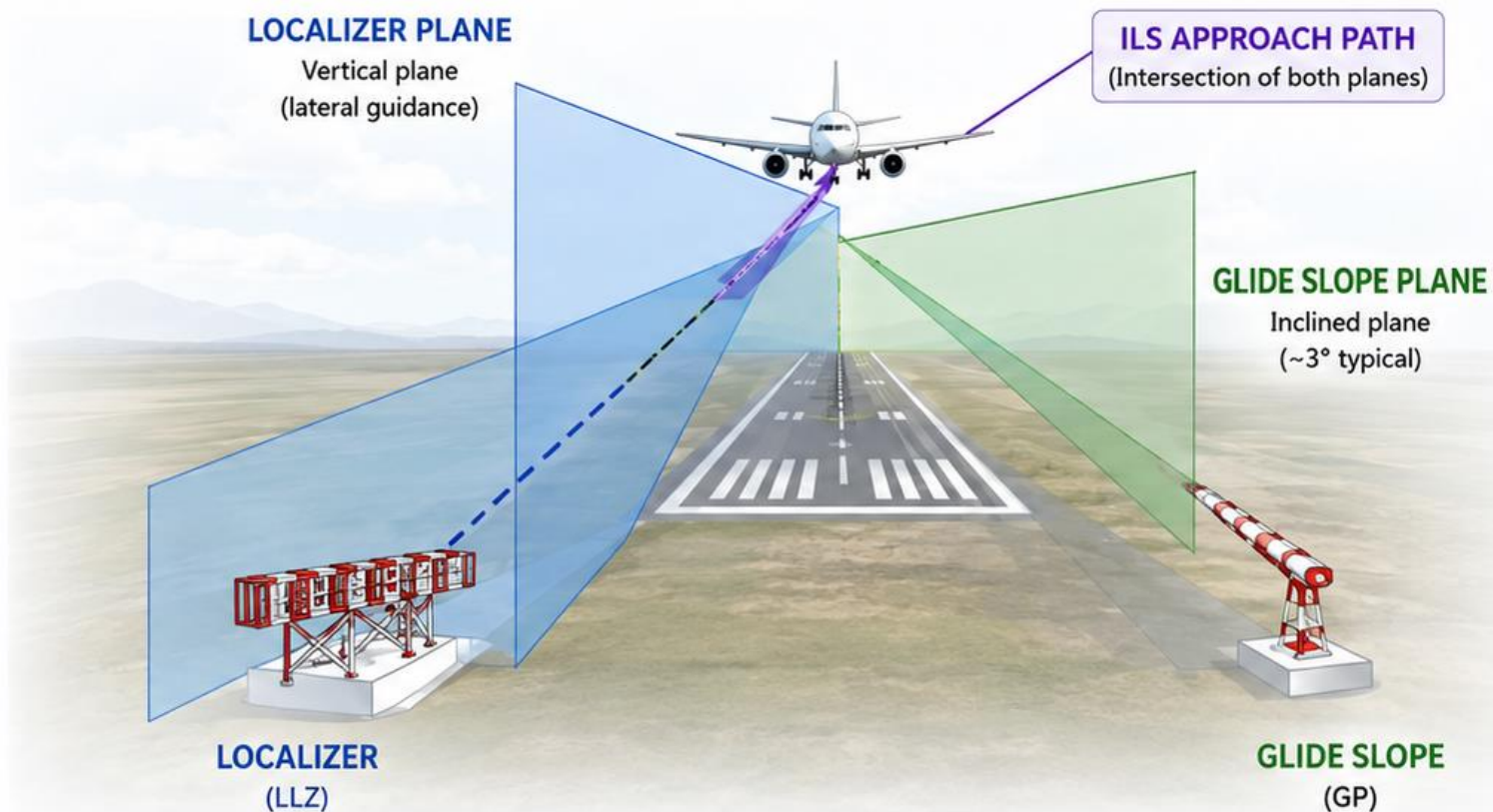
HIGH / CORRECT DESCENT PATH / LOW



INTERSECTION

The intersection of these two planes produces the desired approach trajectory.

FINAL APPROACH COURSE + DESCENT PATH
= ILS APPROACH PATH



Aircraft continuously measures its displacement from both references.



This is why the ILS can provide extremely precise guidance...



...without calculating the aircraft's geographical position as GNSS does.

It is a **relative radio-navigation system**.

7. DME — Distance Information

Many modern ILS installations are associated with Distance Measuring Equipment (DME).

DME provides another essential dimension:

distance to a defined ground reference.

This allows the crew and avionics to correlate:

Lateral position + Vertical position + Distance

For example, during a nominal 3° approach, altitude and distance should maintain a broadly predictable relationship.

As a useful mental approximation:

3° ≈ 300 ft per NM

Therefore:

10 NM → ~3,000 ft

5 NM → ~1,500 ft

This is only a mental cross-check, not a substitute for published procedure altitudes.

DME is particularly valuable for identifying fixes, checking descent progression and improving situational awareness.



7. DME — DISTANCE INFORMATION



How Distance Measuring Equipment adds distance awareness to an ILS approach

1

WHAT DME ADDS

DME provides distance to a defined ground reference.



LATERAL POSITION + VERTICAL POSITION + DISTANCE

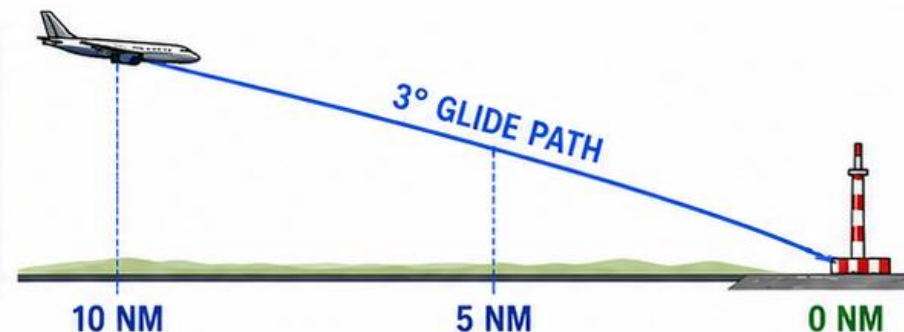
DME adds the distance dimension to ILS guidance.

2

USING DME ON A 3° APPROACH

RULE OF THUMB

3° ≈
300 ft
per NM



10 NM → ~3,000 ft

5 NM → ~1,500 ft

3

WHY PILOTS USE IT



Identify fixes



Check descent
progression



Improve situational
awareness

4

IMPORTANT NOTE



This is a mental cross-check,
not a substitute for published
procedure altitudes.



With DME, the crew can correlate lateral guidance, vertical guidance, and distance for a more complete approach picture.

8. Marker Beacons — The Historical Distance Component

Traditional ILS installations could also use **marker beacons**.

The classic system included:

Outer Marker (OM) — normally located several miles from the threshold.

Middle Marker (MM) — closer to the runway.

Inner Marker (IM) — associated historically with certain low-visibility operations.

They transmitted vertically directed 75 MHz signals, producing characteristic cockpit indications as the aircraft passed overhead.

Modern aviation has progressively replaced many marker-beacon functions with:

DME, GNSS-defined fixes and other navigation references.

Nevertheless, marker beacons remain important when explaining the historical and technical architecture of ILS.

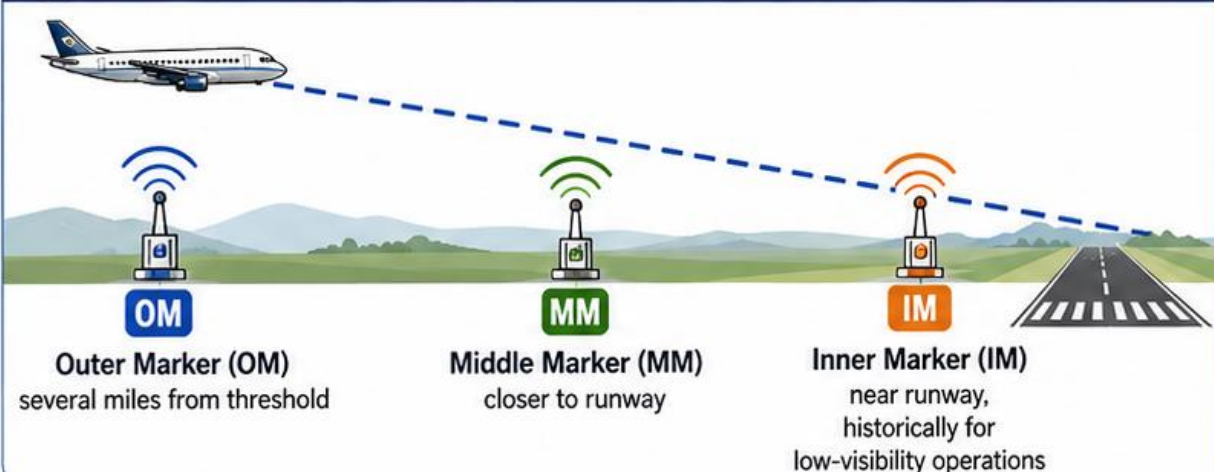


8. Marker Beacons — The Historical Distance Component

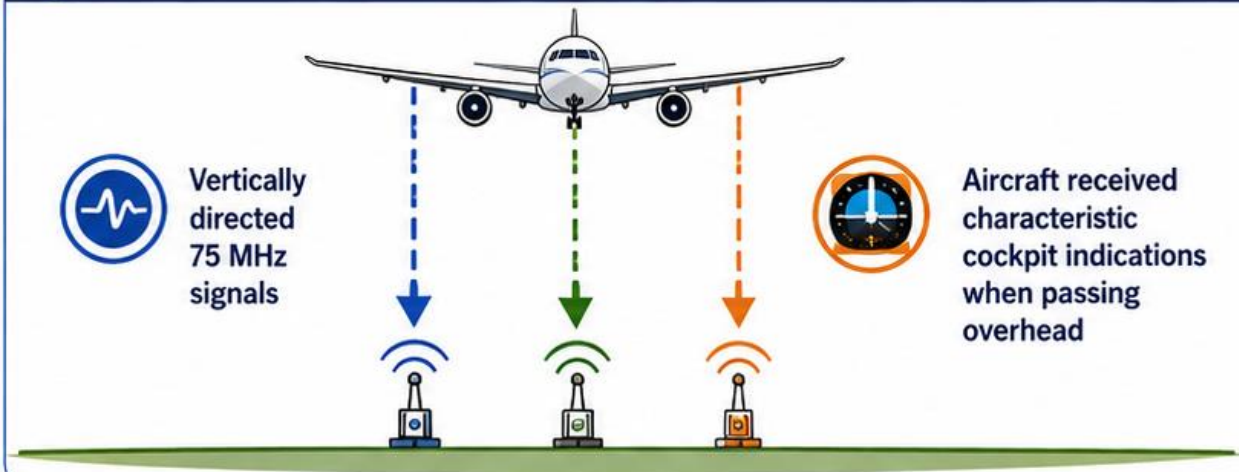
How traditional ILS installations used marker beacons before DME and GNSS became common



1 The Classic Marker Beacon System



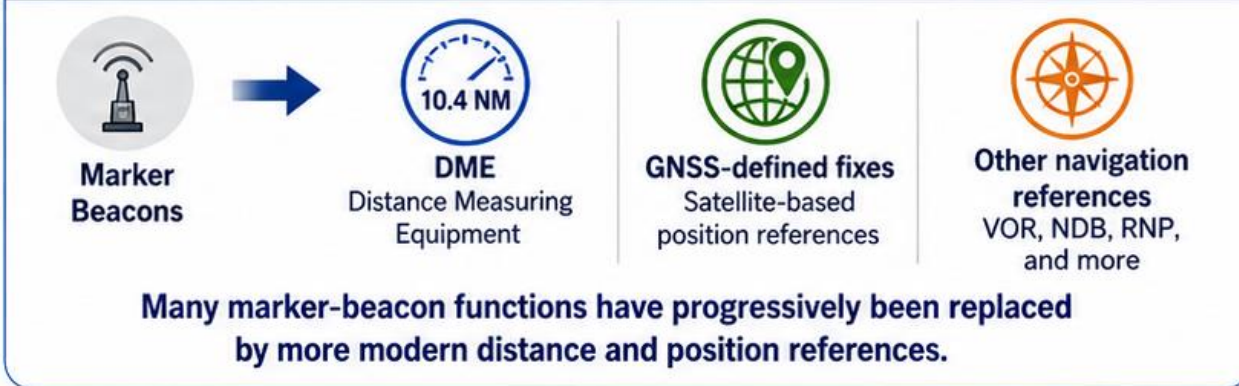
2 What They Did



3 Marker Sequence



4 Modern Replacements



Marker beacons were the historical distance component of some ILS systems.

Today, they are largely replaced by DME and GNSS, but remain important for understanding classic ILS architecture.



9. Ground Monitoring Equipment

One of the less visible but most important parts of an ILS installation is its **monitoring system**.

A precision-approach system cannot simply transmit continuously and assume that its signals remain correct.

The installation monitors parameters such as:

- guidance integrity;
- signal characteristics;
- transmitter operation;
- excessive displacement of the guidance reference;
- equipment failures.

If critical parameters exceed permitted tolerances, the system is designed to trigger appropriate protective action, which can include removing an unreliable navigation signal from service.

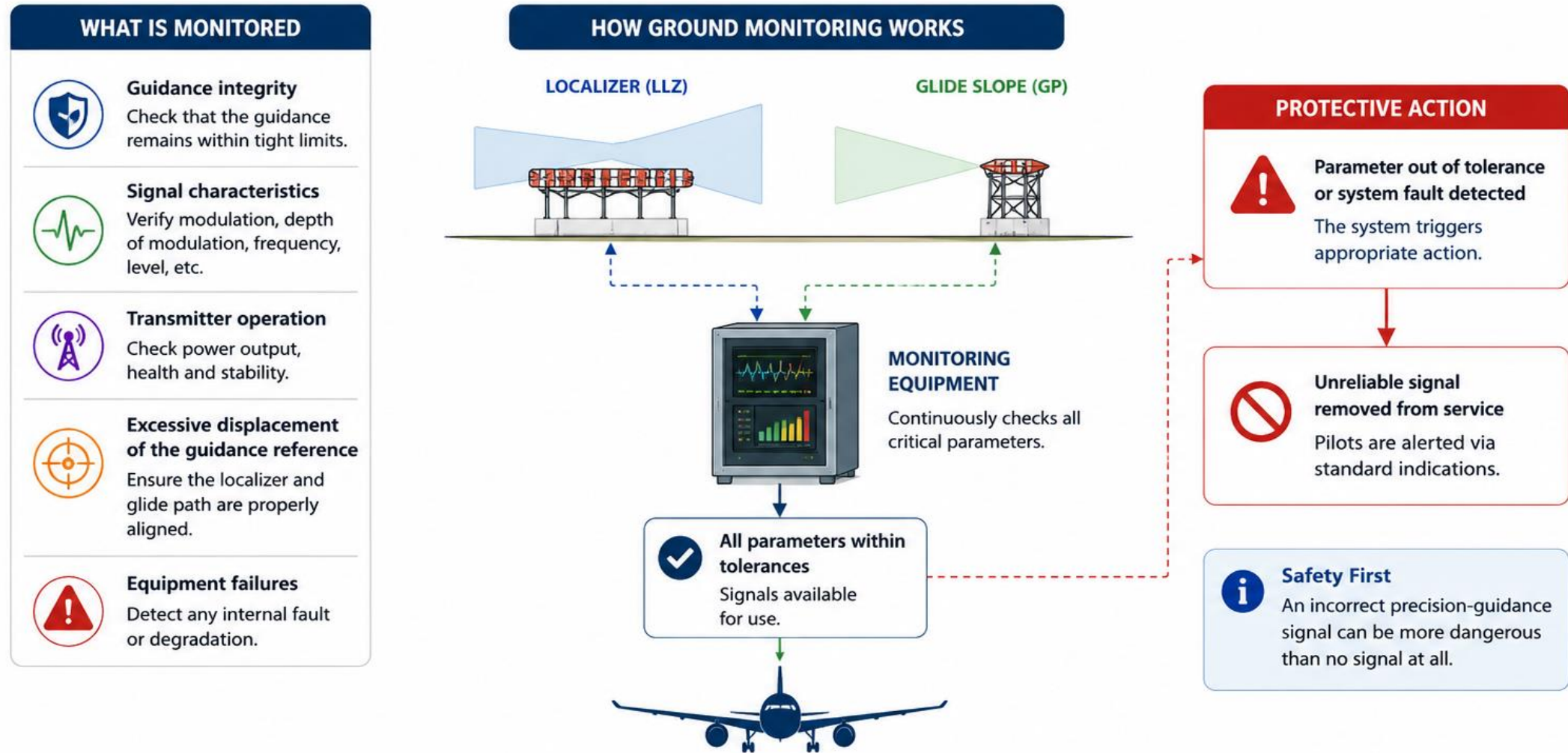
This concept is fundamental:

An incorrect precision-guidance signal can be more dangerous than no signal at all.

Therefore ILS engineering is not only about accuracy, but also about **integrity, continuity and monitoring**.

9. GROUND MONITORING EQUIPMENT

Ensuring ILS signals are accurate, reliable and safe.



ILS engineering is not only about accuracy, but also about **integrity, continuity and monitoring**.



Protects pilots and passengers



Ensures system reliability



Supports safe approach operations

10. Critical and Sensitive Areas

The electromagnetic environment around ILS antennas must also be protected.

Aircraft, airport vehicles, buildings and other large objects can reflect or disturb radio signals.

Airports consequently establish **ILS critical and sensitive areas**, particularly important during low-visibility operations.

Ground traffic may therefore be prevented from entering certain areas while an aircraft is conducting a protected ILS approach.

This explains something pilots sometimes observe during CAT II/III operations: aircraft or vehicles may be held significantly farther away from the runway than during normal weather conditions.

The objective is to preserve the integrity of the electromagnetic guidance environment.

10. CRITICAL AND SENSITIVE AREAS



The electromagnetic environment around ILS antennas must be protected to ensure accurate and reliable guidance.

WHY IT MATTERS



Radio signal reflections or disturbances

Aircraft, vehicles, buildings and other large objects can reflect or disturb ILS signals.



Protected airspace

Airports establish ILS critical and sensitive areas, especially important during low-visibility operations.



Restricted ground traffic

Ground vehicles may be prevented from entering certain areas during a protected ILS approach.



Pilot observation

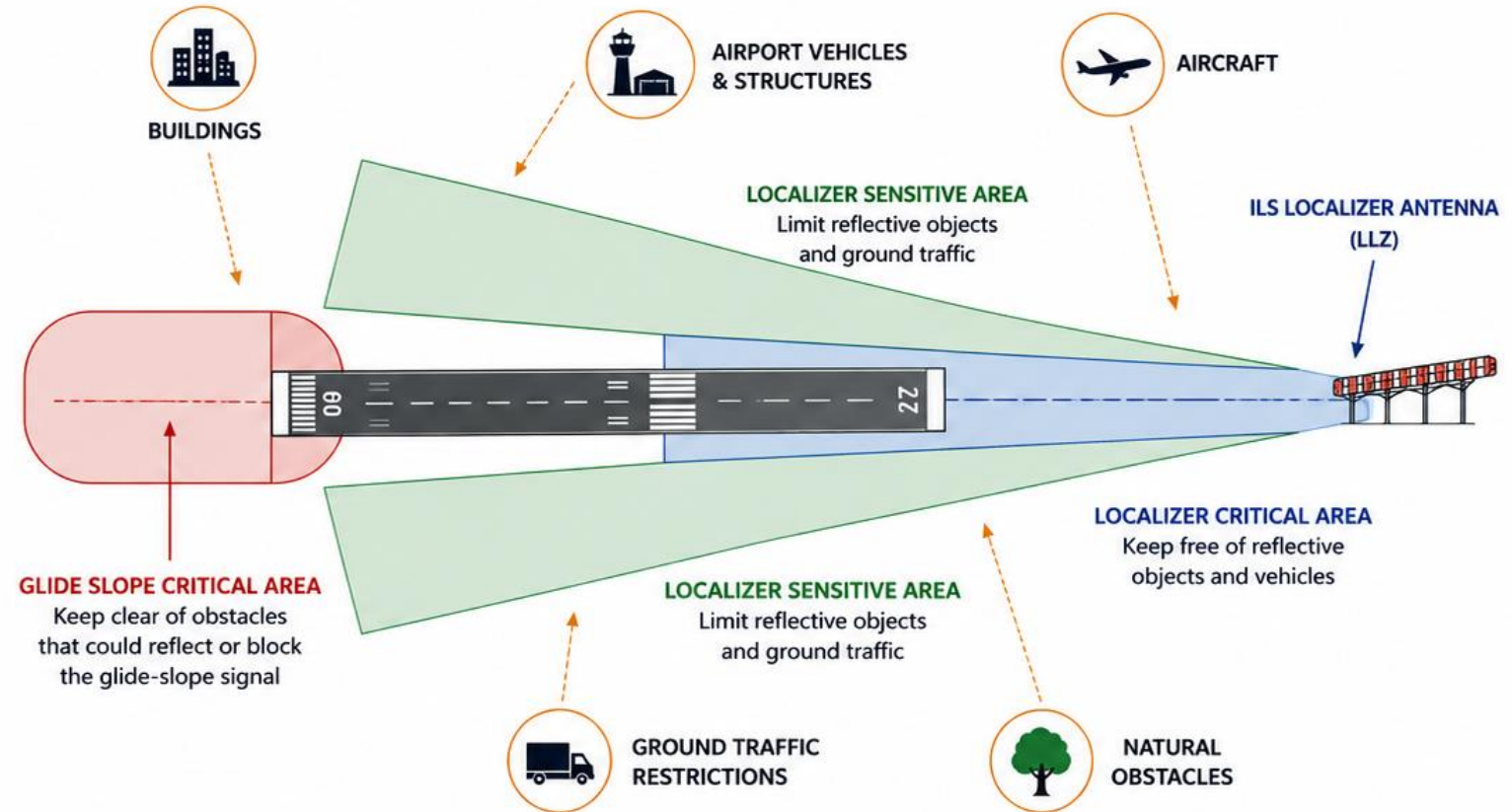
During CAT II/III operations, aircraft or vehicles may be held much farther from the runway than in normal weather.



Main objective

To preserve the integrity of the electromagnetic guidance environment.

TYPICAL ILS CRITICAL AND SENSITIVE AREAS (PLAN VIEW)



Protected areas ensure clean, undisturbed ILS signals.



Ensures accurate guidance



Improves pilot safety



Supports low-visibility operations (CAT II/III)



Protects all users of the airport



11. Airborne ILS Antennas

The aircraft requires antennas capable of receiving the ground signals.

The exact antenna architecture depends on aircraft type and avionics configuration, but the principle remains:

Ground electromagnetic signal → aircraft antenna → navigation receiver

Reception quality is important because the guidance system ultimately depends on accurate measurement of relatively small differences within the received signal.

Redundant receiving chains become particularly important for low-visibility and automatic-landing operations.

11. AIRBORNE ILS ANTENNAS



The aircraft requires antennas capable of receiving the ground signals to provide accurate guidance.

KEY PRINCIPLES



Receive ground signals

The aircraft antennas receive the Localizer (LLZ), Glide Slope (GS) and, when available, DME and marker signals.



Signal path

Ground electromagnetic signal → aircraft antenna → navigation receiver → cockpit indication



High precision required

ILS guidance relies on measuring very small differences in the received signal.



Redundancy matters

Redundant receiving chains improve reliability for low-visibility and automatic-landing operations.



Key for safety

Reliable antenna performance is essential for accurate and stable precision approach guidance.

TYPICAL ILS ANTENNA LOCATIONS (EXAMPLE: BOEING 737)

LOCALIZER ANTENNAS (LLZ)

Usually located on the nose left and right sides.

GLIDE SLOPE ANTENNAS (GS)

Usually located on the nose upper and lower sides.

DME ANTENNA

Usually located on the belly of the aircraft.

MARKER BEACON ANTENNA

Usually located on the top fuselage.



WHAT THEY RECEIVE



LOCALIZER (LLZ)

Provides lateral guidance (left / right of centerline).



GLIDE SLOPE (GS)

Provides vertical guidance (above / below path).



DME

Provides distance information.



MARKER BEACONS

Provide distance reference points (OM, MM, IM).

FROM GROUND TO COCKPIT



Ground ILS transmitter



Electromagnetic signal in space



Aircraft ILS antenna



Navigation receiver



Cockpit indication (PFD / instruments)



Pilot decision



Redundant antennas and receivers ensure the accuracy, integrity and continuity of ILS guidance, especially in low-visibility and automatic-landing conditions.



Improves reception quality



Ensures precise guidance



Enhances safety and reliability



Essential for CAT II / III operations



12. Airborne Navigation Receivers

After reception, the radio-navigation equipment demodulates and processes the signals.

For the Localizer it determines:

lateral deviation from LOC centerline.

For the Glide Slope:

vertical deviation from the G/S path.

The processed information can subsequently be distributed to several aircraft systems:

ILS ANTENNAS



NAV / ILS RECEIVERS



AVIONICS PROCESSING



PFD / FLIGHT DIRECTOR / AUTOPILOT

The important point is that the same underlying radio guidance can serve both **human monitoring** and **automatic aircraft guidance**.

12. AIRBORNE NAVIGATION RECEIVERS

How the aircraft demodulates and distributes ILS guidance information

1. MAIN FUNCTION



Demodulates and processes received ILS signals



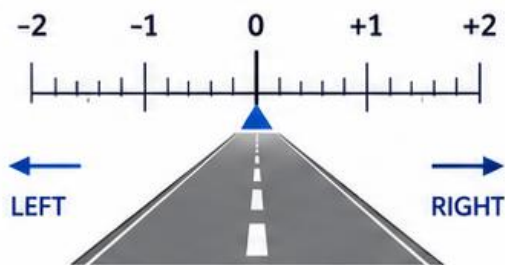
Converts radio information into usable guidance data



Feeds cockpit displays and guidance systems

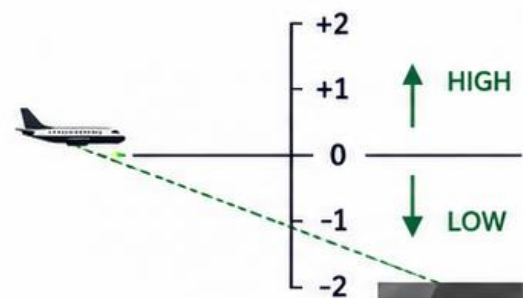
2. WHAT IT DETERMINES

LOCALIZER (LOC)



Determines lateral deviation from the LOC centerline

GLIDE SLOPE (G/S)



Determines vertical deviation from the G/S path

4. WHY IT MATTERS



Same radio guidance supports human monitoring



Also supports automatic aircraft guidance



Accurate processing is essential for stable ILS approach



Critical for low-visibility and automatic-landing operations

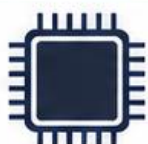
3. PROCESSING CHAIN



ILS Antennas



NAV / ILS Receivers



Avionics Processing



PFD / Flight Director / Autopilot

The processed information is distributed to several aircraft systems.



Key idea: After reception, the airborne navigation receivers transform ILS radio signals into lateral and vertical guidance that can be used both by pilots and by the flight director / autopilot.

13. Primary Flight Display — The Pilot's Main ILS Interface

On a Boeing 737, the PFD becomes the central instrument for monitoring the approach.

It brings together:

- Localizer deviation;
- Glide-Slope deviation;
- aircraft attitude;
- airspeed;
- altitude;
- vertical speed;
- Flight Director commands;
- autopilot/flight-mode information.

This integration is extremely important.

A centered LOC alone does not prove that the approach is correct.

Neither does a centered G/S.

The pilot cross-checks the complete aircraft energy and trajectory state.

13. PRIMARY FLIGHT DISPLAY—THE PILOT'S MAIN ILS INTERFACE

How the Boeing 737 PFD brings together the essential cues for monitoring an ILS approach

1. WHAT THE PFD BRINGS TOGETHER

-  Localizer deviation
-  Glide Slope deviation
-  Aircraft attitude
-  Airspeed
-  Altitude
-  Vertical speed
-  Flight Director commands
-  Autopilot / flight-mode information

2. CENTRAL INSTRUMENT DURING THE APPROACH



3. WHY INTEGRATION MATTERS



Centered LOC
alone does not prove
the approach is correct.



Centered G/S
alone does not prove
the approach is correct.



Cross-check the
complete aircraft energy
and trajectory state.

4. PILOT CROSS-CHECK CONCEPT



LOC
deviation

+



G/S
deviation

+



Altitude

+



Airspeed

+



Altitude

+



Vertical
speed

+



Flight Director
commands

+



A/P
LNAV V/S
FMA /
Autopilot modes

=



**Correct Approach
Monitoring**



The PFD is the pilot's main ILS interface because it combines guidance, aircraft state, and flight-mode information in one central display.



IDEO-LAB

14. Flight Mode Annunciator — FMA

For an automatic or Flight Director-coupled ILS approach, one of the most important monitoring areas is the **Flight Mode Annunciator**.

The FMA tells the pilots what the automatic-flight system is actually doing.

This distinction is essential:

MCP = pilot's selection/request

whereas:

FMA = actual autoflight mode status

During an ILS approach, the crew therefore monitors the progression from armed to captured guidance modes.

Conceptually:

APP selected

↓

LOC armed

↓

LOC captured

14. Flight Mode Annunciator — FMA

How pilots monitor the actual autoflight mode status during an ILS approach

1. WHAT THE FMA TELLS THE CREW



Shows what the automatic-flight system is actually doing.



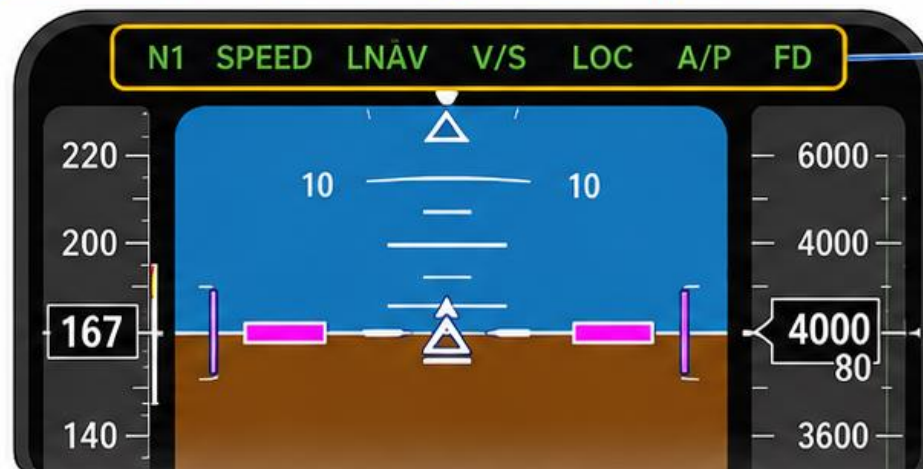
Essential during automatic or Flight Director-coupled ILS approaches.



Confirms the active / armed guidance modes.



Helps pilots verify mode progression during the approach.



FMA area

(Flight Mode Annunciator)

2. MCP VS FMA

MCP



Pilot's selection / request

VS

FMA



Actual autoflight mode status



Important distinction: selection does not always equal active mode.

3. TYPICAL ILS MODE PROGRESSION

APP selected



approach mode requested



LOC armed



localizer ready to capture



LOC captured



aircraft tracking the localizer

4. WHY PILOTS MONITOR THE FMA



Confirms the aircraft is following the expected guidance logic.



Helps detect incorrect or unexpected mode engagement.



Supports safe monitoring of the ILS approach.



During an ILS approach, the crew monitors the FMA to confirm what the autoflight system is really doing — not just what was selected.



15. Flight Director

The **Flight Director (FD)** converts guidance information into steering commands displayed on the PFD.

Instead of the pilot mentally translating raw LOC and G/S deviations into pitch and roll corrections, the Flight Director calculates appropriate commands.

The pilot can then manually fly those commands.

The architecture becomes:

ILS deviation → flight-control computation → FD command → pilot → aircraft

When the autopilot is engaged, the human pilot is removed from the immediate control loop but remains responsible for monitoring it.

15. FLIGHT DIRECTOR (FD)

From guidance information to steering commands



The Flight Director converts ILS guidance information into steering commands displayed on the PFD to help the pilot fly the approach.

1. WHAT THE FLIGHT DIRECTOR DOES



Converts guidance into commands
Transforms raw LOC and G/S deviations into appropriate pitch and roll steering commands.



Displays commands on the PFD
Provides visual cues (bars) for pitch and roll guidance.



The pilot flies the commands
The pilot manually controls the aircraft to follow the FD commands.



Autopilot (optional)
When engaged, the autopilot follows the FD commands automatically.



Pilot remains responsible
Even with autopilot engaged, the human pilot remains responsible for monitoring and safety.

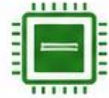
2. HOW IT WORKS (ARCHITECTURE)

ILS DEVIATION
(INPUT)



LOC and G/S
deviations from
the ILS receiver

FLIGHT-CONTROL
COMPUTATION



Flight Director computer
calculates appropriate
steering commands

FD COMMANDS
(OUTPUT)



Pitch command (bars)
Roll command (bars)
displayed on the PFD

PILOT



Pilot interprets the
commands and
controls the aircraft

AIRCRAFT



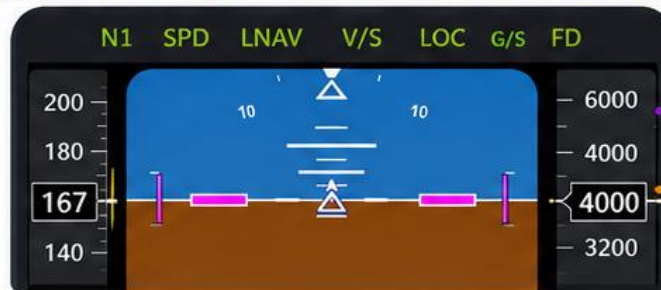
Aircraft responds
to pilot inputs



ARCHITECTURE SUMMARY

ILS deviation → flight-control computation → FD command → pilot → aircraft

3. FLIGHT DIRECTOR INDICATIONS ON THE PFD (EXAMPLE: BOEING 737)



Pitch command (G/S)
Command bars (pink)
move up/down to show
pitch guidance.

Roll command (LOC)
Command bars (pink)
move left/right to show
lateral guidance.



The FD does not move the control surfaces — it only provides commands.
The pilot (or autopilot) makes the aircraft respond.

4. KEY POINTS



Not raw indications

The FD does not show raw deviations — it shows how to correct them.



Reduces workload

Helps the pilot by presenting clear steering commands.



Manual or automatic

Commands can be flown manually or followed by the autopilot.



Monitoring remains essential

Autopilot removes the pilot from the control loop but does not remove responsibility.

5. PILOT'S ROLE

- Understand the FD commands
- Fly or monitor the aircraft response
- Ensure the approach is stable and safe
- Be ready to intervene at any time



The Flight Director is the bridge between guidance and control. It turns deviations into actionable commands that help the pilot fly an accurate, stable and safe approach.



Converts guidance
into commands



Displays on the
PFD



Flown by pilot
or autopilot



Pilot remains
responsible



16. Autopilot and ILS Coupling

The automatic-flight system can use ILS information directly.

Once the appropriate modes are armed and captured, the autopilot can command the aircraft to follow:

Localizer laterally

and

Glide Slope vertically.

This creates a closed-loop control system:

ILS transmitter

→ Aircraft receiver

→ Autoflight system

→ Flight controls

→ Aircraft trajectory

→ New ILS deviation

→ Autoflight correction

The process repeats continuously throughout the approach.

16. AUTOPILOT AND ILS COUPLING

ILS guidance directly drives the aircraft — in a closed loop.

WHAT THE AUTOPILOT DOES



Follows LOCALIZER
Keeps the aircraft centered on the runway centerline.



Follows GLIDE SLOPE
Keeps the aircraft on the correct descent path.

REQUIRED CONDITIONS



Modes ARMED
(APP / LOC / G/S)

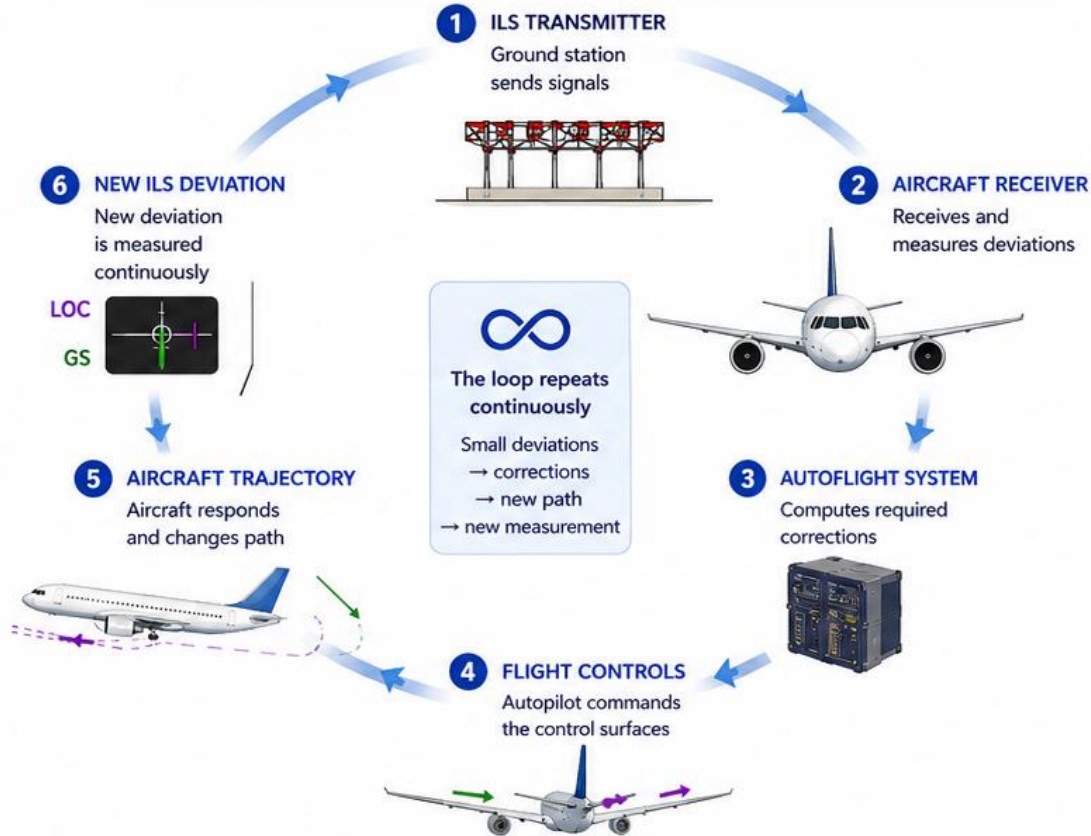


Modes CAPTURED
(LOC / G/S)

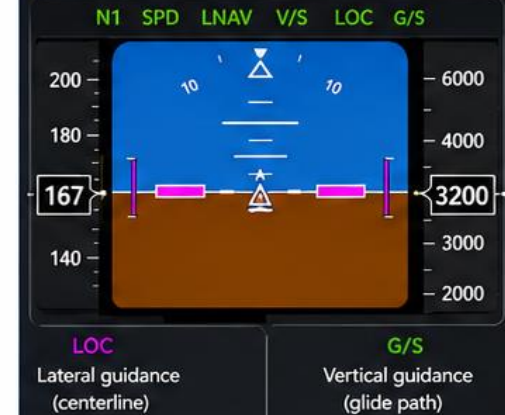


Autopilot ENGAGED

THE CLOSED-LOOP CONTROL SYSTEM



PFD (EXAMPLE: BOEING 737)



AUTOPILOT MODES (EXAMPLE)



RESULT



Stable approach

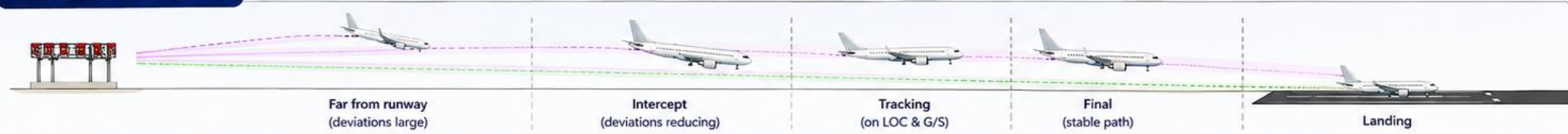


Reduced workload



Safe landing

THE APPROACH IN ACTION



The autopilot uses ILS guidance in real time to keep the aircraft on the centerline and glide path.



ILS Transmitter



Aircraft Receiver



Autoflight System



Flight Controls



Aircraft Trajectory



New Deviation Measured



Loop Repeats



17. Dual-Channel and Autoland Capability

On appropriately equipped and certified 737s, the ILS architecture can support **automatic landing operations**.

This requires much more than merely having an autopilot engaged.

Redundancy becomes central.

Multiple navigation, flight-control and monitoring resources are used so that certain individual failures do not immediately result in loss of the required guidance capability.

Depending on aircraft certification, airport facilities, crew qualification and operational approval, this architecture supports **CAT II/CAT III** operations.

The essential philosophy is:

precision + redundancy + integrity monitoring + fail-safe/fail-operational behavior as applicable.

17. DUAL-CHANNEL AND AUTOLAND CAPABILITY

How redundancy allows a Boeing 737 ILS system to support CAT II / CAT III automatic landing operations

CORE IDEA



Automatic landing needs more than autopilot ON



Redundancy is essential

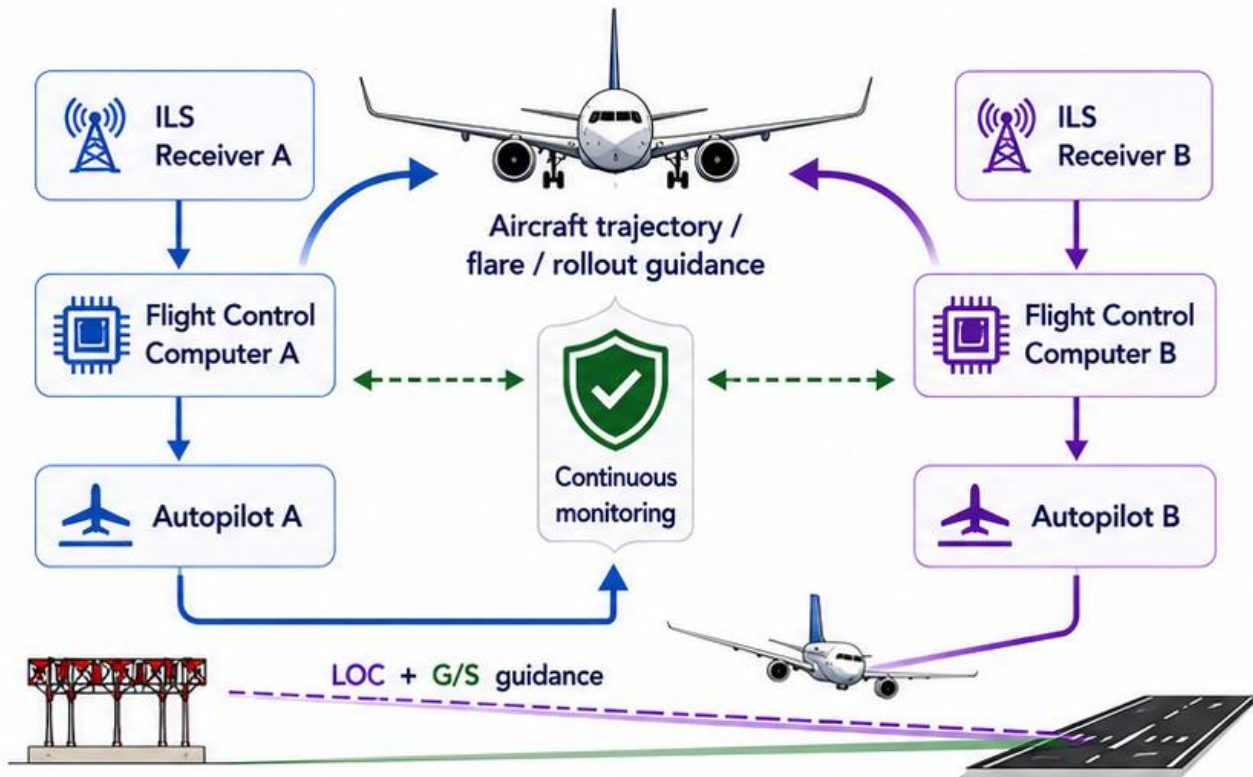


Multiple systems cross-check each other



Precision + integrity monitoring = safe autoland

DUAL-CHANNEL ILS GUIDANCE ARCHITECTURE



WHY DUAL-CHANNEL MATTERS



Reduces single-point failure risk



Maintains required guidance capability



Supports CAT II / CAT III operations



Enables fail-safe / fail-operational behavior (as certified)

THE ESSENTIAL PHILOSOPHY



Precision

+



Redundancy

+



Integrity monitoring

=



Autoland capability

RESULT



Stable approach



Safe landing



Low-visibility capability

18. Approach Lighting — Transition from Instruments to Visual Flight

Although technically separate from the radio guidance itself, the Approach Lighting System (ALS) is operationally closely associated with an ILS.

The radio system brings the aircraft accurately toward the runway.

The lighting environment assists the crew in making the transition from:

instrument references → external visual references.

Approach lights, threshold lights, runway edge lights, centerline lights and touchdown-zone lighting can therefore form an essential part of low-visibility precision-approach operations.

18. APPROACH LIGHTING — TRANSITION FROM INSTRUMENTS TO VISUAL FLIGHT

How the Approach Lighting System (ALS) helps pilots transition from instrument references to external visual references

1. RADIO GUIDANCE



ILS brings the aircraft accurately toward the runway



Instrument references



2. THE TRANSITION



Instrument references



External visual references



3. VISUAL LIGHTING CUES

Threshold lights

Runway edge lights

Centerline lights

Approach lights

Touchdown zone lights



4. WHY IT MATTERS



Supports low-visibility operations



Helps the crew acquire visual references



Bridges instruments and visual landing



Improves final approach awareness



The ALS is closely associated with ILS operations because it helps pilots safely transition from **radio guidance** to **visual landing cues**.





CRONO
SIDE STICK PRIORITY



CRONO
SIDE STICK PRIORITY



19. The Complete ILS Chain

The entire system can finally be represented as:

GROUND

LOCALIZER

GLIDE SLOPE

DME / other distance reference

GROUND MONITORS

APPROACH & RUNWAY LIGHTING



RADIO PROPAGATION



AIRCRAFT

ANTENNAS



NAV / ILS RECEIVERS



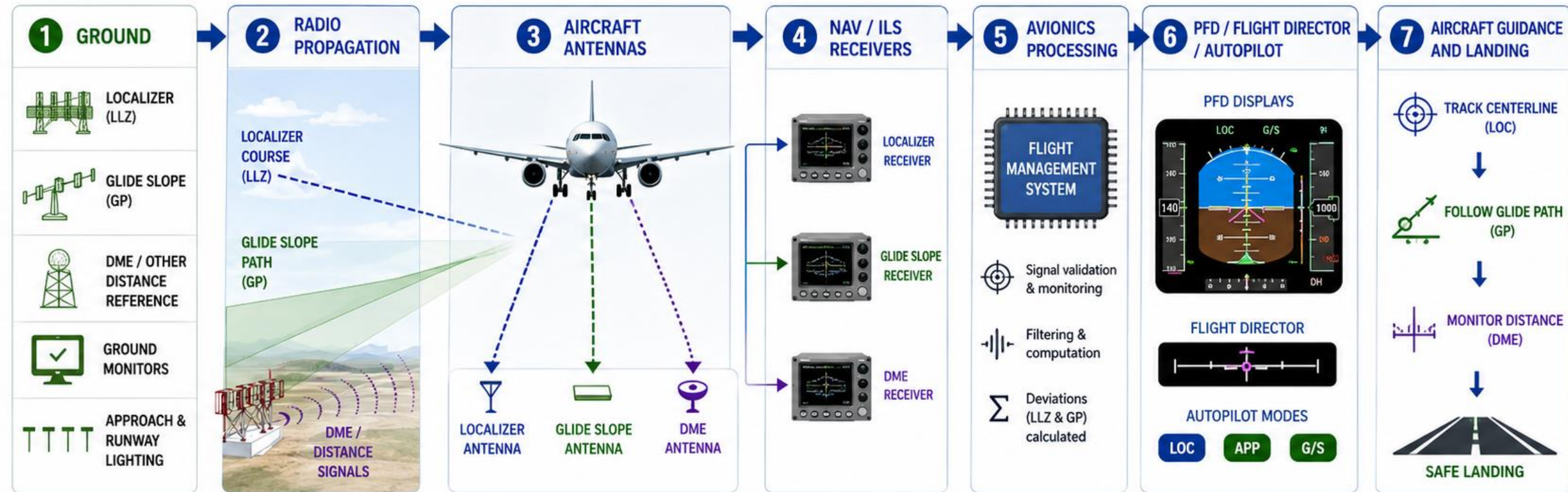
AVIONICS PROCESSING

19. THE COMPLETE ILS CHAIN

How all ILS elements connect from ground systems to aircraft guidance and landing

KEY IDEA

Ground guidance signals are transmitted, received, processed, displayed, and used to guide the aircraft to a safe landing.



20. The Key Concept

The elegance of ILS comes from its relative simplicity.

It does not fundamentally need to tell the aircraft:

“You are at latitude X, longitude Y and altitude Z.”

Instead, it continuously answers two extremely precise questions:

“How far are you from the runway centerline guidance plane?”

and

“How far are you from the required descent guidance plane?”

Bring both errors toward zero and the aircraft converges toward the desired final approach trajectory.

That is the fundamental engineering principle behind the ILS:

LOC = lateral error

G/S = vertical error

DME = distance reference

PFD = pilot monitoring

FD/AP = guidance and control

Ground monitoring = signal integrity

20. THE KEY CONCEPT

Why ILS is elegant: it continuously drives lateral and vertical error toward zero

ILS does NOT
mainly tell you



Latitude X /
Longitude Y /
Altitude Z

**LOCALIZER
(LOC)**

Vertical guidance
plane aligned with
runway centerline

**GLIDE SLOPE
(G/S)**

Inclined guidance
plane for the
required descent

**DME
4.2 NM**

LOC error
(lateral)

G/S error
(vertical)



Reduce both errors toward zero
→ converge to the final approach path



ILS continuously answers
two precise questions

1



How far are you
from the runway
centerline
guidance plane?

2



How far are you
from the required
descent
guidance plane?



FUNDAMENTAL ENGINEERING IDEA



LOC =
lateral error



G/S =
vertical error



DME =
distance reference



PFD =
pilot monitoring

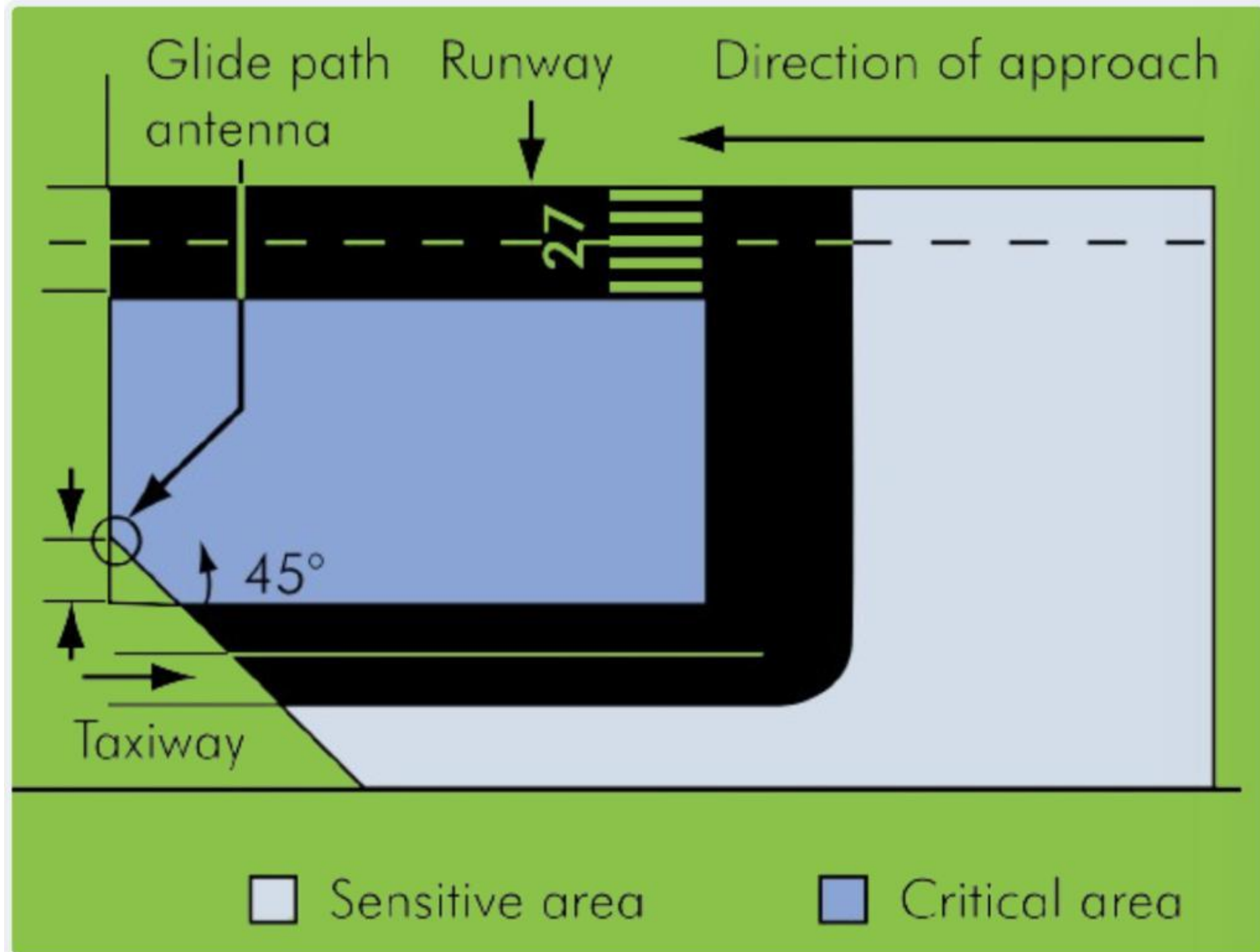


FD/AP =
guidance
and control

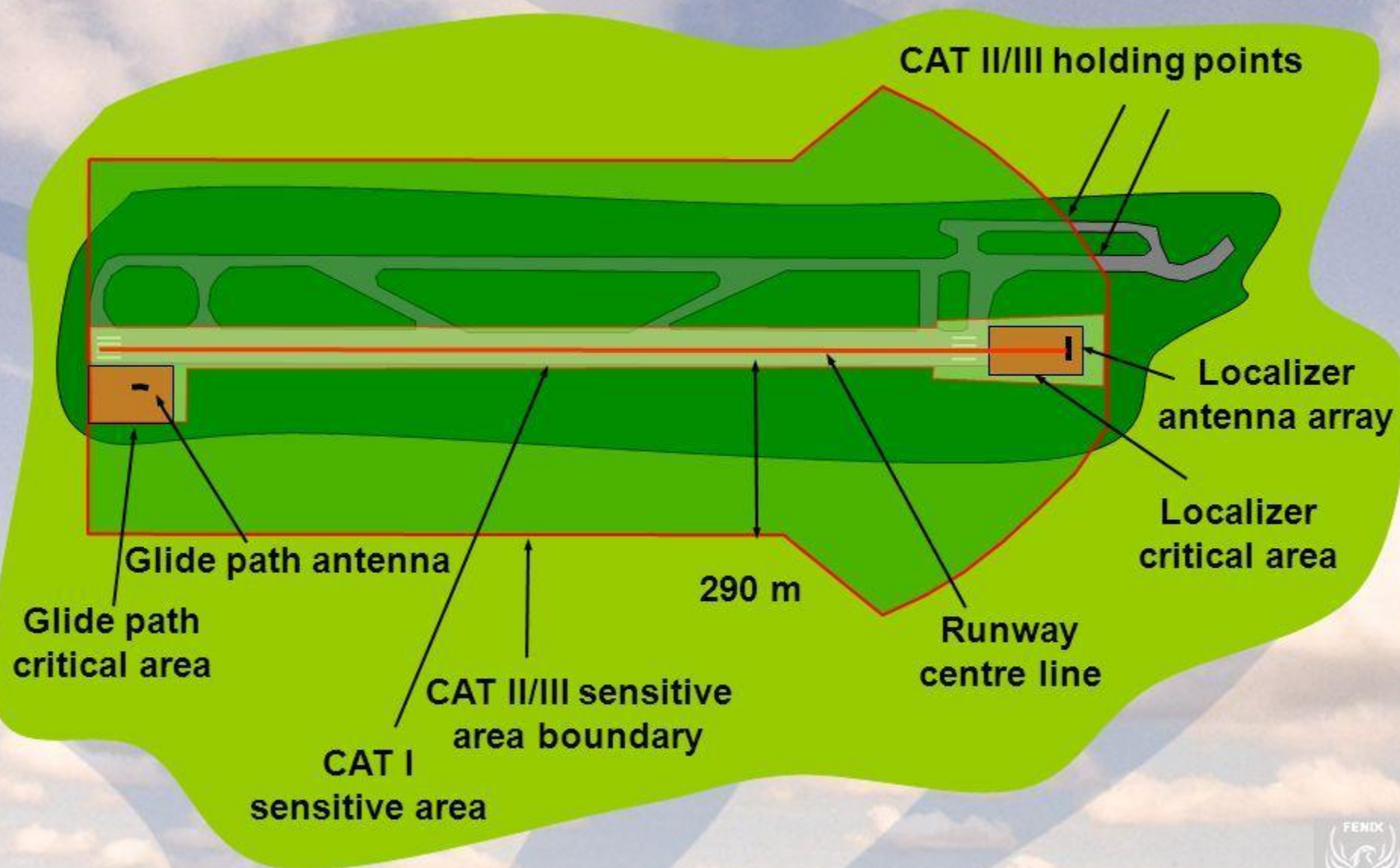


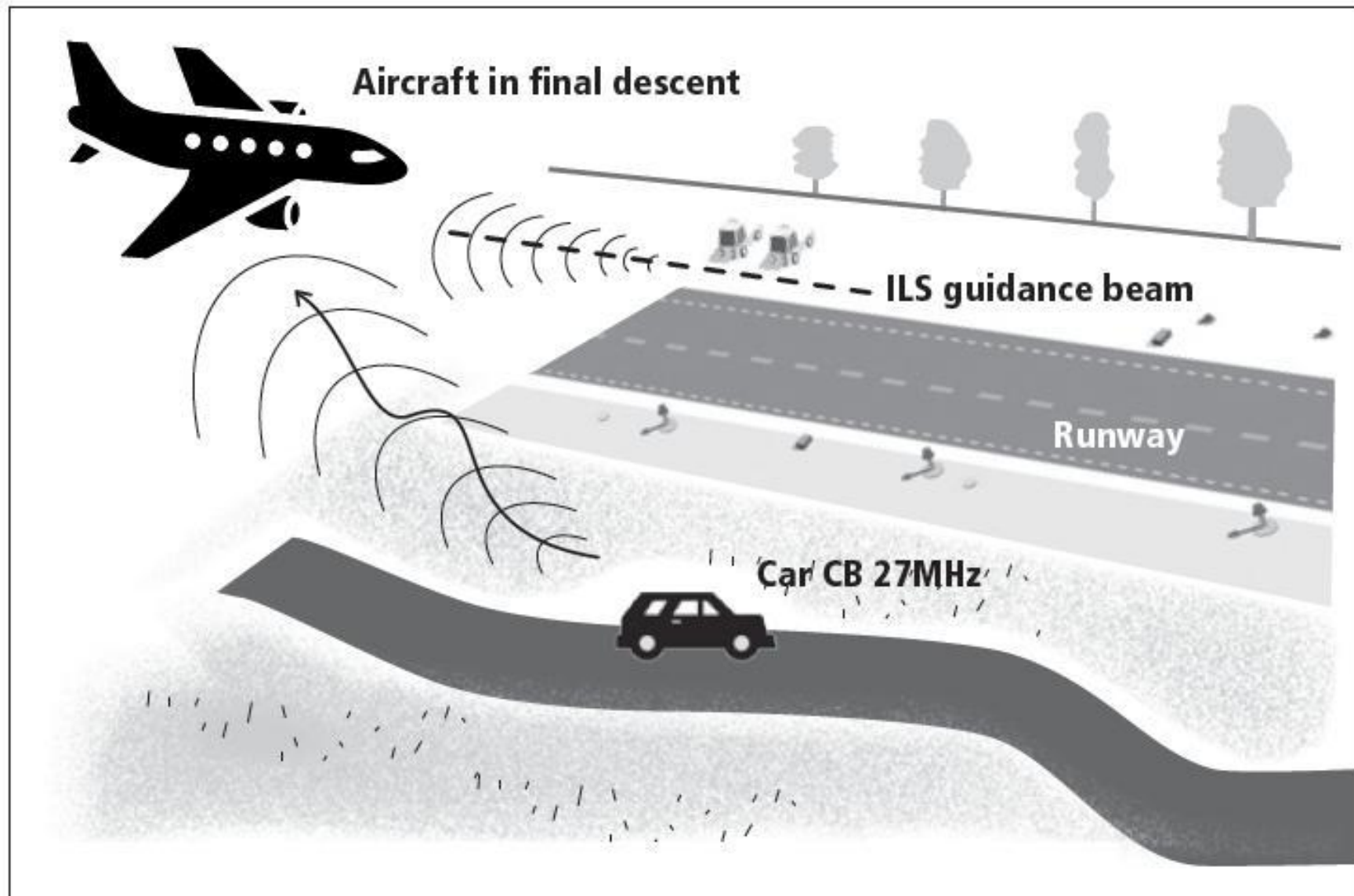
Ground monitoring =
signal integrity

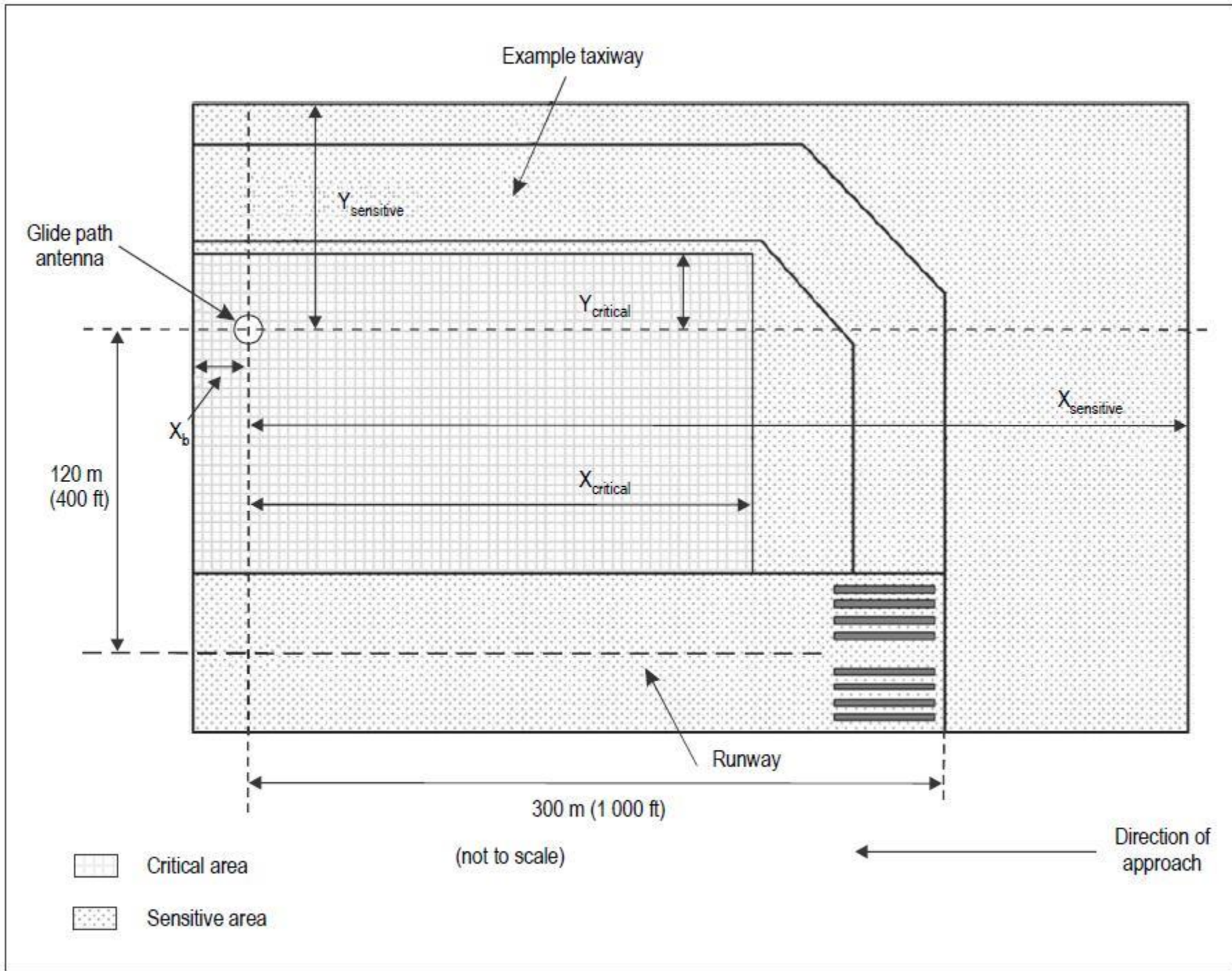
5. Redundancy & Safety Features

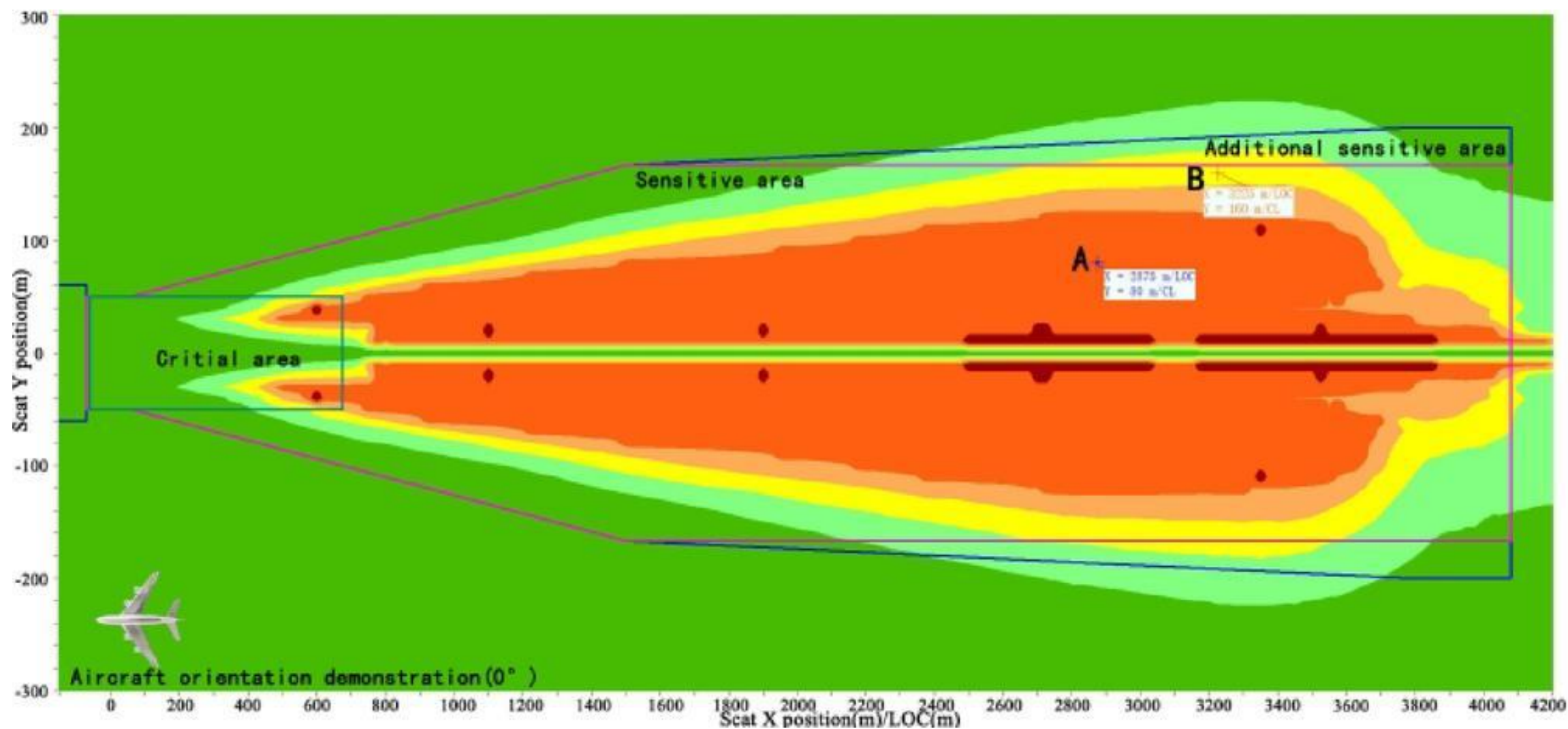


ILS PROTECTION AREA









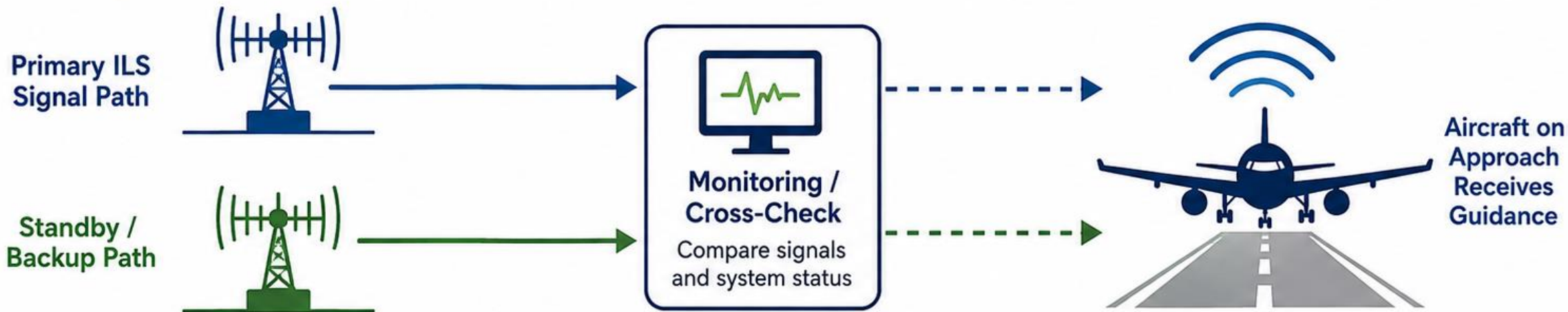
ILS — Redundancy & Safety Features

The Instrument Landing System (ILS) is designed around a fundamental aviation-safety principle: a precision approach must not depend on a single unmonitored source of guidance. As weather deteriorates from CAT I toward CAT II and CAT III operations, the aircraft increasingly relies on radio guidance, avionics, automatic flight controls, airport infrastructure, and continuous system monitoring.

The objective is therefore not merely accuracy, but also integrity, continuity, availability, redundancy, fault detection, and safe degradation.

ILS — Redundancy & Safety Features

Safe precision guidance depends on backup systems, monitoring, and fail-safe behavior.



Redundancy

Backup transmitter / receiver available



Monitoring

Continuous integrity checks



Fault Detection

Bad signals detected quickly



Safe Degradation

Unreliable guidance removed or downgraded safely



A wrong guidance signal is more dangerous than no signal.



ILS safety = integrity + continuity + availability + redundancy.

Chapter 1 — Fundamental ILS Safety Philosophy

Four concepts form the foundation of ILS safety:

Accuracy

Accuracy describes how precisely the ILS guides the aircraft relative to the desired approach path:

- **Localizer (LOC):** lateral guidance.
- **Glide Slope (G/S):** vertical guidance.

However, accuracy alone is insufficient. A very accurate system can still become dangerous if a failure produces erroneous guidance without being detected.

Integrity

Integrity is the ability of the system to prevent incorrect information from being presented and used as valid guidance.

This leads to one of the most important principles in precision navigation:

A detected loss of guidance is safer than undetected misleading guidance.

If an ILS becomes unreliable, the system should detect the condition rapidly enough for appropriate protective action to occur.

Chapter 1 — Fundamental ILS Safety Philosophy

The two essential ideas behind safe ILS guidance

1. ACCURACY



- ✓ LOC = lateral guidance
- ✓ G/S = vertical guidance
- ✓ Goal: keep the aircraft on the correct approach path

2. INTEGRITY



- ✓ Wrong guidance must be detected quickly
- ✓ Unsafe signals must not be used
- ✓ Protection comes before precision



DETECTED LOSS OF GUIDANCE IS SAFER THAN MISLEADING GUIDANCE



ACCURATE GUIDANCE



CONTINUOUS MONITORING



SAFE USE OR
SAFE SHUTDOWN



Continuity

Continuity describes the ability of the ILS service to remain available throughout the critical period of an approach without an unexpected interruption.

Availability

Availability represents the probability that the required ILS service is available when an aircraft needs it.

The overall philosophy can therefore be summarized as:

**ACCURATE + INTEGRITY-MONITORED + CONTINUOUS + AVAILABLE = TRUSTWORTHY
GUIDANCE**

Chapter 2 — Ground-System Redundancy

The first level of redundancy exists at the airport.

The ground infrastructure includes:

LOCALIZER TRANSMITTERS

-

GLIDE-SLOPE TRANSMITTERS

-

MONITORING SYSTEMS

-

POWER SYSTEMS

-

CONTROL AND STATUS SYSTEMS

Higher-category installations may incorporate redundant equipment so that certain equipment failures do not immediately eliminate the required navigation service.

Conceptually:

PRIMARY TRANSMITTER

↓ failure detected

STANDBY EQUIPMENT

↓ changeover where supported

SERVICE MAINTAINED OR SAFELY WITHDRAWN

The important point is that redundancy is not simply duplication.

A properly engineered redundant architecture must also be able to detect which component has failed and prevent faulty equipment from continuing to provide misleading guidance.

ILS GROUND-SYSTEM REDUNDANCY

Multiple layers of backup on the ground ensure continuous navigation service.



REDUNDANT GROUND SYSTEMS = CONTINUOUS AND RELIABLE ILS SERVICE

Chapter 3 — Continuous Ground Monitoring

ILS transmitters cannot simply be switched on and assumed to remain correct.

Their performance must be monitored.

Ground monitoring equipment supervises important characteristics of the radiated LOC and G/S signals.

Conceptually:

ILS TRANSMITTER

↓

RADIATED GUIDANCE

↓

MONITOR

↓

SIGNAL WITHIN PERMITTED LIMITS?

YES

→ Continue operation

NO

→ Protective action

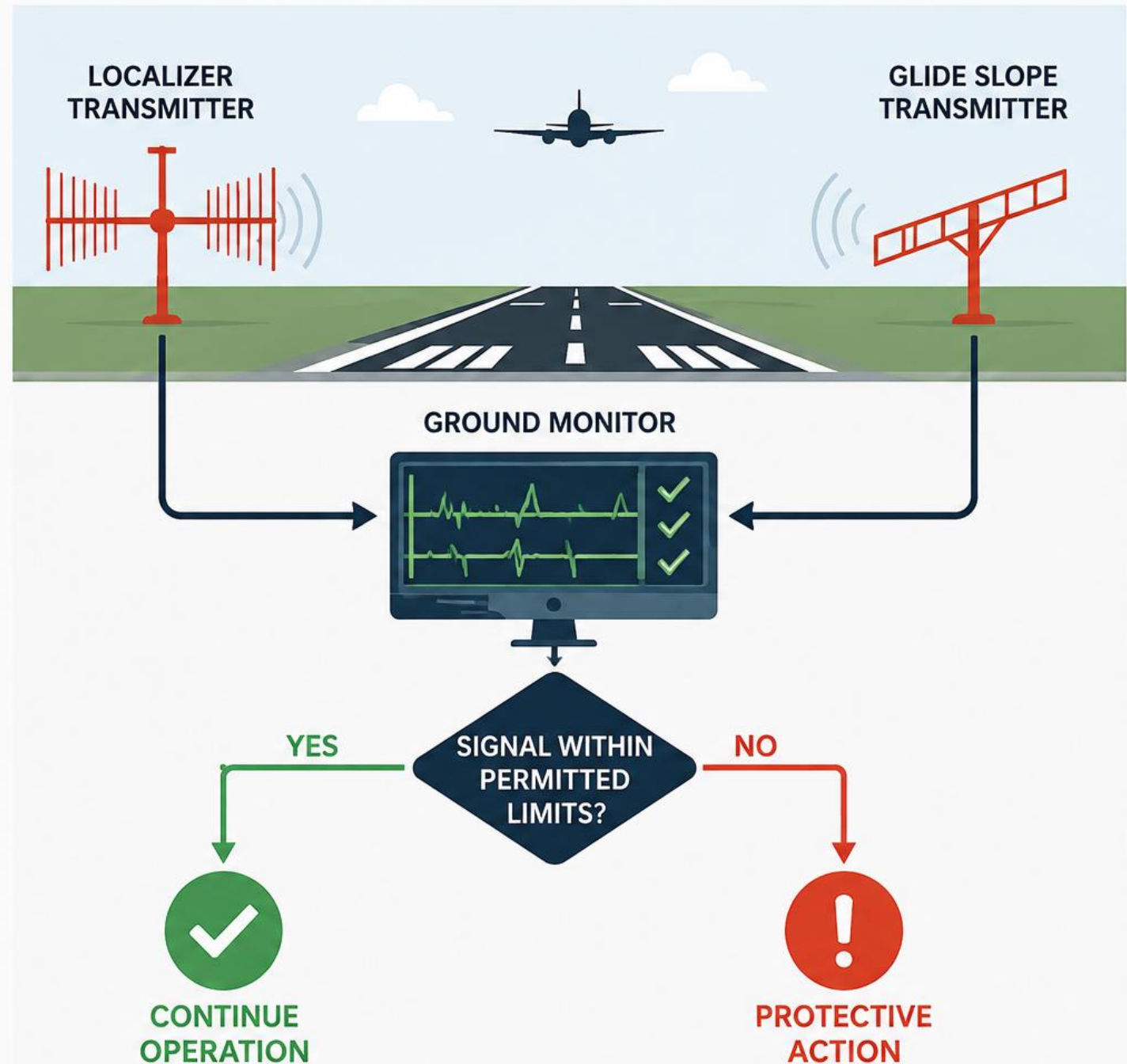
Chapter 3 — Continuous Ground Monitoring

ILS transmitters are continuously monitored on the ground.

The system checks that the signals stay within permitted limits.

If everything is normal → **operation continues.**

If a fault is detected → **protective action.**



Depending on the failure and installation, this can result in alarms, equipment changeover, or withdrawal of the affected navigation guidance.

This is particularly important because an apparently normal but displaced guidance signal could potentially be more hazardous than a complete and obvious signal loss.

The safety philosophy is therefore:

Detect → Isolate → Annunciate → Remove or restore safely.

Chapter 4 — Electrical Power Redundancy

Precision approach capability also depends on reliable electrical power.

An ILS ground installation therefore requires an appropriately reliable power architecture, with backup arrangements depending on the operational category and airport installation.

Conceptually:

NORMAL POWER

↓

ILS EQUIPMENT

while an alternate or standby capability may provide another layer of protection against loss of the normal electrical source.

This becomes increasingly important during low-visibility operations.

Consider an aircraft descending through:

200 ft → 100 ft → 50 ft

during an automatic approach.

At this stage, sudden loss of required ground infrastructure may have considerably greater operational consequences than during an approach conducted in good visual conditions.

Power-system reliability is consequently part of the complete ILS safety case.

Chapter 4 — Electrical Power Redundancy

ILS must keep operating even if the normal power fails.

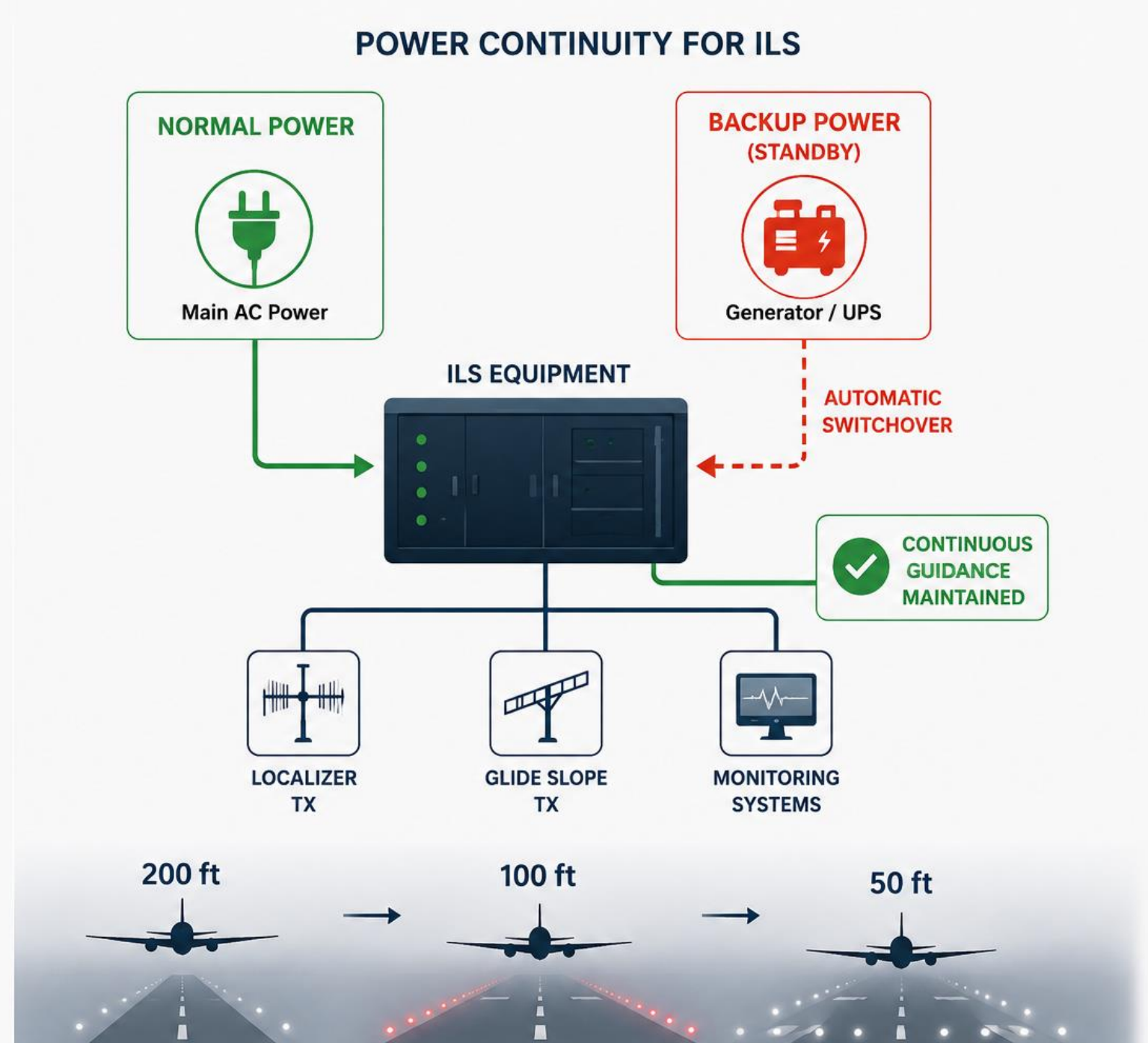
A backup power system takes over instantly to ensure continuous guidance.



**RELIABLE POWER =
SAFE APPROACH**



**MOST CRITICAL
DURING LOW VISIBILITY
(200 ft → 100 ft → 50 ft)**



Chapter 5 — ILS Critical and Sensitive Areas

Not every threat to ILS integrity comes from an electronic failure.

ILS signals can be affected by the physical environment around the antenna installations.

Large objects such as:

- aircraft;
- airport vehicles;
- buildings;
- construction equipment;

can cause electromagnetic reflections or disturbances.

Airports therefore establish **ILS Critical Areas** and, where applicable, **ILS Sensitive Areas** around portions of the ILS infrastructure.

During low-visibility operations, ATC procedures can restrict aircraft and vehicle movements within these protected areas.

The objective is to prevent an aircraft on the ground from disturbing the guidance being used by another aircraft on final approach.

Thus ILS protection involves both:

Electronic integrity

and

Operational/environmental integrity.

Chapter 5 — ILS Critical and Sensitive Areas



Large objects near ILS antennas can **disturb the signals**.



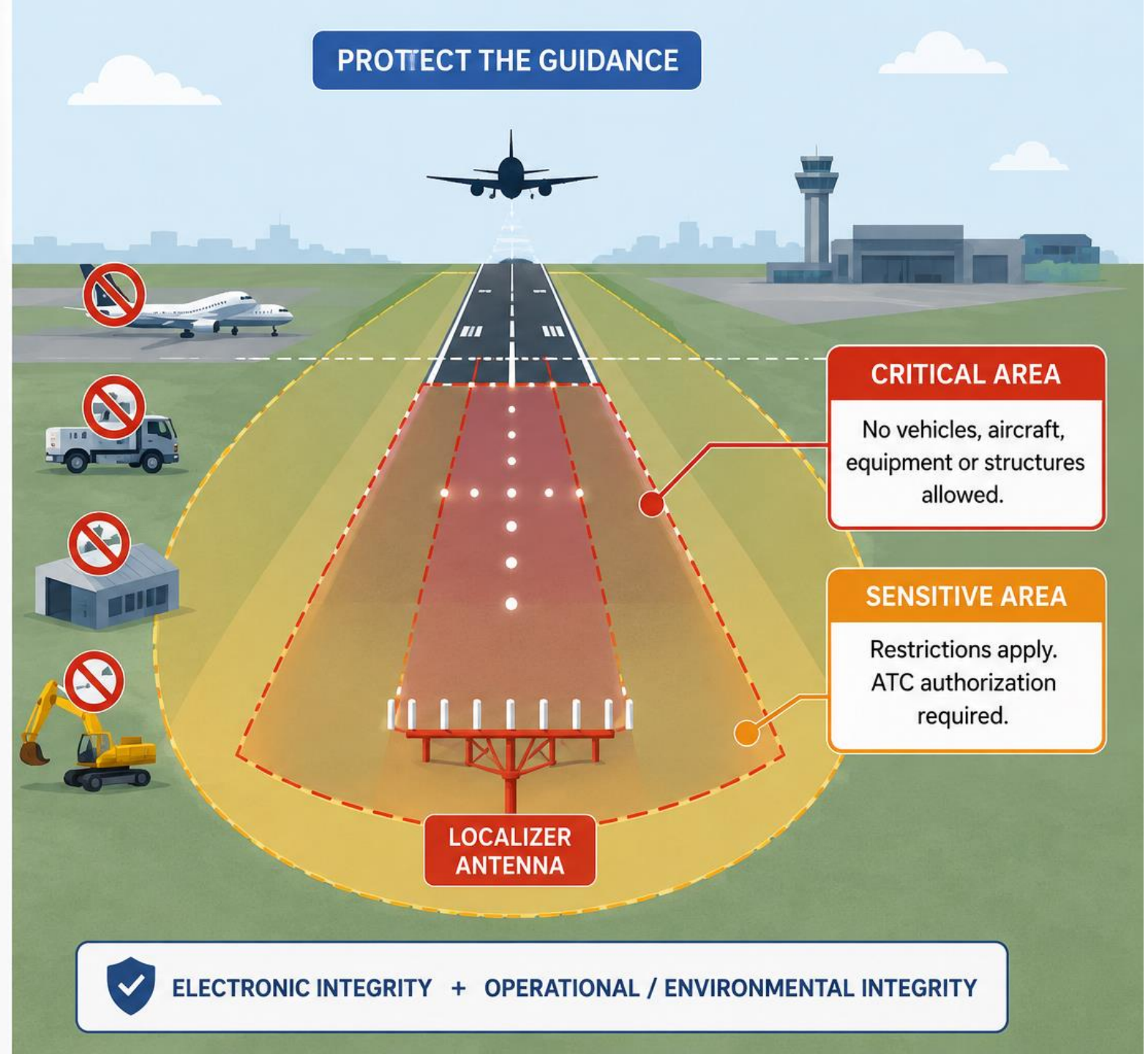
Airports define **CRITICAL AREAS** and **SENSITIVE AREAS**.



ATC **restricts movements** in these areas during low-visibility operations.



Goal:
Protect guidance for every aircraft on final approach.



Chapter 6 — Airborne Receiver and Avionics Redundancy

Redundancy continues inside the aircraft.

A transport-category aircraft equipped for advanced low-visibility operations does not simply depend on one uncontrolled chain consisting of:

Antenna → Receiver → Autopilot.

Instead, appropriately certified architectures provide multiple navigation, processing, display and/or flight-control resources according to aircraft design and operational capability.

A simplified representation is:

ILS GROUND SIGNAL



RECEIVING / PROCESSING CHAIN A

RECEIVING / PROCESSING CHAIN B



GUIDANCE / FLIGHT-CONTROL SYSTEM

Redundant systems can also provide opportunities for **cross-comparison**.

If independent systems receive or calculate incompatible information, the disagreement can be detected rather than silently accepted.

Airborne Receiver & Avionics Redundancy

Two onboard paths for one safe guidance decision



1. Dual receiving chains



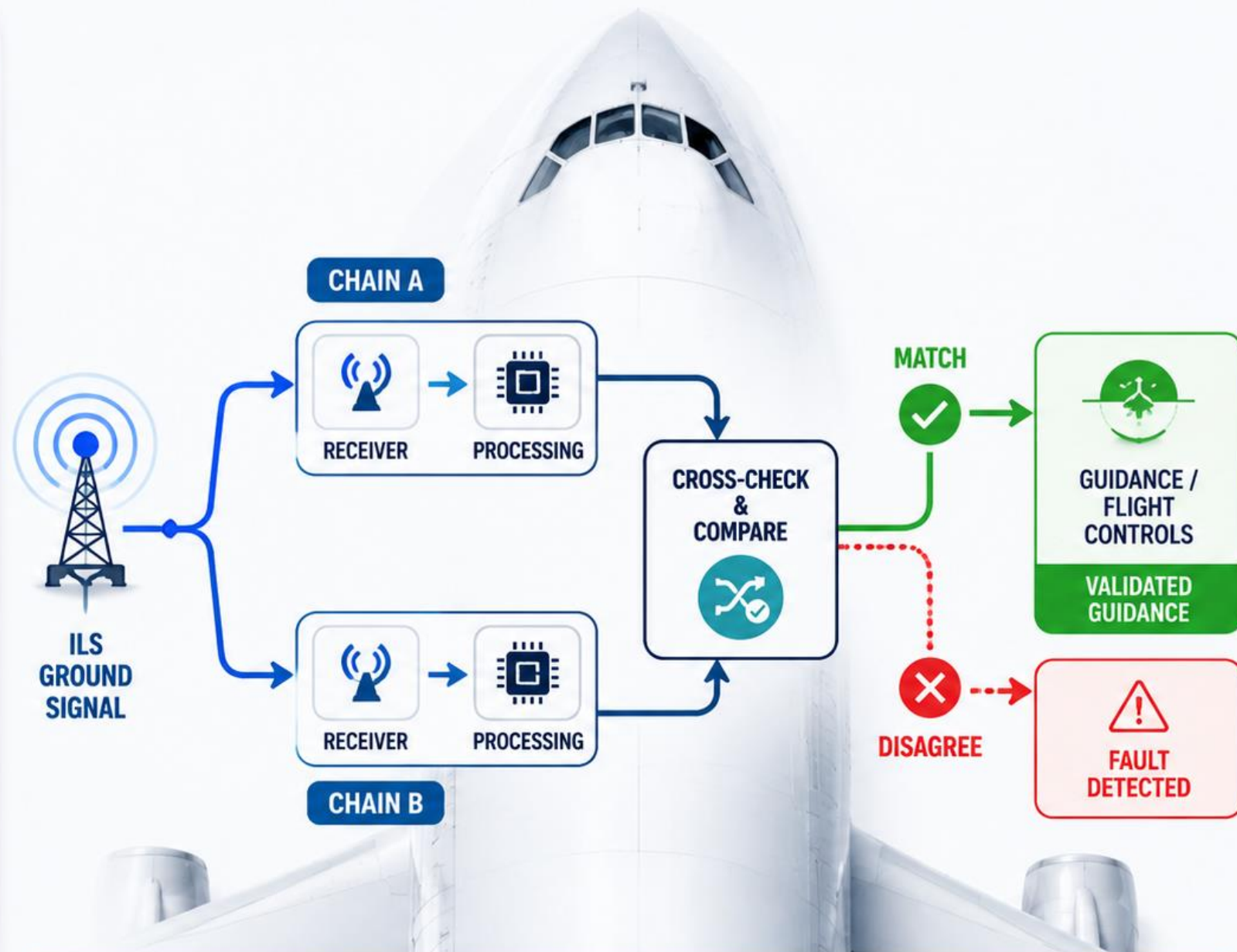
2. Independent processing



3. Cross-check & disagreement detection



4. Safe guidance to flight controls



Redundancy allows **comparison** before guidance is accepted.

Chapter 7 — Autopilot and Flight-Control Redundancy

Redundancy becomes particularly important during automatic approaches and automatic landings.

During a manually flown ILS approach, the basic control loop is approximately:

ILS → Flight Instruments → Pilot → Flight Controls

During an automatic approach:

ILS



Navigation Receivers



Flight-Control / Autoflight Processing



Autopilot



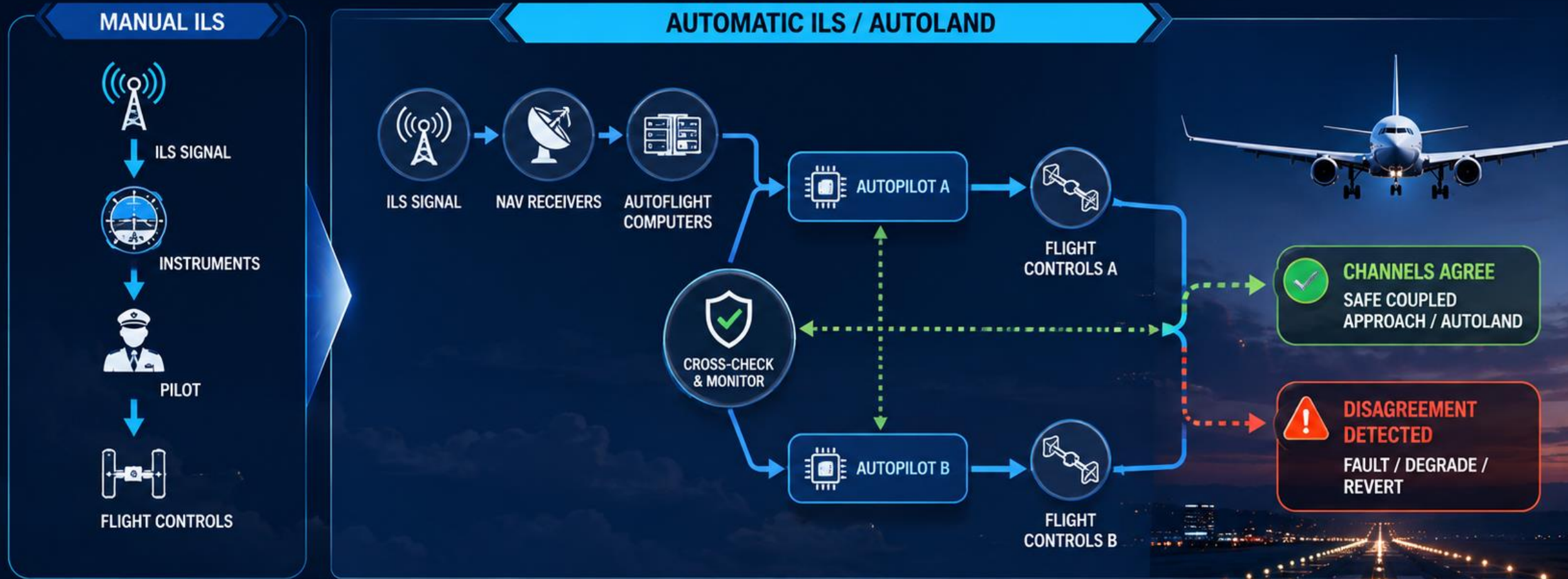
Flight Controls



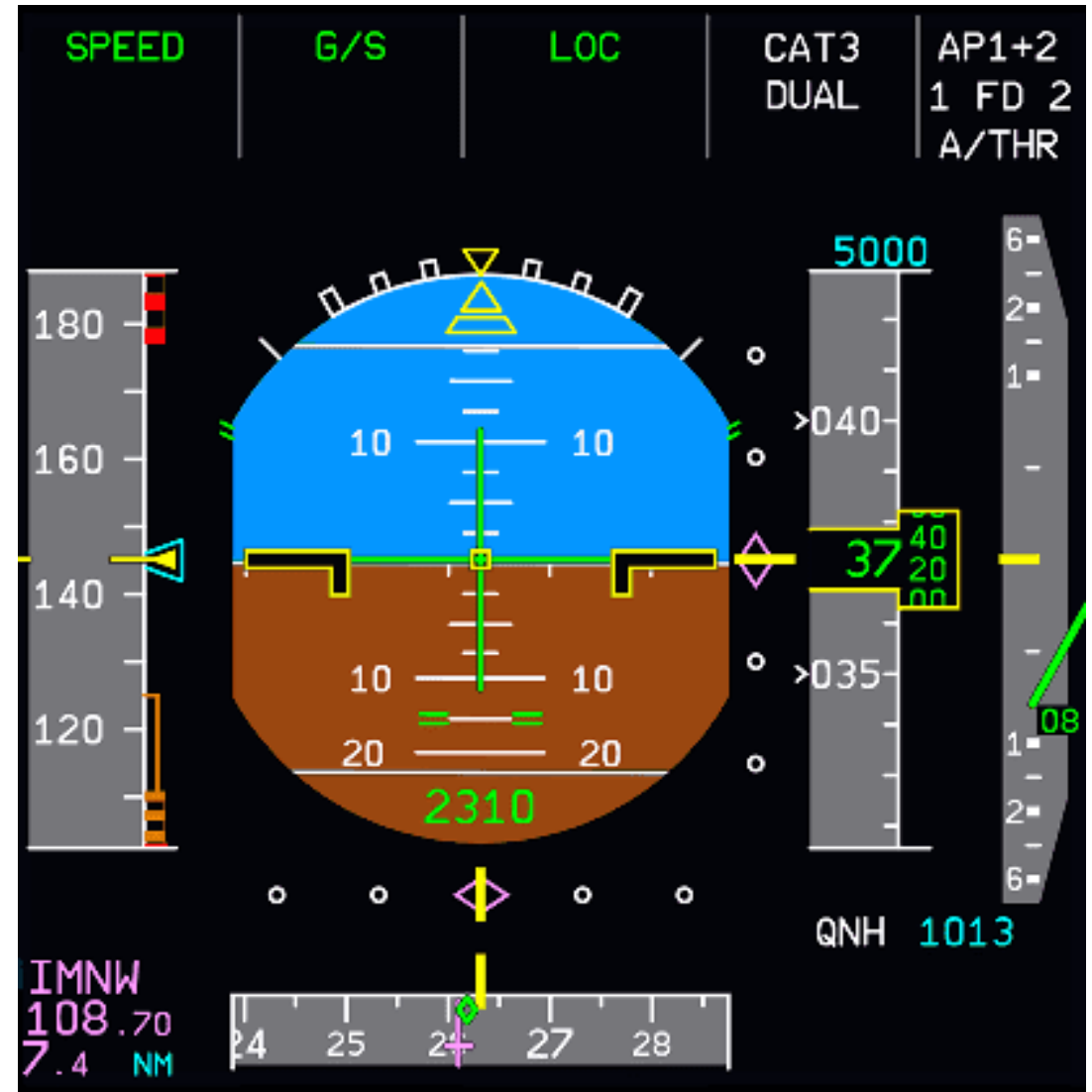
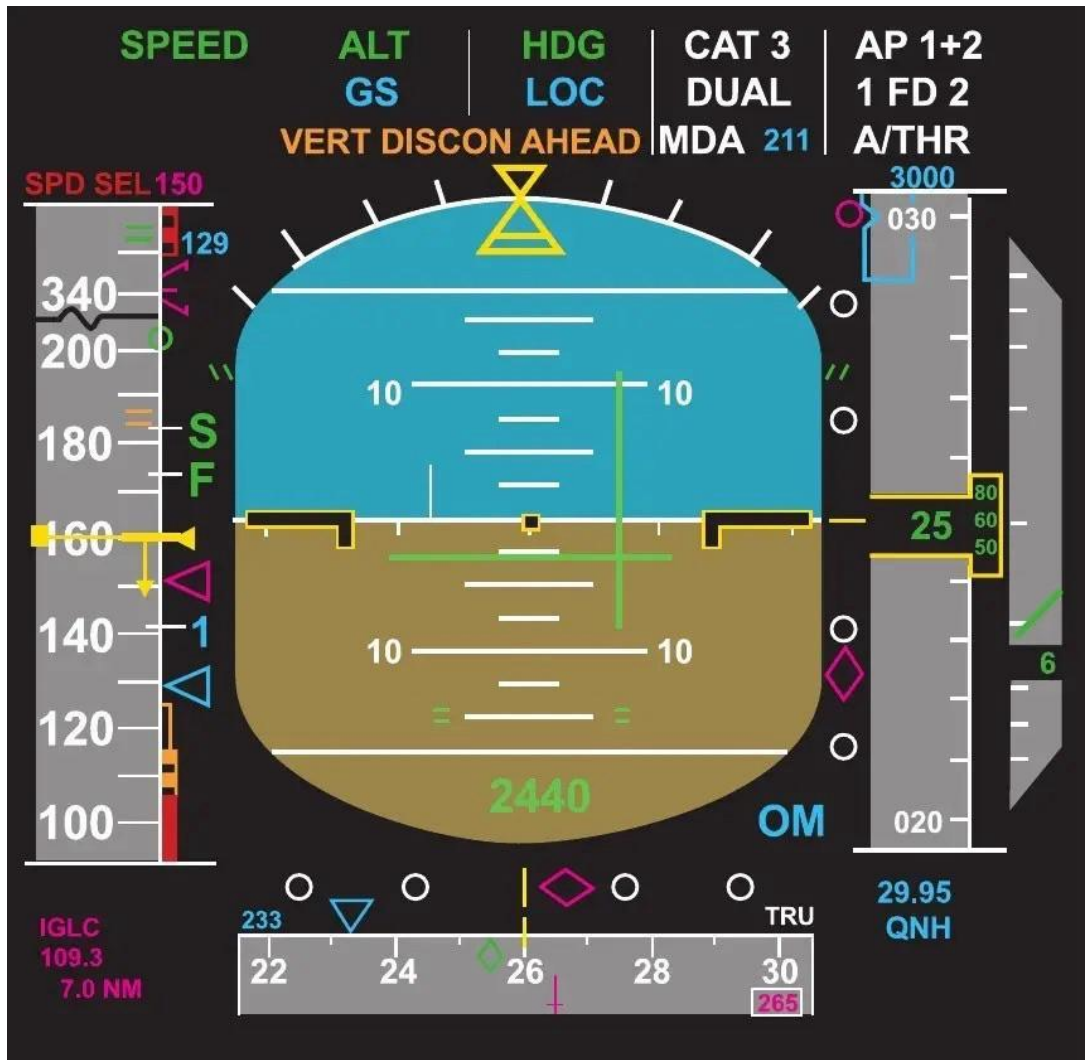
Aircraft

Chapter 7 – Autopilot & Flight-Control Redundancy

Automatic approach safety depends on monitored backup control paths.



REDUNDANCY MEANS THE SYSTEM **COMPARES** BEFORE IT **COMMANDS**.



New LOC/G/S deviations

The automatic system continuously attempts to minimize those deviations.

On appropriately equipped and certified Boeing 737 variants, multiple autopilot resources can participate in the required automatic approach/landing architecture.

The pilots consequently monitor not only LOC and G/S but also the relevant **Flight Mode Annunciations and autoland status indications**.

This illustrates an important principle:

Automation does not replace monitoring.

Greater automation generally requires **better monitoring of the automation itself**.

Automatic ILS Monitoring

Automation reduces deviations — pilots monitor the automation.



Autopilot continuously corrects LOC / G/S deviations



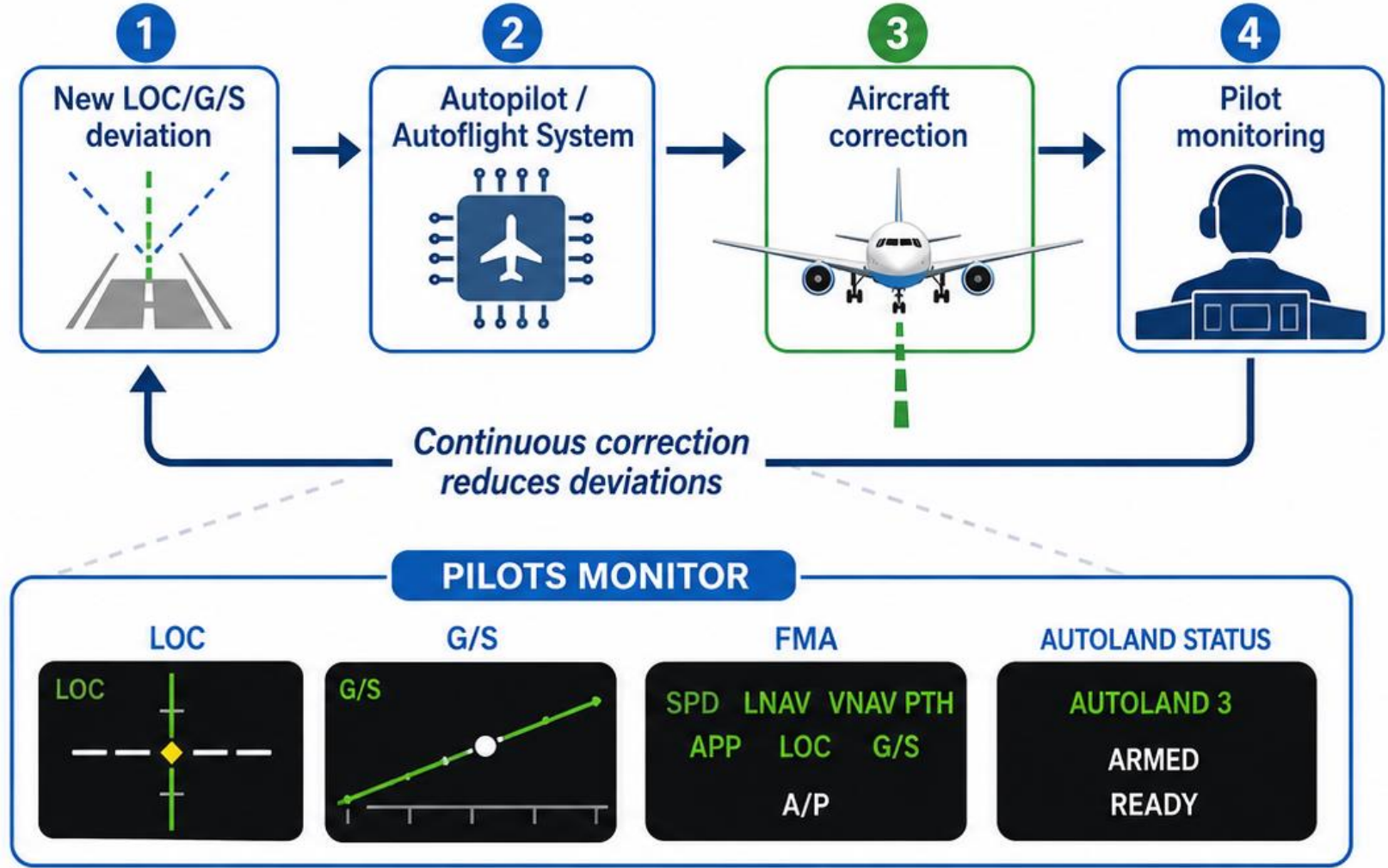
Multiple autopilot resources can support autoland architecture



Pilots monitor LOC, G/S, FMA, and autoland status



Key idea:
Automation does not replace monitoring



More automation requires better monitoring of the automation itself.

Chapter 8 — Fail-Passive and Fail-Operational Architecture

Two concepts become especially important when studying CAT III operations.

Fail-Passive

A **fail-passive** automatic landing system is designed so that, following certain failures, the resulting system condition does not cause a significant aircraft deviation or unsafe attitude, although the automatic landing capability may no longer be available.

Conceptually:

NORMAL AUTOMATIC APPROACH

↓

FAILURE

↓

FAILURE DETECTED

↓

AIRCRAFT REMAINS CONTROLLABLE

↓

AUTOLAND CAPABILITY MAY BE LOST

Fail-Operational

A fail-operational architecture provides a higher level of redundancy.

Following certain failures, sufficient capability remains for the automatic system to continue the required operation within its certification criteria.

Conceptually:

MULTIPLE OPERATIONAL CHANNELS



ONE PERMITTED FAILURE



REMAINING CAPABILITY AVAILABLE



AUTOMATIC OPERATION CAN CONTINUE

The exact capabilities depend on aircraft certification, installed equipment, airport facilities and operational approval.

This is why CAT III capability involves considerably more engineering than simply coupling an autopilot to an ILS.

Chapter 8 – Fail-Passive Architecture

Goal: Keep the aircraft safe even if something fails.

FAIL-PASSIVE

After a failure, the system does not cause dangerous deviations.

The aircraft stays controllable, but autoland may no longer be available.



SAFE FIRST.

Maintain control, even if automation is degraded.

FAIL-PASSIVE ARCHITECTURE

Designed for CAT III Operations



PRINCIPLE: Automation can fail, but safety must never fail.

Chapter 9 — Flight Crew as an Independent Safety Layer

One of the most important redundancy layers remains the **flight crew**.

During the approach, pilots continuously compare multiple indications.

FMA — Flight Mode Annunciator

The crew asks:

What mode is armed?

What mode has captured?

What is actually controlling the aircraft?

LOC

Is the aircraft remaining on the lateral guidance path?

Glide Slope

Is the aircraft remaining on the correct vertical path?

Altitude

Is the altitude consistent with the expected approach profile?

Distance

Does DME or another approved distance reference agree with the expected aircraft position?

Airspeed

Is aircraft energy properly controlled?

Configuration

Are landing gear, flaps, speed and checklists appropriate for the current stage of the approach?

This creates three particularly useful levels of cockpit reasoning:

MCP → PILOT INTENTION

What has been selected.

FMA → AUTOMATION STATE

What the autoflight system is actually doing.

RAW DATA → TRAJECTORY VERIFICATION

Whether the navigation indications remain consistent with the expected aircraft trajectory.

Therefore:

SELECT → VERIFY → CAPTURE → CROSS-CHECK → MONITOR

The pilots remain an active part of the safety architecture even during a fully automatic approach.

Chapter 9 — Flight Crew as an Independent Safety Layer



THE CREW IS THE
FINAL GUARDIAN.

THE CREW ASKS:

- ✓ WHAT MODE IS ARMED?
- ✓ WHAT MODE HAS CAPTURED?
- ✓ WHAT IS ACTUALLY CONTROLLING THE AIRCRAFT?



**CROSS-CHECK.
CONFIRM.
STAY AHEAD.**

Redundancy is only
effective when monitored.

REDUNDANCY IN ACTION = MULTIPLE INDEPENDENT CHECKS



**INDEPENDENT THINKING.
SHARED AWARENESS.**



**SAFE APPROACH.
SAFE LANDING.**



IDEO-LAB

Chapter 10 — Complete ILS Safety Chain

The strength of ILS does not come from one particular component.

It comes from multiple layers of protection.

Layer 1 — Ground Guidance

LOCALIZER + GLIDE SLOPE

↓

Layer 2 — Ground Integrity Monitoring

SIGNAL PERFORMANCE MONITORED

↓

Layer 3 — Infrastructure Protection

POWER + PROTECTED ILS AREAS

↓

Layer 4 — Airborne Reception

ILS RECEIVERS / AVIONICS

Layer 5 — Guidance Processing

LOC + G/S INFORMATION

↓

Layer 6 — Flight-Control Redundancy

FLIGHT DIRECTOR + AUTOPILOT ARCHITECTURE

↓

Layer 7 — Cockpit Monitoring

PFD + FMA + RAW ILS DATA

↓

Layer 8 — Crew Cross-Check

LOC + G/S + ALTITUDE + DISTANCE + SPEED + CONFIGURATION

↓

Layer 9 — Stabilized Approach

STABLE AND CONSISTENT?

YES → CONTINUE

NO → GO-AROUND

Layer 10 — Decision

At the applicable decision point:

Required conditions and visual references satisfied

→ CONTINUE

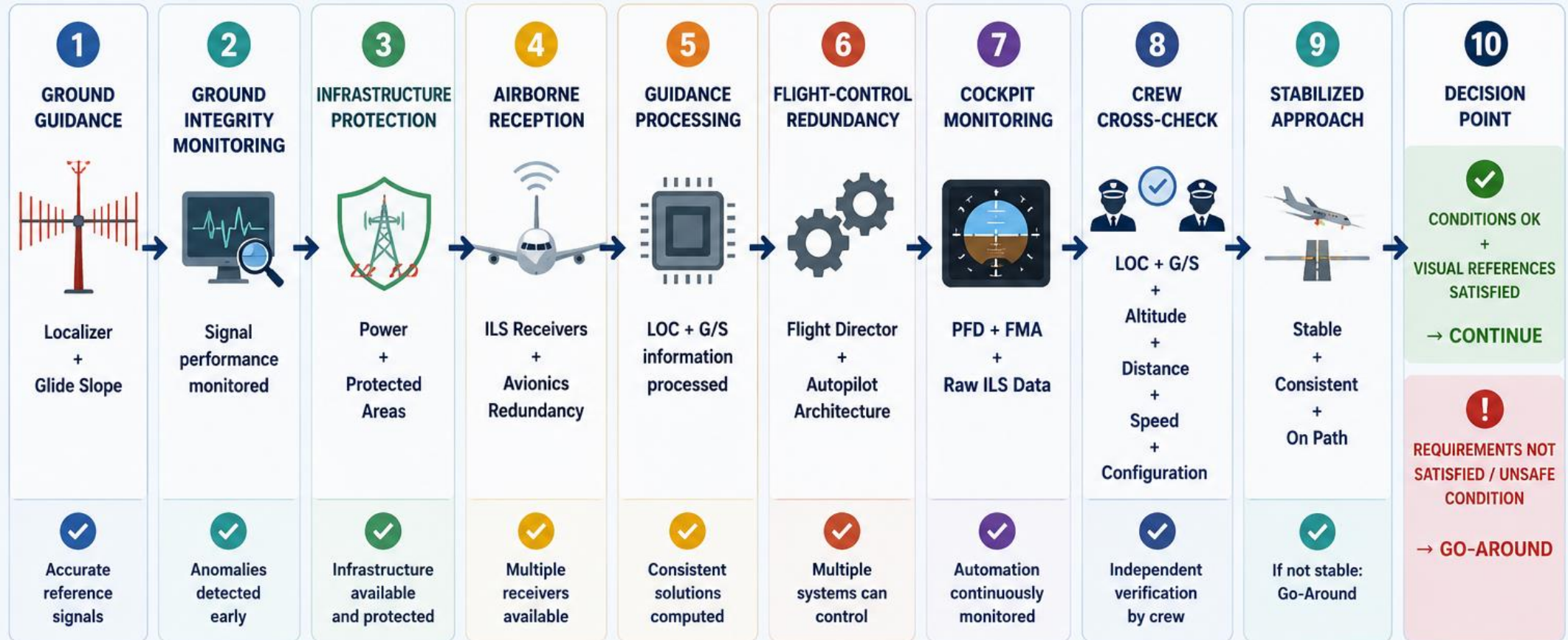
or

Requirements not satisfied / unsafe condition

→ GO-AROUND

ILS SAFETY CHAIN — 10 LAYERS OF PROTECTION

MULTIPLE BARRIERS. ONE GOAL: A SAFE LANDING.



SAFETY IS NOT THE RESULT OF ONE SYSTEM, BUT THE STRENGTH OF ALL LAYERS WORKING TOGETHER.
REDUNDANCY + MONITORING + CROSS-CHECK = SAFE LANDING

Key Takeaway — Redundancy Is a Complete Safety Architecture

ILS redundancy should therefore never be reduced to:

“There are two receivers, so the system is redundant.”

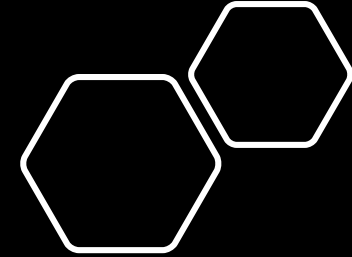
True ILS safety comes from the combination of:

Ground equipment redundancy

- Continuous signal integrity monitoring
- Reliable power architecture
- Protection of ILS critical/sensitive areas
- Airborne receiver and avionics redundancy
- Autoflight redundancy
- Failure detection and comparison
- Fail-passive / fail-operational concepts
- Independent cockpit monitoring
- Flight-crew cross-checking
- Go-around capability

This leads to the fundamental principle behind low-visibility precision approaches:

As external visual references decrease, the required integrity, redundancy and monitoring of the entire guidance chain increase.



THE POWER OF REDUNDANCY

ONE CHAIN IS STRONG ONLY IF EVERY LINK HOLDS



**NOT ONE SYSTEM.
NOT ONE PERSON.
BUT TOGETHER: A SAFE LANDING.**

6. LS Operational Categories

ILS Operational Categories

A Detailed 10-Chapter Technical Overview

ILS operational categories define how low an aircraft may descend and how little external visibility may be available while still conducting a precision approach under approved conditions. They are not simply “different versions” of the same ILS. Each category reflects a progressively more demanding combination of ground infrastructure, aircraft capability, crew qualification, visual aids, automatic-flight capability, redundancy, monitoring, and operational approval.

The central progression is:

CAT I → CAT II → CAT III

As visibility decreases, the system must compensate with greater technical capability and greater assurance.

Chapter 1 — Why ILS Operational Categories Exist

The purpose of ILS categorization is to match the precision and reliability of the complete landing system to progressively lower weather minima.

Two parameters are particularly important:

Decision Height — DH

The height at which the pilot must make the decision to continue the approach or execute a missed approach, according to the applicable procedure and operational approval.

Runway Visual Range — RVR

The measured distance over which a pilot can see runway markings or lights along the runway environment.

RVR therefore describes operational visibility much more precisely than a general meteorological visibility report.

7. ILS APPROACH ON A320

AGENDA ILS APPROACH – A320

- Airbus A320 ILS Approach Architecture – ECAM
- Standard Operating Procedures – SOP
- MCDU Setup
- ILS Display Activation
- Arming the APPR Mode on the FCU
- Second Auto Pilot Engagement
- Localizer Capture
- Glide Slope Capture

- **Cockpit Display Roles in Final Approach:**

- **PFD (Primary Flight Display):** Primary instrument for pilot monitoring (PMA) & flight path control (LOC / GLIDE deviation scales, Flight Mode Annunciator - FMA).
- **ND (Navigation Display):** Situational awareness, terrain clearance, weather radar overlays, and approach track monitoring.
- **ECAM System (E/WD & SD):** Centralized hub for **system integrity, landing configuration status, failure alerts, and landing capability management.**

- **Core Functions of the ECAM During ILS Operations:**

- **System Health Monitoring:** Continuous surveillance of avionics (MMR 1/2, Radio Altimeters 1/2) and flight controls.
- **Landing Capability Determination:** Live degradation tracking determining maximum approach capability (CAT 3 DUAL, CAT 3 SINGLE, CAT 2, or CAT 1).
- **Configuration & Checklist Execution:** Automatic display of the **LDG MEMO** and electronic Landing Checklist.
- **ECAM Warning & Caution Management:** Automatic triggering of ECAM actions and reversion modes in case of system failures during approach.

When flying an ILS approach, the pilots' eyes are primarily on the **PFD** for trajectory guidance—watching the Localizer and Glide Slope diamonds, as well as the FMA modes—and on the **ND** for situational awareness.

However, the **ECAM** acts as the electronic brain running in the background. It does not display the ILS guidance bars themselves, but it performs critical functions behind the scenes:

1. It continuously monitors the hardware supporting the approach, such as the Multi-Mode Receivers (MMR) and Radio Altimeters.
2. It calculates the aircraft's current landing capability—telling the crew whether the aircraft is equipped and capable for a CAT 3 DUAL autoland or if it has downgraded to CAT 2 or CAT 1.
3. It manages aircraft configuration by verifying gear, flaps, spoilers, and cabin readiness through the ECAM Landing Memo.
4. Finally, should any system fail during the approach, the ECAM immediately alerts the crew and provides step-by-step procedures to handle the abnormality safely."

ILS in the Airbus A320 Cockpit

PFD, ND, ECAM, Navigation & Settings During Final Approach

1 PFD — Primary Flight Display



LOC (Localizer)

2
1
1
2

Full Scale
±2.5°

G/S (Glide Slope)

2
1
1
2

Full Scale
±1.0°

- Primary instrument for pilot monitoring and flight path control.
- Shows LOC and GLIDE deviation scales.
- Shows the FMA (Flight Mode Annunciator) at the top.
- Used to monitor localizer capture, glide path capture, speed, altitude, and attitude.

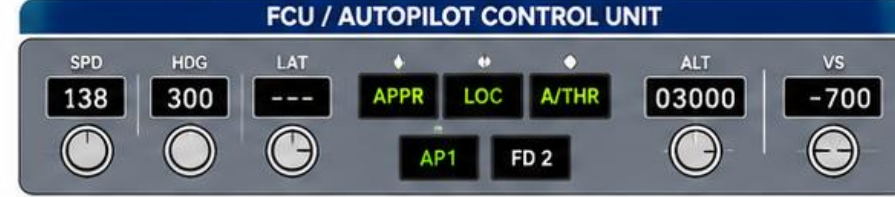
2 ND — Navigation Display



- Provides situational awareness.
- Used for terrain clearance, weather radar overlays, and approach track monitoring.
- Helps confirm runway alignment and overall approach path.

4 ILS Navigation & Settings

- ☒ ILS frequency tuned and identified (ILS / CRS).
- ☒ LS mode / ILS scales displayed on PFD.
- ☒ Barometric or radio minima set.
- ☒ APPR mode armed on the FCU.
- ☒ Final approach course / runway selected.
- ☒ Autopilot or flight directors available for LOC and GLIDE capture.



Autopilot / FD Cues

- APPR armed →
- LOC capture →
- GLIDE capture →
- A/THR active

3 ECAM — System Integrity & Landing Capability



E/WD (Upper Display)

- Centralized hub for system integrity.
- Shows landing configuration status and failure alerts.
- Manages landing capability determination.
- Live degradation tracking can indicate CAT 3 DUAL, CAT 3 SINGLE, CAT 2, or CAT 1.



SD (Lower Display)

- Displays LDG MEMO and electronic landing checklist.
- Triggers ECAM warnings, cautions, and reversion modes if failures occur during approach.

5 ECAM Core Functions During ILS Operations



System Health Monitoring

Continuous surveillance of avionics (MMR 1/2), radio altimeters 1/2, and flight controls.



Landing Capability Determination

Live degradation tracking determining maximum approach capability.

CAT 3 DUAL CAT 3 SINGLE CAT 2 CAT 1



Configuration & Checklist Execution

Automatic display of the LDG MEMO and electronic landing checklist.



Warning & Caution Management

Automatic triggering of ECAM actions and reversion modes in case of failures during approach.

FINAL APPROACH WORKFLOW



In the A320, the PFD guides the flight path, the ND provides approach awareness, and the ECAM monitors aircraft status, landing configuration, and approach capability for a safe ILS approach.



ILS Final Approach — Pilot Monitoring and ECAM Support

Where the crew looks during an ILS approach, and what ECAM does in the background

1 Primary Pilot Focus — PFD

During an ILS approach, the pilots' eyes are primarily on the PFD for trajectory guidance.



- ✓ Main instrument for trajectory guidance
- ✓ Monitor LOC and GLIDE deviations
- ✓ Check FMA mode annunciations

2 Situational Awareness — ND

The ND supports situational awareness by monitoring the approach track and surroundings.



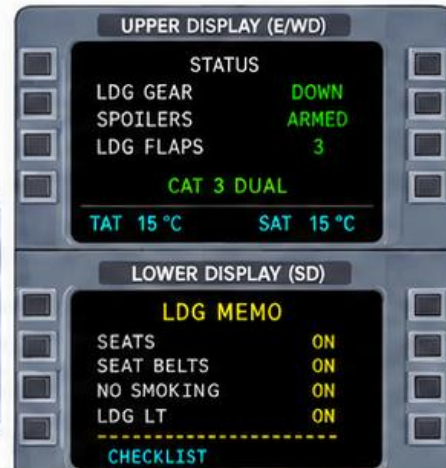
- ✓ Supports situational awareness
- ✓ Helps monitor approach track
- ✓ Complements the PFD during final approach

3 ECAM — The Electronic Brain in the Background

The ECAM does NOT display the ILS guidance bars themselves. It performs critical support functions behind the scenes.



ECAM does not show LOC/GLIDE guidance bars; it supports the approach by monitoring aircraft systems, landing capability, configuration, and failures.



- i If any system fails during the approach, the ECAM immediately alerts the crew and provides step-by-step procedures to handle the abnormality safely.

4. ECAM Core Functions During ILS Approach

A

System Health Monitoring



Continuously monitors the hardware supporting the approach.

- Multi-Mode Receivers (MMR)
- Radio Altimeters



MMR



RADIO ALT

B

Landing Capability Determination



Calculates the aircraft's current landing capability based on systems status and conditions.

CAT 3 DUAL CAT 2 CAT 1

Displays current capability on ECAM.

C

Configuration Management



Verifies aircraft configuration for landing.

- Gear, flaps, spoilers
- Cabin readiness
- Through the ECAM Landing Memo

D

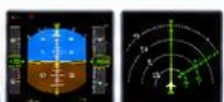
Failure Alerts & Procedures



If a system fails during approach, the ECAM:

- Alerts the crew immediately
- Provides step-by-step procedures to handle the abnormality safely

5. ILS Approach Workflow



PFD + ND watched by pilots for guidance and situational awareness



ECAM monitors in the background for systems, capability, configuration, and failures



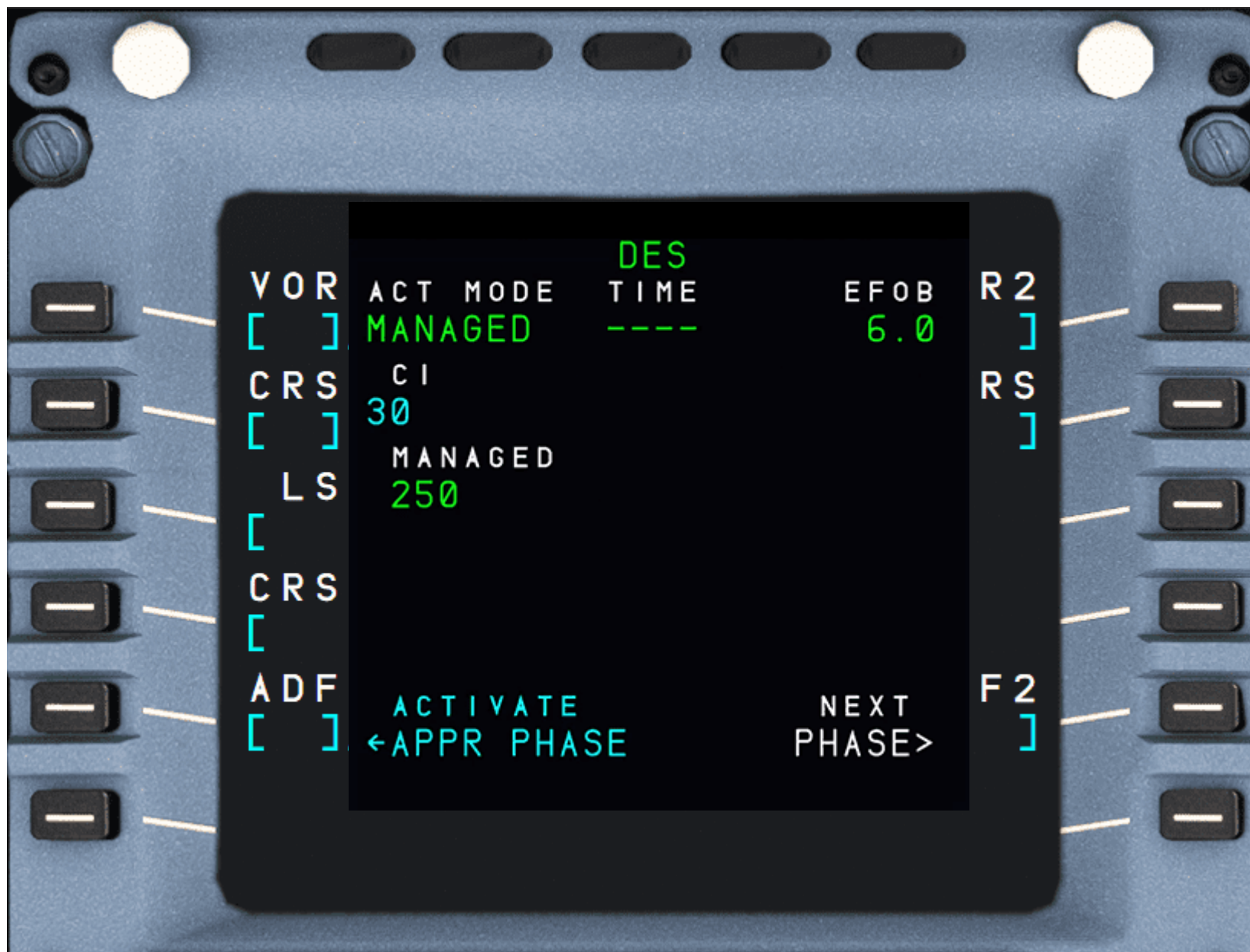
Crew continues / adjusts as needed

- Continue approach (CAT 3 DUAL)
- Downgrade capability (CAT 2 / CAT 1)
- Handle abnormality using ECAM procedures



During an ILS approach, the PFD provides the primary guidance, the ND supports situational awareness, and the ECAM silently manages system integrity, landing capability, configuration, and failure handling.





① MCDU Setup: PERF APPR & RAD NAV Pages

Performed approximately 10 to 15 minutes before Top of Descent (TOD)

The crew prepares the Flight Management System (FMGS) via the MCDU during approach preparation:

-

PERF APPR Page: Input destination QNH, temperature, surface wind, transition level, and verify the **DH** (Decision Height) or **MDA** according to the approach category (CAT I, II, or III).

-

RAD NAV Page: Verify that the ILS frequency and front-course (**CRS**) have been automatically tuned by the system (autotuning). Manual tuning can be forced if required.



MCDU Programming for ILS Approach

PERF APPR & RAD NAV setup — typically 10 to 15 minutes before Top of Descent (TOD)



10-15 MIN



1 Approach Preparation in the FMGS

The crew prepares the Flight Management and Guidance System (FMGS) via the MCDU during approach preparation.

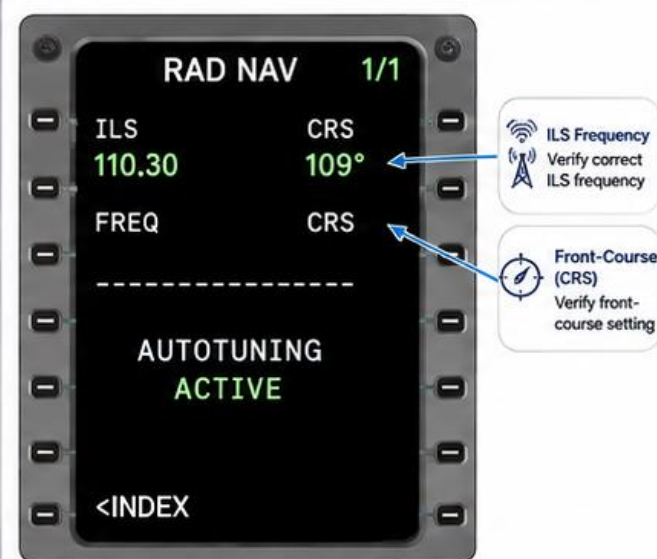


2 PERF APPR Page



On the PERF APPR page, pilots enter destination weather and minima to ensure the aircraft uses the correct minima for the selected approach category (CAT I, II or III).

3 RAD NAV Page



On the RAD NAV page, the crew verifies that the ILS frequency and front-course (CRS) have been automatically tuned by the system (autotuning). Manual tuning can be forced if required.

4 Pilot Checks

- ✓ Confirm airport pressure setting (QNH)
- ✓ Review minima (DH / MDA)
- ✓ Verify ILS frequency and CRS
- ✓ Confirm CAT relevance (CAT I / II / III)
- ✓ Ensure manual backup possible if needed



5 Programming Workflow



6 Why It Matters



Correct MCDU programming ensures the aircraft is configured with the right minima, local atmospheric data, and ILS tuning before final approach. This supports situational awareness, reduces workload, and enhances approach safety.

② ILS Display Activation on the PFD

Upon reaching the approach or interception sector

Each pilot presses the **LS** push-button located on their respective EFIS Control Panel:

- The **Localizer** deviation scale (lateral axis) appears at the bottom of the PFD.
- The **Glide Slope** deviation scale (vertical axis) appears on the right side of the PFD.
- The ILS identifier code (e.g., I-CDG), frequency, and DME distance display on the bottom left of the PFD for audio/visual identification.



ILS Display Activation on the PFD

Upon reaching the approach or interception sector



10-15 MIN



RAD / NAV



FINAL APPROACH

1 LS Pushbutton Activation

Upon reaching the approach or interception sector:

Each pilot presses the **LS** push-button on their respective EFIS Control Panel.



CAPTAIN
Press LS

FIRST OFFICER
Press LS



Activating LS makes the ILS guidance symbology (LOC and G/S scales, and identifier data) appear on the PFD.

2 What Appears on the PFD



3 ILS Identifier, Frequency, and DME Distance
Appears at the bottom left of the PFD.

1 Localizer Deviation Scale (Lateral Axis)
Appears at the bottom of the PFD.

2 Glide Slope Deviation Scale (Vertical Axis)
Appears on the right side of the PFD.

LEGEND

- On-Course
- Small Deviation
- Large Deviation

3 Pilot Interpretation



Localizer Deviation Scale (Lateral Axis)

- Helps monitor lateral alignment with the runway centerline.



Glide Slope Deviation Scale (Vertical Axis)

- Helps monitor vertical path capture and deviation.



Identifier / Frequency / DME (Bottom Left)

- Confirms audio-visual tuning and supports approach awareness.



Use the scales to maintain guidance within acceptable limits and crosscheck the aircraft's flight path with ATC clearances and procedures.

4 Activation Sequence

1 Reach Approach Sector



Intercept approach or receive final approach clearance.

2 Press LS



Each pilot presses the LS pushbutton on their EFIS panel.

3 Display LOC / G/S Scales



Localizer scale appears at the bottom; Glide Slope scale appears on the right.

4 Verify Identifier / Frequency / DME



Confirm identifier, frequency, and DME distance for audio-visual verification and awareness.

5 Continue Monitoring



Monitor LOC and G/S deviations and crosscheck with aircraft path throughout final approach.



The LS selection displays the key ILS symbology on the PFD, allowing the crew to monitor localizer alignment, glide slope tracking, and navigation identification during final approach.



③ Arming the APPR Mode on the FCU

Usually under radar vectors or on an approach flight plan intercept point

When cleared for the ILS approach by Air Traffic Control:

-

The Pilot Flying (PF) presses the **APPR** push-button on the FCU.

-

FMA Annunciation (PFD): Armed modes appear in blue on the second line of the Flight Mode Annunciator: LOC (armed) and G/S (armed).

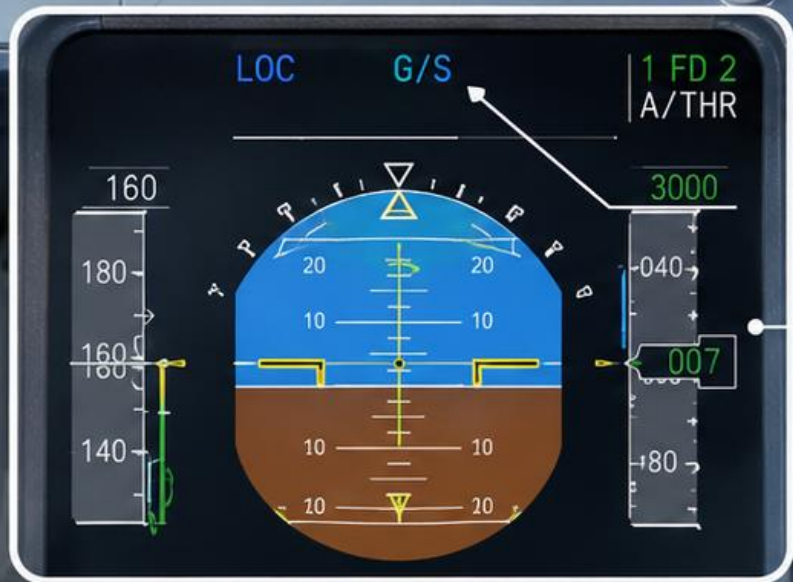
A320 ILS — APPR Mode on the FCU

Arm LOC and G/S for the ILS approach



1 ATC clears ILS approach

2 PF presses APPR



3 FMA shows
LOC and G/S armed

4

Second Autopilot Engagement (Optional - Autoland / CAT II/III)

Mandatory for low-visibility precision approaches or Autoland

-

The PF engages the second autopilot by pressing **AP 2** on the FCU (activating both **AP 1 + AP 2**).

-

This establishes full system redundancy required for fail-operational capabilities (CAT 3 DUAL).

A320 ILS — Second Autopilot Engagement

Required for low-visibility / autoland capability

1 PF engages AP2



2 AP1 + AP2 active

Both autopilots engaged



3 CAT 3 DUAL / full redundancy

Fail-operational capability for autoland

5

Localizer Capture (Runway Centerline)

Lateral Interception

-

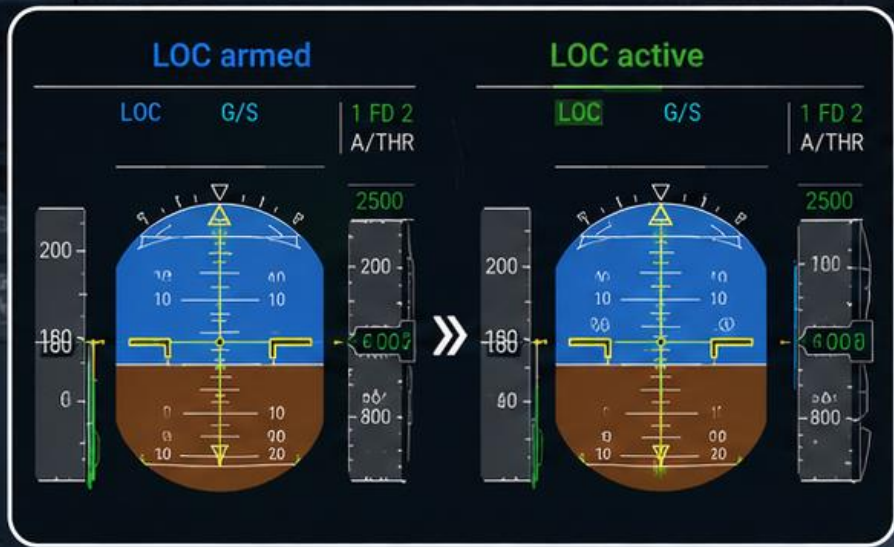
As the aircraft approaches the extended runway centerline, the LOC mode turns from blue (armed) to green (active) on the top line of the FMA.

-

The Autopilot (or Flight Director) turns the aircraft to intercept and track the runway centerline.

LOCALIZER CAPTURE

Runway Centerline



INTERCEPT



TRACK CENTERLINE



FD COMMAND

Bank command guides the turn to capture and track the centerline.

⑥ Glide Slope Capture (Descent Path)

Vertical Interception

-

When the green Glide Slope diamond centers on the vertical scale, the G/S mode turns from blue (armed) to green (active) on the FMA.

-

The aircraft begins its continuous 3° descent path.

-

Airbus Safety Standard: The G/S must always be captured from below to prevent intercepting false radio signal lobes (false glides).

THR

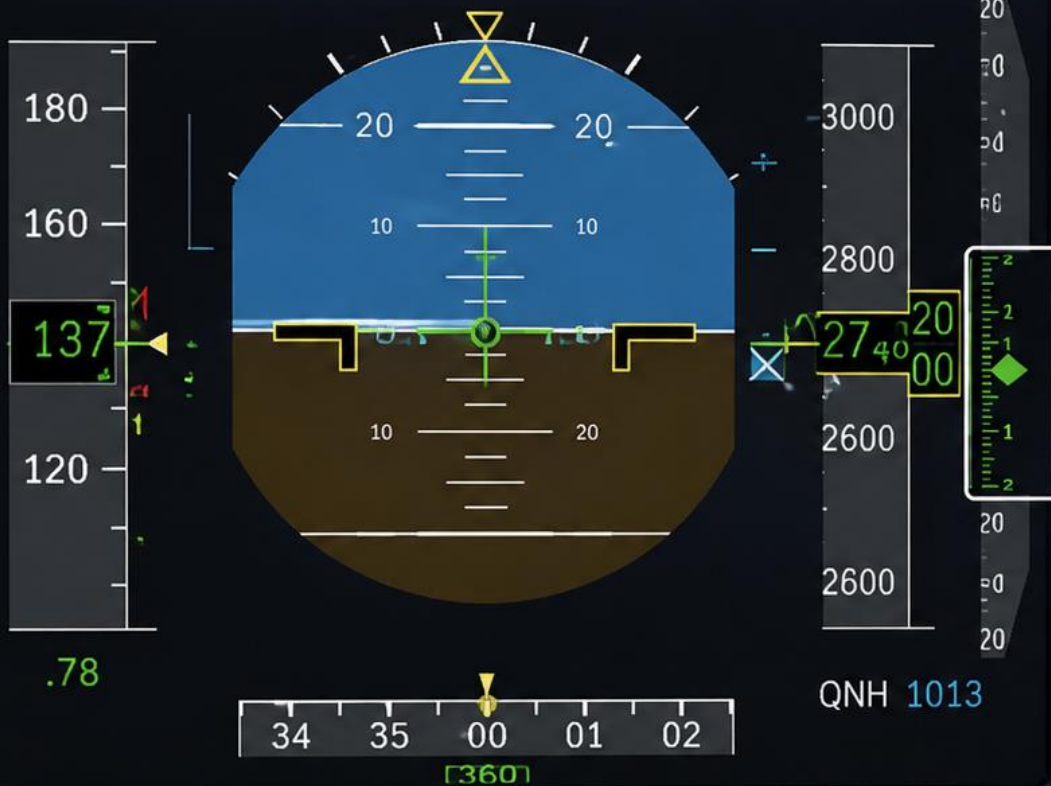
LOC

G/S

CAT 3

AP1+2

1 FD 2 A/THR



GLIDE SLOPE CAPTURED

G/S ACTIVE (GREEN)



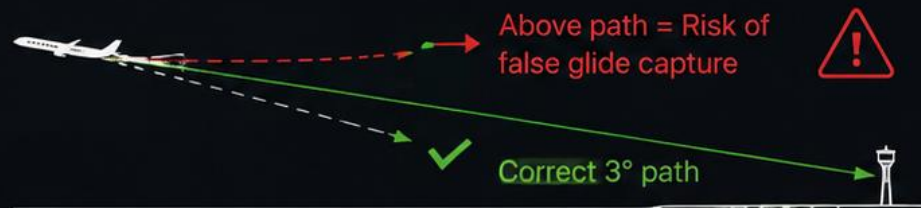
G/S

Green diamond centered
= Glide Slope captured
G/S mode changes from
blue (armed) to **green (active)**
on the FMA.



SAFETY STANDARD:

Capture the Glide Slope from below
to avoid false glide captures.



ILS: EASY IN THEORY...
HARD IN REALITY!

APPR MODE?
LOC? G/S?
PF? PFD?
WHAT DOES
ANY OF THIS
DO?!

⚠️ RUNWAY AHEAD
GETTING CLOSER FAST!

APPR
MODE

SECOND
AUTOPILOT
(WHY NOT?)

PRESS!

PRESS!

PRESS!

MAYBE IF I
PRESS **EVERYTHING**,
IT WILL WORK ?!

PFD
PLEASE HELP
ME !

💡 **REALITY CHECK:**
ILS DOESN'T NEED CONFIDENCE...
IT NEEDS **KNOWLEDGE** !

LOC CAPTURED ?
GREEN GOOD !

EVERYTHING
PRESSED.
NOW IT MUST
WORK... **RIGHT?!**

KEEP CALM, FOLLOW THE PROCEDURES,
LET THE SYSTEM DO ITS JOB! 😊

TO DO LIST:
✅ AVIATE
✅ NAVIGATE
✅ COMMUNICATE
... **AND DON'T PANIC!** 😊

8. Sheremetyevskoye ILS Installations









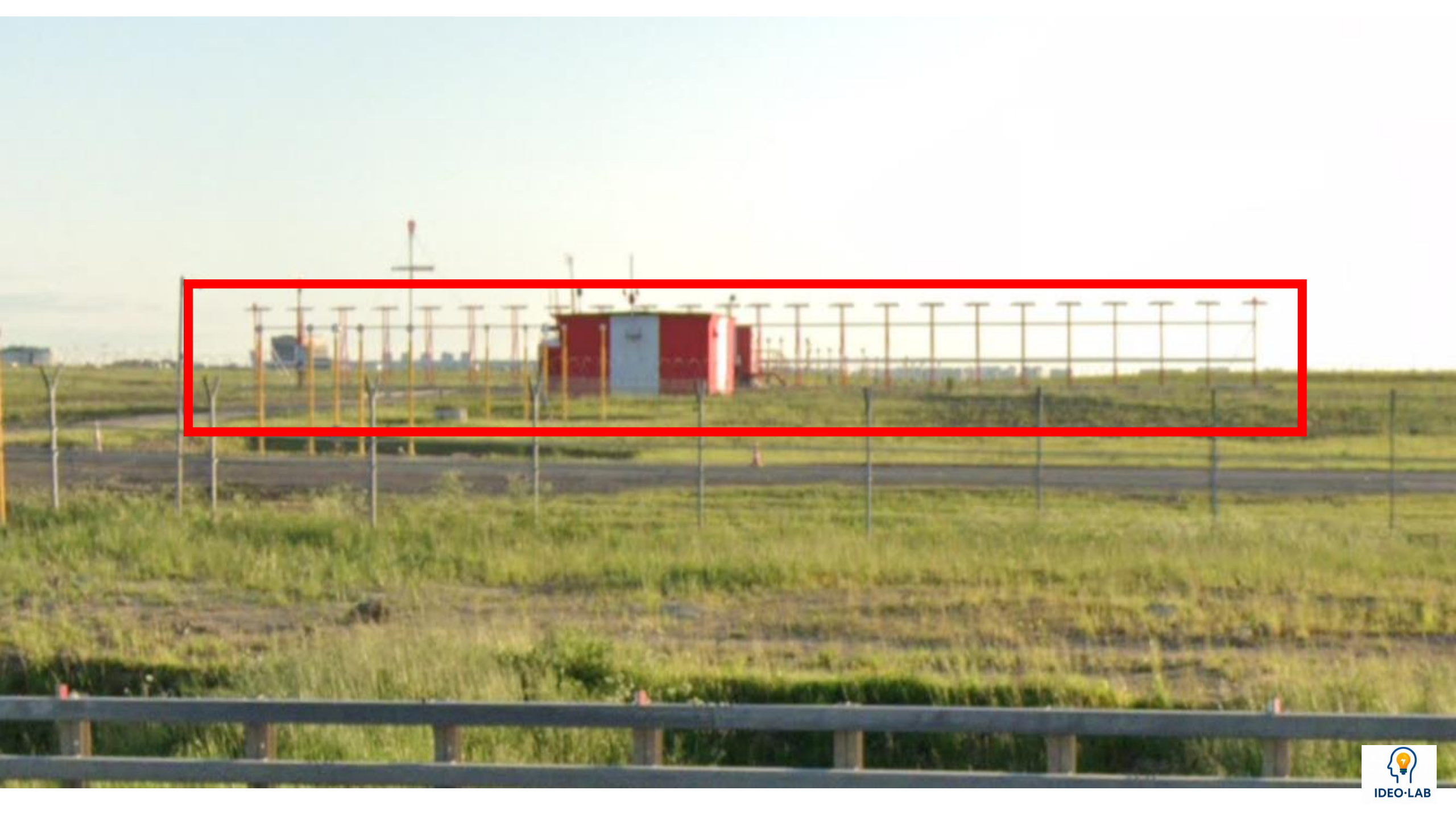




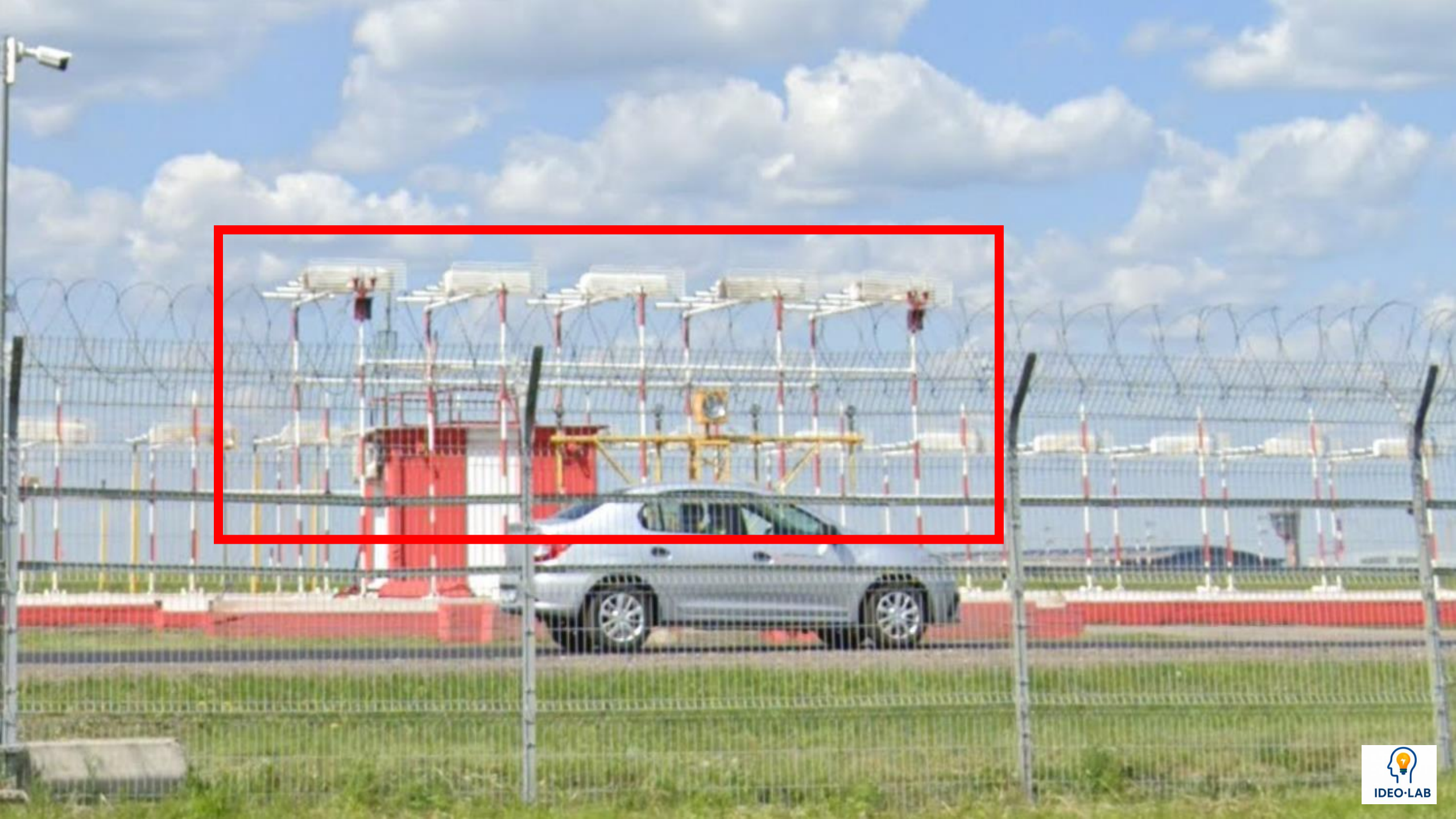












OPERATION BLINDFALL

- **Phase I: Intelligence & Target Acquisition**
- **Phase II: Asset Preparation**
- **Phase III: Execution**
- **Phase IV: Aftermath**
- **Phase V: Attribution**

Phase I: Intelligence & Target Acquisition

Moscow's Sheremetyevo International Airport (UUEE) handles 40+ million passengers annually. Its Instrument Landing System (ILS) infrastructure—specifically the localizer arrays at Runway 24R and glide path antennas near the threshold—represents a high-value, low-risk target set. Unlike runways (easily repaired), ILS equipment requires specialized calibration, imported components, and weeks of certification.

Satellite imagery identifies three critical nodes:

- **Localizer Station 24R:** 110-meter antenna array at 55°58'32"N, 37°25'15"E
- **Glide Path Facility:** 15-meter tower assembly northeast of threshold
- **DME/Transmitter Building:** Backup navigation aid 800m south

Phase II: Asset Preparation

Ukrainian Military Intelligence (HUR) deploys three modified UJ-22 Airborne drones—each retrofitted with 15kg shaped-charge warheads and enhanced SATCOM navigation. Launch sites: forested areas 280km northwest, near the Belarusian border corridor. Flight path programmed to exploit radar gaps in the Klin-Solnechnogorsk sector, hugging terrain at 150m AGL until final approach.

Moscow Sheremetyevo (UUEE): Critical ILS Node Intelligence

1 Phase I: Target Identification & Assessment

High-Value Target: ILS Equipment



- Complex System
- Imported Components
- Weeks for Certification

asset contrast easily repaired runways



Targeting interconnects the ILS system causes system-wide failure.



Complex technical interdependencies of ILS system causes targeter specific nodes cause system-wide failure.

Moscow Sheremetyevo,
40+ Million Passengers Annually

Localizer Station 24R
(110m Array)
55°58'32"N, 37°25'15"E

Glide Path Facility (15m Tower)
NE of Threshold

DME/Transmitter Building
800m South

2 Phase II: Asset & Attack Vector Preparation

Modified UJ-22 Airborne Drone

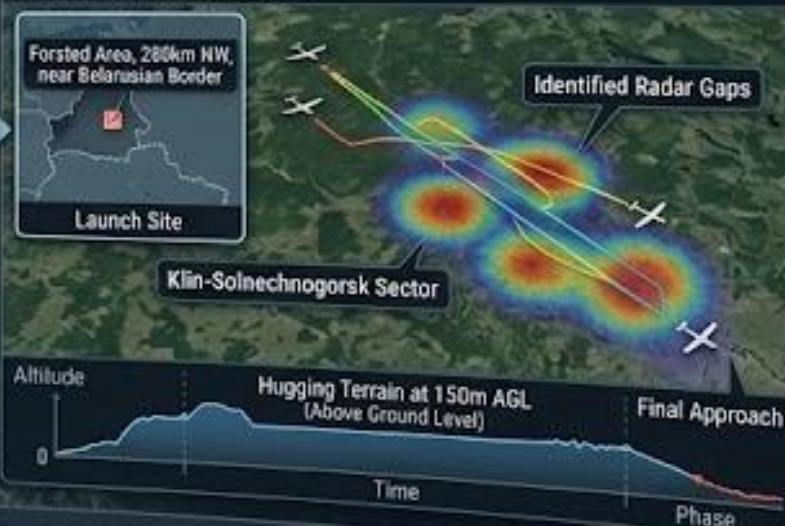
15kg Shaped-Charge Warhead

Enhanced SATCOM
Navigation System

- Deployment Unit: HUR (Ukrainian Military Intelligence)
- Total Assets: 3 Drones

Modification mission retrofits: aerofits

Planned Mission Vector



Phase III: Execution

T-Minus 00:00: Launch at dusk, 45 minutes before scheduled Aeroflot long-haul arrivals from Dubai and Beijing.

T+22:00: Drones climb to 400m, switching to GPS waypoint navigation. Russian Pantsir-S1 batteries at Khimki detect faint returns but classify as birds or weather clutter.

T+38:00: Lead drone acquires thermal signature of Localizer 24R. Descent to 80m. Impact detonation severs the antenna array at midpoint, scattering waveguide components across 200 meters.

T+41:00: Second drone strikes Glide Path facility. Explosion collapses the metal tower into the transmitter shed.

T+44:00: Third drone aborts primary (DME) target due to wind shear, instead impacting the airport's central transformer substation—plunging Terminal D into darkness and disabling backup ILS power.

Phase IV: Aftermath

- **Immediate:** All ILS approaches to 24R/06L suspended. Controllers switch to VOR/NDB procedures, reducing capacity by 70%. Three inbound flights divert to Domodedovo; two hold for 90 minutes before fuel-critical emergency landings in visibility below CAT-I minimums.
- **24 Hours:** Emergency repairs begin, but localizer antenna alignment requires German-manufactured dipole elements (sanctions-blocked). Russian technicians cannibalize Vnukovo's secondary system.
- **Strategic Effect:** For 11 days, Sheremetyevo operates as a regional airport. International carriers (Emirates, Lufthansa, Air China) suspend routes citing insurance clauses. The \$40M daily economic bleed compounds pressure on Moscow's war logistics.

1 T-Minus 00:00 - Dusk



Lancement au crépuscule.
Arrivées Aeroflot bloquées

Hidden, mobile,
multi-copter drone
launches

2 T+22:00 - Detection



Détection Pansir-S1 - Clutter/Oiseaux.
Passage navigation GPS

4 T+44:00 - Diverted Chaos



Échec cible primaire (DME) -
Impact Sous-station Centrale

Terminal D dans le noir.
Alimentation secours ILS HS

3 T+38:00 a T+41:00 - Impacts



Détérioration Localizer 24R.
Impact détruit l'antenne

Impact Glide Path.
Affaissement de la tour

Section IV : Conséquences (Après l'Attaque)

• Immediate: All approaches

24R/06L **SUSPENDUS**
24R/06L **SUSPENDUS**
24R/06L **SUSPENDUS**
24R/06L **SUSPENDUS**

• Contrôleurs passent en VOR/NDB Capacité réduite de 70%



Détournements vers Domodedovo.
Atterrissages d'urgence
(Visibility < CAT-I, Carburant-Critique)



• 24 Hours: Début des réparations. Alignement Localizer : Pièces allemandes (Sanctions)



• Strategic Effect: Pour 11 jours : Statut "Aéroport Régional"



\$40M daily economic bleed.
Pression logistique de guerre

Phase V: Attribution

Ukrainian command maintains operational silence. Telegram channels "Grey Zone" and "Rybar" blame "sabotage cells," but shrapnel analysis confirms airborne delivery. Russian MoD retaliates with Kinzhal strikes on Ukrainian power infrastructure—proving the airport's vulnerability touched a nerve.

Tactical Notes: No casualties. Pure infrastructure warfare. The ILS arrays took six months to install originally. Replacement under sanctions: potentially years.

9. Microsoft Simulator 2020/2024

10. Software Development Across the Complete ILS Infrastructure

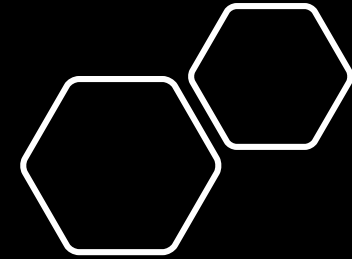
A 10-Chapter Engineering Architecture

An Instrument Landing System is often presented as a radio-navigation system, but a modern ILS environment is also a substantial software ecosystem. Software participates in configuration, signal generation and supervision, equipment health monitoring, airport integration, airborne signal processing, cockpit presentation, autoflight guidance, maintenance, simulation, recording, cybersecurity, and safety assurance.

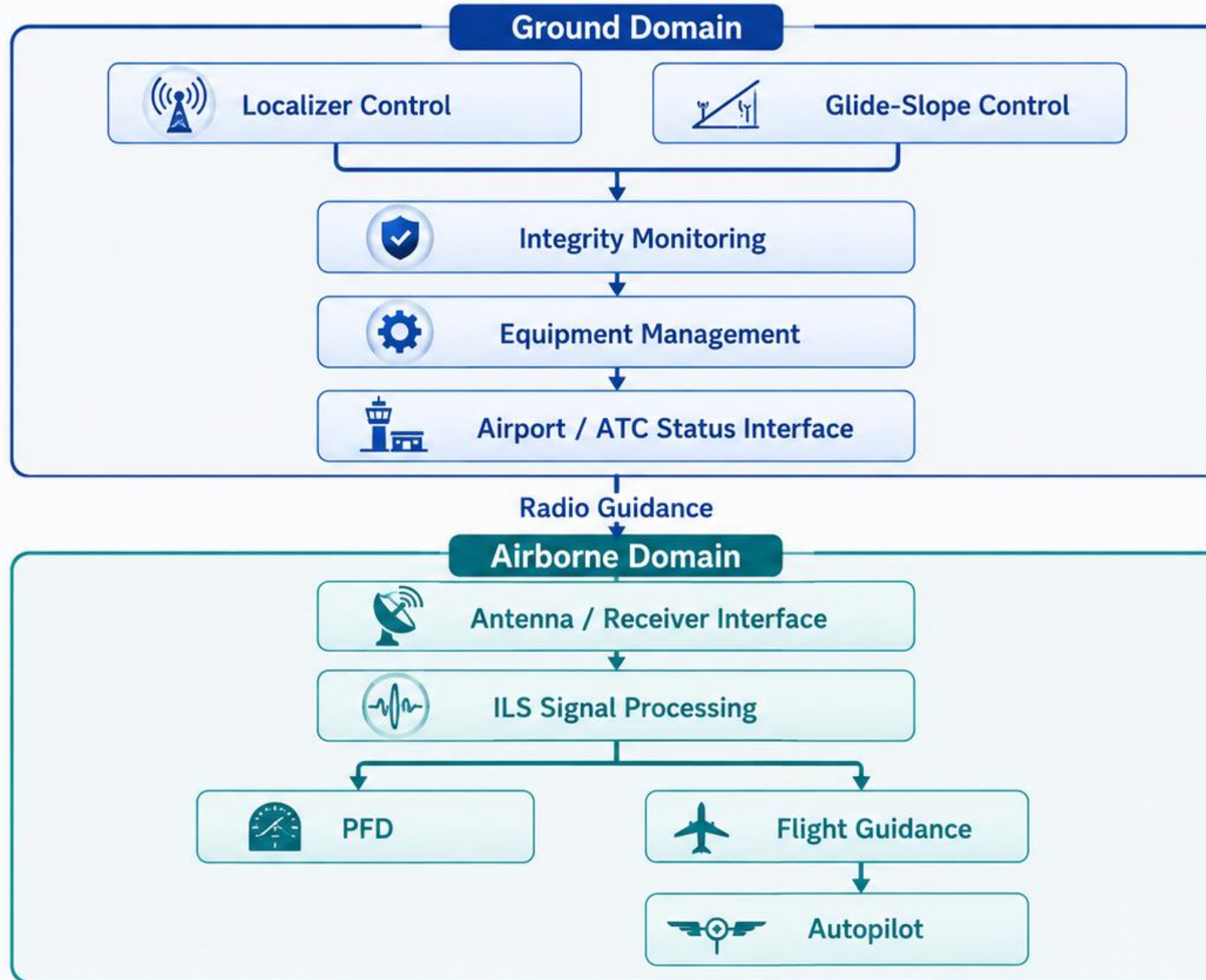
The complete software chain can therefore be viewed as:

GROUND ILS → MONITORING → AIRPORT SYSTEMS → RADIO LINK → AIRBORNE
AVIONICS → FLIGHT GUIDANCE → AUTOPILOT → CREW MONITORING

The crucial engineering requirement is that software must never turn a detectable equipment failure into **credible but misleading guidance**.



ILS Software Ecosystem



Each domain should have a clearly defined responsibility.

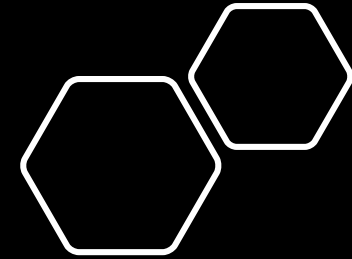
This is especially important in safety-critical engineering because one monolithic software application should not simultaneously be responsible for:

- generating guidance;
- determining whether that guidance is valid;
- declaring itself healthy;
- presenting operational status.

Independent monitoring provides a much stronger architecture.

A useful principle is:

The component generating safety-critical information should not be the only component deciding whether that information is trustworthy.



Chapter 2 — Localizer and Glide-Slope Ground Software

At ground level, software supports the management of the two fundamental ILS subsystems:

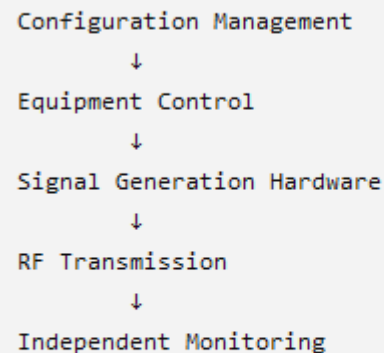
LOC — Localizer

and

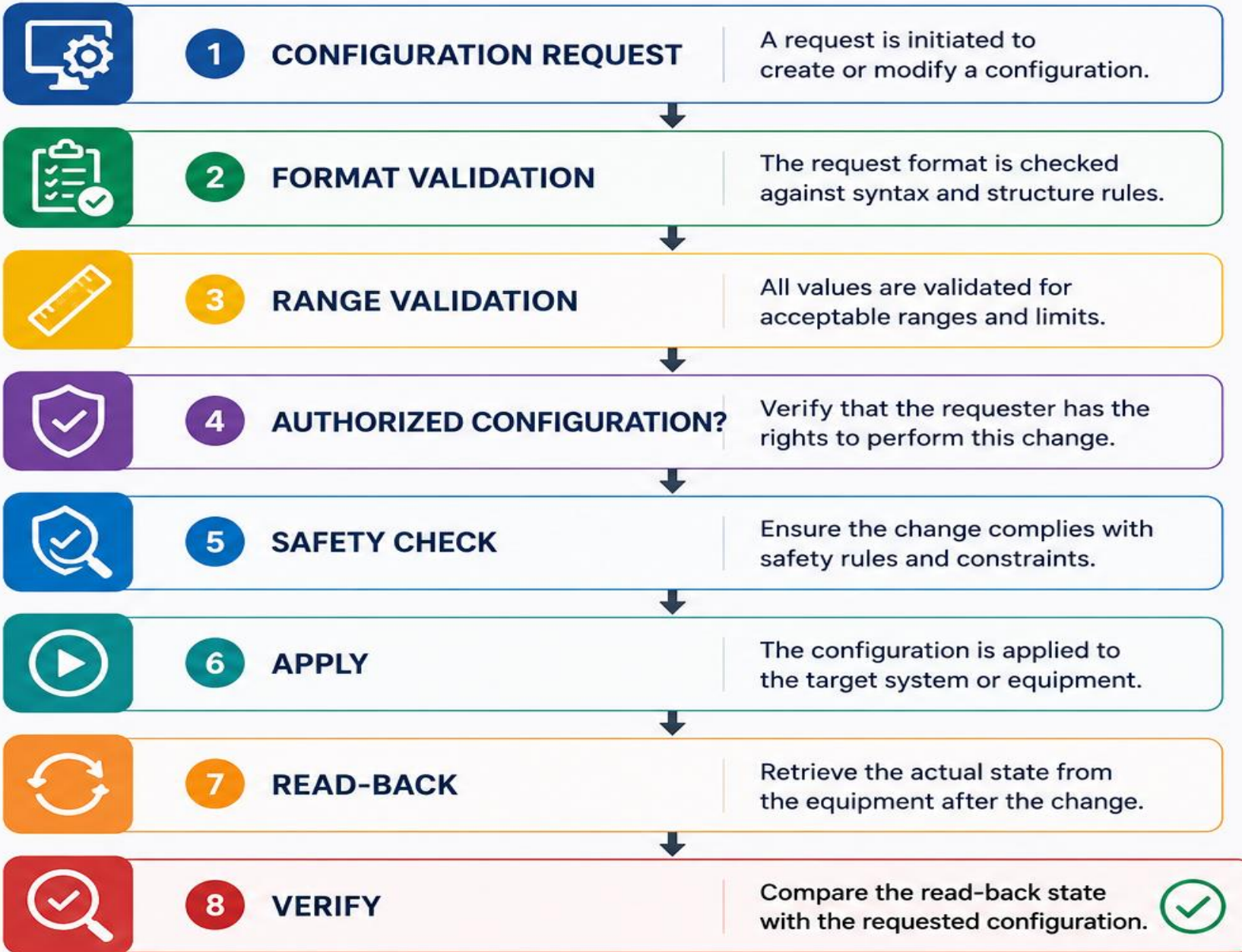
G/S — Glide Slope.

The radio-frequency and modulation functions ultimately depend on specialized certified hardware, but software and firmware can participate in equipment configuration, control and supervision.

The software architecture may therefore include:



Important software-controlled parameters can include authorized equipment configuration, operating mode, transmitter selection, calibration state and maintenance status.



FINAL READ-BACK VERIFICATION = CRITICAL STEP FOR SAFETY AND RELIABILITY



WHY READ-BACK VERIFICATION MATTERS

The software should not merely assume that because a command was sent, the physical equipment entered the requested state.



Objective

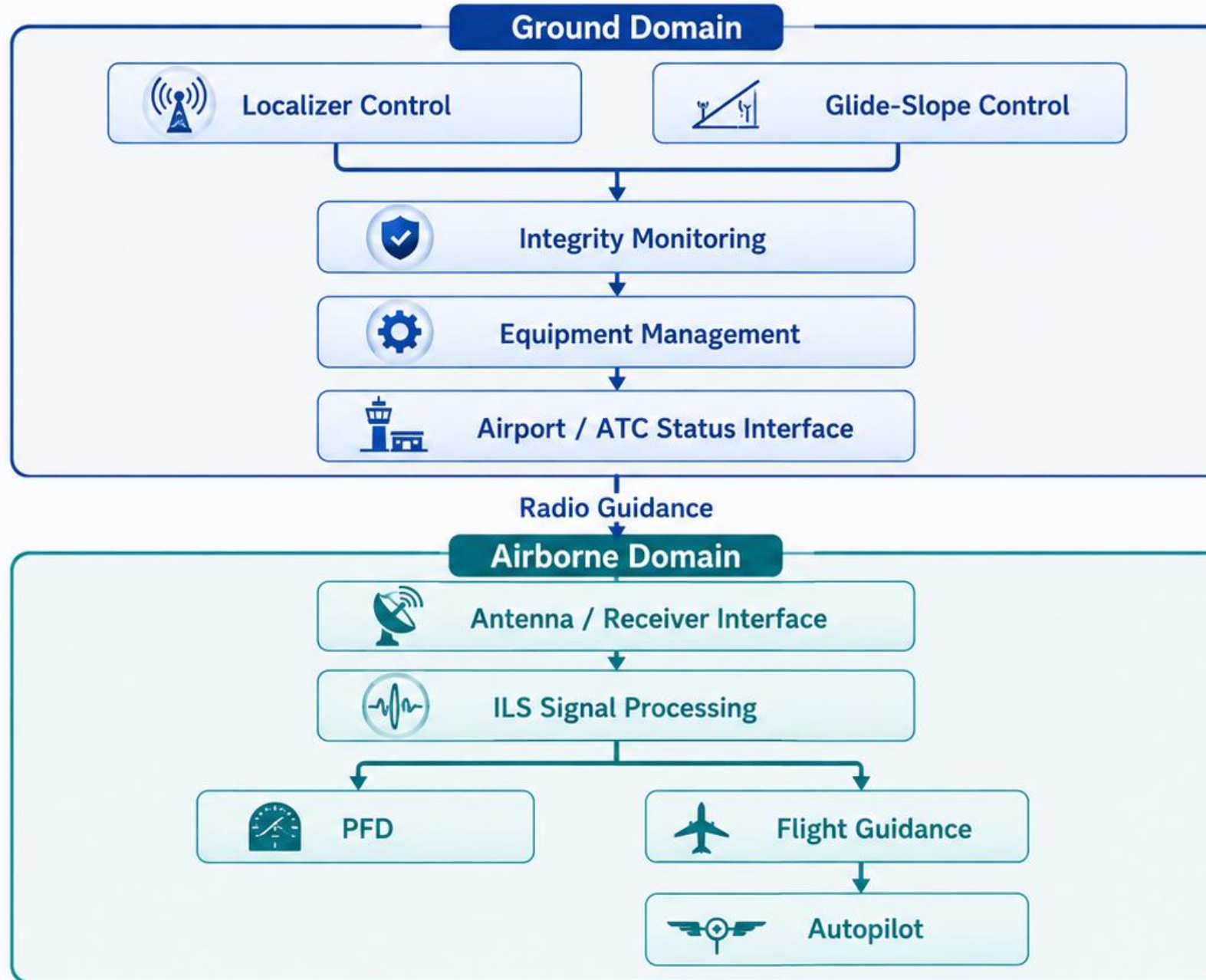
Ensure that the system is truly in the desired and safe configuration.



Benefit

Prevents undetected errors, enhances safety, and guarantees operational integrity.

ILS Software Ecosystem



Signal validity

Is the monitored guidance within permitted parameters?

Equipment consistency

Do redundant components agree?

Timing

Has the anomaly persisted long enough to qualify as a fault?

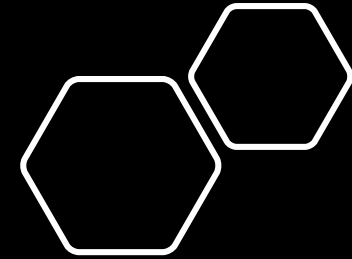
Sensor validity

Can the monitoring measurement itself be trusted?

Communication integrity

Is monitoring information arriving correctly and within the expected time?

This naturally leads to a state-machine architecture.



Chapter 4 — Redundancy and Fault-Management Software

Redundant hardware becomes useful only if software knows how to manage it safely.

Suppose an installation contains:

TRANSMITTER A

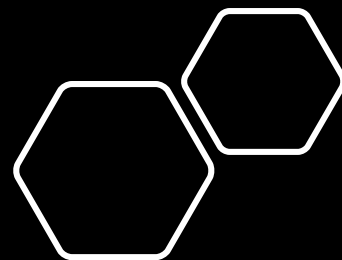
TRANSMITTER B



The software needs to know:

- which unit is active;
- which unit is standby;
- whether each unit is healthy;
- whether they agree;
- whether automatic changeover is permitted;
- whether the resulting configuration remains operationally valid.

This requires a **Fault Detection, Isolation and Recovery** architecture — FDIR.

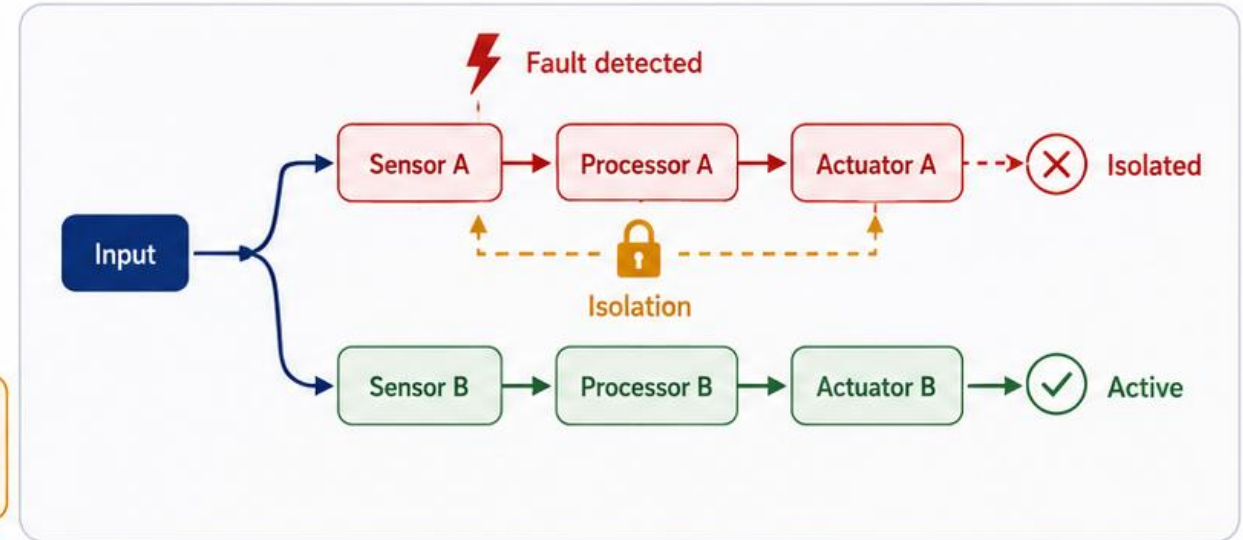


Fault Isolation & Safe Reconfiguration

When a fault occurs, the system must detect it, isolate it, and protect the valid redundant chain.



Redundant System Example



Goal



Prevent a faulty component from contaminating the healthy chain.

Fault Types



Transient fault

Temporary disturbance



Persistent fault

Repeated or lasting fault



1

Fault

An abnormal condition occurs.



2

Detection

The system detects a potential issue.



3

Confirmation

Validate that the fault is real.



4

Isolation

Separate the faulty component to protect the healthy chain.

★ Critical step

Most important to system safety



5

Reconfiguration

Update routing / control to use the healthy redundancy.



6

Verification

Confirm the system operates within safe limits.



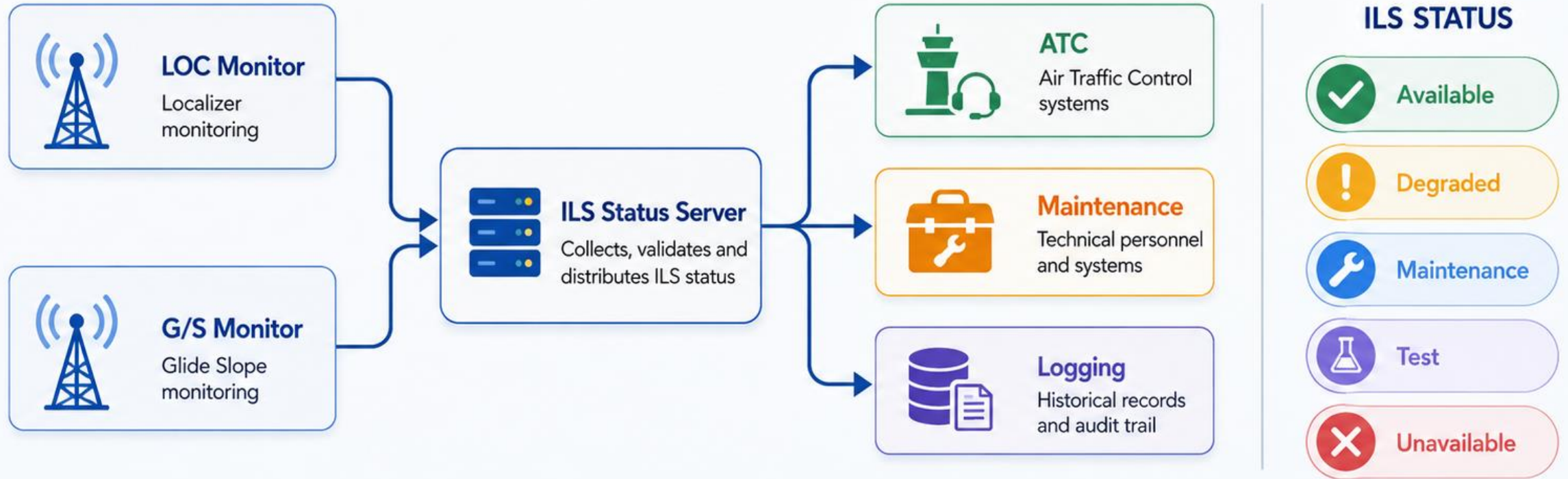
7

Status Annunciation

Inform crew / ground of the fault status and actions taken.

Airport, ATC & Remote-Monitoring Integration

ILS status is distributed to the people and systems that need it.



Shared status

One source of truth across the airport.



Operational awareness

Real-time visibility for better decisions and safety.

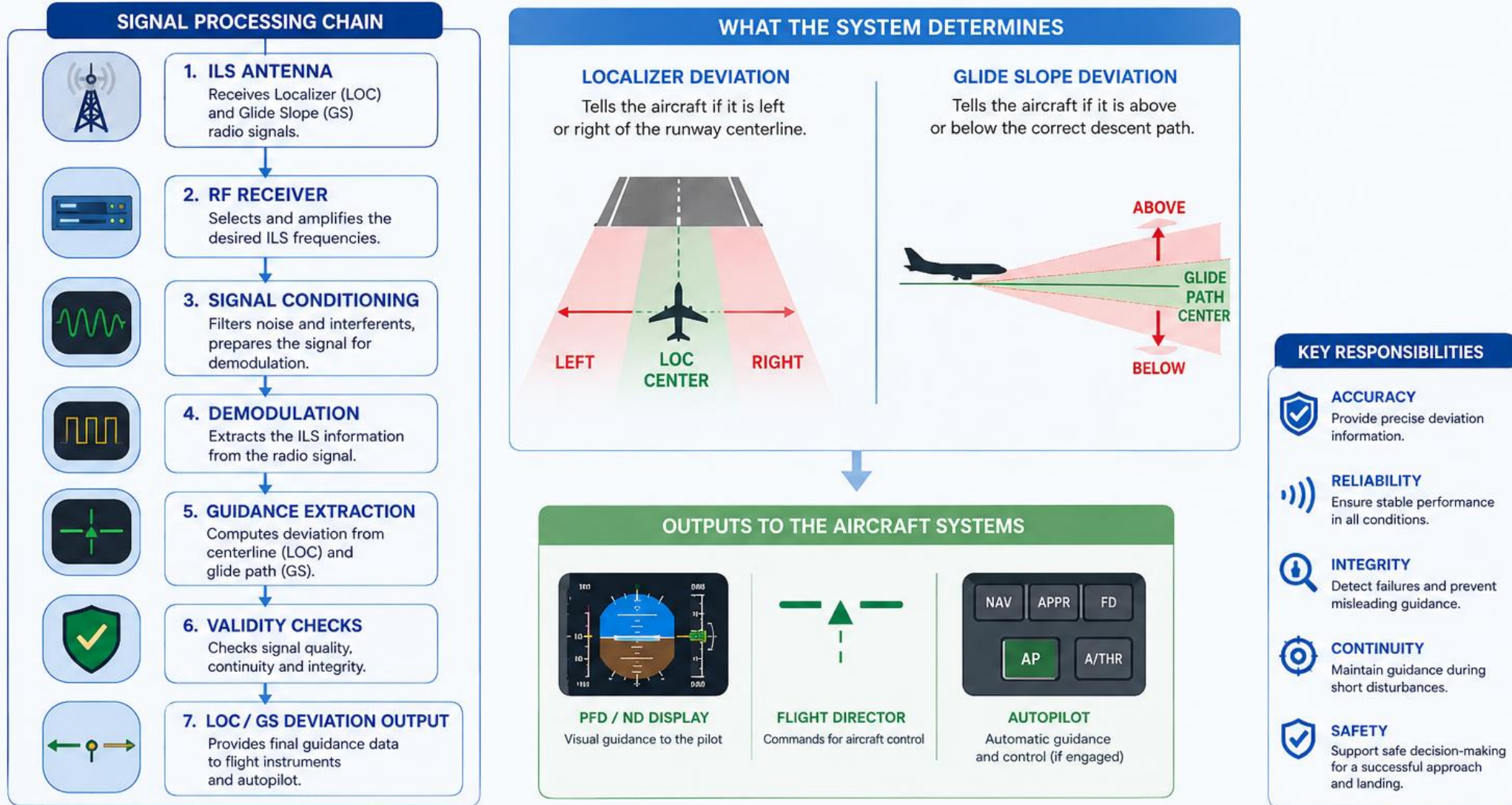


Technical follow-up

Enables timely action, maintenance and compliance

Airborne ILS Signal-Processing Software

From radio signals to precise guidance for a safe approach.



SUMMARY

The airborne ILS software chain converts radio signals into reliable left/right and up/down guidance, continuously checked for validity, and delivered to the pilot and autopilot for a safe approach.

*Reliable signals. Accurate guidance.
Safer landings.*

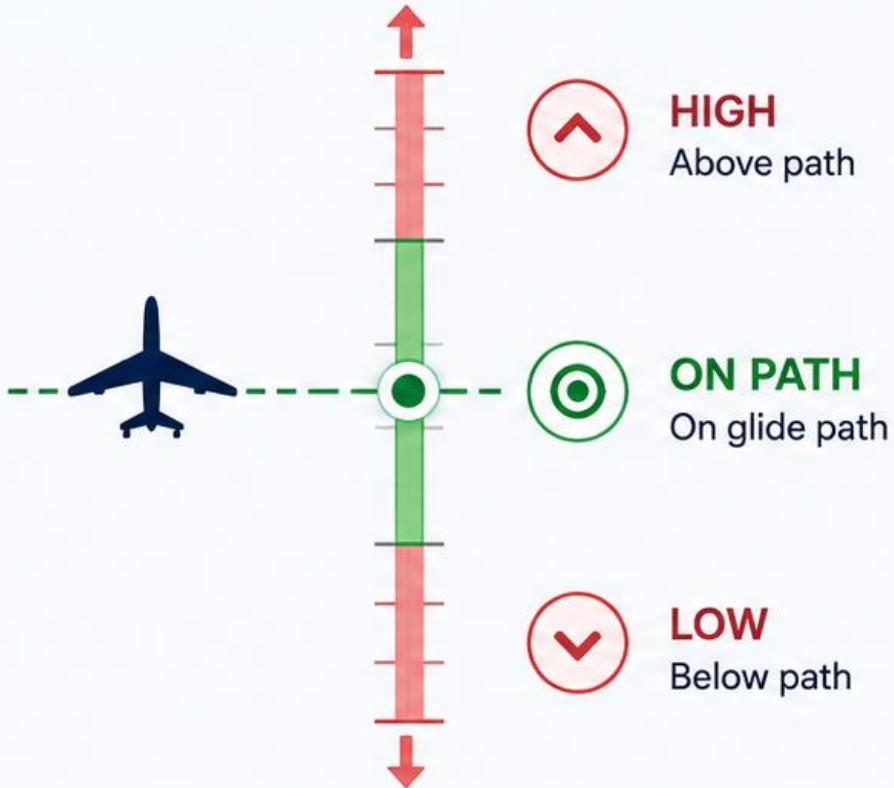


Valid ILS Guidance Data

A deviation value alone is not enough.



GLIDE SLOPE DEVIATION



NAVIGATION OUTPUT

	VALUE	LOC/GS deviation +0.12°
	VALIDITY	VALID
	SOURCE	ILS Receiver
	STATUS	NORMAL
	TIMESTAMP	2025-05-18T14:32:45Z



Navigation data **without validity information** is incomplete.

Chapter 7 — Flight Guidance and Autopilot Software

The next software layer converts ILS deviation into aircraft guidance.

There is an important distinction between:

Navigation

and

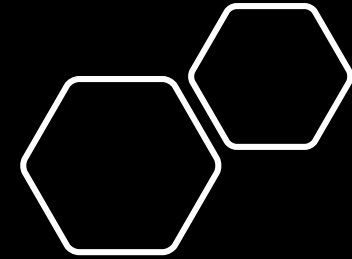
Control.

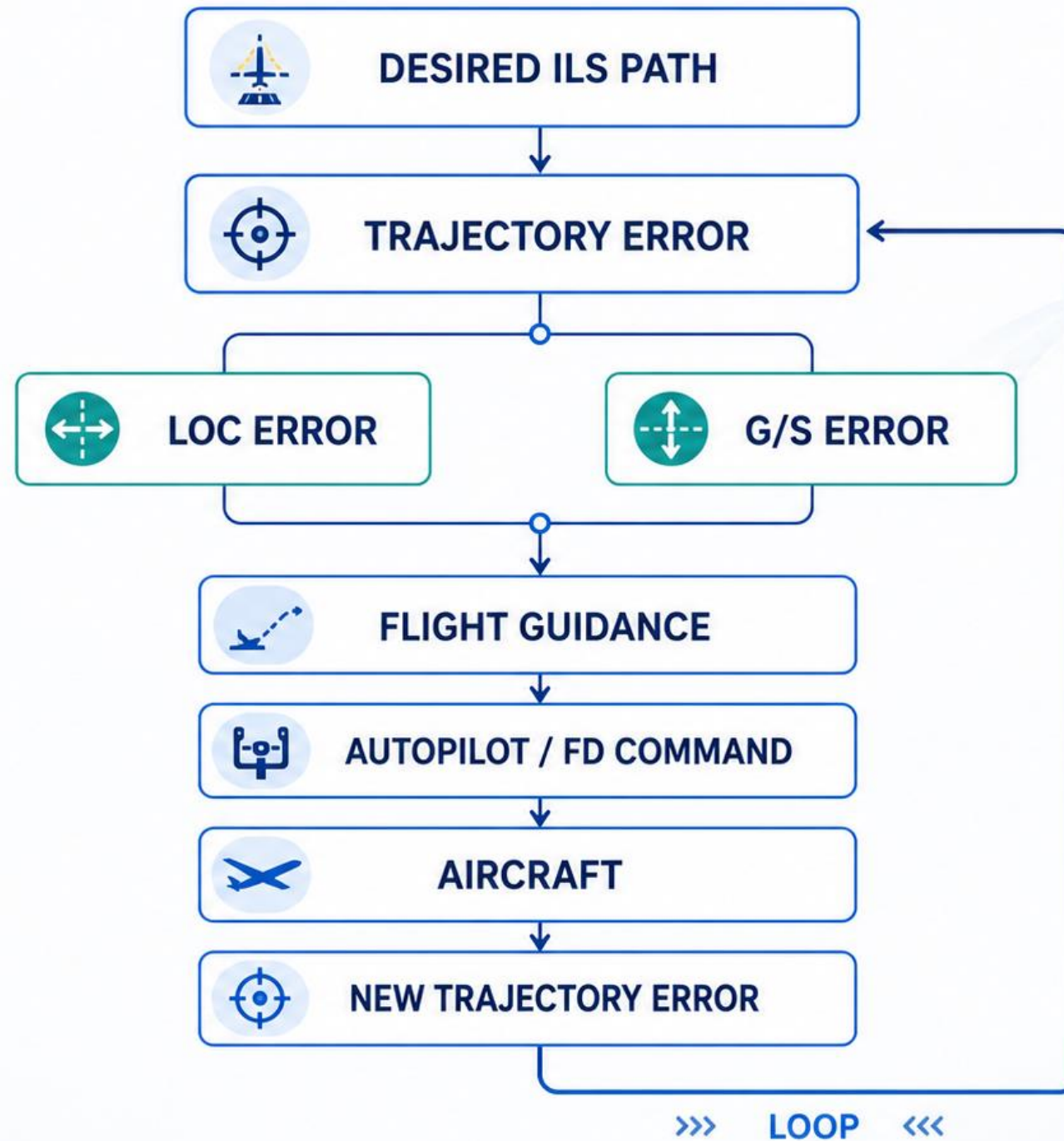
The navigation system essentially reports:

- Aircraft is displaced from the desired ILS trajectory.

The flight-guidance system determines:

- What aircraft guidance response is appropriate?





Chapter 8 — Cockpit HMI and Crew-Monitoring Software



Clear Information. Shared Awareness. Safer Operations.



One of the most underestimated areas of safety-critical software is the **Human-Machine Interface**.



The system may calculate everything correctly and still be unsafe if the crew cannot clearly understand what the automation is doing.



Clear, timely, and relevant information — and proper alerting — are essential for crew situational awareness and safety.

INFORMATION DISTRIBUTION ON AIRCRAFT (EX: BOEING 737)

Information is distributed through multiple integrated systems:

PFD



Primary Flight Display

ND



Navigation Display

FMA



Flight Mode Annunciator

MCP



Mode Control Panel

NAV DISPLAYS / CONTROLS



Navigation Displays & Controls

ASSOCIATED ALERTING



WARNING
Requires immediate crew action



CAUTION
Requires crew attention



ADVISORY
Provides situational information



STATUS
Indicates system or mode status

THE SOFTWARE MUST COMMUNICATE THREE DIFFERENT CONCEPTS CLEARLY



1. PILOT INTENTION

What did the pilot request?



- Selected altitude
- Selected speed
- Selected route
- Selected mode

Reflects the crew's desired outcome.



2. AUTOMATION STATE

What is the automation doing?



- Active modes
- Engagement status
- System status
- Flight phase logic

Shows the current state of the system and automation.



3. SYSTEM STATUS

What is the system condition?



- Data validity
- Sensor status
- Integrity monitoring
- Failure indications

Indicates the health and reliability of the data and systems.

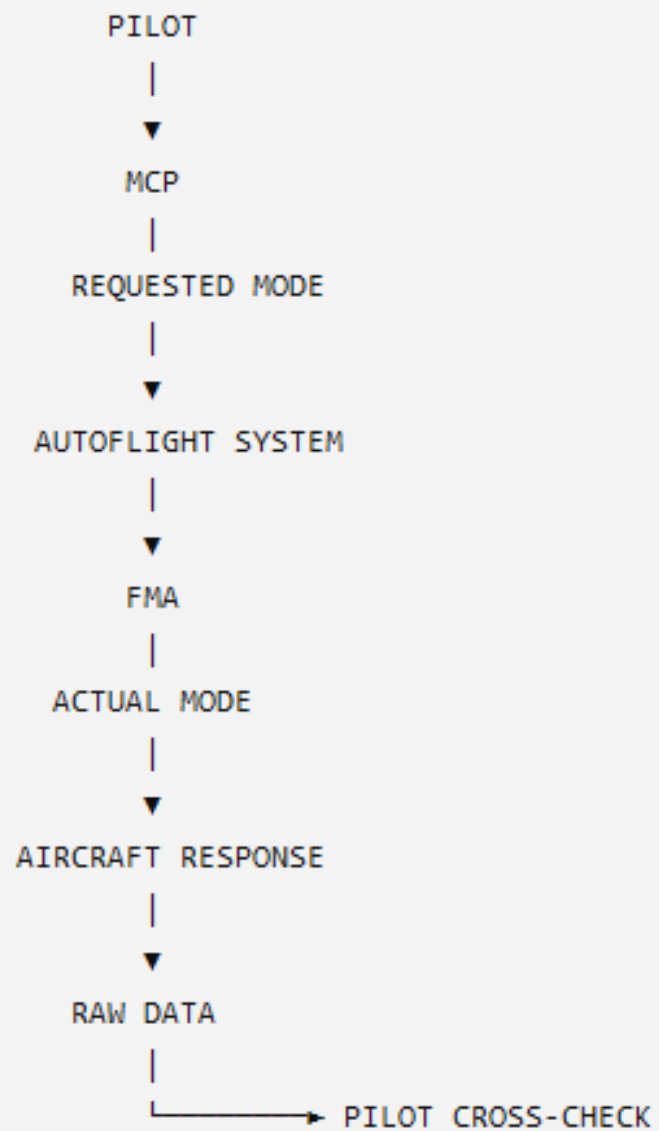


WHY IT MATTERS

When pilot intention, automation state, and system status are aligned and clearly presented, the crew can make better decisions, detect anomalies earlier, and maintain control — even in complex or abnormal situations.



GOOD HMI IS NOT JUST ABOUT DISPLAYS — IT'S ABOUT BUILDING TRUST AND ENSURING SAFETY.



Software development therefore includes **human factors engineering**, not simply algorithms.

Chapter 9 — Maintenance, Simulation, Testing and Digital Twin

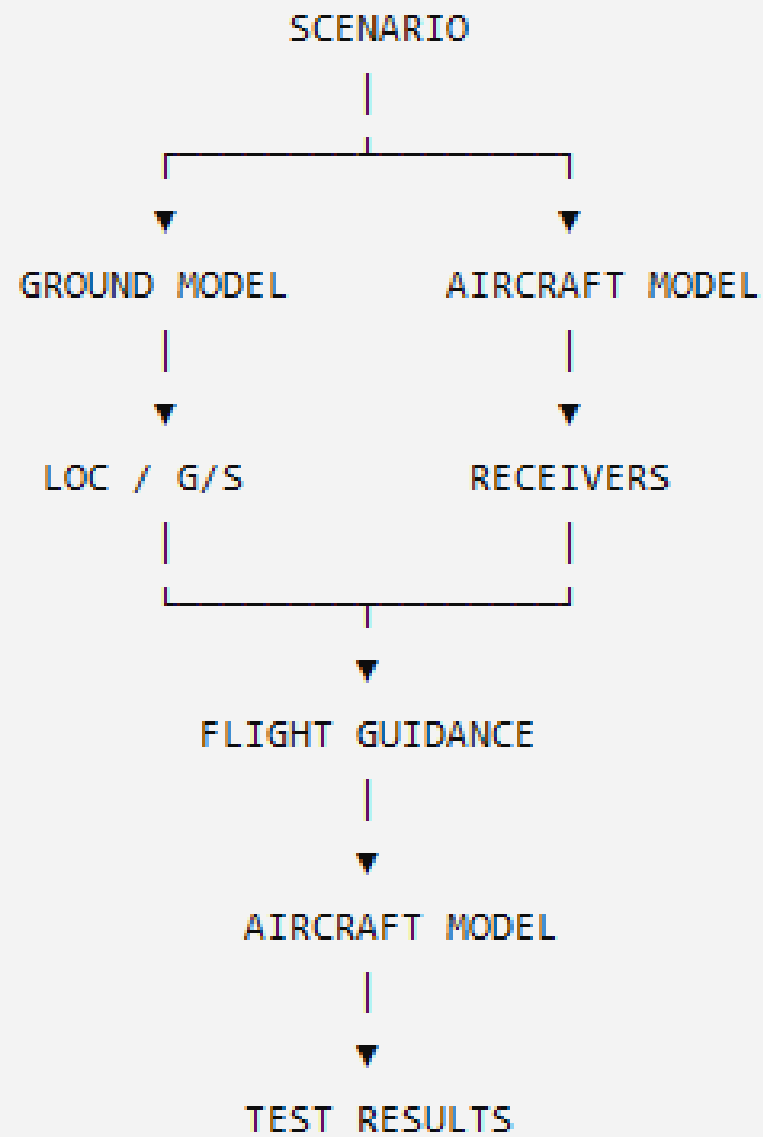
A modern ILS software project should contain a substantial non-operational testing ecosystem.

This is where conventional software engineering becomes extremely powerful.

A simulator can model:

- nominal LOC behavior;
- nominal G/S behavior;
- receiver noise;
- equipment failures;
- communication failures;
- sensor disagreement;
- power interruptions;
- redundant-system transitions;
- invalid data;
- degraded operating states.

ILS DIGITAL TWIN



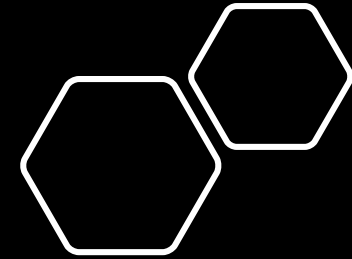
Chapter 10 — Safety-Critical Software Engineering, Cybersecurity and Certification

The final chapter surrounds all the previous nine.

ILS-related software cannot be developed like an ordinary web application.

A conventional application often follows:

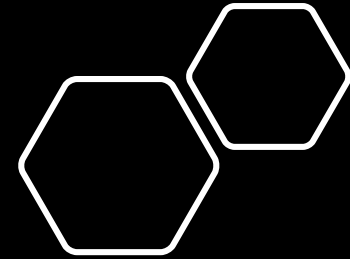
```
CODE
↓
TEST
↓
DEPLOY
↓
FIX BUGS
```



Safety-critical aviation requires a much stronger philosophy:

```
graph TD; A[SYSTEM REQUIREMENT] --> B[SAFETY REQUIREMENT]; B --> C[SOFTWARE REQUIREMENT]; C --> D[ARCHITECTURE]; D --> E[IMPLEMENTATION]; E --> F[VERIFICATION]; F --> G[VALIDATION]; G --> H[TRACEABILITY]; H --> I[CONFIGURATION CONTROL]; I --> J[CERTIFICATION EVIDENCE];
```

SYSTEM REQUIREMENT
↓
SAFETY REQUIREMENT
↓
SOFTWARE REQUIREMENT
↓
ARCHITECTURE
↓
IMPLEMENTATION
↓
VERIFICATION
↓
VALIDATION
↓
TRACEABILITY
↓
CONFIGURATION CONTROL
↓
CERTIFICATION EVIDENCE



For ILS infrastructure, cybersecurity engineering should concentrate on defensive properties:

Network segmentation

Strict access control

Authenticated administration

Configuration integrity

Signed software/firmware where applicable

Secure update processes

Tamper-evident audit logging

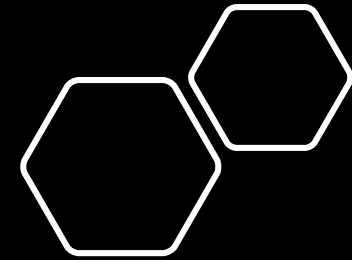
Least privilege

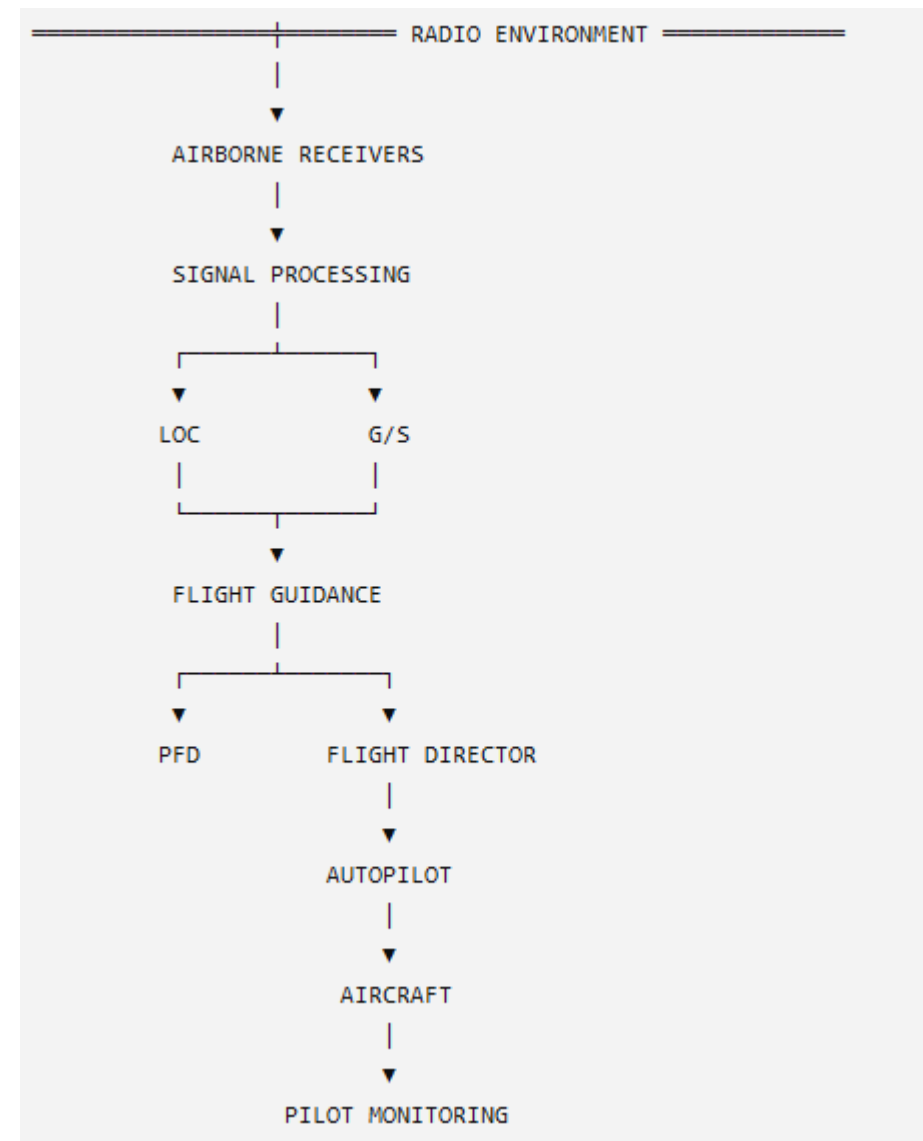
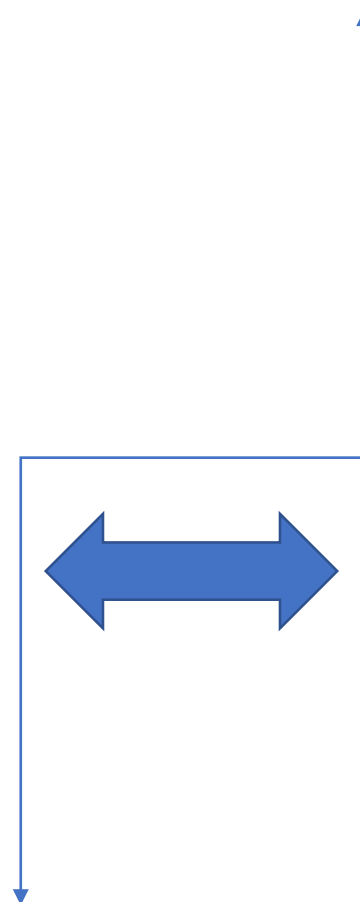
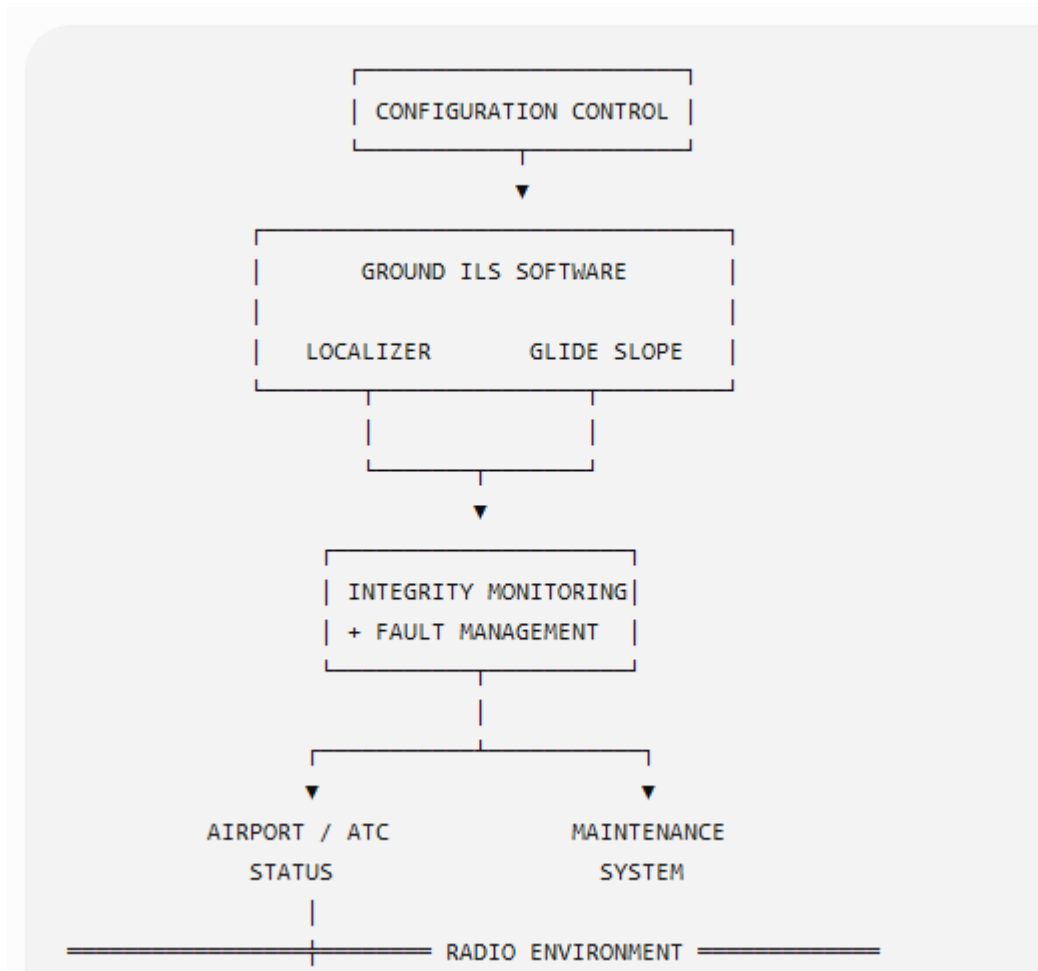
Monitoring

Backup and recovery

Controlled maintenance interfaces

Supply-chain assurance







SAFETY ENGINEERING

+

CYBERSECURITY

+

CONFIGURATION CONTROL

+

REQUIREMENT TRACEABILITY

+

DIGITAL TWIN

+

FAULT INJECTION

+

AUTOMATED TESTING

+

CERTIFICATION EVIDENCE

10. Weaknesses of an ILS — Single Points of Failure (SPF)

Weaknesses of an ILS — Single Points of Failure (SPF)

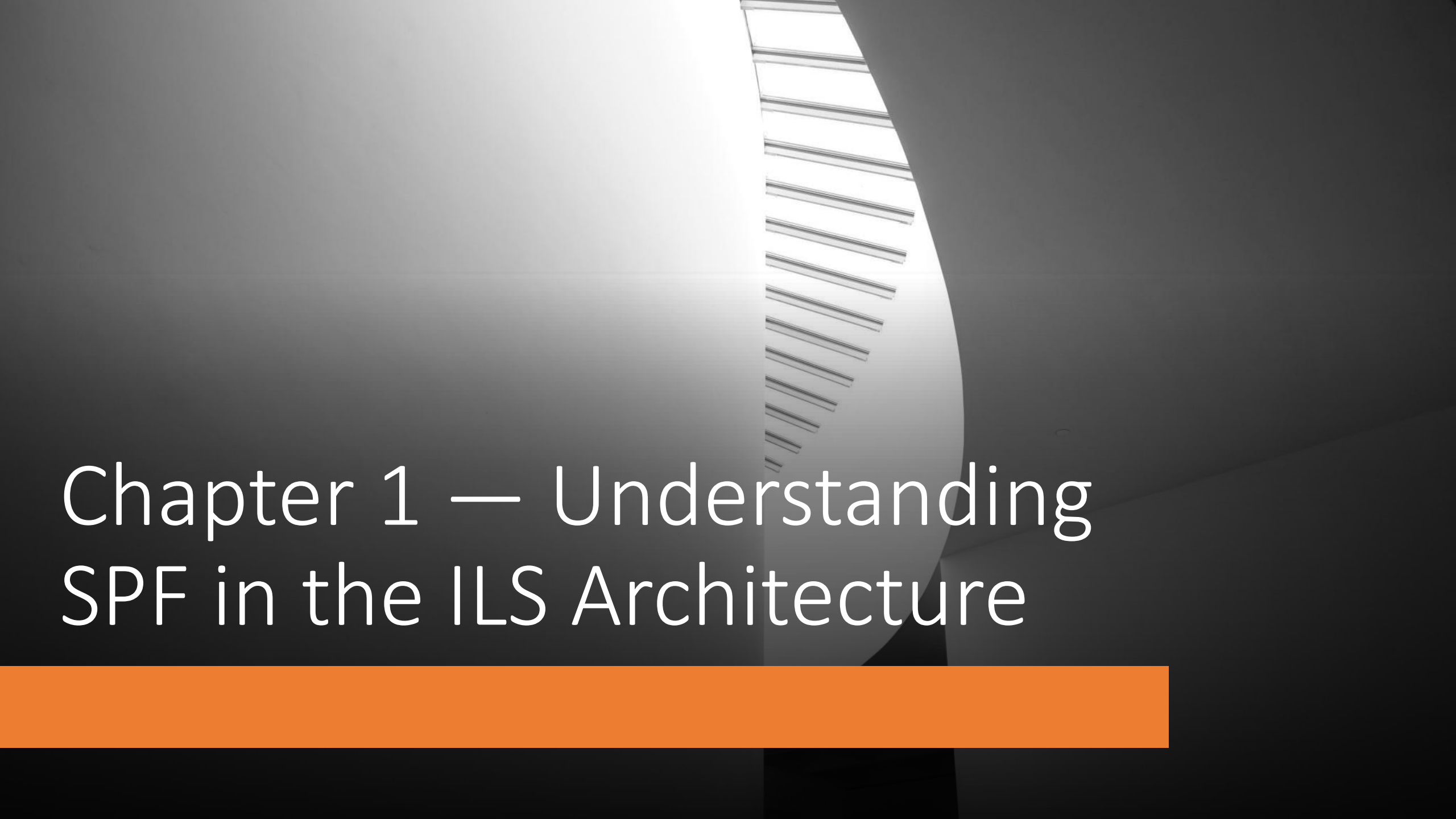
A Five-Chapter Technical Analysis

Although ILS is one of aviation's most mature precision-approach technologies, it is **not inherently immune to failure**. Its safety comes from a combination of redundancy, monitoring, operational procedures, protected airport areas, airborne cross-checking, and the ability to discontinue an approach when required.

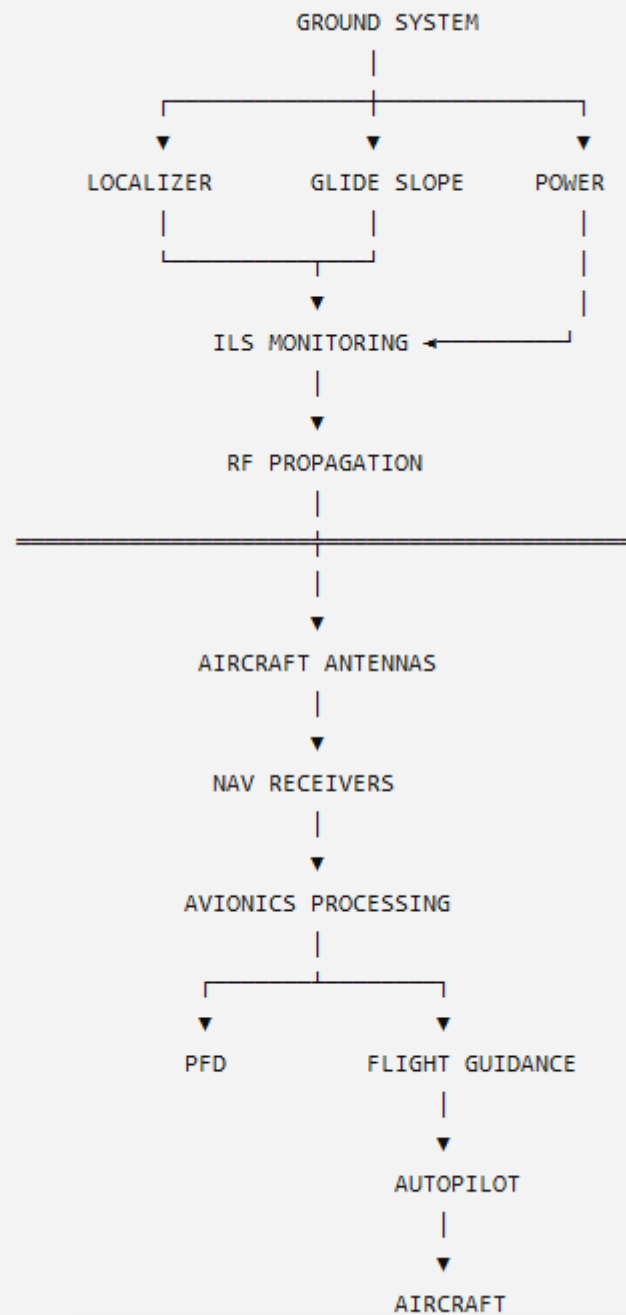
A Single Point of Failure (SPF) is particularly important:

A component, function, interface, or dependency whose failure alone can cause the loss—or unacceptable degradation—of a required system function.

For an ILS, the objective is therefore not to pretend that failures cannot occur, but to ensure that safety-critical failures are **detected, contained, annunciated, and prevented from becoming misleading guidance**.

The background features a dark, gradient surface with a prominent, curved, ribbed structure that resembles a large, modern architectural element or a stylized letter 'C'. A bright, circular light source is positioned at the top center, creating a strong lens flare and illuminating the scene. The overall aesthetic is clean and modern.

Chapter 1 — Understanding SPF in the ILS Architecture



What happens if each element disappears or becomes corrupted?

But there is an important distinction between two types of failure.

Loss of function

For example:

VALID LOC → FAILURE → NO LOC

This is undesirable, but generally straightforward to detect.

Misleading function

Potentially more serious:

VALID LOC → FAILURE → INCORRECT LOC PRESENTED AS VALID

The second case deserves particular attention because the aircraft could potentially follow incorrect guidance.

Therefore ILS safety engineering concentrates strongly on **integrity monitoring**, not simply equipment availability.

The background features a dark, gradient surface with a prominent, curved, ribbed structure on the right side, resembling a large, curved architectural element or a stylized letter 'C'. A bright, circular light source is positioned at the top center, creating a strong lens flare and illuminating the scene. The overall aesthetic is modern and technical.

Chapter 2 — Ground-Side Single Points of Failure

2.1 Localizer failure

The Localizer provides the lateral reference.

If valid LOC guidance is lost:

LOC FAILURE



LATERAL PRECISION GUIDANCE LOST



APPROACH CAPABILITY AFFECTED



A monitored failure should result in appropriate system/operational action rather than allowing invalid guidance to remain trusted.

2.2 Glide-Slope failure

The same principle applies vertically:

G/S FAILURE



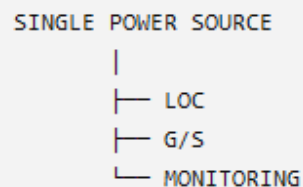
PRECISION VERTICAL GUIDANCE LOST



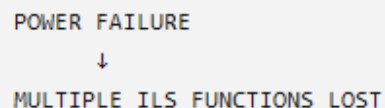
Depending on procedure, regulatory framework and circumstances, loss of the glide slope may mean the published precision approach can no longer be continued as that ILS operation.

2.3 Power-system dependency

A poorly designed architecture could create:



Then:



This is why higher-integrity installations use appropriate backup and power-restoration arrangements.

2.4 Monitoring-system failure

This is particularly interesting.

The monitoring system itself is part of the safety architecture.

Therefore engineers must ask:

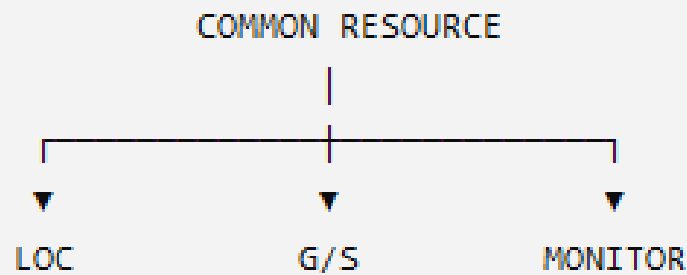
Who monitors the monitor?

A monitoring architecture must avoid situations where a single hidden monitoring failure allows corrupted guidance to remain declared healthy.

2.5 Common infrastructure

A major SPF may not even be an ILS transmitter.

It could exist in a shared dependency:



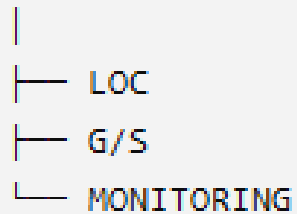
Failure of the common resource could defeat apparently independent systems simultaneously.

This introduces the concept of a **Common Cause Failure (CCF)**.

2.3 Power-system dependency

A poorly designed architecture could create:

SINGLE POWER SOURCE



Then:

POWER FAILURE



MULTIPLE ILS FUNCTIONS LOST



This is why higher-integrity installations use appropriate backup and power-restoration arrangements.

2.4 Monitoring-system failure

This is particularly interesting.

The monitoring system itself is part of the safety architecture.

Therefore engineers must ask:

Who monitors the monitor?

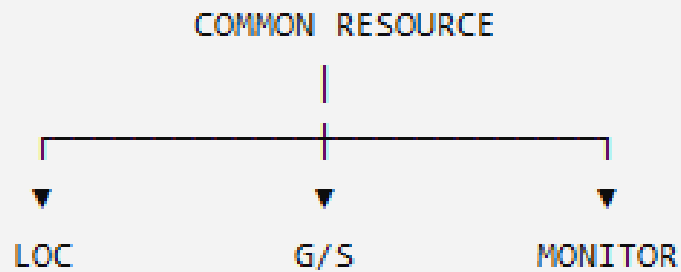
A monitoring architecture must avoid situations where a single hidden monitoring failure allows corrupted guidance to remain declared healthy.

This is a classic safety-engineering problem.

2.5 Common infrastructure

A major SPF may not even be an ILS transmitter.

It could exist in a shared dependency:



Failure of the common resource could defeat apparently independent systems simultaneously.

This introduces the concept of a **Common Cause Failure (CCF)**.



Chapter 3 — RADIO PROPAGATION



Chapter 3 — Radio Propagation and Environmental Vulnerabilities

ILS has an unusual vulnerability compared with satellite-based navigation:

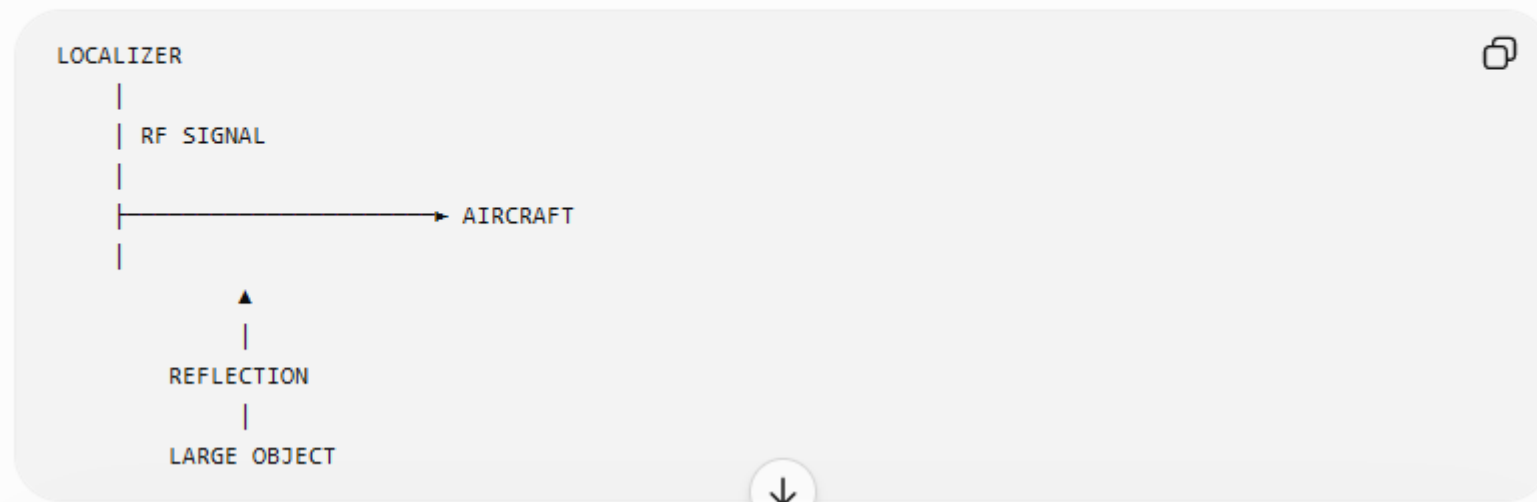
the surrounding physical environment is part of the system.

The guidance signal propagates through real airport terrain.

Objects can potentially affect that propagation:

- aircraft;
- vehicles;
- buildings;
- terrain;
- temporary structures;
- construction equipment;
- environmental changes.

Conceptually:



The receiver may see a combination of:

DIRECT SIGNAL + REFLECTED ENERGY

This is one reason ILS installations require careful site engineering and protected **critical/sensitive areas**.

The important SPF lesson

The antenna itself may be perfectly healthy.

The transmitter may be perfectly healthy.

The monitoring electronics may be healthy.

Yet the **radiated field experienced by the aircraft** can still be influenced by its environment.

Therefore the safety boundary must extend beyond the electronic cabinet.

It includes:

Equipment + Antennas + Airport Geometry + Protected Areas + Operational Procedures

This is an excellent example of why system safety analysis must examine the complete environment rather than individual components in isolation.

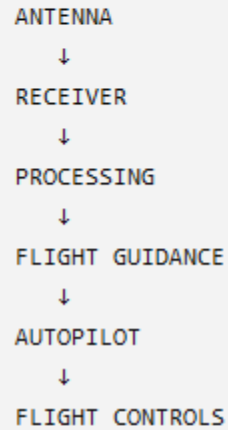
The background features a dark, curved surface with a series of parallel, light-colored lines that create a sense of depth and movement. A bright, circular light source is positioned in the upper left, casting a strong glow across the scene. The overall composition is modern and architectural.

Chapter 4 — AIRBORNE SPF

Chapter 4 — Airborne SPF and Common-Mode Failures

The same analysis must be performed inside the aircraft.

Consider the simplified chain:



```
graph TD; ANTENNA --> RECEIVER; RECEIVER --> PROCESSING; PROCESSING --> FLIGHT_GUIDANCE[FLIGHT GUIDANCE]; FLIGHT_GUIDANCE --> AUTOPILOT; AUTOPILOT --> FLIGHT_CONTROLS[FLIGHT CONTROLS];
```

ANTENNA
↓
RECEIVER
↓
PROCESSING
↓
FLIGHT GUIDANCE
↓
AUTOPILOT
↓
FLIGHT CONTROLS



Any critical dependency requires examination.

Receiver failure

If one receiver becomes unavailable, system capability depends on aircraft architecture and the operational category being flown.

For higher-category approaches, redundancy becomes increasingly important.

Processing failure

A receiver can produce correct data while downstream processing becomes faulty.

Processing failure

A receiver can produce correct data while downstream processing becomes faulty.

Therefore:

Correct input $\neq$ guaranteed correct output

Independent processing and comparison mechanisms can reduce this risk.

Display failure

The autopilot might possess valid guidance while the crew loses an important monitoring indication.

That matters because crew monitoring is itself a safety barrier.

Autopilot failure

During CAT I, loss of an autopilot may still leave other options depending on aircraft, conditions and procedures.

During very-low-visibility CAT III operations, losing required automatic-flight capability can have much greater consequences.

This leads directly to:

Fail-passive

and

Fail-operational

Common-Mode Failure

Suppose we install:

SYSTEM A

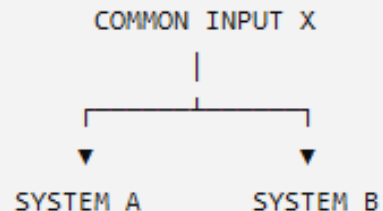
SYSTEM B



At first sight:

Redundancy achieved.

But suppose both depend upon:



Failure of **X** can defeat both systems.

The architecture was duplicated, but the **failure independence** was not.

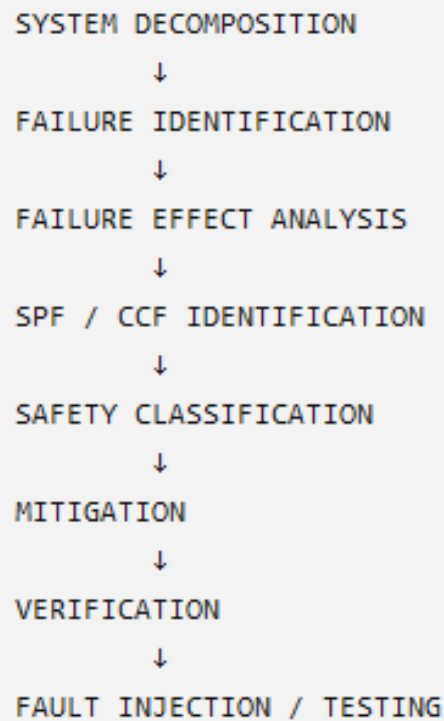
This produces an essential engineering principle:

True redundancy requires independence, not merely duplication.

Chapter 5 — Eliminating SPF: From Failure Analysis to Fault-Tolerant ILS

The objective of engineering is therefore to identify SPFs systematically and either eliminate them or mitigate their consequences.

A useful process is:



Several complementary techniques are particularly important.

FMEA — Failure Modes and Effects Analysis

For every component:

How can it fail?

What is the local effect?

What is the system-level effect?

Can the failure be detected?

What safety barrier remains?

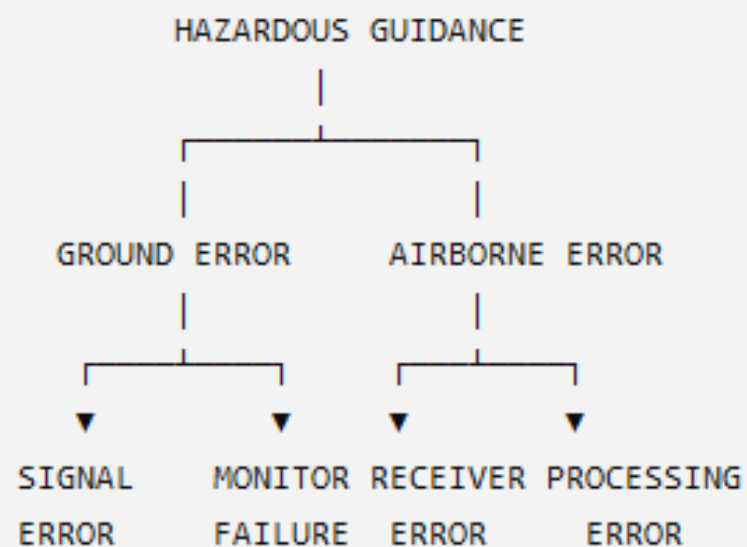
A simplified engineering table might look like:

Component	Failure	Consequence	Detection	Protection
Localizer	Signal unavailable	Loss of lateral guidance	Monitoring	Approach capability downgraded/withdrawn
Glide Slope	Signal unavailable	Loss of vertical precision guidance	Monitoring	Appropriate operational response
Power source	Supply loss	Equipment unavailable	Power monitoring	Backup architecture
Receiver channel	Channel failure	Loss of one airborne source	Built-in monitoring/comparison	Redundant channel where required
Autopilot channel	Channel failure	Reduced automatic-flight capability	Autoflight monitoring	Remaining capability / go-around as applicable

Fault Tree Analysis — FTA

Instead of starting with components, FTA starts with an undesirable system event.

For example:



Engineers then work downward to determine which combinations of failures could produce the top event.

Defense in Depth

The final architecture should contain multiple safety barriers:

FAILURE OCCURS



1. REDUNDANCY



2. FAILURE DETECTION



3. FAULT ISOLATION



4. RECONFIGURATION



5. INTEGRITY MONITORING



6. COCKPIT ANNUNCIATION



7. CREW CROSS-CHECK



8. GO-AROUND / ALTERNATIVE PROCEDURE



No individual layer should automatically be assumed infallible.

The Fundamental SPF Principle

The weakness of an ILS is therefore not simply:

“The Localizer could fail.”

A mature safety analysis asks much deeper questions:

Can the Localizer fail incorrectly rather than simply disappear?

Can the monitor fail at the same time?

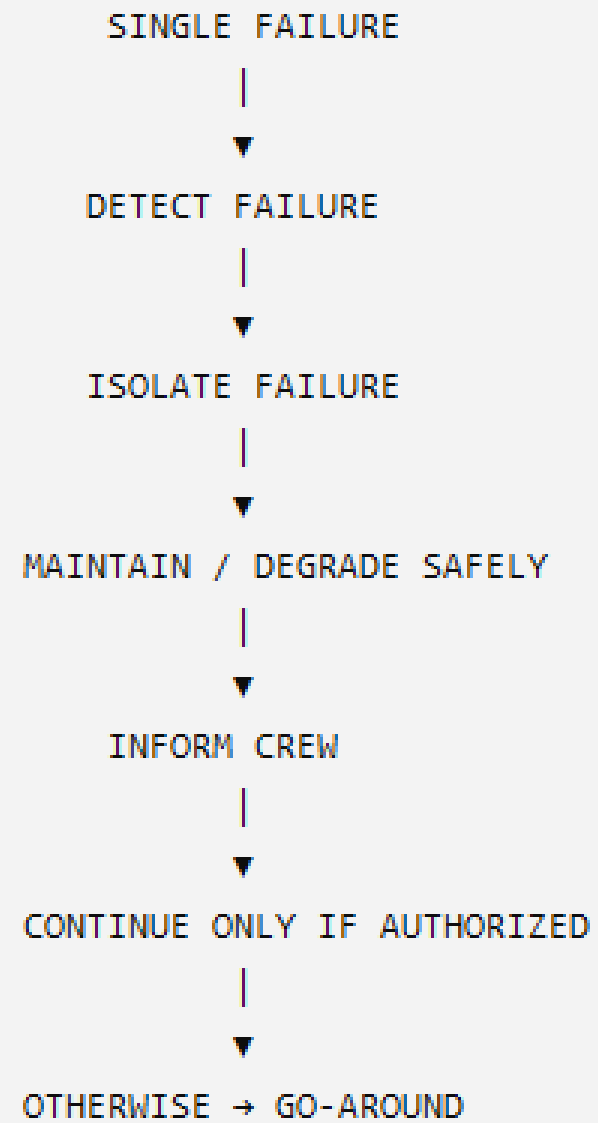
Do redundant systems share a common dependency?

Can environmental interference affect otherwise healthy equipment?

Can the aircraft detect inconsistent guidance?

Can the crew recognize the degradation?

Does a safe escape path remain?





11. ALTERNATIVES TO ILS IN CASE OF FAILURE



ALTERNATIVES TO ILS IN CASE OF FAILURE

- 1. The Fundamental Question
- 2. GBAS / GLS — The Closest Technological Alternative to ILS
- 3. GBAS and Low-Visibility Operations
- 4. SBAS / LPV — Satellite-Based Precision-Like Guidance
- 5. RNAV / GNSS Approaches
- 6. RNP and RNP AR
- 7. Conventional Navigation — The Last Independent Layer
- 8. Visual Approach
- 9. The Critical Weakness of GNSS Alternatives
- 10. Comparison — ILS vs Modern Alternatives
- 11. What Happens at a Mega-Hub After an ILS Failure?
- 12. The Real Future: ILS + GLS + PBN, Not Simply “Replace ILS”

1. The Fundamental Question

What happens when ILS becomes unavailable at a major international airport?

Loss of ILS does not automatically mean that aircraft can no longer land.

Modern airliners such as the Boeing 737/777/787 and Airbus A320/A330/A350/A380 families may have access — depending on aircraft equipment, airline approvals, airport infrastructure and published procedures — to several alternative approach technologies.

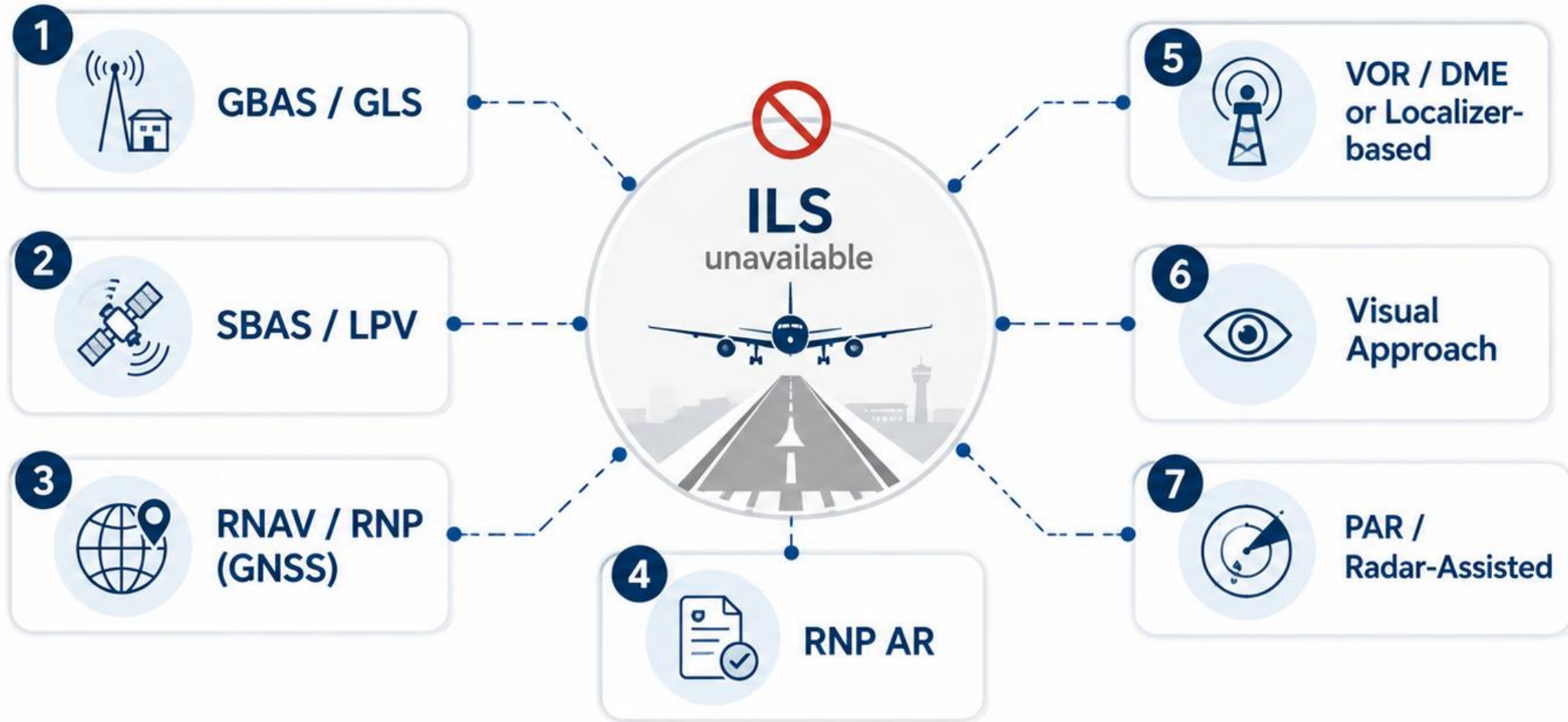
The principal alternatives are:

1. GBAS / GLS — Ground Based Augmentation System
2. SBAS / LPV — Satellite Based Augmentation
3. RNP / RNAV GNSS approaches
4. RNP AR — Authorization Required approaches
5. Conventional VOR/DME or Localizer-based approaches
6. Visual approaches
7. In specific environments, radar-assisted approaches such as PAR

But their capabilities are not equivalent, particularly in extremely poor visibility.

Alternatives to ILS if Unavailable

Modern airliners can still land using several approved approach options.



Alternatives exist — but they are not equivalent in very low visibility.

2. GBAS / GLS — The Closest Technological Alternative to ILS

This is probably the most important system to introduce after ILS.

Principle

Instead of transmitting two radio beams defining the approach path, as an ILS does, GBAS uses GNSS positioning corrected by a ground station located at the airport.

The ground installation monitors satellite signals using several precisely surveyed reference receivers.

It calculates corrections and integrity information and broadcasts them to approaching aircraft through a VHF Data Broadcast (VDB).

The aircraft then flies a:

GLS — GBAS Landing System approach

From the pilot's perspective, GLS can resemble an ILS:

Lateral Guidance + Vertical Guidance → Precision Approach

The FAA describes GLS as providing three-dimensional angular lateral and vertical guidance for precise runway alignment and descent.  Administration F...

Major advantage

One GBAS installation can potentially support multiple runway ends.

GBAS / GLS — THE CLOSEST TECHNOLOGICAL ALTERNATIVE TO ILS

Satellite precision, ground verified — guidance as precise as ILS.



HOW GBAS / GLS WORKS



1 GNSS SATELLITES

Aircraft receives signals from multiple satellites.



2 GROUND REFERENCE STATION

At the airport, multiple precisely surveyed receivers monitor satellite signals.



3 CORRECTIONS & INTEGRITY

The system calculates corrections and integrity information.



4 VHF DATA BROADCAST (VDB)

Corrections and integrity data are broadcast to aircraft via VDB.



5 AIRCRAFT RECEIVER

The aircraft applies the corrections and computes accurate position.



6 GLS GUIDANCE

Provides lateral and vertical guidance for precision approach and landing.

GROUND GBAS STATION

Monitors GNSS signals, computes corrections and integrity, and broadcasts via VDB.

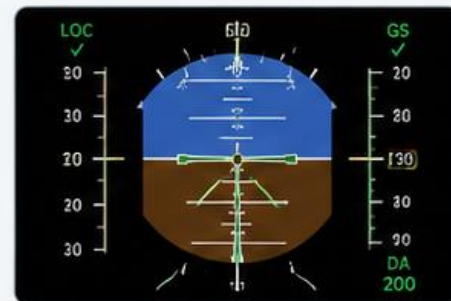
VHF DATA
BROADCAST (VDB)

GLS PATH
Lateral + Vertical Guidance

FROM THE PILOT'S PERSPECTIVE

GLS — GBAS Landing System approach

From the cockpit, GLS can resemble an ILS:



Lateral Guidance + Vertical Guidance
→ Precision Approach

MAJOR ADVANTAGE



One GBAS installation can potentially support **multiple runway ends**.



PRECISION

Comparable to ILS (Category I–III).



INTEGRITY

Continuous monitoring ensures high safety.



FLEXIBILITY

Supports multiple runways and curved approaches.



PERFORMANCE

Reliable even in poor visibility.



FAA RECOGNITION

Provides 3D angular guidance for alignment and descent.

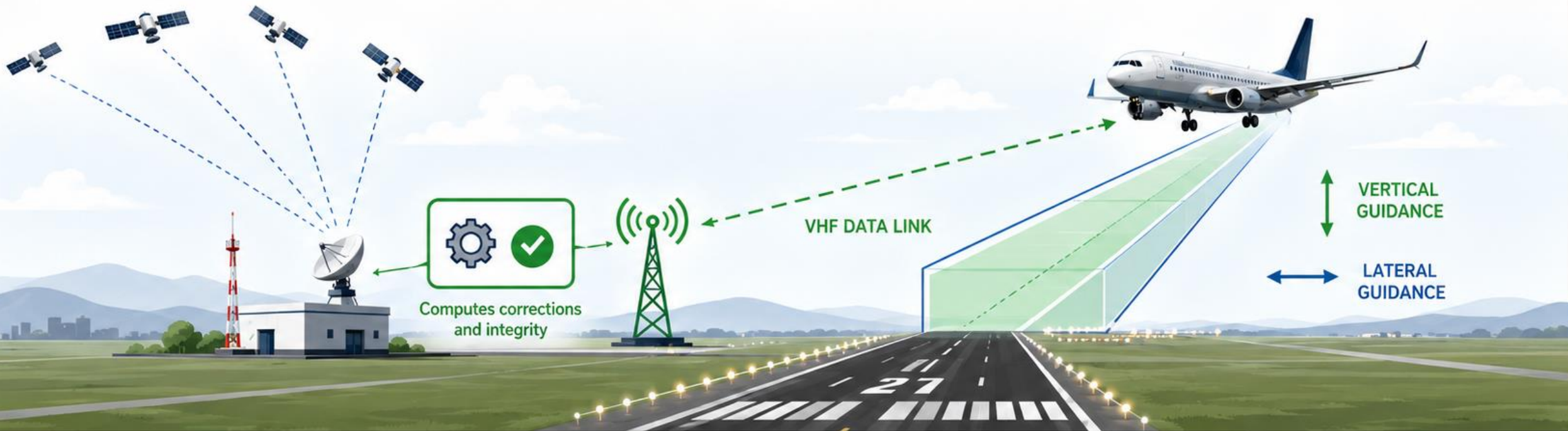
GBAS / GLS

A precision approach system using GNSS corrected by an airport ground station



Closest technological alternative to ILS

- 1 GNSS Satellites
- 2 Ground GBAS Station
- 3 VHF Data Broadcast
- 4 GLS Precision Approach



Precision guidance



Integrity monitoring



Multiple runway support



Poor-visibility capable

Major advantage

One GBAS installation can potentially support multiple runway ends.

ILS:

1 runway end → dedicated LOC + GS infrastructure

GBAS:

1 airport GBAS → multiple runway approaches

The FAA gives the illustrative example of an airport with six runway ends: a single GBAS installation can potentially supplement or replace the six corresponding ILS installations.

 Administration F...

That becomes extremely interesting for Heathrow, CDG, Frankfurt, Amsterdam, JFK-type environments.

3. GBAS and Low-Visibility Operations

This is where the comparison becomes particularly important.

Historically, operational GBAS deployment has been primarily associated with CAT I operations.

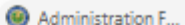
However, the technology and standards have progressed toward low-visibility operations.

The important terminology is:

GAST-C → CAT I

and

GAST-D → designed to support CAT III operations

The FAA notes that ICAO GAST-D standards enabling GBAS approaches to CAT III minima became effective in 2018. 

Therefore, technologically:

GLS is the strongest candidate for an ILS-class precision landing alternative.

But deployment, aircraft certification, operator approval and airport availability still matter enormously.

An airport cannot simply declare:

“ILS failed — switch everybody to GLS.”

GBAS and Low-Visibility Operations

GLS is the most credible technological alternative to ILS for precision approaches.

GBAS EVOLUTION



TRADITIONAL GBAS

Ground station computes corrections and integrity



GAST-C / CAT I

Historically associated with CAT I operations



GAST-D / CAT III CAPABLE

Advanced standard designed to support CAT III operations. Effective since 2018 (FAA/ICAO)



WHAT YOU NEED TO KNOW



TECHNOLOGY

GBAS/GLS is the strongest ILS-class alternative for precision approaches.



CAPABILITY

With GAST-D, GBAS is designed to support CAT III operations.



REALITY CHECK

Low-visibility operations require



Aircraft Certification



Operator Approval



Airport Availability

Deployment is not instant or universal.



AN AIRPORT CANNOT SIMPLY DECLARE:
“ILS failed — switch everybody to GLS.”



TAKEAWAY: GLS is a leading ILS-class alternative — but not an automatic one-for-one replacement.



4. SBAS / LPV — Satellite-Based Precision-Like Guidance

The second major alternative is SBAS.

Examples include:

EGNOS — Europe

WAAS — United States

MSAS — Japan

GAGAN — India

SBAS sends GNSS correction and integrity information through geostationary satellites.

This allows an aircraft to fly an:

LPV — Localizer Performance with Vertical Guidance

LPV provides very accurate:

Lateral guidance

and

Vertical guidance

and can therefore feel operationally similar to an ILS approach.

EASA's March 2026 rules explicitly address SBAS LPV operations with a **200-ft Decision Height**, provided the SBAS system is approved accordingly. 

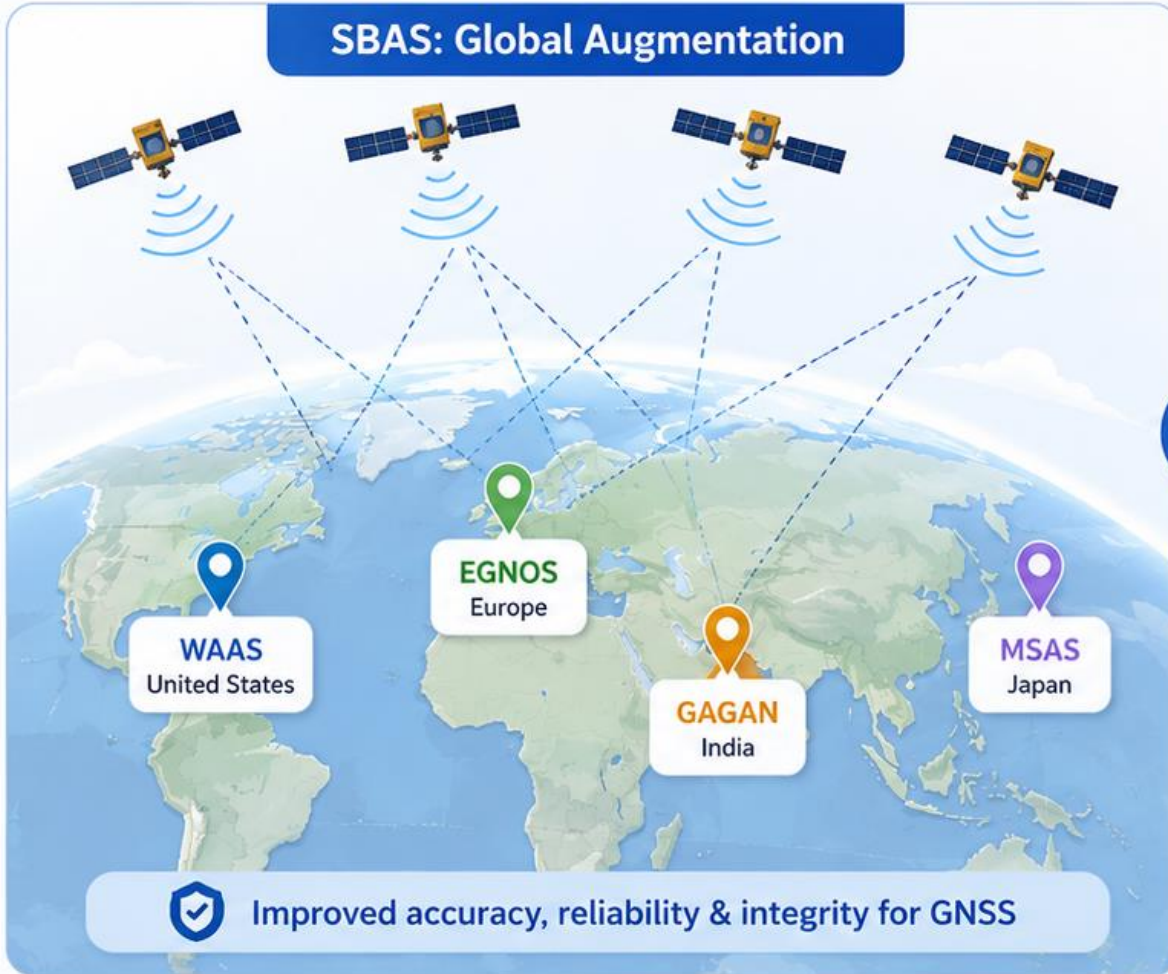
That is excellent capability.

SBAS / LPV — Satellite-Based Precision-Like Guidance



GNSS corrections + integrity via geostationary satellites

SBAS: Global Augmentation



LPV Approach



SBAS enables LPV approaches with both lateral and vertical guidance, operationally similar to an ILS approach.

**where approved*

5. RNAV / GNSS Approaches

Another fallback is the increasingly widespread family of:

RNAV (GNSS) approaches

The aircraft determines its position using GNSS and follows a predefined three-dimensional flight path.

Modern Flight Management Systems make these procedures highly effective.

And their deployment is enormous.

As an indication of how widespread PBN has become, the FAA's June 2026 inventory lists **6,617 RNAV (GPS) approach charts** serving **2,991 airports**, plus hundreds of RNAV/RNP procedures.  Administration F...

That demonstrates something important:

Satellite-based navigation is no longer an experimental backup. It is a fundamental part of modern aviation infrastructure.

RNAV / GNSS Approaches



A mainstream, satellite-based alternative to ILS



1. Satellite Positioning

GNSS satellites provide precise, reliable positioning.



2. Predefined 3D Flight Path

Aircraft follow a precisely designed 3-dimensional approach to the runway.



3. Highly Effective with Modern FMS

Advanced Flight Management Systems deliver accuracy, safety and efficiency.



FMS + GNSS

Onboard systems compute position and guide the aircraft along the path.

WIDELY DEPLOYED



6,617

RNAV (GPS) approach charts



2,991

Airports



Hundreds of RNAV/RNP procedures worldwide



RNAV / GNSS is no longer just a backup — it is a core part of modern aviation.



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6. RNP and RNP AR

RNP goes further.

Required Navigation Performance

The aircraft does not simply navigate.

It continuously monitors whether it is achieving the required navigation accuracy.

This enables extremely precise trajectories.

RNP procedures can also permit curved approach paths that would be impossible with conventional ILS geometry.

For example:

RNAV → flexible navigation

RNP → navigation + onboard performance monitoring

RNP AR → highly demanding RNP operations requiring specific authorization

RNP AR is particularly useful where terrain, obstacles or airspace constraints make conventional approaches difficult.

But again:

RNP AR is not automatically equivalent to CAT III ILS.

It is an extraordinary navigation capability, but that does not mean it provides the same ultra-low-visibility landing minima.

RNP & RNP AR



Precision navigation beyond RNAV

01



RNAV

Flexible navigation



02



RNP

Navigation +
onboard performance
monitoring



03



RNP AR

High-precision
operation requiring
special authorization



Continuous
accuracy
monitoring



Curved
approach
paths



Useful in
terrain-constrained
airports

ONBOARD MONITORING



TRACK
ACCURACY



PERFORMANCE
MONITORING



CONTINUOUS
ASSESSMENT



TERRAIN
OR OBSTACLE



IMPORTANT:

RNP AR is not automatically
equivalent to CAT III ILS



Extraordinary precision — but different from ultra-low-visibility ILS capability.



7. Conventional Navigation — The Last Independent Layer

A resilient airport should not depend exclusively upon GNSS.

This point is extremely important for the cybersecurity/resilience chapter of your presentation.

Older technologies can still provide another independent navigation layer:

VOR

DME

VOR/DME

Localizer-only procedures

and other conventional instrument procedures.

Their precision is generally lower.

Their minima are generally higher.

But their greatest advantage is different:

They can provide technological diversity.

Imagine:

ILS unavailable

Conventional Navigation — The Last Independent Layer



When ILS is unavailable, conventional navigation keeps you on course.



GNSS / ILS
Unavailable



Conventional Navigation
Independent backup layer
still available



VOR

DME

LOC
(Localizer)

Examples of
conventional options



VOR



DME



VOR/DME



LOC-only
procedures



Independent backup
Does not rely on GNSS.



Lower precision
Generally less precise
than ILS.



Higher minima
Typically requires
higher minima.



Main advantage: TECHNOLOGICAL DIVERSITY AND RESILIENCE



8. Visual Approach

If weather permits, the simplest alternative remains:

Visual approach.

No ILS is required.

No GLS is required.

The pilot can acquire the airport/runway environment visually and complete the approach under the applicable procedure and ATC conditions.

For a major airport in good weather, visual operations can therefore remain entirely practical.

But introduce:

fog + low cloud + heavy rain + night + poor visibility

and this alternative rapidly becomes unavailable or operationally unsuitable.

That is precisely when precision approach infrastructure becomes critical.

VISUAL APPROACH

THE SIMPLEST AND MOST PRACTICAL ALTERNATIVE WHEN WEATHER PERMITS



NO ILS REQUIRED

Operates without ILS infrastructure.



NO GLS REQUIRED

Operates without GBAS/GLS infrastructure.



PILOT VISUAL REFERENCE

The pilot acquires the airport and runway environment visually.



PROCEDURE & ATC GUIDED

Completed under applicable procedures and ATC conditions.



PRACTICAL IN GOOD WEATHER

For major airports in good weather, visual operations remain entirely practical.



LIMITATIONS



- + Fog
- + Low Cloud
- + Heavy Rain
- + Night
- + Poor Visibility



Under these conditions, visual approach quickly becomes unavailable or operationally unsuitable.

KEY TAKEAWAY



GOOD WEATHER

Sufficient visibility and ceiling.



VISUAL REFERENCE

Pilot acquires airport and runway visually.



PROCEDURE FOLLOWED

Approach completed under published procedures and ATC.



SAFE LANDING

Visual approach remains a practical and reliable option.



VISUAL APPROACH

Simple. Independent. Effective when conditions allow.

9. The Critical Weakness of GNSS Alternatives

This is where your presentation can become particularly interesting.

Moving from:

ILS → GNSS

does not necessarily eliminate vulnerability.

It changes the vulnerability model.

ILS is predominantly dependent on local terrestrial infrastructure.

GNSS depends on a much larger architecture:

satellites → signals → augmentation → receivers → ground monitoring → data processing

GNSS signals reaching an aircraft are extremely weak and can be susceptible to:

JAMMING

Intentional or accidental RF interference prevents reliable reception.

SPOOFING

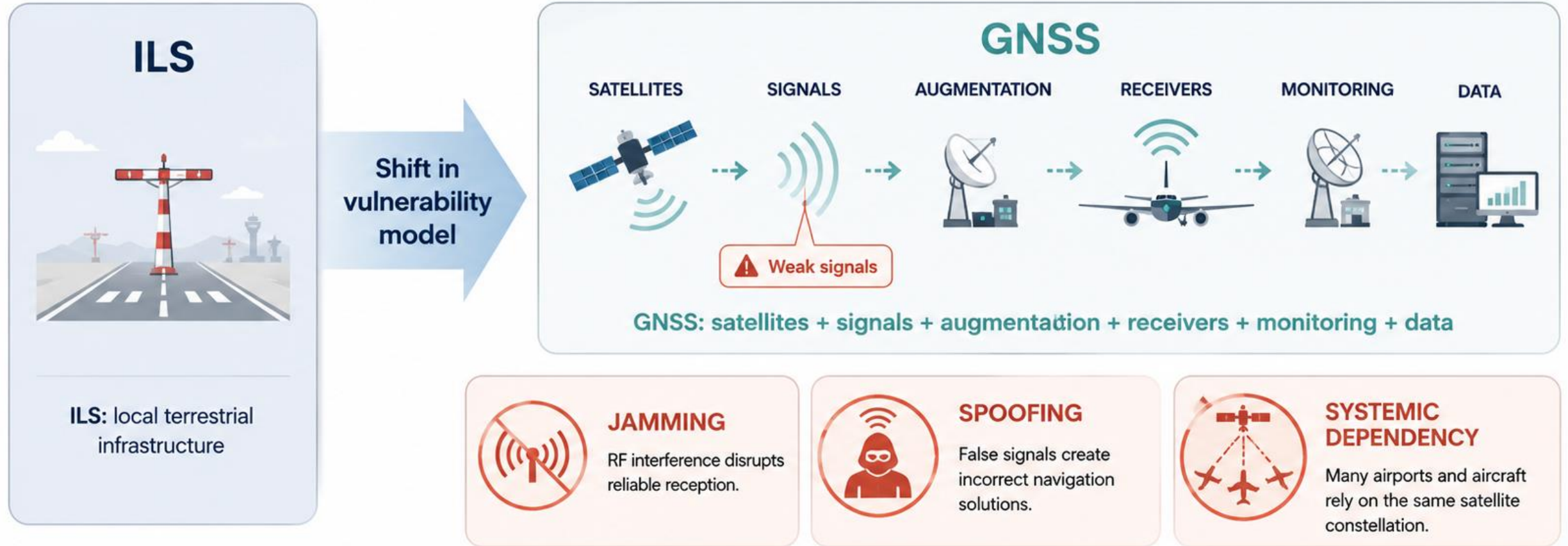
False signals attempt to create an incorrect navigation solution.

SYSTEMIC DEPENDENCY

Multiple airports and aircraft may depend on the same satellite constellation.

The Critical Weakness of GNSS Alternatives

Replacing ILS with GNSS changes the vulnerability model — it does not remove vulnerability.



GNSS is powerful — but its risks are broader, shared, and less local than ILS.





ILS vs Modern Alternatives

Performance comparison for precision approach operations

 TECHNOLOGY	 PRECISION	 VERY LOW VISIBILITY	 TRAFFIC CAPACITY	 GNSS INDEPENDENT	 INFRASTRUCTURE
 ILS CAT III	★★★★★	★★★★★	★★★★★	YES	Heavy / runway-specific
 GBAS / GLS	★★★★★	★★★★★*	★★★★★	NO	Light / multi-runway
 SBAS / LPV	★★★★★	★★★★★	★★★★★	NO	Very light locally
 RNP / RNAV GNSS	★★★★★	★★★★★	★★★★★	NO	Very light
 VOR/DME	★★★★★	★★★★★	★★★★★	YES	Ground infrastructure
 Visual	—	×	Weather- dependent	YES	Minimal



*CAT III-class GLS capability depends on the deployed GBAS service, aircraft certification, procedure and operational authorization; **it should not be read as meaning that every existing GLS installation offers CAT III today.** FAA material distinguishes current CAT-I GAST-C service from GAST-D standards intended to enable CAT III.

11. What Happens at a Mega-Hub After an ILS Failure?

Now let's take the scenario you originally proposed.

DAY — CAVOK — GOOD VISIBILITY

ILS FAILURE

↓

RNAV / RNP / GLS / visual procedures

↓

Airport largely operational

There may be disruption, but it is manageable.

NIGHT — MODERATE WEATHER

ILS FAILURE

↓

GLS / RNAV / RNP / LPV where available

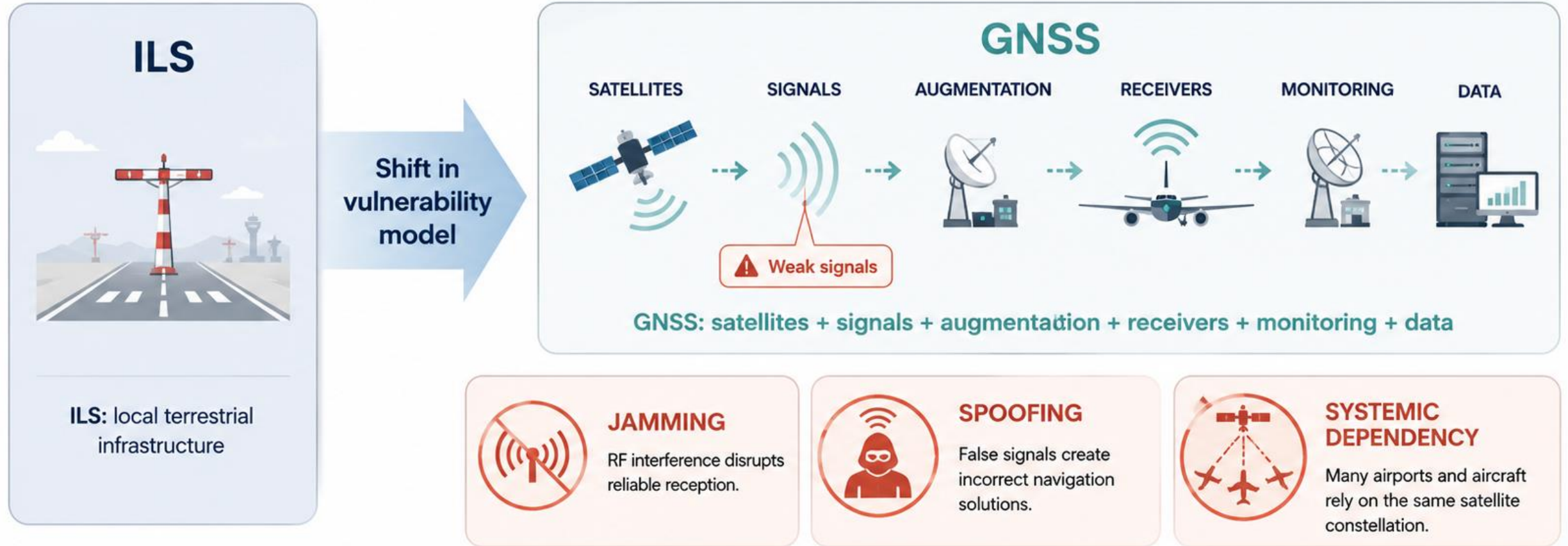
↓

Airport operational but potentially degraded

Capacity may decrease.

The Critical Weakness of GNSS Alternatives

Replacing ILS with GNSS changes the vulnerability model — it does not remove vulnerability.



GNSS is powerful — but its risks are broader, shared, and less local than ILS.



NIGHT — DENSE FOG — VERY LOW RVR

ILS CAT III FAILURE



If equivalent certified GLS/other low-visibility capability is unavailable:



Higher landing minima



Aircraft unable to commence/continue approaches



Holding



Diversions



Arrival flow restrictions



12. The Real Future: ILS + GLS + PBN, Not Simply “Replace ILS”

And this is, in my view, the strongest conclusion for your presentation.

The ideal architecture of a major international airport is not:

ILS OR GNSS

It is:

ILS + GBAS/GLS + SBAS/PBN + conventional terrestrial backup

These technologies have **different failure modes**.

That diversity is itself a safety mechanism.

A modern mega-hub should therefore be thought of as a **multi-layer navigation architecture**:

LAYER 1 — ILS CAT III

Ultra-low-visibility precision landing.

LAYER 2 — GBAS / GLS

High-performance precision approach and potentially CAT III-class operations where fully implemented.

LAYER 3 — SBAS / LPV / RNP

Flexible satellite-based approach capability.

LAYER 4 — Conventional terrestrial navigation

Independent fallback against GNSS disruption.

LAYER 5 — Visual procedures

Available when meteorological conditions permit.

The Real Future: ILS + GLS + PBN

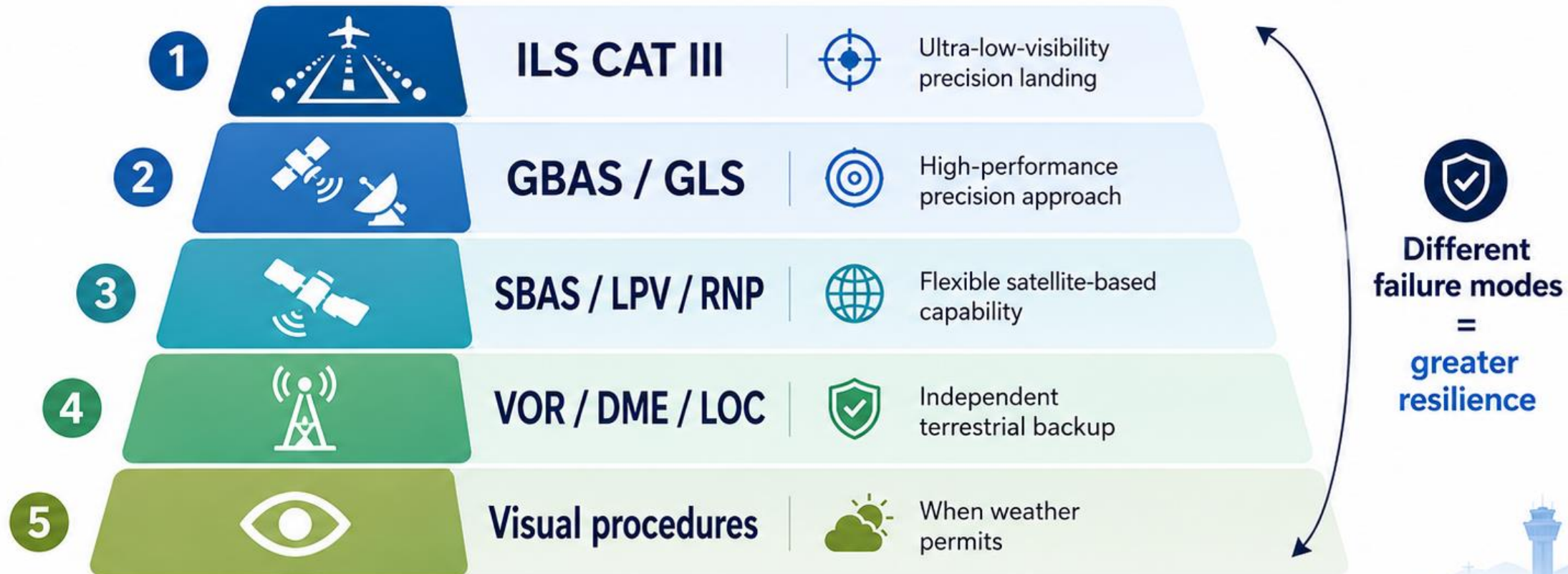
A multi-layer navigation architecture



Not: ILS OR GNSS



Better: ILS + GLS + PBN + terrestrial backup + visual procedures



Diversity is a safety feature



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IMPROVEMENTS

IMPROVEMENTS

- COST OF AN ILS
- TIME REQUESTED TO CONSTRUCT AND INSTALLATION
- ILS AT SCHOOL (ENAC AIRBUS BOEING TEXTRON AVIATION)
- OFFICIAL URL LINKS
- ILS CYBER ATTACK EXPOSITION
- NETWORK ARCHITECTURE



Thank You

We hope this presentation helped you better understand the ILS concept.

The Ideo-lab Team

 September 2026

