PANS-OPS Flight Procedure Design Training for CAAs

23 August – 03 September 2021

01 – RNAV General principles

Outlines

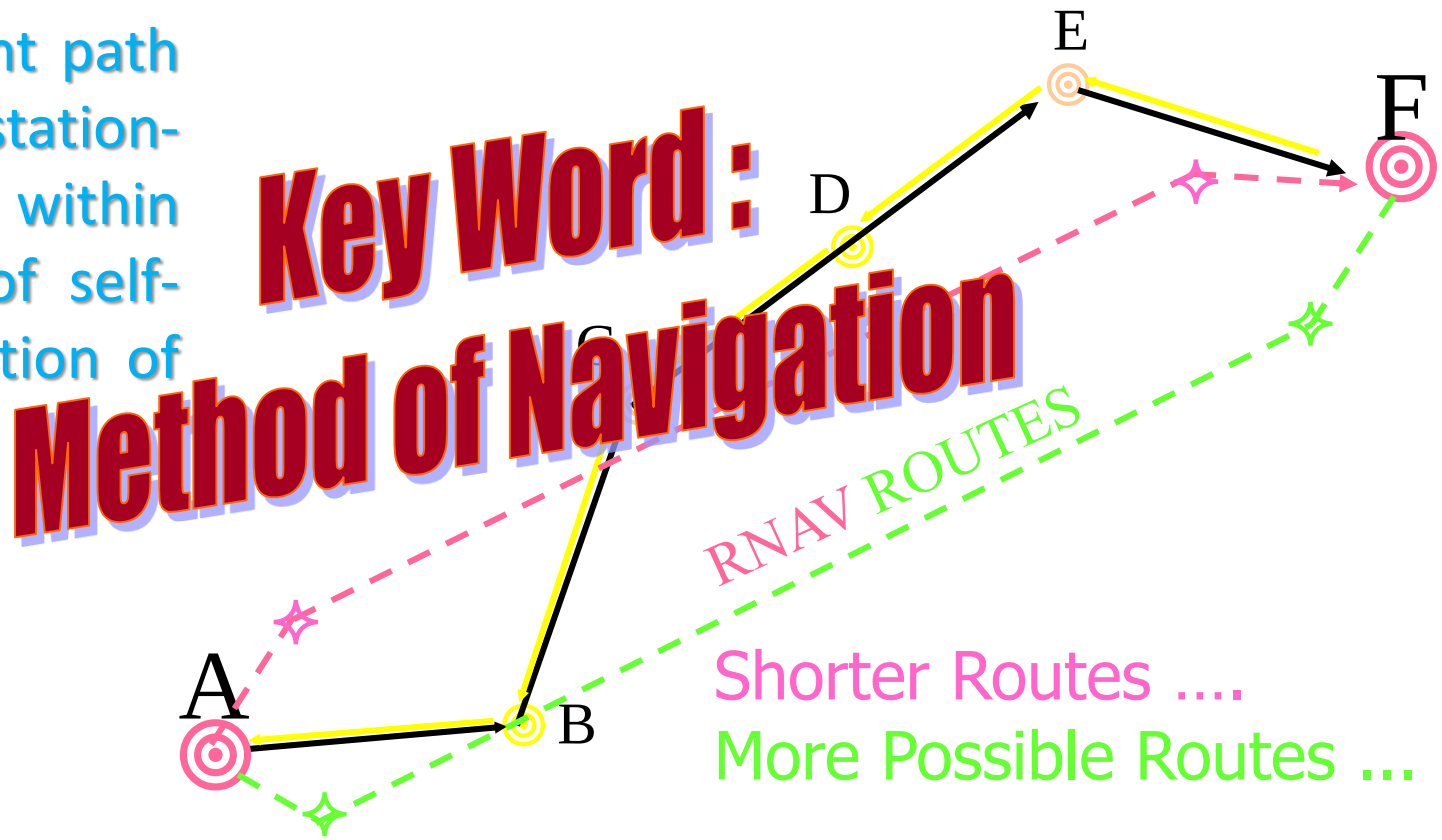
1. Navigation history
2. RNAV positioning method
3. Fixes, path terminators and transitions
4. Navigation systems and sensors
5. Global Navigation Satellite System (GNSS)
6. Benefits

Navigation history

- Non-directional Beacon (NDB) : 1920 (Fisher);
- Instrument Landing System (ILS) : 1938
- Radar : 1935 - 1940
- VOR (Airways) : 1960^{s} (First VOR approved in 1947)
- Introduction of 2D RNAV VOR/DME : 1975
- GPS navigation : 1994
- RNP : 1996
- PBN ICAO mandate : 2016

Navigation history

- **Area navigation:** A method of navigation which permits aircraft operation on any desired flight path within the coverage of the station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.



RNAV positioning method

- The RNAV system (on-board):
  - Identifies the next waypoint;
  - Selects the most appropriate source of navigation to determine its position;
  - Displays data on navigation display (ND)or (CDI);
  - Provides information to FD to the auto-pilot to fly to the next waypoint.

- An RNAV route can be flown manually

Fixes, path terminators and transitions

Fixes

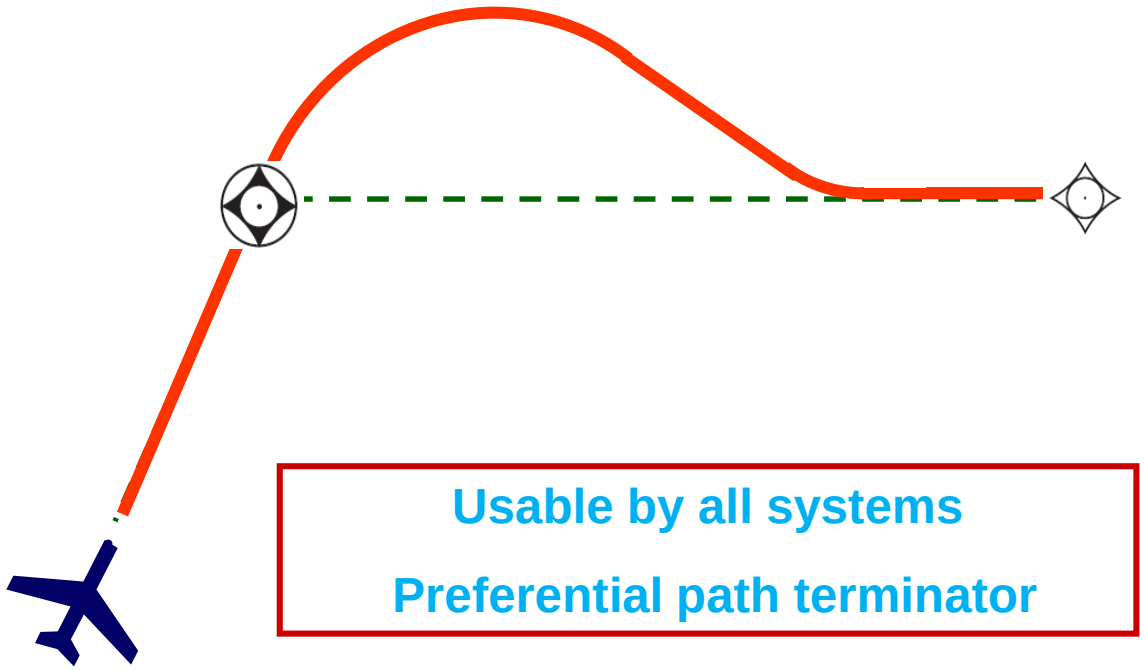
- Generally designated as “Waypoints”
- Defined in latitude and longitude;
- Two types of waypoints:
  - ☞Flyover waypoint (Strong constraint)
  - ☞Fly-by waypoint (General case)

Path terminator (Path and terminator)

- Two-letter code defining:
  - a specific type of flight path along a segment of a procedure and
  - a specific type of termination of that flight path.
- Path terminators are assigned to PBN:
  - SIDs
  - STARs and
  - Approach procedure segments
    - In an airborne navigation database.

Fixes, path terminators and transitions

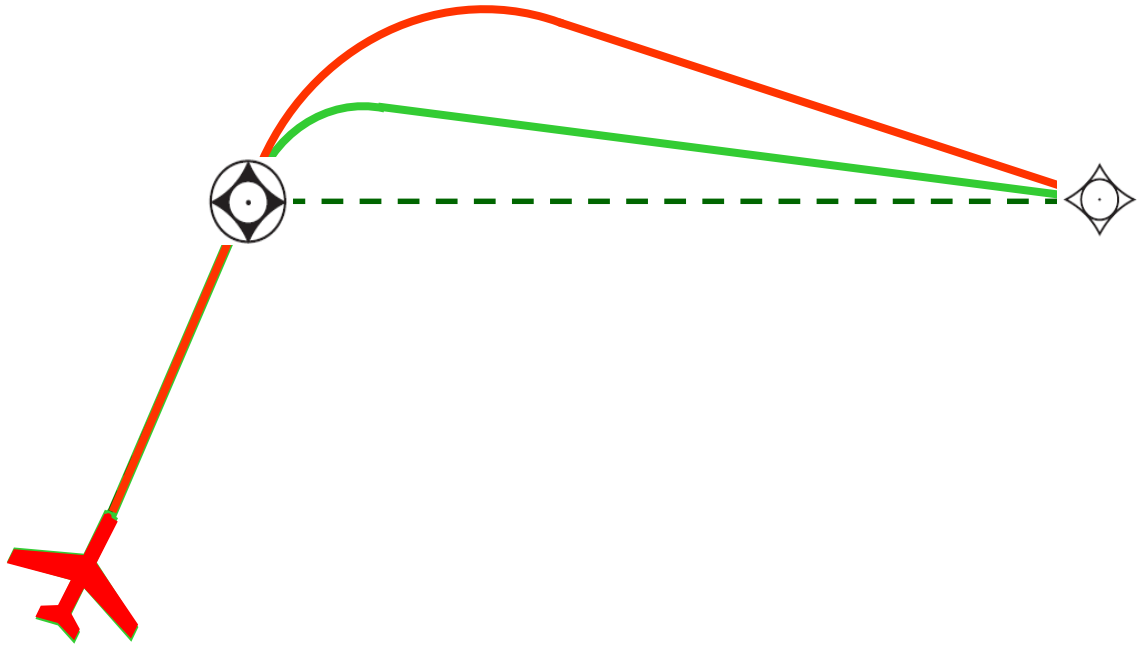
TF : Track between Fixes



Usable by all systems

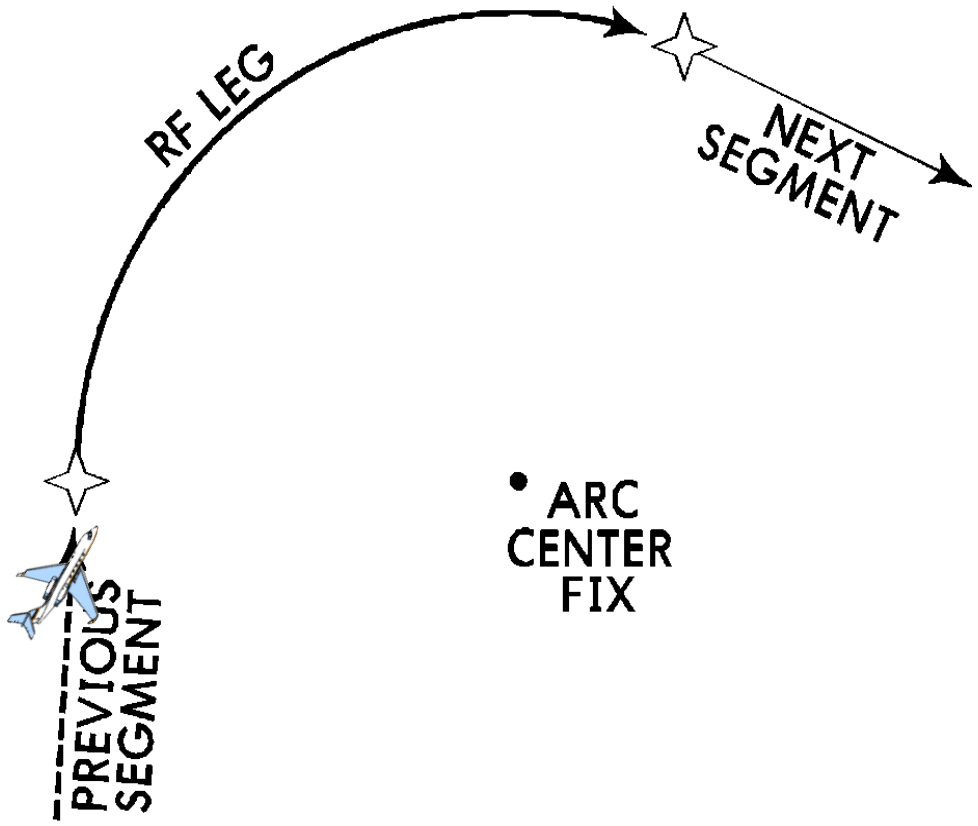
Preferential path terminator

DF : Direct to Fix



RF : Radius to Fix transition

- Follows an arc of a circle, defined by **radius to a fix**;
- RF initially required by the **RNP AR APCH**;
- RF can be for:
  - STARs;
  - SIDs;
  - RNP APCH.



Navigation systems and sensors

- Five main RNAV navigation systems:
  - GNSS, INS, DME/DME, DME/DME/IRU and VOR-DME.
- The green are ground-based NAVAID dependent and the red are independent of ground-based NAVAIDs
  - GNSS, INS are the only navaids usable in Oceanic/Remote airspace.
  - DME/DME, DME/DME/IRU and VOR-DME can be used in En-route and Terminal.
- RNAV "NAVAID dependent" is different from conventional navigation using individual VOR or DME NAVAIDs.

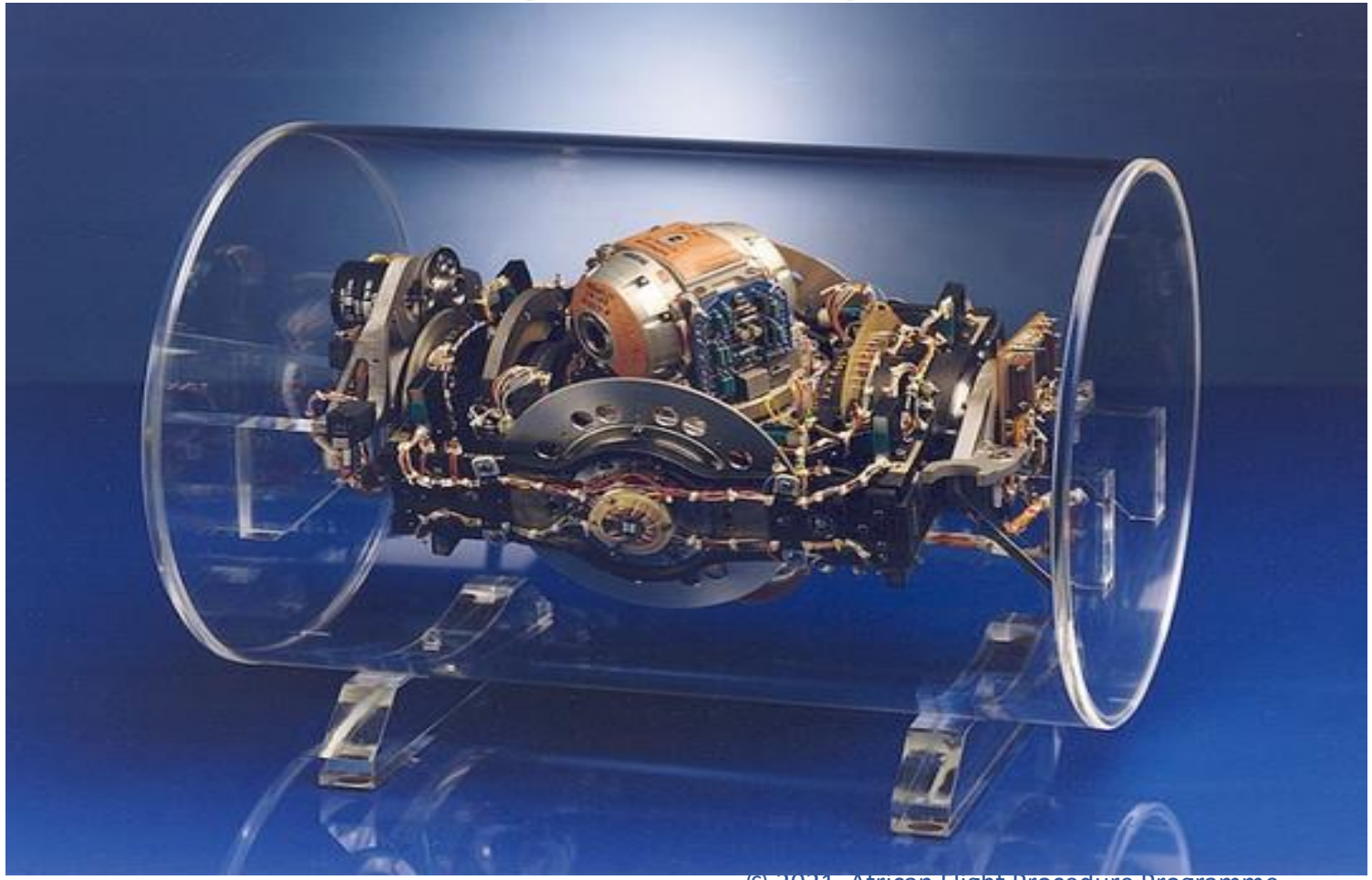
INS vesrus IRS

- Provide aircraft POSITION by reference to an INITIAL position.
- Very accurate accelerometers measure the horizontal acceleration
  - ☞ By integration calculation:
    - Acceleration ➡ Ground Speed ➡ POSITION / Initial position.
- INS: Equipped with a platform remaining horizontal all along the flight (use of gyroscopes)
  - ☞ Provide data for horizontal navigation
    - Inertial drift 2 NM/hour
      - High drift the first ½ hour of navigation (8 NM/hour)
- IRS: Platform integral with the aircraft structure, it generates a fictitious platform to be kept horizontal by computation(using gyrolaser information, detecting the pitch variation)
  - ☞ Provide data for horizontal and vertical navigation (vertical acceleration)

DME/DME/IRU

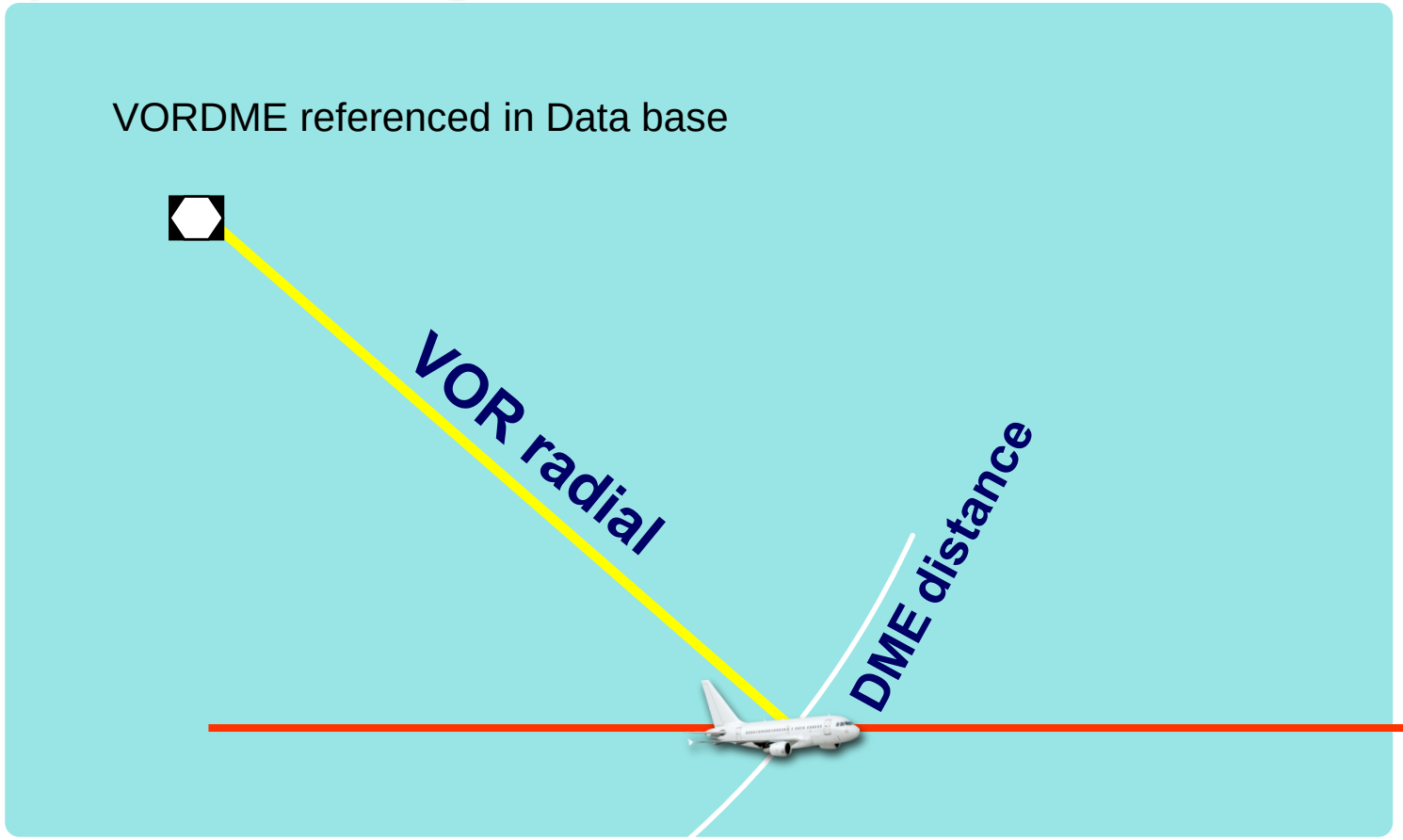
- Another type of area navigation system:
  - ☞Adds the inertial functionality to a DME/DME navigation system by coupling IRU with DME/DME to improve the continuity of the navigation system performance.
- DME/DME with IRU position updating enables the aircraft's FMS to cross-check its navigation systems against each other;
- Having DME/DME and an INS not coupled ≠ having DME/DME/IRU
- Has the capability to provide navigation through DME/DME gaps, for example through an area 30 to 150 degrees between two DME facilities.

Mechanical INS (B747-200)

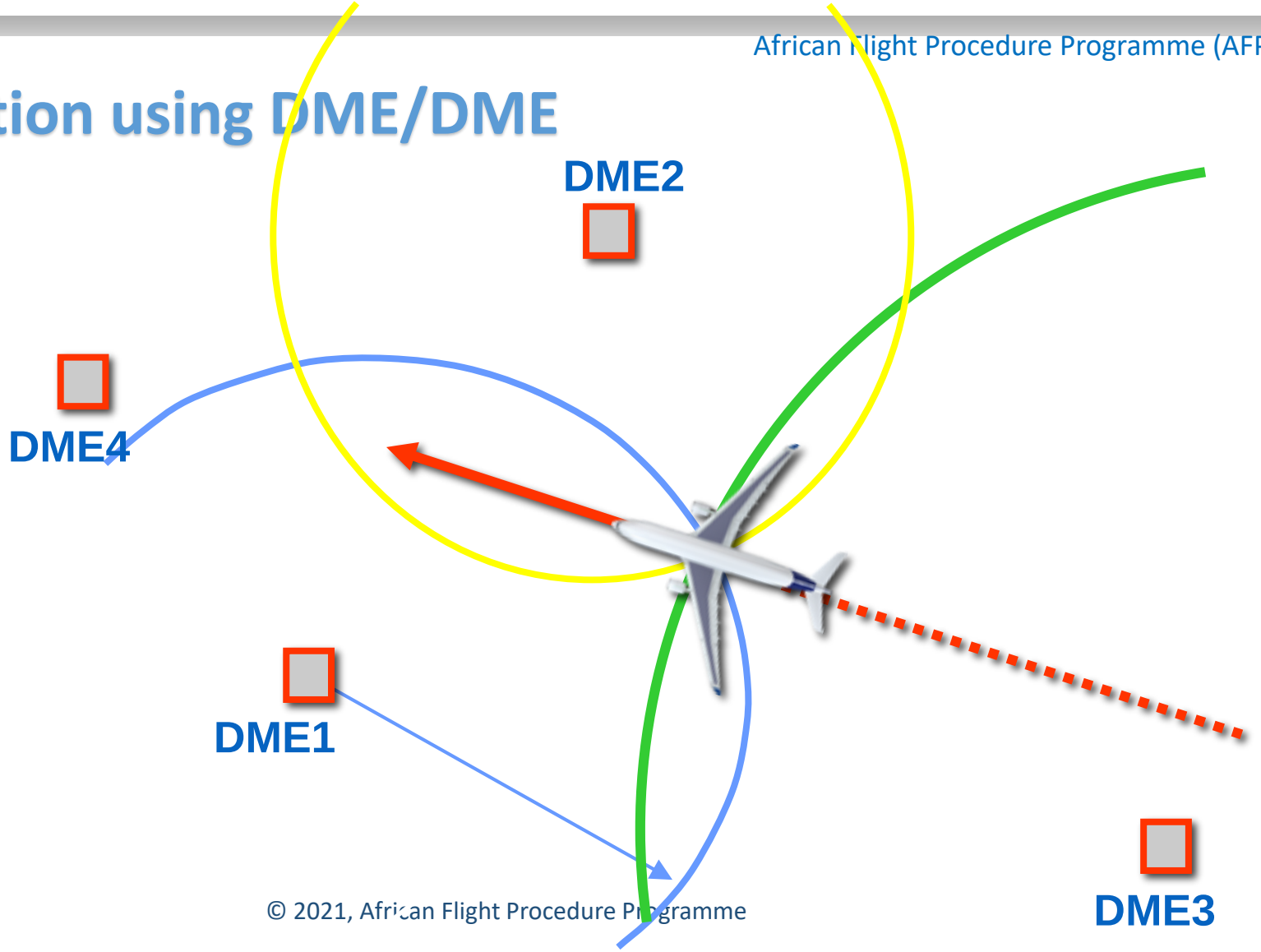


…as opposed to **Laser-gyro IRS** in modern aircraft

Position computation using VOR-DME



Position computation using DME/DME



Global Navigation Satellite System (GNSS)

- GNSS:
  - Worldwide coverage (global);
  - Position in WGS-84 and time.
- Encompasses existing and future global positioning systems:
  - GPS, GLONASS, Galileo, etc.
- Three components:
  - Space segment;
  - Control segment;
  - User segment.

Performance requirements

- Accuracy:
  - Degree of conformance between the estimated or measured value and the true value.
- Integrity:
  - Degree of assurance that an aeronautical data and its value has not been lost nor altered since the data origination or authorized amendment.
- Continuity:
  - Degree of assurance that an aeronautical data and its value has not been lost nor altered since the data origination or authorized amendment.
- Availability:
  - Portion of time during which the system is simultaneously delivering the required accuracy and integrity (integrity always determines availability).

Global Navigation Satellite System (GNSS)

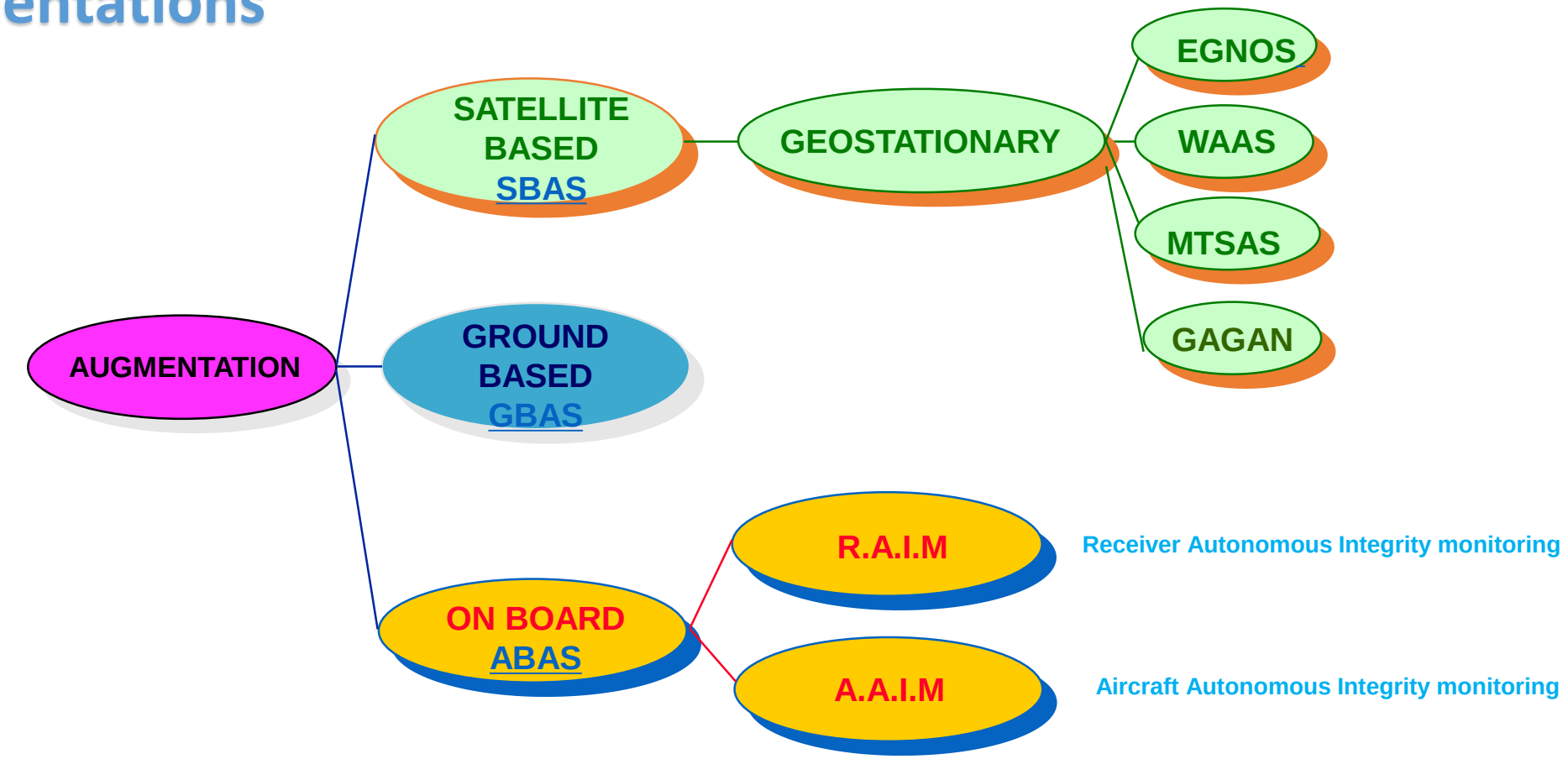
ICAO performance requirements

Typical operation	Accuracy horizontal 95% (Notes 1 and 3)	Accuracy vertical 95% (Notes 1 and 3)	Integrity (Note 2)	Time-to-alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
En-route	3.7 km (2.0 NM)	N/A	$1 - 1 \times 10^{-7}$/h	5 min	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1 - 1 \times 10^{-7}$/h	15 s	$1 - 1 \times 10^{-4}$/h to $1 - 1 \times 10$	0.99 to 0.9999
Initial approach, Intermediate approach, Non-precision approach (NPA), Departure	220 m (720 ft)	N/A	$1 - 1 \times 10^{-7}$/h	10 s		
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1 - 2 \times 10^{-7}$ in any approach	10 s		
Approach operations with	16.0 m	8.0 m	$1 - 2 \times 10^{-7}$	6 s	$1 - 8 \times 10$	0.99 to

Core GNSS performances doesn't meet ICAO SIS requirement!
Need of augmentations

Global Navigation Satellite System (GNSS)

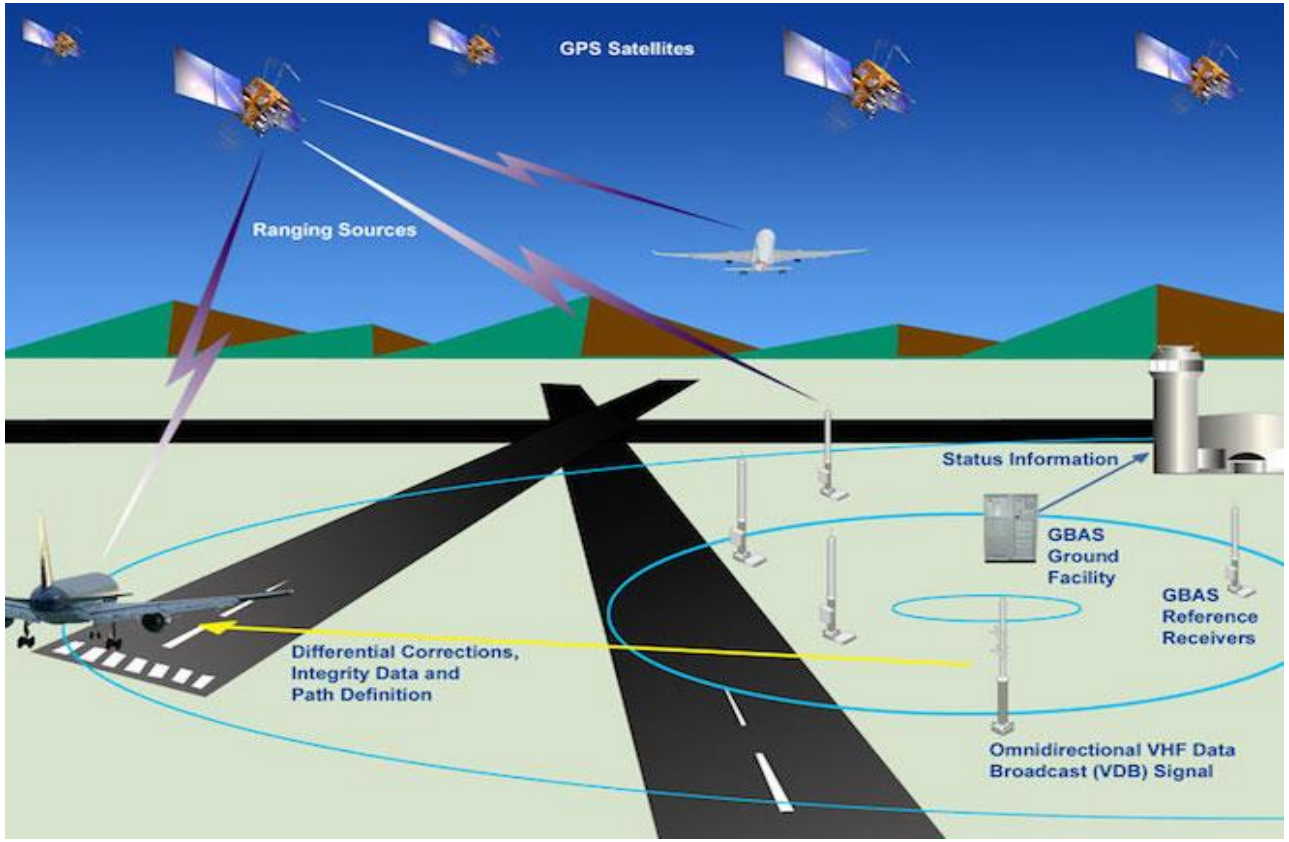
GNSS augmentations



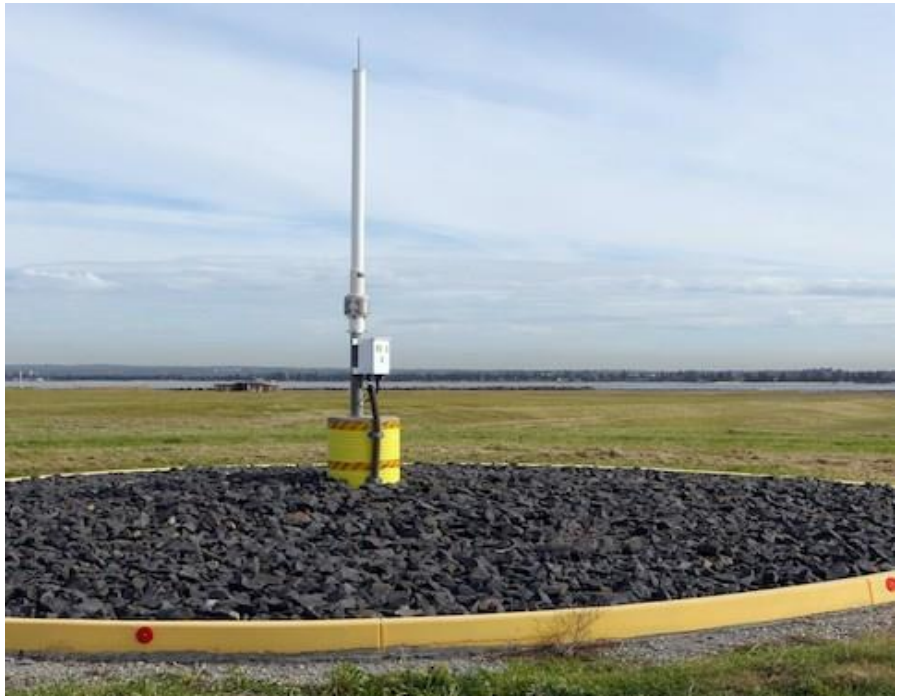
GNSS augmentations: ABAS

- Based on redundancy of the signal used in the position computation;
- RAIM : Receiver Autonomous Integrity Monitor:
  - Uses signal from one system (GPS);
  - At least 5 satellites (6 for exclusion).
- AAIM : Aircraft Autonomous Integrity Monitor:
  - For multisensor aircraft;
  - Uses information from other sensors.

GNSS augmentations: GBAS architecture



GNSS reference station



SBAS architecture

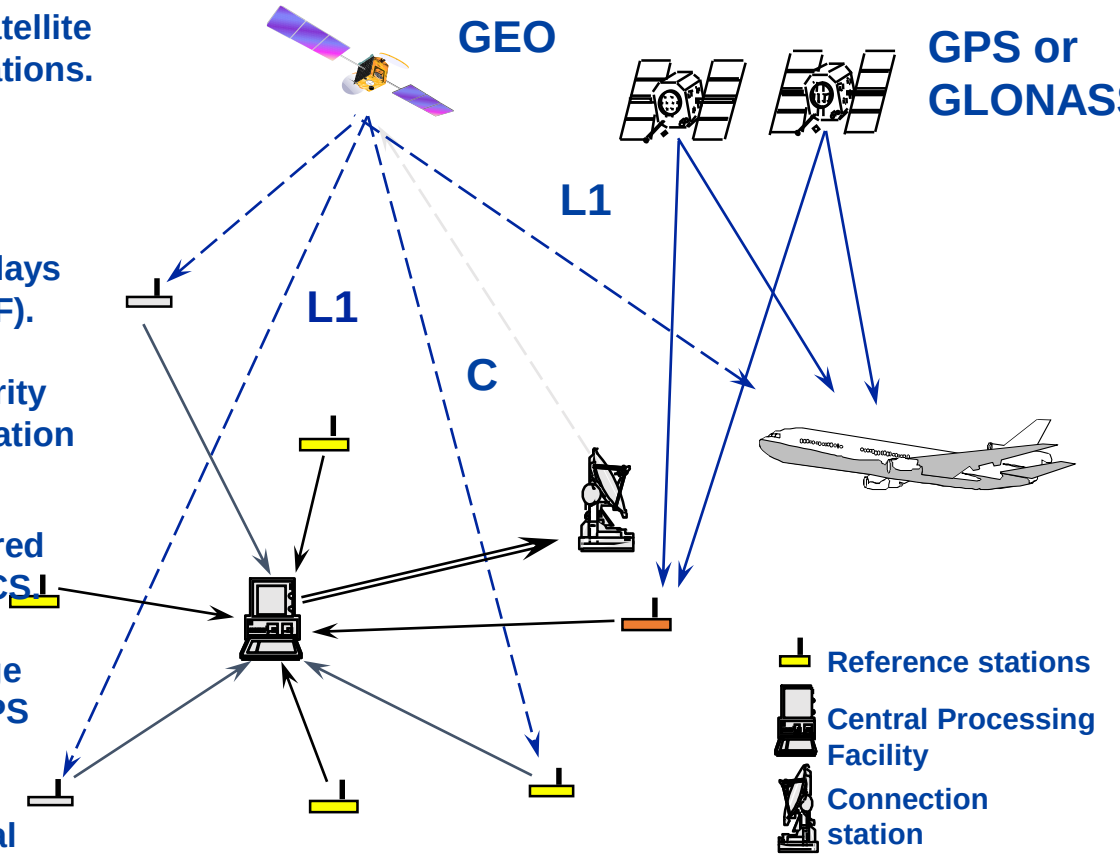
1. Signals from GPS and GEO satellite are received by the reference stations. Each of them precisely surveyed determine if any errors exist

2. Each station in the network relays the data to a master station (CPF). The CPF computes corrections (clock and ephemeris) and integrity data and adds them to the navigation message.

3. A correction message is prepared and uplinked to the GEO via the CS.

4. The Geo broadcast the message on the same frequency as the GPS receivers on board aircraft.

Users are provided with additional navigation signal for position determination with integrity and a better accuracy



Benefits

Which augmentation for which type of approach ?

ABAS Non Precision Approach NPA

+ VNAV: APproach with Vertical Guidance APV baroVNAV

SBAS APproach with Vertical Guidance

APV I - SBAS cat I (LPV200)

GBAS Precision Approach

CAT 1

Benefits

❑ RNAV approach procedures

Type of Approach		Title of IAP	Guidance	Minima	Minima box
NPA	GNSS	RNAV(GNSS) RWY XY or RNP RWY XY	Lateral	MDA	LNAV
	SBAS		Lateral	MDA	LP*
APV	Baro-VNAV		Lateral & vertical	DA	LNAV/VNAV
	APV 1 SBAS		Lateral & vertical	DA	LPV
PA	SBAS		Lateral & vertical	DA	LPV
	GBAS	GLS RWY XY	Lateral & vertical	DA	GLS

**Note: LPV and LP lines of minima shall not be published on the same chart*

Benefits

- Approach strategy's objectives :
  - ☞Improve safety providing vertical guidance;
  - ☞Improve accessibility;
  - ☞Improve capacity (point merge);
  - ☞Avoid high density population area;
  - ☞Improve noise abatement and environmental impact;
  - ☞Curved path in mountainous area;
  - ☞Improve OCH;
  - ☞Improve cost effectiveness with CDO.

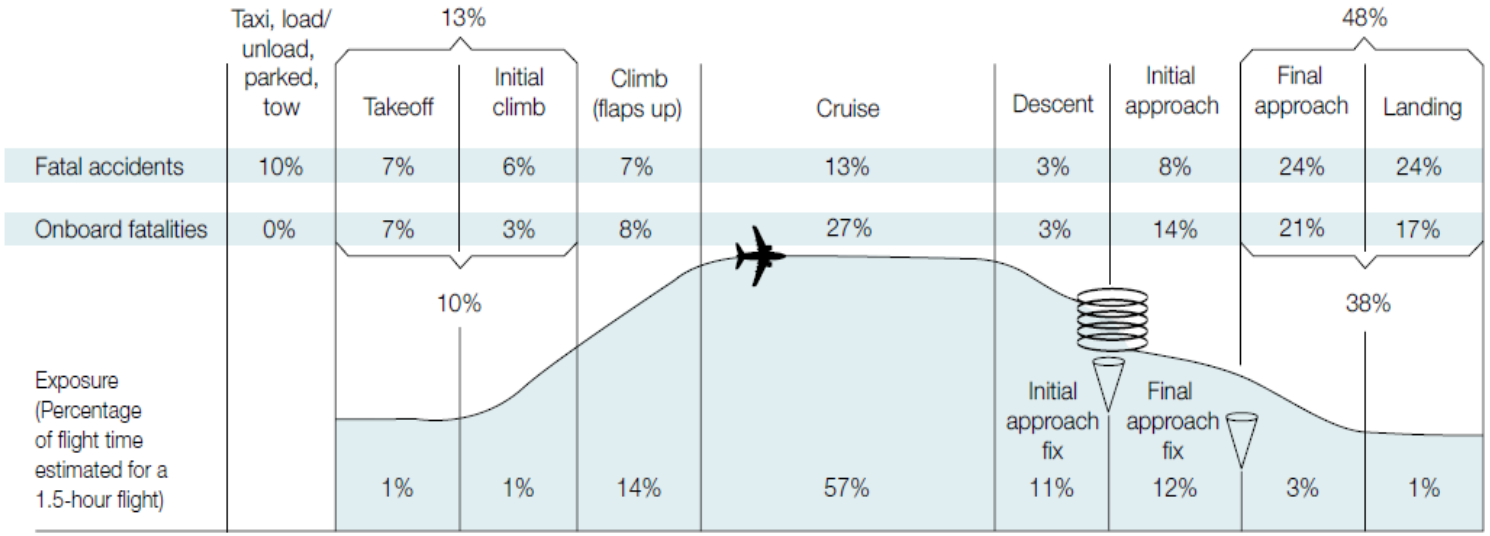
Benefits

- ICAO goal to prevent from Collision Flight Into Terrain (CFIT)
  - Vertical guidance for all approaches and QFU in 2016;
  - Provide stabilized approach.
- APV baro-VNAV as back up for ILS equipped THR:
  - for all other APV Baro-VNAV and LNAV for back up

Fatal Accidents and Onboard Fatalities by Phase of Flight

Worldwide Commercial Jet Fleet | 2005 through 2014

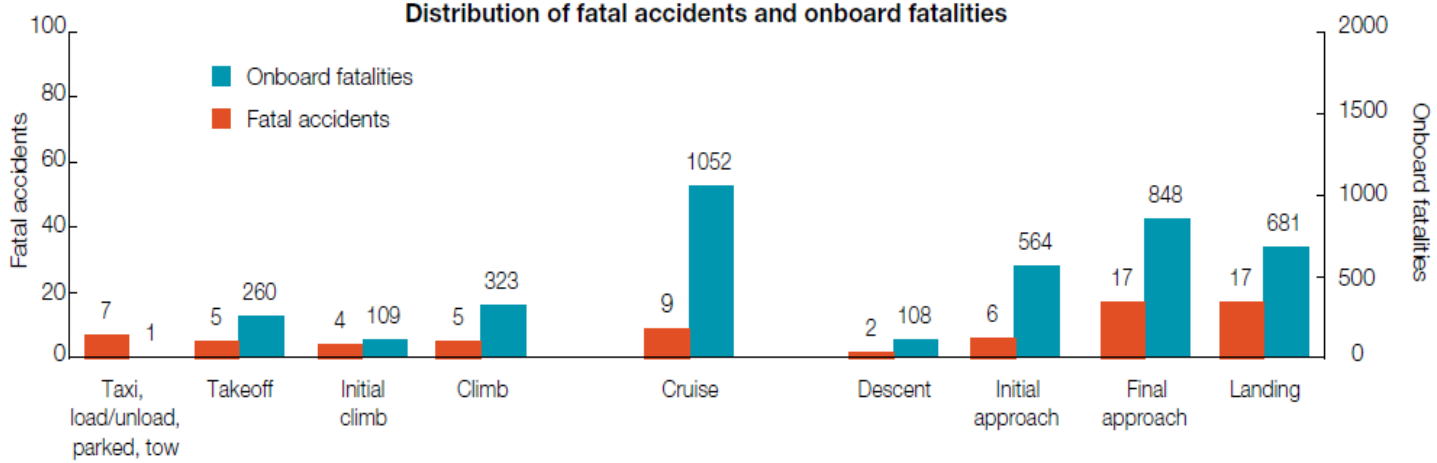
Percentage of fatal accidents and onboard fatalities



	Taxi, load/ unload, parked, tow	Takeoff	Initial climb	Climb (flaps up)	Cruise	Descent	Initial approach	Final approach	Landing
Fatal accidents	10%	7%	6%	7%	13%	3%	8%	24%	24%
Onboard fatalities	0%	7%	3%	8%	27%	3%	14%	21%	17%
Exposure (Percentage of flight time estimated for a 1.5-hour flight)		1%	1%	14%	57%	11%	12%	3%	1%

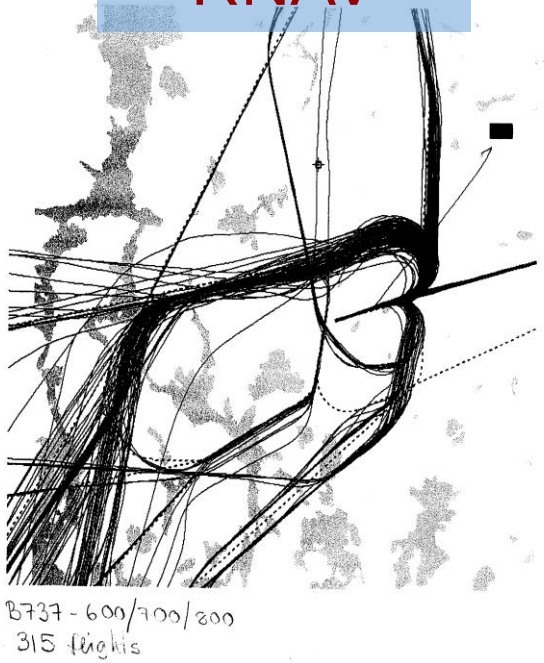
Note: Percentages may not sum to 100% due to numerical rounding.

Distribution of fatal accidents and onboard fatalities

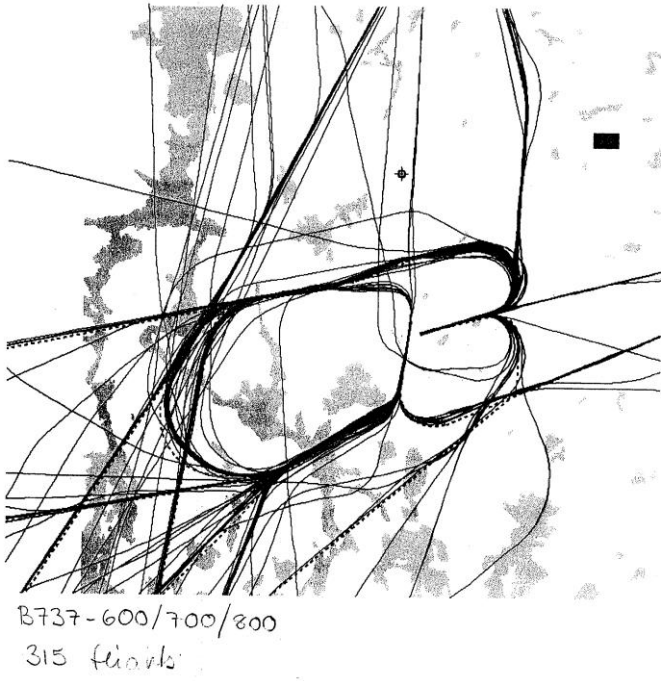


Benefits

NON RNAV



RNAV



- CFIT reduction;
- Access and quality:
  - Flight time reduction
  - Aligned on runway centerline
  - Improve visualization of markings and lightings
  - Easy use (piloting ,no misunderstanding)
  - Improvement of guidance
  - Improvement of accessibility
- Enable better airspace design and ASBU.

Questions:

Alexandre DAMIBA
adamiba@icao.int