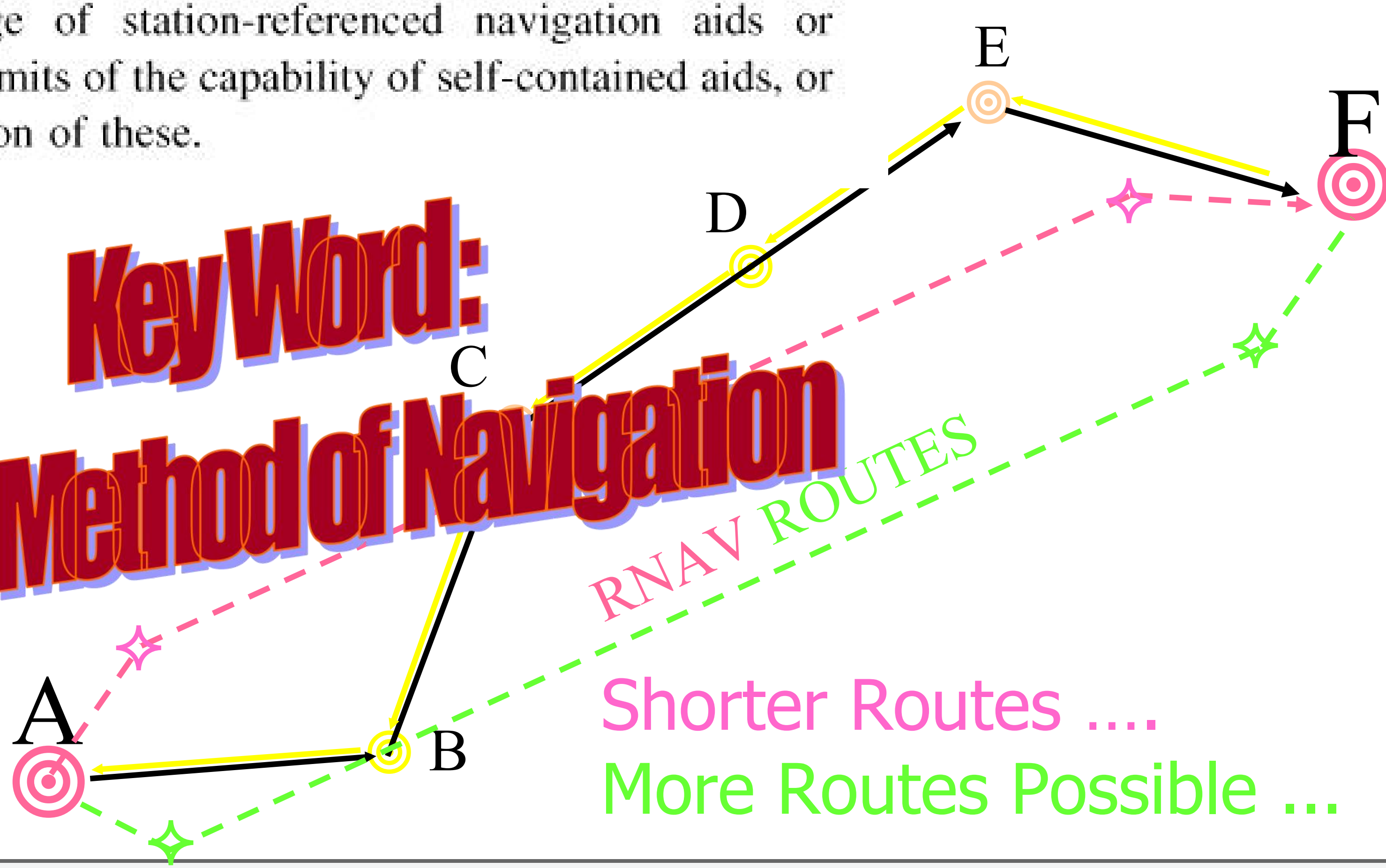
RNAV PRINCIPLES

OBJECTIVES

- RNAV history
- What is RNAV ?
- How A/C position is computed ?
- What's a waypoint ?
- RNAV operations

RNAV: AREA NAVIGATION

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



Key Word:

RNAV: Method of Navigation

Shorter Routes ....

More Routes Possible ...

RNAV System - History

- Instrument landing System: **1938**
- VOR (Airways): **1960s**
- Introduction of 2D RNAV VOR/DME: **1975**
- GPS navigation: **1994**   RNP: **1996**
- PBN ICAO mandate: **2016**

RNAV System - History

- RNAV began in the US in the 1970's and the certification/approval requirements followed evolutions of this concept and of its associated technologies.

  – AC 90-45 « Approval of area navigation systems for use in the US issued in 1969.
  – AC 90-45A issued in 1975
    - 2D RNAV with vertical guidance for advisory
    - Positioning based on VOR/DME
  – AC 20-130 Approval of multi-sensor navigation system for use in the US NAS » issued in 1988. Positioning based on VOR/DME, DME/DME and/or Inertial
  – AC 20-130A issued in 1995 addressing FMS and GPS systems.
  – AC 90-100A (RNAV for Enroute and Terminal area) and AC 90-101 (RNAV for specific approaches: RNP AR) issued in 2007

- Conventional Navigation
  - Defined based on old aircraft capabilities and use of conventional navigation means
    - Large protection areas and separation criteria to cope with limited accuracy of position estimation
  - Based on Ground Navigation Aids
    - Overfly
    - Relative position
  - Limited design flexibility
    - Flight paths cannot be modified easily
    - Impact of a suppression or displacement of a navaid
    - For instance : All arrivals and departures may have to be modified if a single VOR transmitter is displaced.

Widely used but no more suitable due to traffic increase and high fuel cost

Conventional navigation (versus RNAV)

- A robust system :
  - Many sensors and indicators on board, based on different technologies and wave-lengths (LF/MF, VHF, UHF).
  - No single failure will affect navigation performance.
- Need to get different avionics receivers on board (VOR, DME, ADF)
- A conventional flight path may be flown with an RNAV system provided that the raw data are monitored
  - overlay condition

RNAV advantage

- Navigation is no more based on fixed ground navaids
- Capability to fly any desired flight path, defined by waypoints such as geographic fixes (LAT/LONG)
  - Concept flexibility for the route or for the procedure design
  - Concept efficiency
- Performance in terms of accuracy and integrity positioning are improved thanks to RNAV computer
  - Route separation or obstacle clearance may take credit of this improvement
- From an airborne point of view crew workload is lower compared to conventional navigation
  - Flight plan is loaded into the RNAV system (and can be flown automatically)
  - Smooth transition from leg to leg
  - All navigation information are displayed to the crew: distance to the wpt, bearing to the waypoint, cross track deviation,….

RNAV limitations

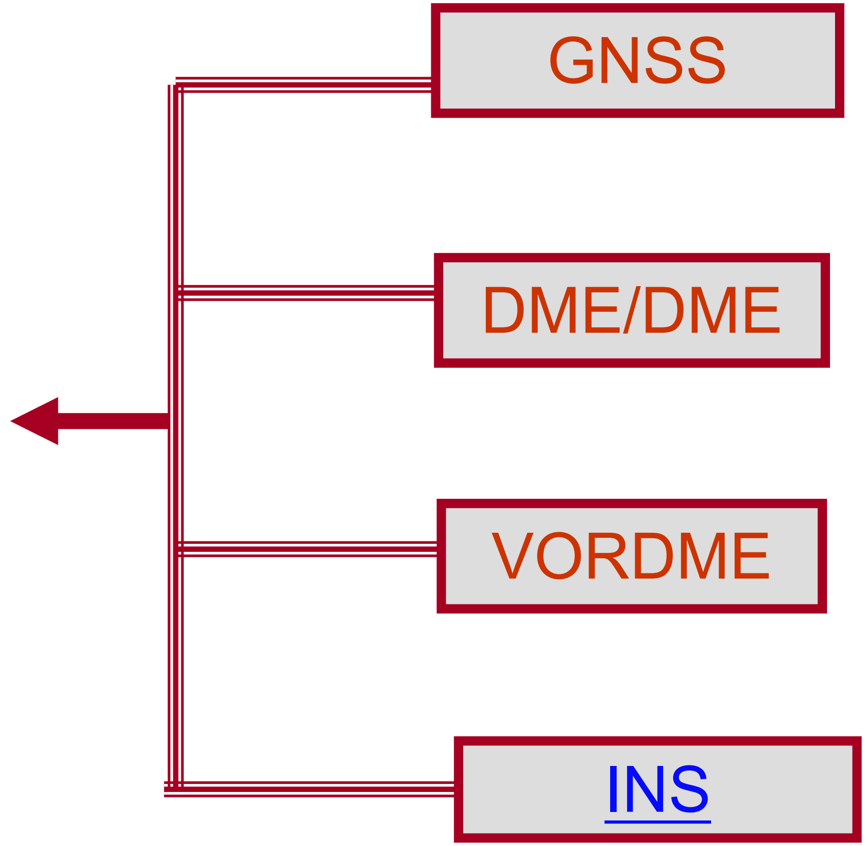
- Performance may be degraded in case of sensor failure
  - The crew should monitor the navigation system status
    - For instance in pure inertial navigation mode accuracy decreases with the time (e.g 2Nm/hr)
- In case of positioning based on radio navaids (VOR, DME) accuracy is dependent on Navaids geometry and navaids distance
  - May be a problem for procedure requiring a high degree of accuracy (e.g better than 1 Nm)

RNAV calculator

- Navigation function
  - The Navigation function consists in determining the best estimate of the aircraft position and evaluating the accuracy of this estimate. The FMS uses data coming from the different sensors.
  - Compute a guidance to follow the required path
    - Based on the positioning
    - Based on a selected trajectory

RNAV SYSTEM

The aircraft can determine its position on the following sensors:



A/C POSITION

RNAV POSITIONING METHOD

- The RNAV system
  - identifies the next waypoint,
  - selects the most appropriate source of navigation to determine its position
  - provides information to the auto-pilot to fly to the next waypoint.
- An RNAV route can be flown manually

NAVIGATION FUNCTION AND DISPLAY DEVICES

- The 'Navigation' function computes data that includes aircraft position, velocity, track angle, etc. This data is displayed on the Navigation Display (ND) or a Course Deviation Indicator (CDI) and may be displayed on the Flight Director (FD) and fed to the Auto Pilot.

- CDI: Course Deviation Indicator.

An avionics display used in aircraft navigation to show the aircraft position relative to a defined track or radial.

ND: Navigation Display, found in the cockpit on which any information pertinent to the flight of the aircraft is recorded and displayed

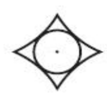
WAYPOINT

- Waypoints expressed in WGS84 coordinates
  - IAF, IF, FAF, MAPt, MAHF
  - Arrival or departure waypoint

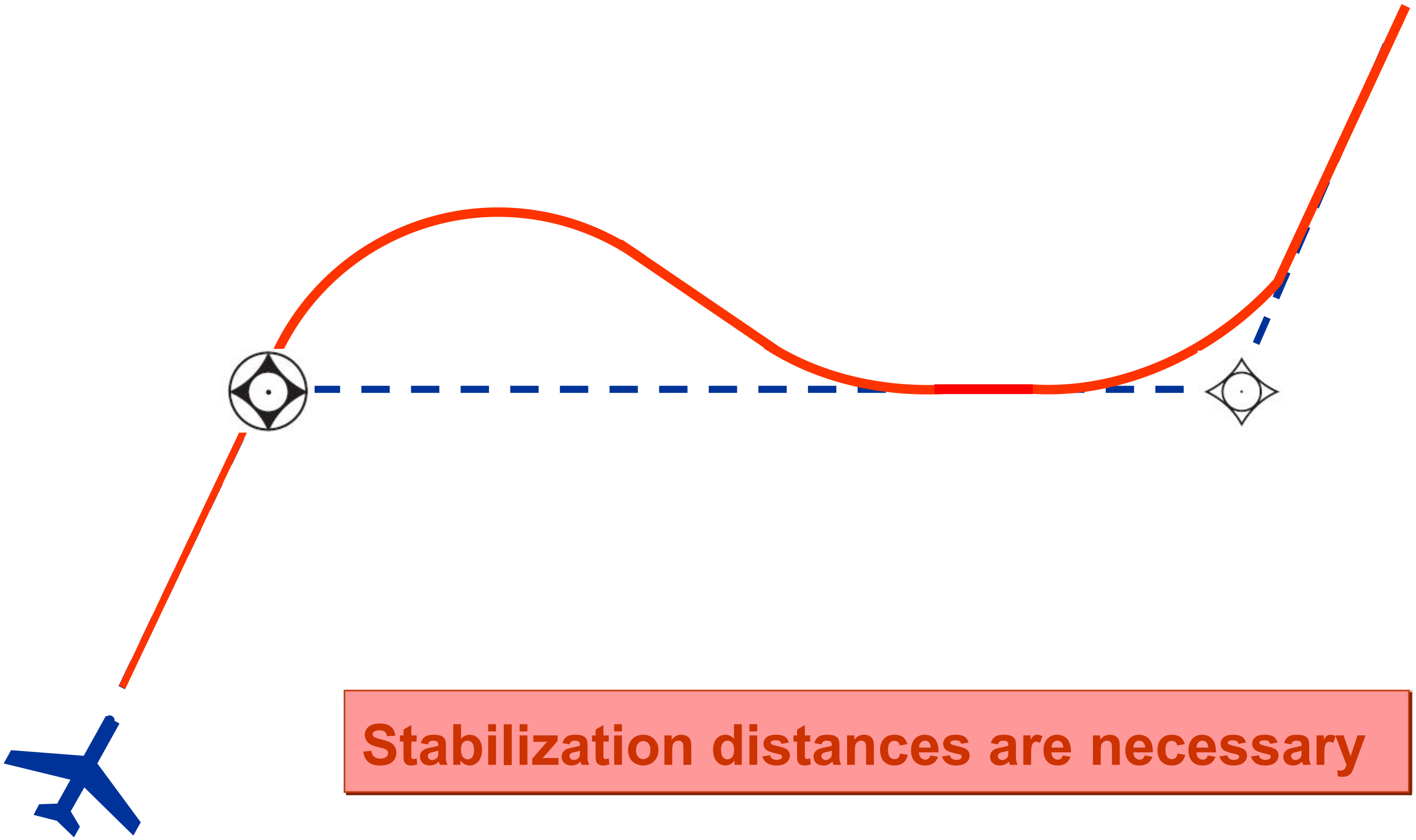
- **Fly-over waypoint**

  Symbol : 

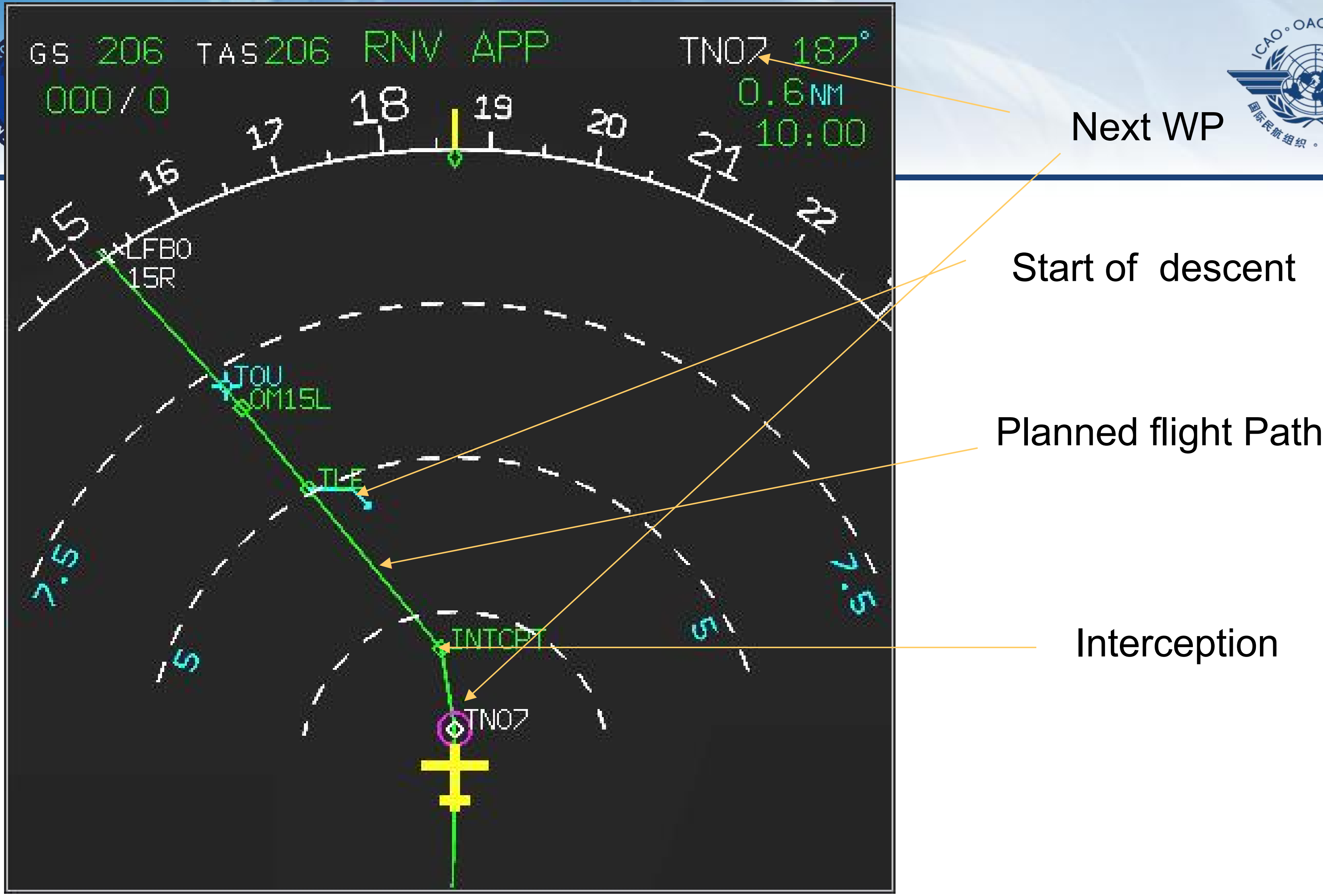
- **Fly-by waypoint**

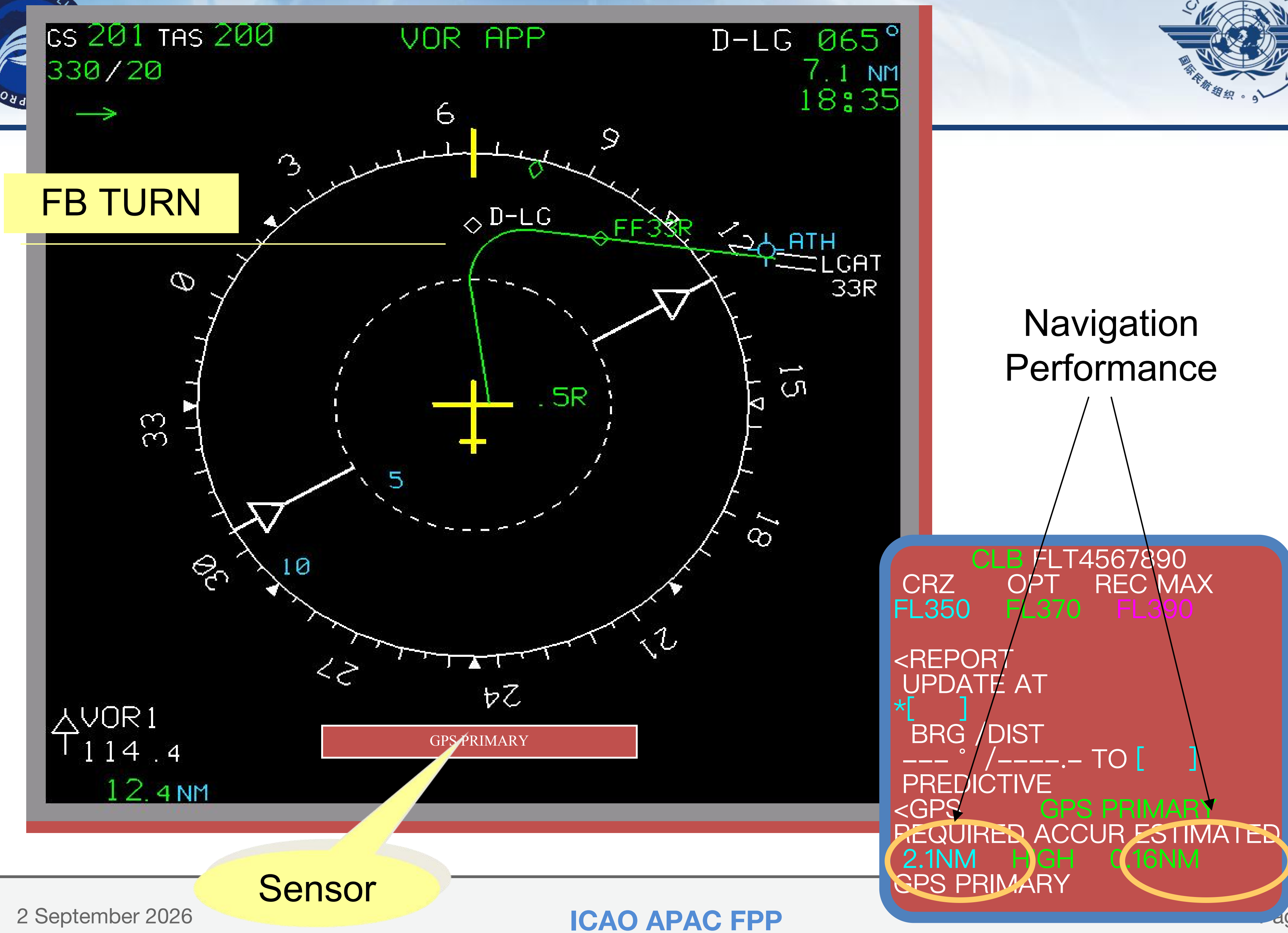
  Symbol : 

WP1 : FLY-OVER WP2 : FLY-BY



Stabilization distances are necessary


GS 206 TAS 206 RNV APP
000 / 0
TN07 187°
0.6 NM
10:00
LFBO
15R
TOU
OM15L
TLE
INTCPT
TN07
Next WP
Start of descent
Planned flight Path
Interception



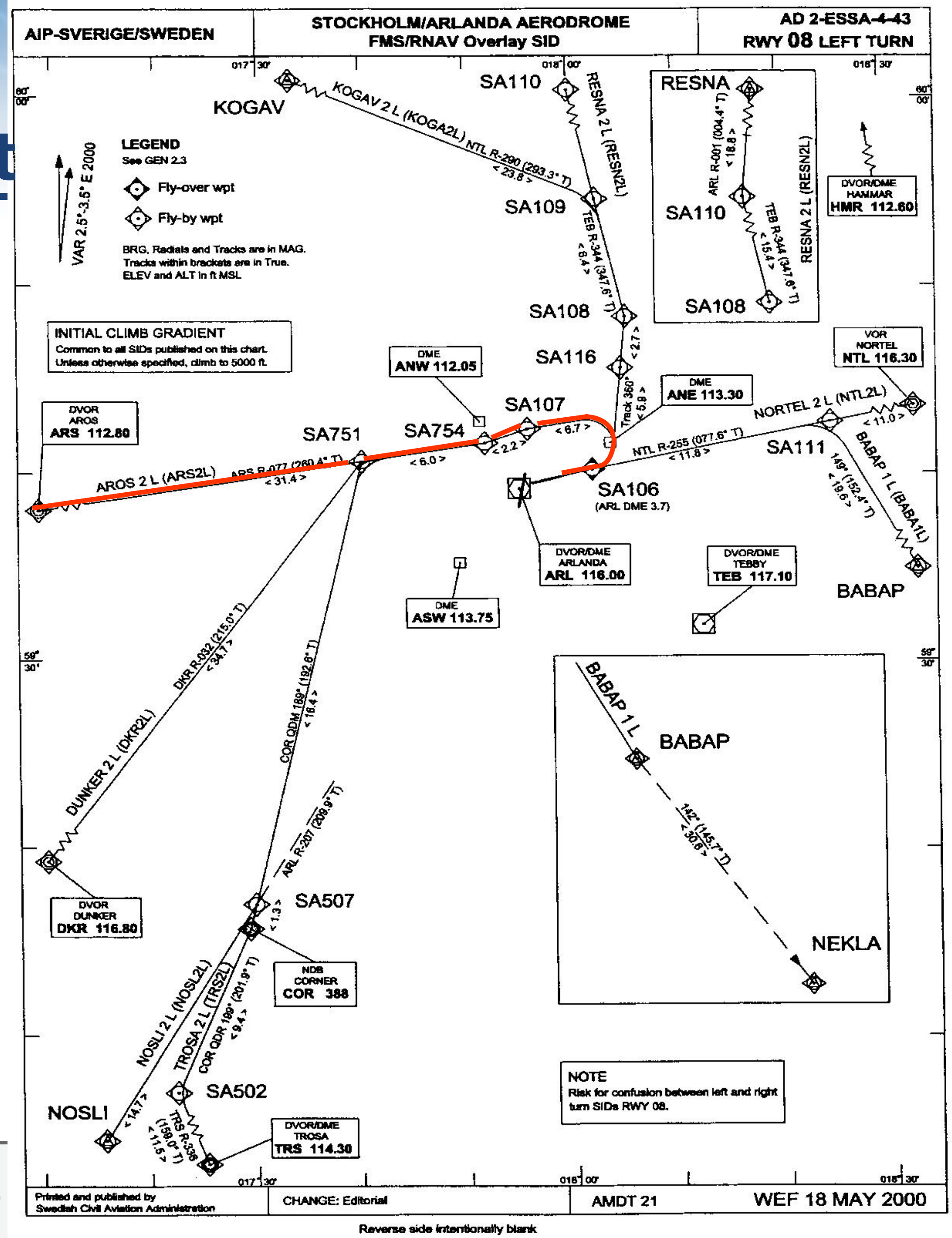
GS 201 TAS 200
330/20
VOR APP
D-LG 065°
7.1 NM
18:35
FB TURN
D-LG
FF33R
ATH
LGAT
33R
.5R
5
10
VOR1
114.4
12.4NM
GPS PRIMARY
Sensor
Navigation Performance
CLB FLT4567890
CRZ OPT REC MAX
FL350 FL370 FL390
<REPORT
UPDATE AT
*[ ]
BRG /DIST
--- ° /----.- TO [ ]
PREDICTIVE
<GPS GPS PRIMARY
REQUIRED ACCUR ESTIMATED
2.1NM HIGH 0.16NM
GPS PRIMARY

On board database

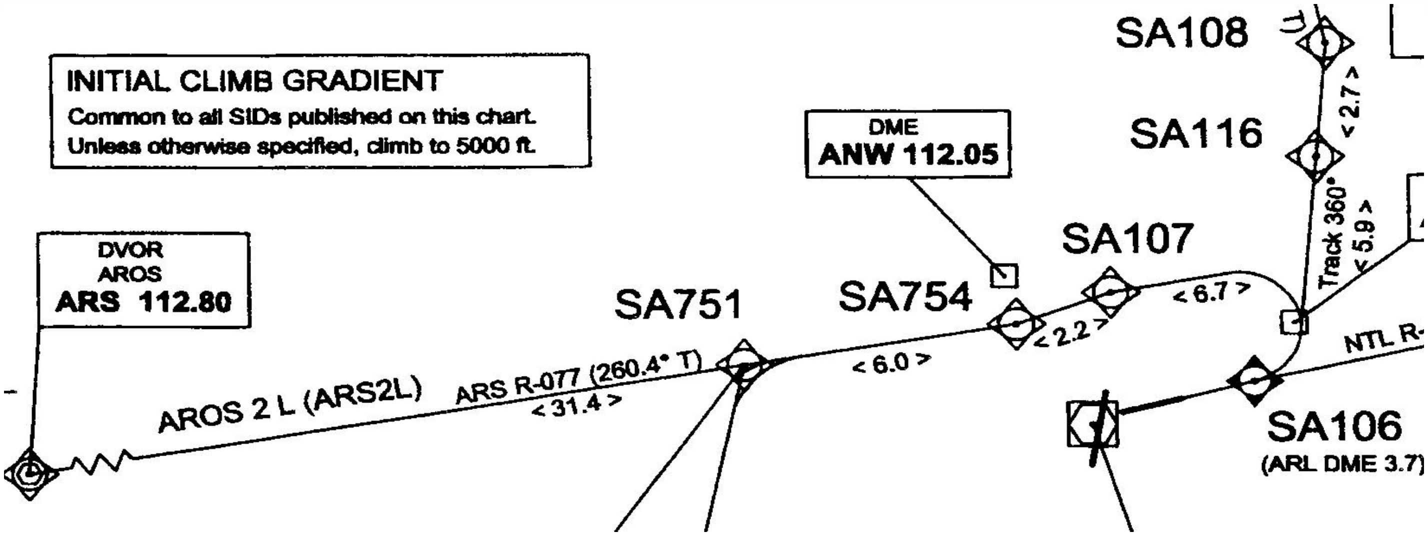
- Aerodrome data
- Available navaids
- **Flight paths to follow (charts)**

ALL RNAV TRAJECTORIES ARE CODED INTO THE DATABASE

Example : Departure chart



Coding a departure trajectory



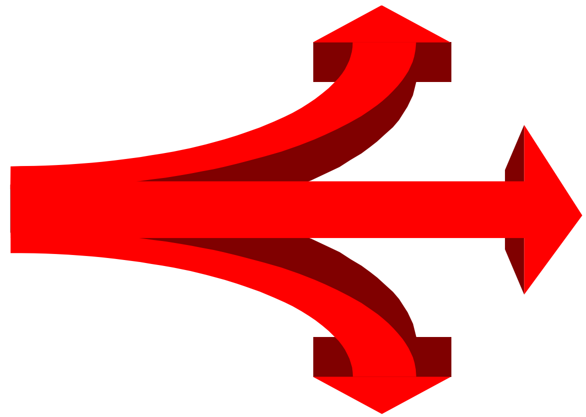
AROS 2 L	CF	SA106	EY	073.0
(ARS2L)	DF	SA107	E	

CODING INFLUENCE

PATH

CODING

AROS 2 L	CF	SA106	EY	073.0
(ARS2L)	DF	SA107	E	

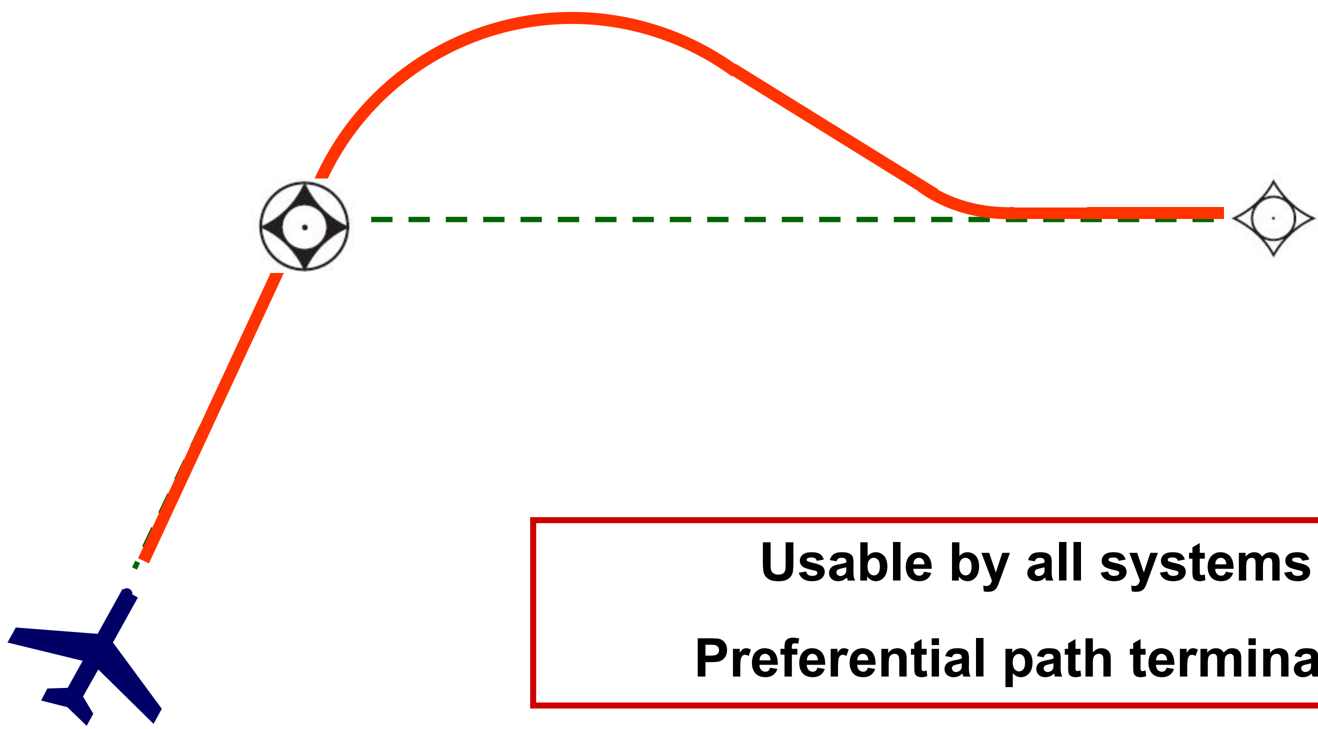


CONSTRAINTS

How to navigate

PATH TERMINATOR

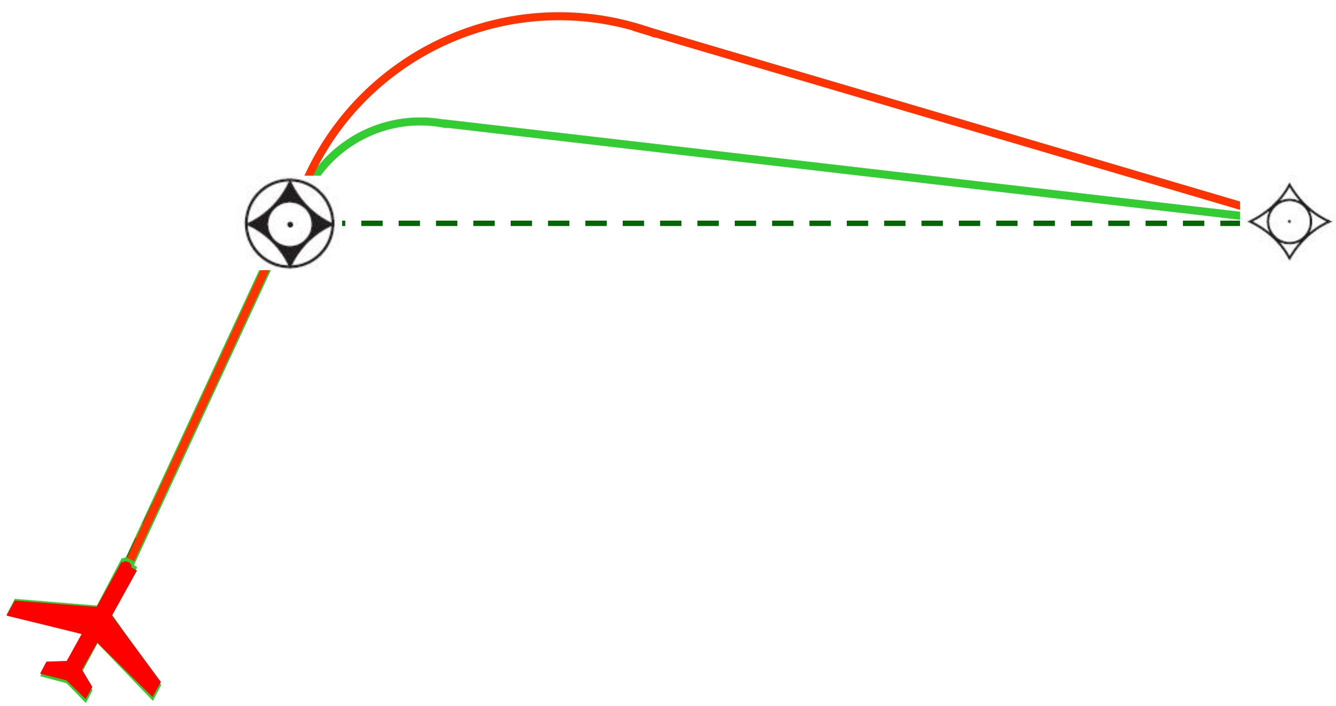
TF : TRACK BETWEEN FIXES



Usable by all systems

Preferential path terminator

DF : DIRECT TO FIX



KEY POINT 1

Type of waypoint

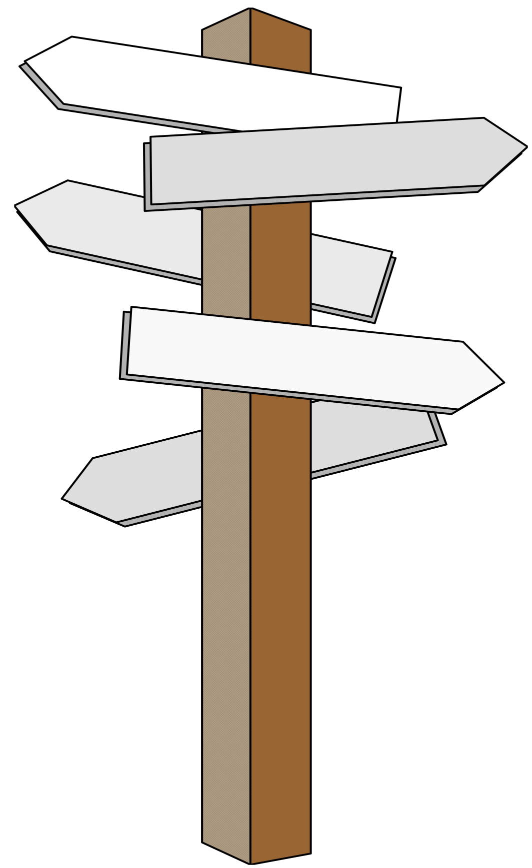
PATH Terminator

Nominal trajectory
Protection area

Be aware of coding influence

Real need of COMMUNICATION with coding suppliers

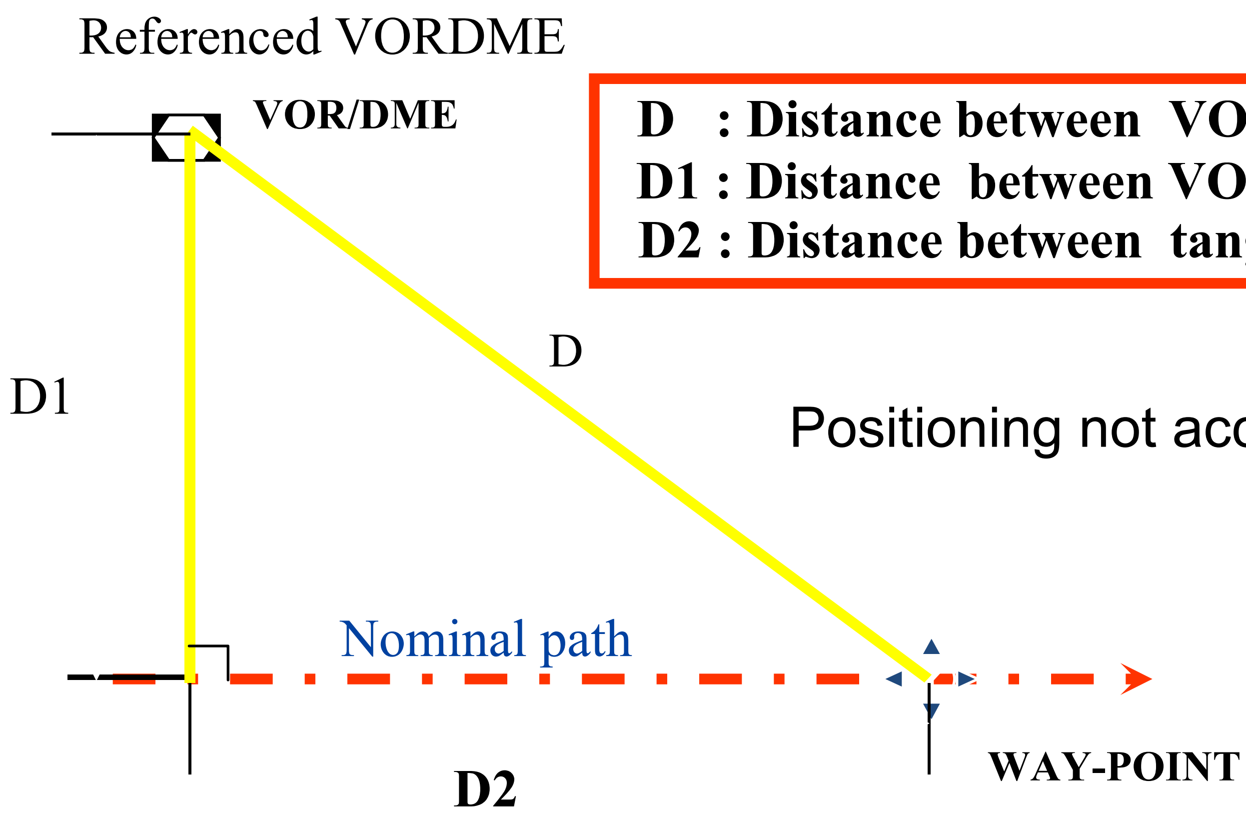
Where are we ?



Main RNAV navigation sensors

- **GNSS**
  - 3D or 4D position
    - Time + 2D or 3D positioning
- **DME/DME**
  - 2D position
    - Less accurate than GNSS
  - Baro-Altimeter gives the 3rd Dimension: Height/Altitude
- **VOR/DME**
  - 2D position
    - Less accurate than GNSS, use is restricted
  - Baro-Altimeter gives the 3rd Dimension: Height/Altitude
- **Inertial nav (INS)**
  - This navigation sensor supplies a 2D position
  - Requires an initialisation and resetting process (to compensate Ins drifting)
    - The time with autonomous INS use depends on the phase of flight and quality of the INS(few hours in Oceanis nav., a few minutes in approach)
  - Often hybridized with GNSS and DME/DME

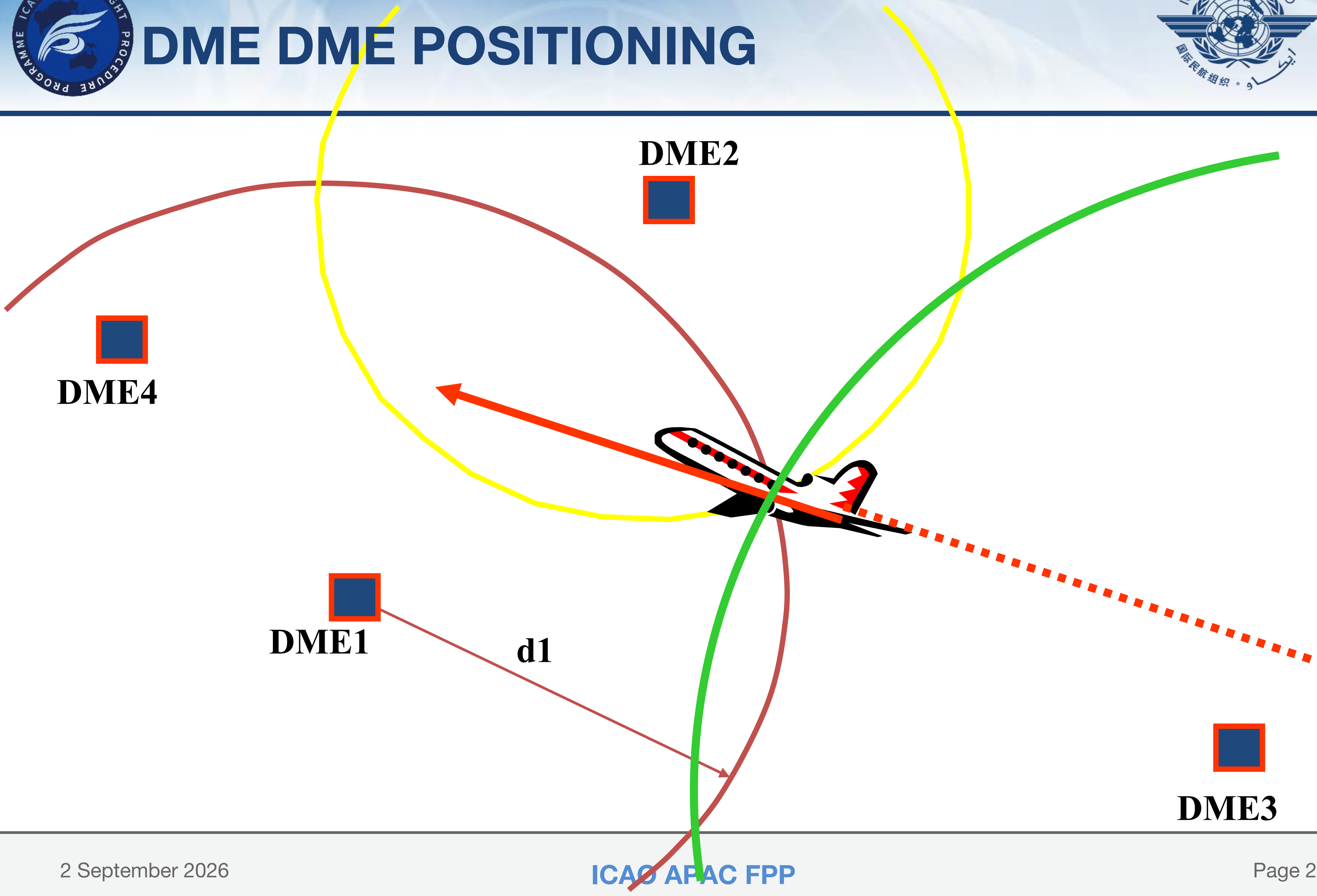
RNAV VOR-DME DEFINITION



D : Distance between VOR-DME /Waypoint
D1 : Distance between VOR-DME and tangential point
D2 : Distance between tangential point and waypoint

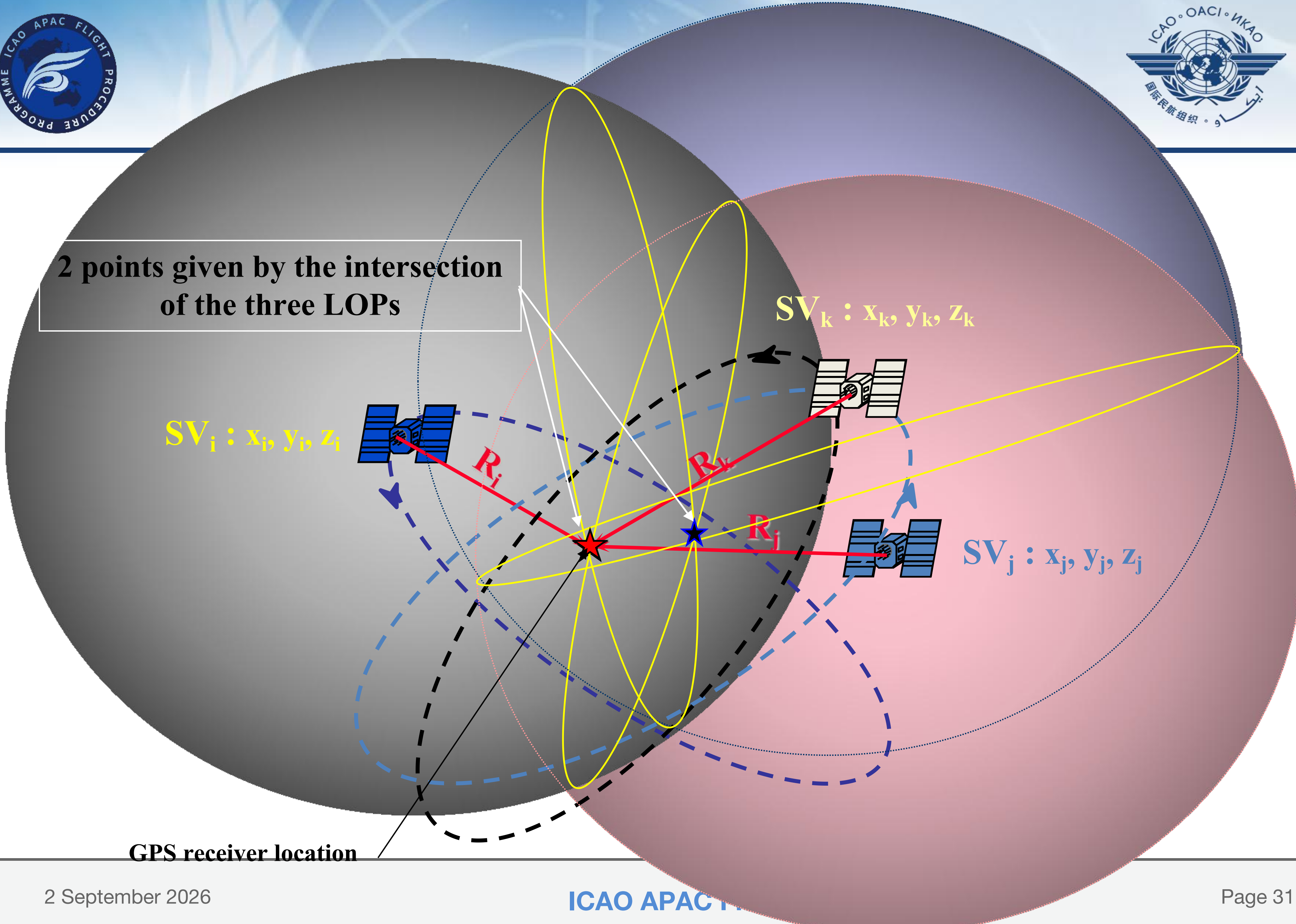
Positioning not accurate enough (no future)

DME DME POSITIONING

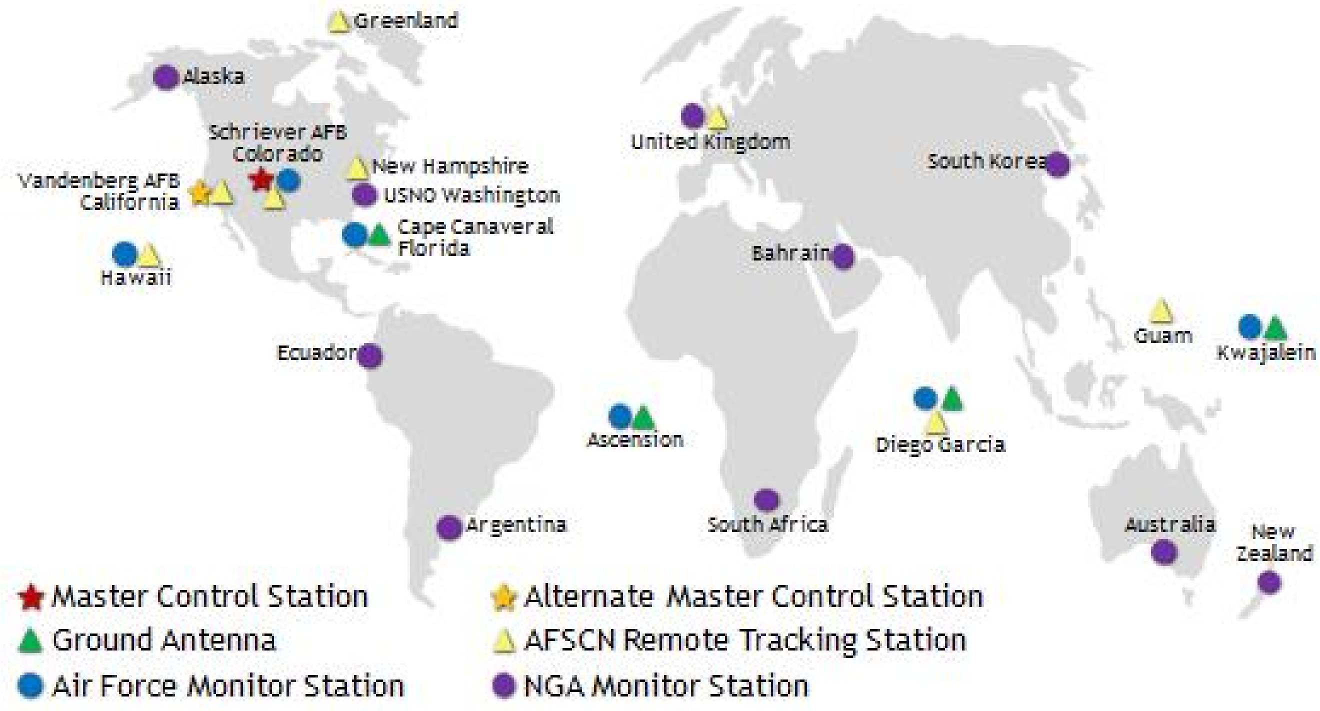


A little bit of vocabulary (annex 10)

- GNSS: *Global navigation satellite system*
  - **A worldwide** position and time **determination system that includes one or more satellite constellations, aircraft receivers and system integrity monitoring, augmented as necessary to support the required navigation performance for the intended operation.**
- **GPS :** *Global positioning system*
  - **The satellite navigation system operated by the United States**

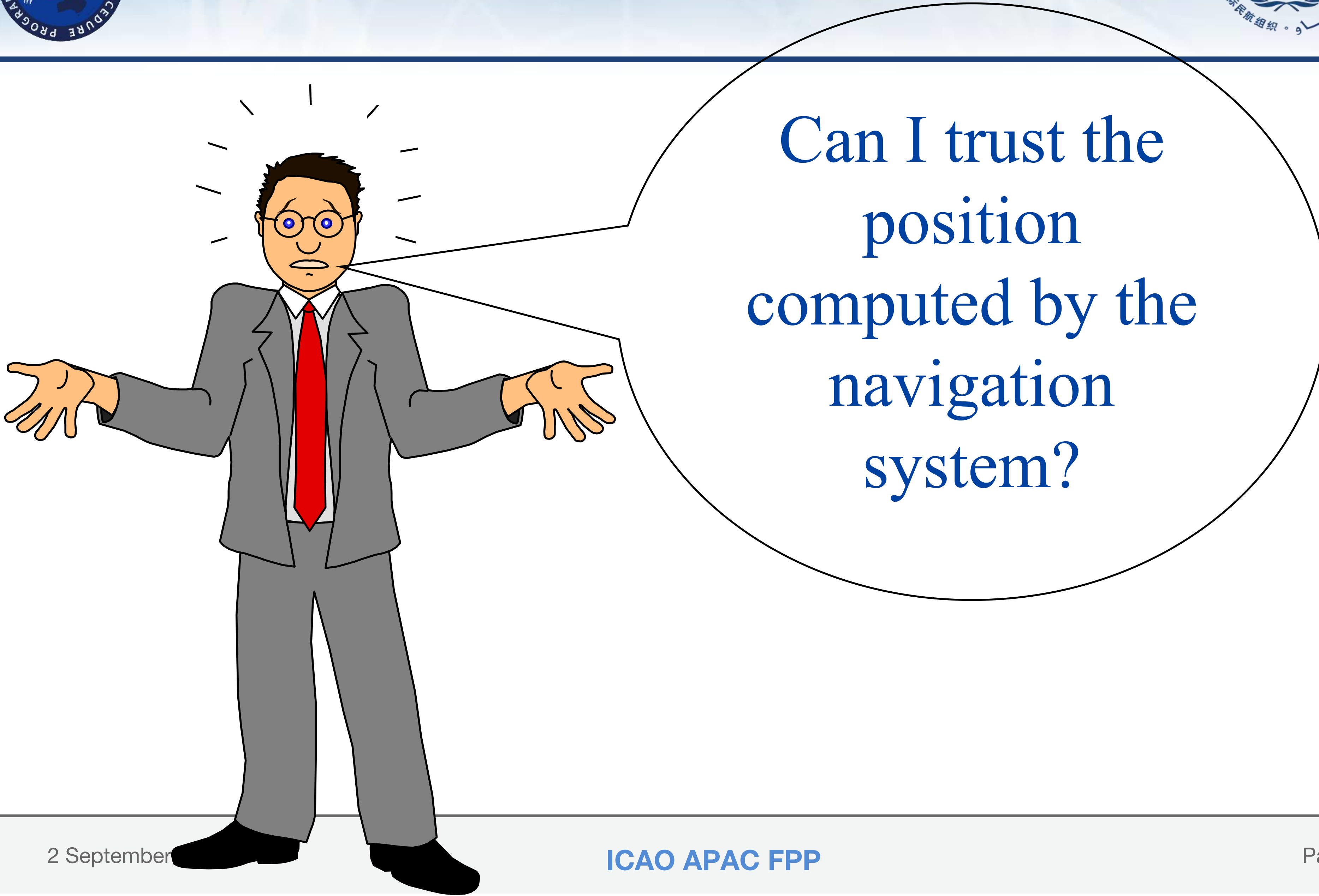

2 points given by the intersection of the three LOPs
SVk : xk, yk, zk
SVi : xi, yi, zi
Ri
Rk
Rj
SVj : xj, yj, zj
GPS receiver location

Control segment



The GPS control segment consists of a global network of ground facilities that track the GPS satellites, monitor their transmissions, perform analyses, and send commands and data to the constellation.

INTEGRITY

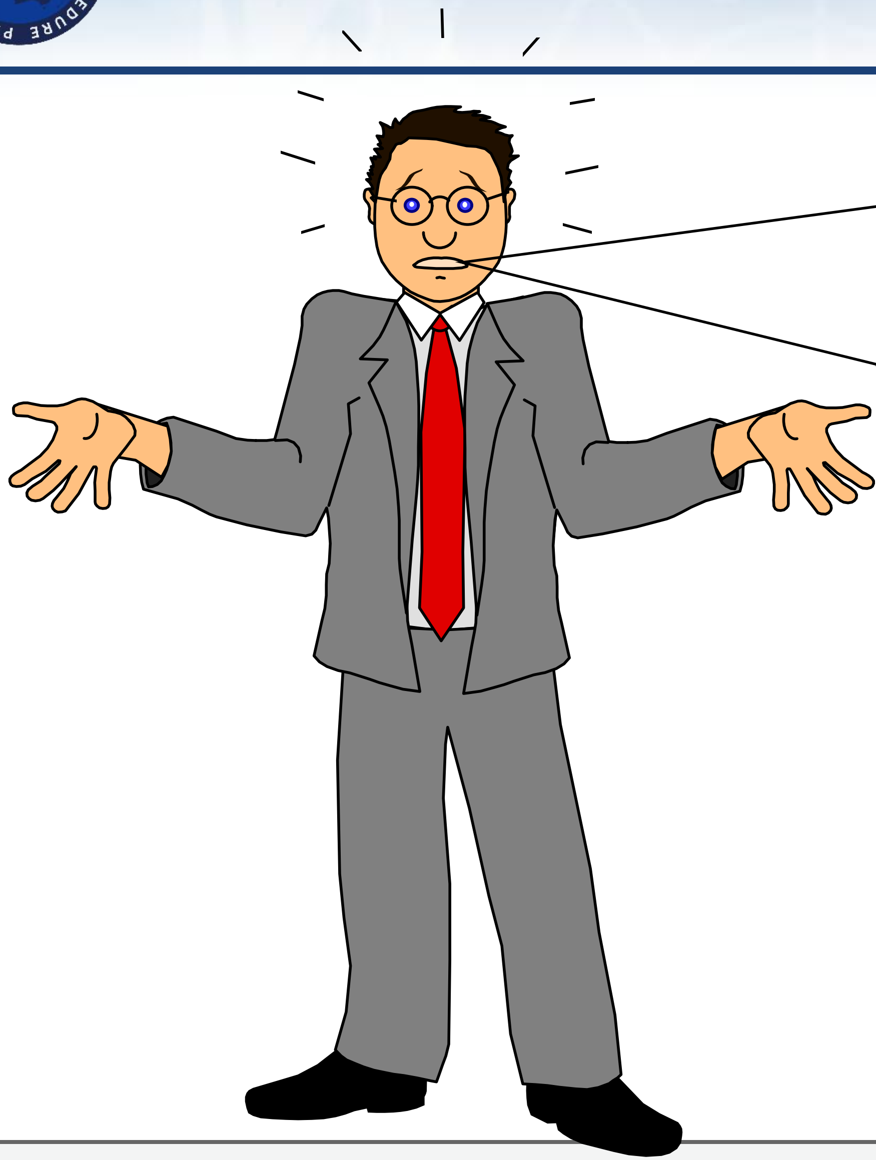


Vocabulary again.. (annex 10 again..)

- *Integrity :*
  - A measure of the **trust** that can be placed in the correctness of the information supplied by the total system.
  - includes the ability of a system to provide **timely and valid** warnings to the user (**alerts**).
- *Accuracy :*
  - GNSS position error is the difference between the **estimated** position and the **actual** position. For an estimated position at a specific location, the probability should be at least **95 per cent** that the position error is within the **accuracy requirement**.

Vocabulary again.. (annex 10 again..)

- *Continuity :*
  - **Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation.**
- *Availability :*
  - **Availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the aircraft.**



Does the position meet the requirements to be used for navigation

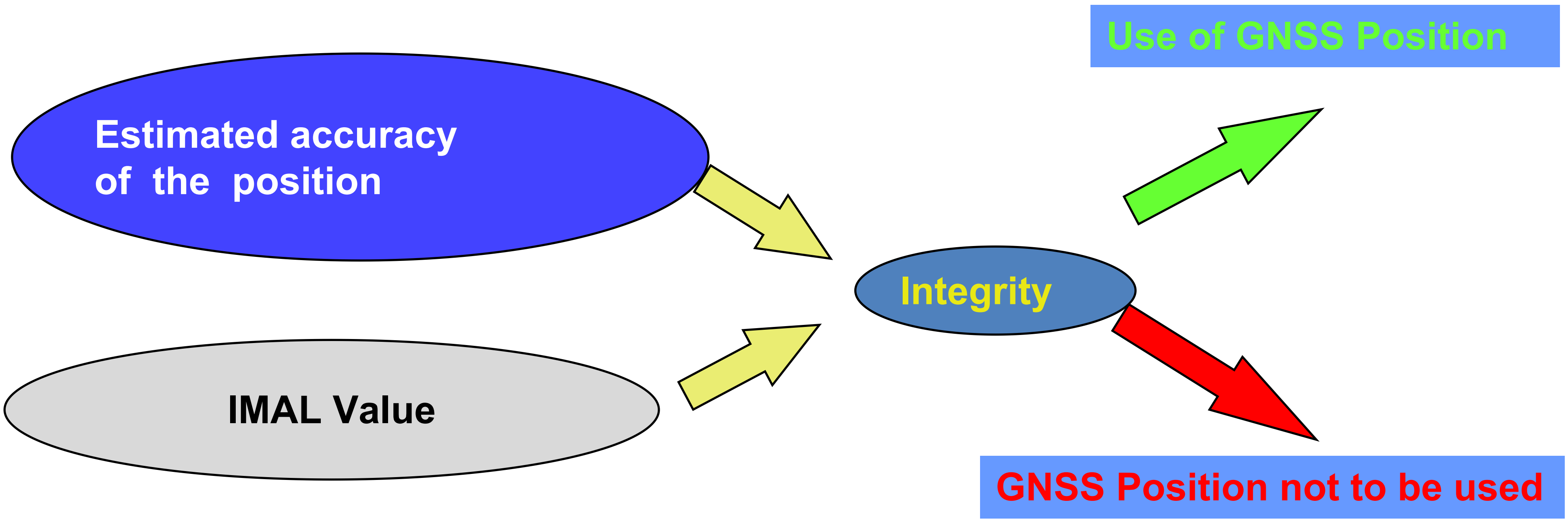
ICAO GNSS Concept

Signal in space requirements (Annexe 10)

Typical operation(s)	Accuracy horizontal 95%	Accuracy vertical 95%	Integrity	Time to alert	Continuity	Availability
En-route	3.7 km (2.0 NM)	N/A	$1-10^{-7}$/h	5 min	$1-10^{-4}$/h to $1-10^{-8}$/h	0.99 to 0.99999
En-route, Terminal	0.74 km (0.4 NM)	N/A	$1-10^{-7}$/h	15 s	$1-10^{-4}$/h to $1-10^{-8}$/h	0.999 to 0.99999
Initial approach, Intermediate approach, Non-precision approach, Departure	220 m (720 ft)	N/A	$1-10^{-7}$/h	10 s	$1-10^{-4}$/h to $1-10^{-8}$/h	0.99 to 0.99999
Approach operations with vertical guidance (APV-I)	16.0 m (52 ft)	20 m (66 ft)	$1-2\times10^{-7}$ per approach	10 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999
Approach operations with vertical guidance (APV-II)	16.0 m (52 ft)	8.0 m (26 ft)	$1-2\times10^{-7}$ per approach	6 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999
Category I precision approach	16.0 m (52 ft)	6.0 m to 4.0 m (7) (20 ft to 13 ft)	$1-2\times10^{-7}$ per approach	6 s	$1-8\times10^{-6}$ in any 15 s	0.99 to 0.99999

INTEGRITY

Integrity: the ability to provide timely warnings when the system is not safe to use



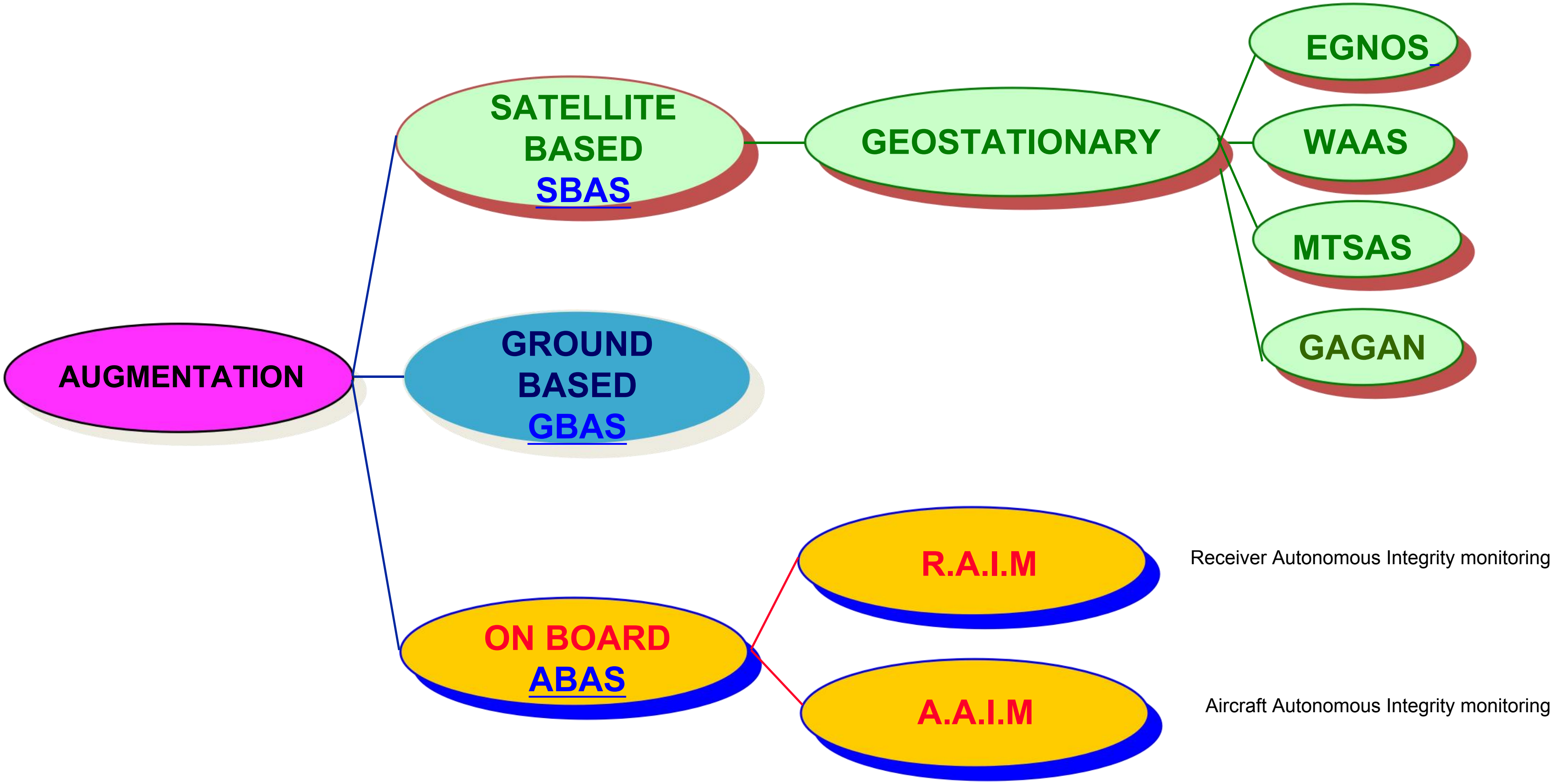
IMAL : Integrity monitoring alarm limit
The value depends on the phase of flight

GNSS integrity monitoring

- GNSS integrity monitoring techniques aim at monitoring the quality of GNSS positioning
- Large variety of techniques:
  - In an autonomous manner (ABAS) :
    - Using the redundancy of GNSS measurements only (RAIM)
    - Using additional information from other sensors (AAIM)
  - Using a network of ground stations (SBAS)
  - Using a ground station (GBAS)
- All these systems can include Fault Detection (FD) or Fault Detection and Exclusion (FDE)

ICAO GNSS CONCEPT

GLOBAL NAVIGATION SATELLITE SYSTEM



WHICH AUGMENTATION FOR WHICH KIND OF APPROACH ?

ABAS

Non Precision Approach NPA

+ VNAV: APproach with Vertical Guidance APV baroVNAV

SBAS

APproach with Vertical Guidance

APV I

GBAS

Precision Approach

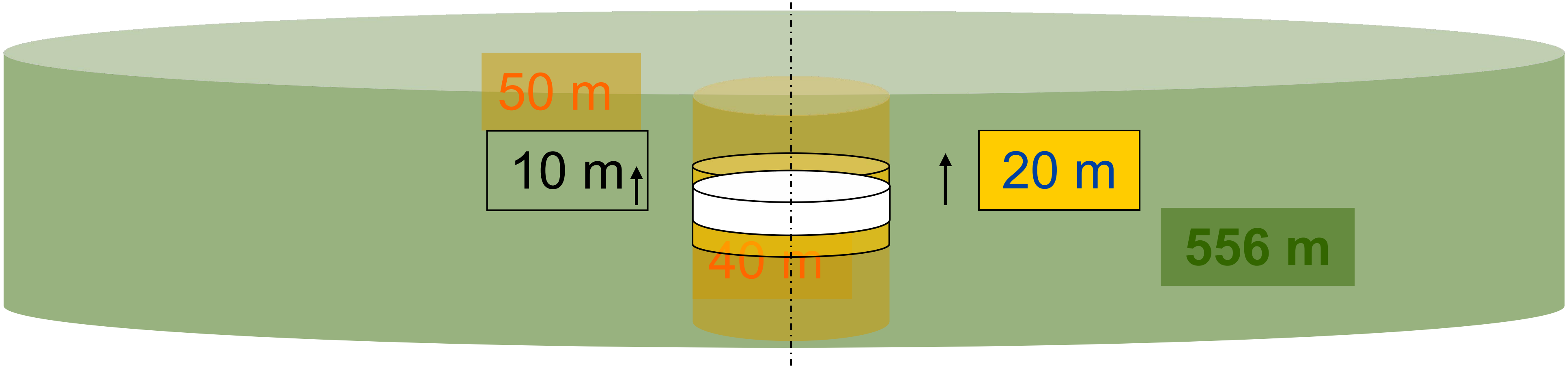
DIFFERENT GNSS PERFORMANCE LEVELS

LNAV/VNAV → Basic GPS (lateral) + barometric (vertical)

APV I → SBAS: EGNOS, WAAS, MSAS, GAGAN

APV II → SBAS: EGNOS, Galileo

Cat I → GLS with GBAS or dual freq SBAS



Sketch of relative Alarm Limit Box for the different GNSS Performance levels. Represents the containment of the uncertainty on aircraft position at 10-7 probability

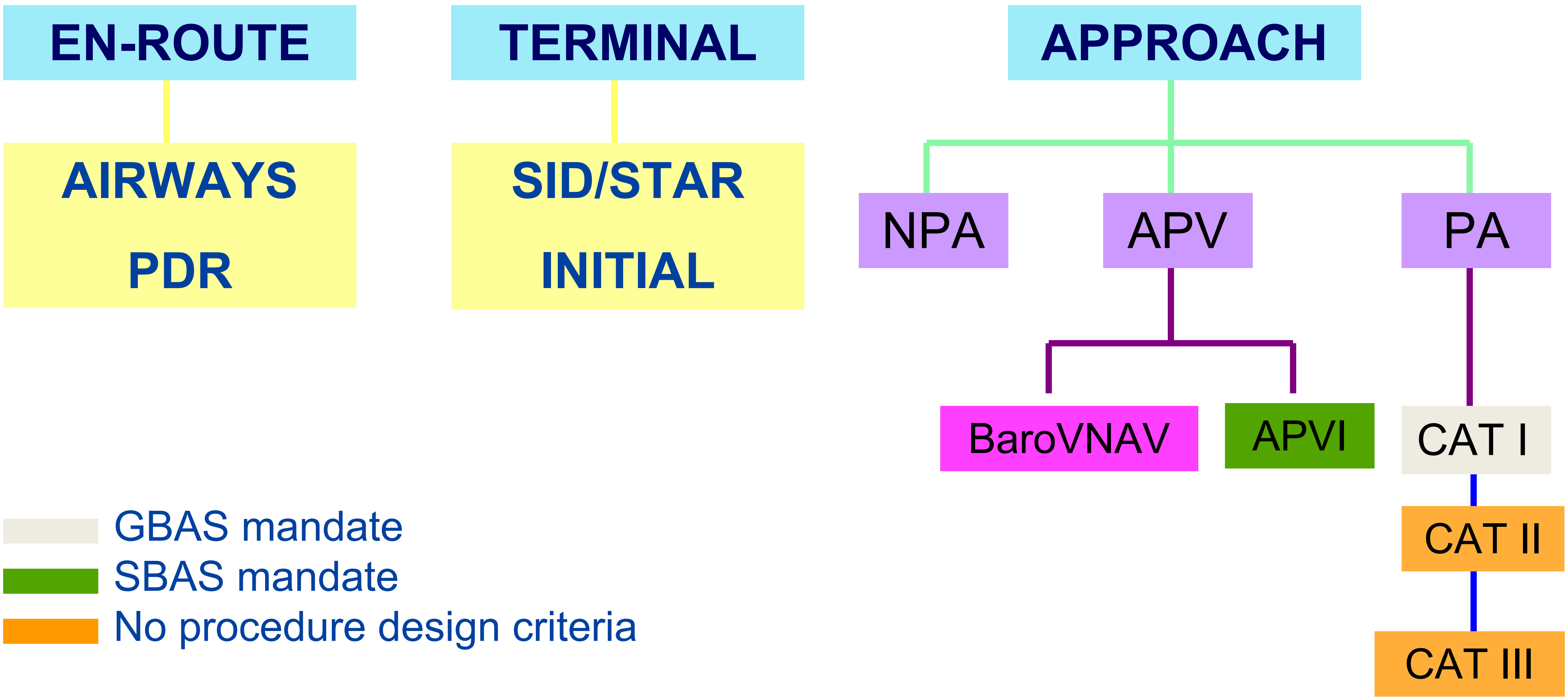
KEY POINT n ° 2

A/C position usable for navigation meets the integrity requirements

Information about the actual navigation performance are provided to pilots

ATC and procedure designers are not responsible for loss of guidance

RNAV OPERATIONS



RNAV : Type of Approaches

NPA
2D RNAV
RNAV system provides lateral guidance in final segment
ABAS as minimum
Sensor used GNSS

PA
Lateral and vertical guidance in final segment
- GBAS augmentation
  - Title of procedure GLS

APV
Approach Procedure with Vertical guidance:
An instrument procedure which utilizes lateral and vertical guidance but DOES NOT MEET the requirements established for PRECISION APPROACH

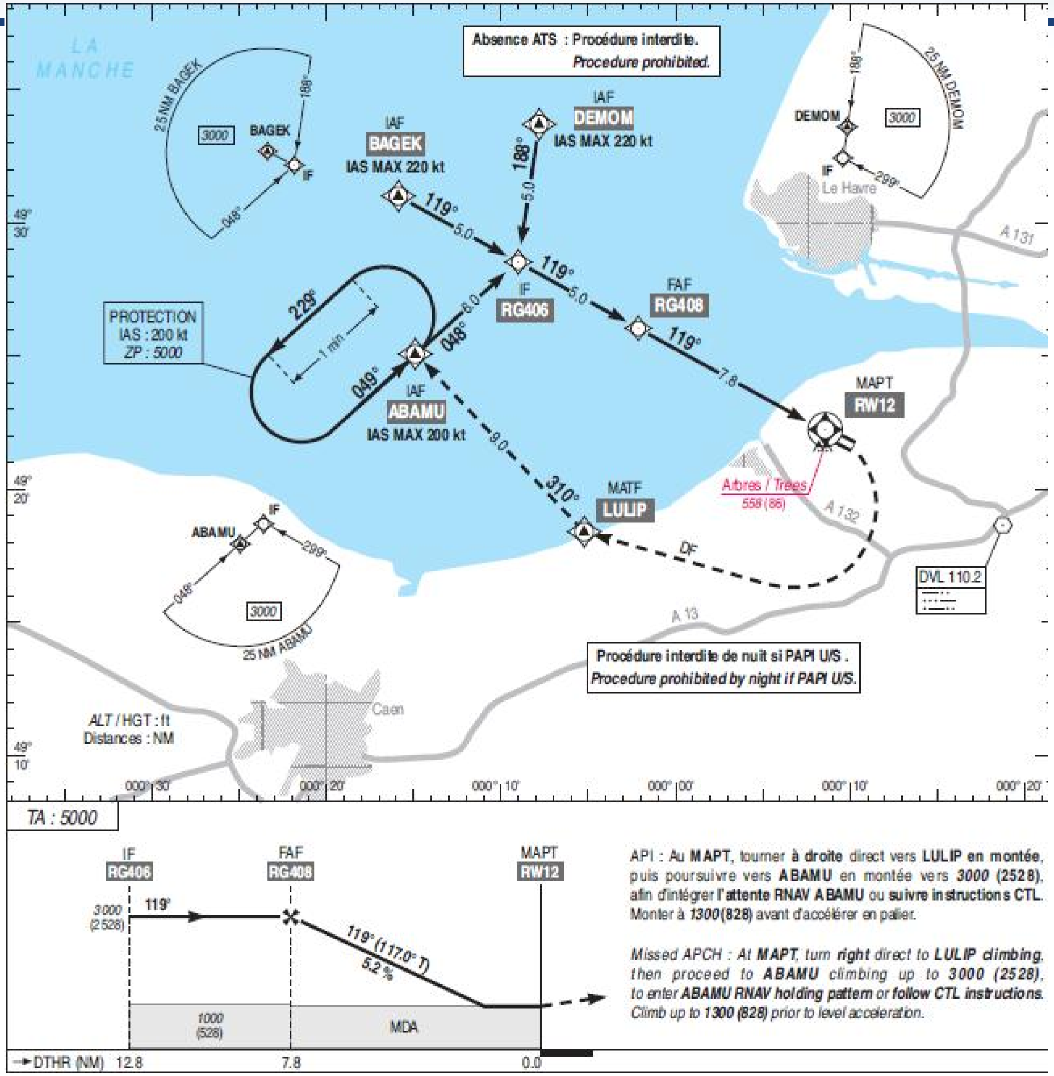
- APV BaroVnav : ABAS + VNAV functionality (Barodependant)
- APV SBAS : SBAS receiver on-board (Geometric vertical path)

RNAV Minima

Type of approach	Type of guidance	MDA or DA	Minima line
NPA	lateral	MDA	LNAV
APV baroVNAV	Lateral Vertical	DA	LNAV/VNAV
APV SBAS	Lateral Vertical	DA	LPV
PA	Lateral Vertical	DA	Title of procedure : GLS

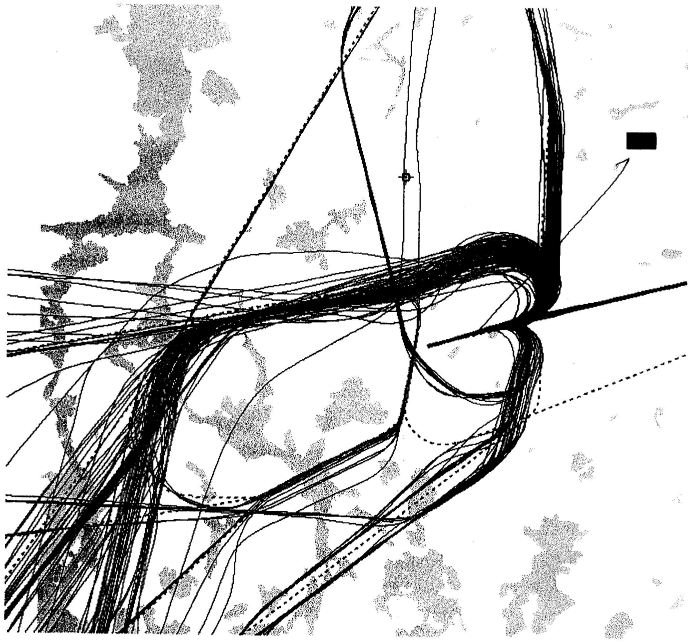
RNAV: Standardization of trajectories

- Flight time reduction
- Aligned on runway centerline
- Improve visualization of markings and lightings
- Easy use (piloting ,no misunderstanding)
- Improvement of guidance
- Improvement of accessibility



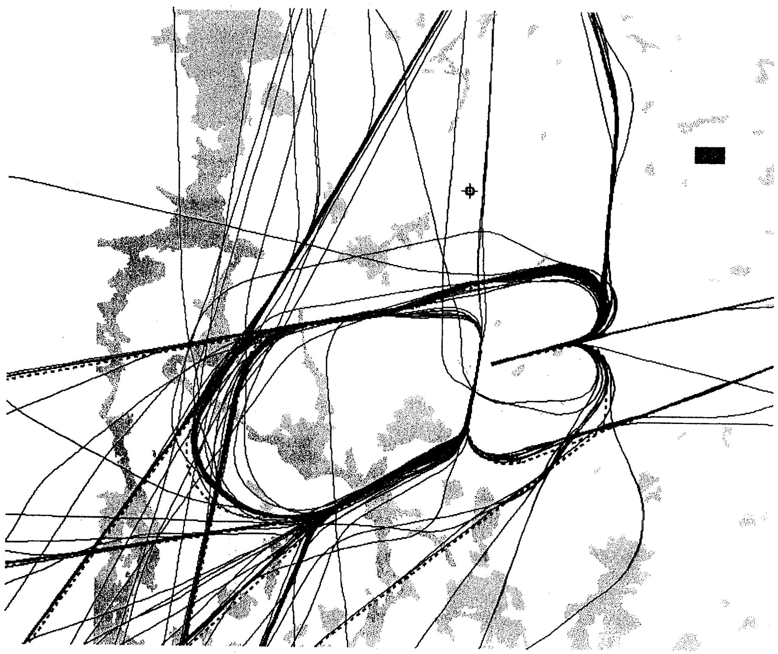
RNAV: Less dispersion

NON RNAV



B737-600/700/800
315 flights

RNAV



B737-600/700/800
315 flights

KEY POINT n ° 3

- Standardization
- Easy design
- All GNSS receivers NPA certified could proceed T and Y procedure
- Efficiency of waypoint location regarding navaid-based fixes
- Less dispersion for track keeping

HOW TO FLY VERTICALLY ?

- Arrival and Approach :
  - CDO : Constant Descent Operation
- Final :
  - Dive and Drive
  - CDFA : Continuous Descent Final Approach

CDO : CONTINUOUS DESCENT OPERATION

- CDO is a flight technique and NOT A NEW TYPE of arrival or instrument approach
- This technique may be implemented:
  - On arrival routes (STAR)
  - On initial and/or intermediate segments of an instrument approach procedure
  - During radar vectoring of an arriving flight
- CDO ends at the latest at the FAF/FAP
- CDO different from CDFA.

CDO : CONTINUOUS DESCENT OPERATION

- Continuous Descent Operation (CDO): A FLIGHT TECHNIQUE in which an arriving aircraft CONTINUOUSLY descends, employing minimum engine thrust preferably in a low drag configuration, PRIOR TO the FAF/FAP.

Note 1.– A CDO uses optimum descent profiles that minimize noise, fuel burn and emissions.

Note 2.– Ideally, a CDO starts from the Top of Descent.

Purpose of a CDO is to generate environmental advantages:

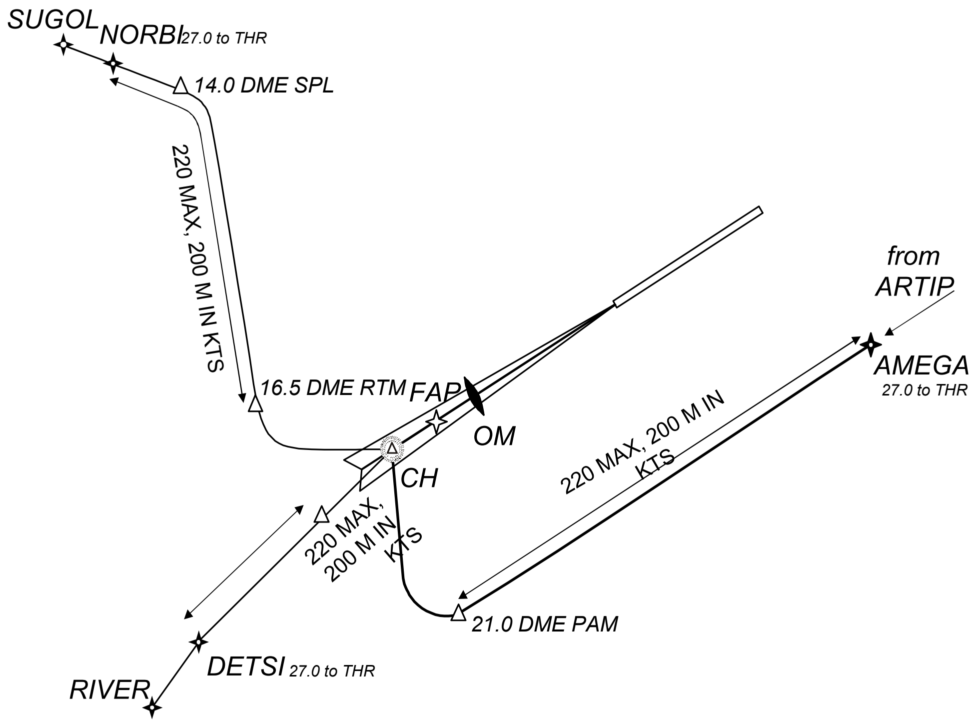
-potentially noise beneficial operations

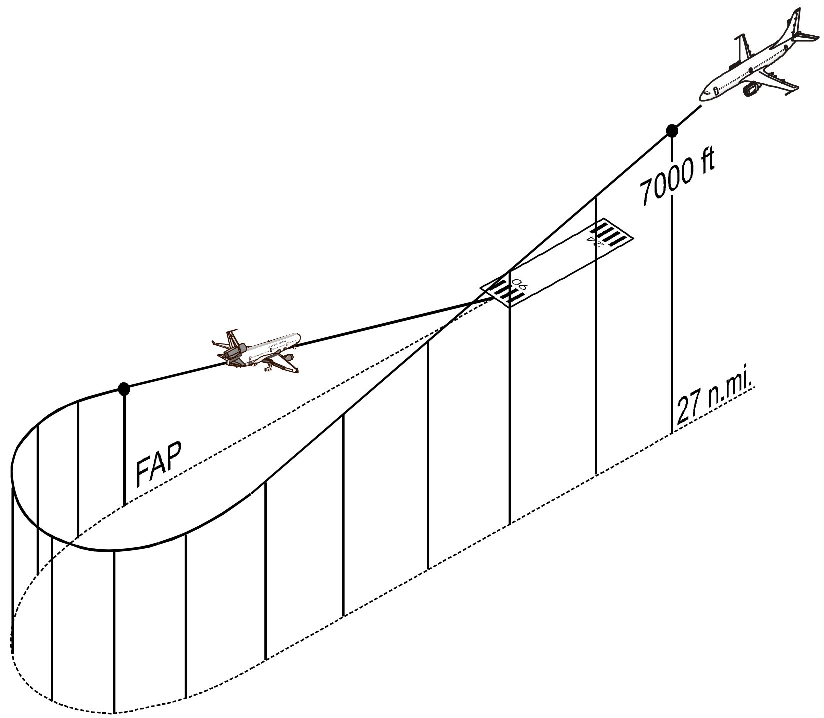
-reduced fuel burn resulting in less emission.

-fuel burn reduction generate an economic benefit

Ideally, a CDO starts from the Top of Descent.

CDO : CONTINUOUS DESCENT OPERATION





HOW TO FLY VERTICALLY NPA ?

- Two different ways to FLY vertically :
  - ‘Dive and Drive’
  - ‘Stabilized approach’
- NO CONSEQUENCE on PROCEDURE DESIGN

STABILIZED APPROACH

- Continuous descent gradient to
  - a point 50 ft above the threshold
  - taking regard of minimum crossing altitude at FAF and step-down fixes.
- Missed approach initiated :
  - Visual reference not achieved approaching MDA/H
  - Not permitted below MDA/H at any time
  - Not permitted after MAPt

Final segment : CDFA
CONTINUOUS DESCENT FINAL APPROACH

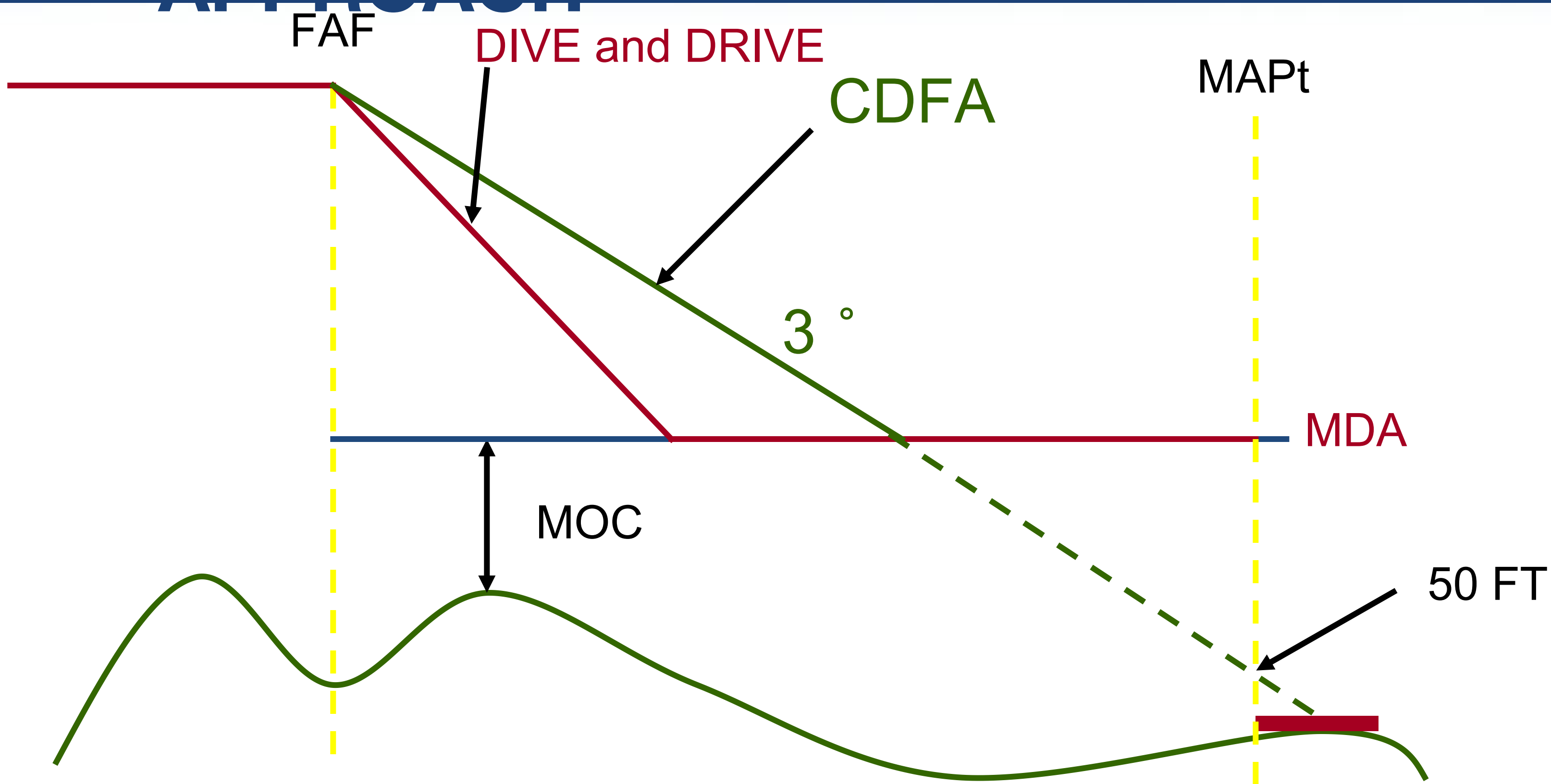
- Stabilized approach technique on FINAL APPROACH segment of a non-precision approach

  Between FAF and runway threshold

  – With a constant vertical descent angle

  – May be supported by a computer generated vertical path (FMC VNAV function)

Final segment : CDFA CONTINUOUS DESCENT FINAL APPROACH



CDFA : A specific METHOD OF FLYING the FINAL approach segment of NPA on pre-determined approach slope with continous descent to DA (H)

Final segment : CDFA
CONTINUOUS DESCENT FINAL APPROACH

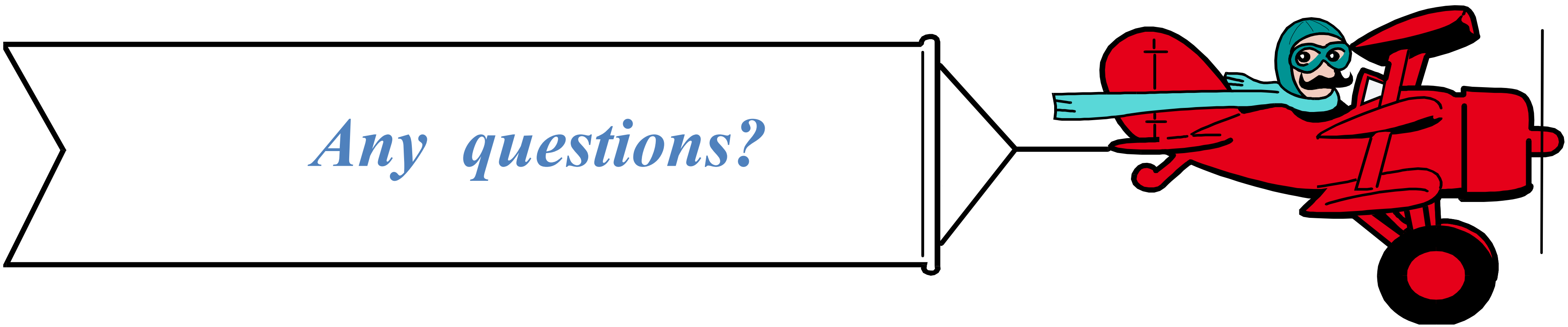
- On NPA procedure, use of BaroVNAV function for ADVISORY = CDFA
- Slope « calculated » to be consistent with the FAF altitude and SDF
- Altimeter remains the primary mean to control the vertical descent
- The vertical system is to ASSIST pilot for piloting
  - Assistance / advisory ≠ Guidance
- Remaining issues for operating :
  - How to convert MDA in DA ?
  - Temperature correction ?
  - QNH checking procedure ?

For CFIT PREVENTIVE MEASURE

- Provide a vertical guidance
  - ILS
  - APV BARO-VNAV
  - APV SBAS
- Continuous Descent in Final Approach

CONCLUSIONS

- RNAV navigation expected benefits
  - Shorter routes
    - Flight time reduction
    - Economic improvement
  - Environmental gains
    - Noise
    - Fuel consumption
  - Enables efficient airspace strategy
    - Performance based navigation concept
- Lots of A/C are RNAV capable
- Implementation of APV procedure enhances safety


Any questions?

INS: Inertial Navigation System
IRS: Inertial Reference System

- 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 2Nm/hour

    High drift the first ½ hour of navigation (8Nm/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)

Flight Director

- FD: Flight Director.
- When FD is selected,
  - steering information (guidance information)
  - calculated by the Autopilot using data derived from the Navigation Computer
  - displayed on the pilot's Primary Flight Display (PFD),
  - but manual control of the aircraft is required to follow the path.

Auto Pilot

- AP: Autopilot
- Mechanical, electrical, or hydraulic system used to guide an aircraft without human assistance.
- When AP is selected
  - steering information,
  - calculated by the navigation computer,
  - transmitted to a flight control system to guide the aircraft.
- This information is also displayed on the pilot's Primary Flight Display (PFD).

ABAS
AIRCRAFT BASED AUGMENTATION SYSTEM

- 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

ABAS

Charting

KDEN/DEN
DENVER INTL

JEPPESEN
26 JAN 18
Eff 1 Feb
12-24

DENVER, COLO
RNAV (RNP) Z Rwy 17L

BRIEFING STRIP ™

D-ATIS Arrival	DENVER Approach (R)	DENVER Tower	Ground
125.6	North 119.3 South 120.35	132.35	121.85

RNAV	Final Apch Crs	Minimum Alt IRINE	RNP 0.10 DA(H)	Apt Elev 5434′
	173°	7000′ (1661′)	5600′ (261′)	TDZE 5339′

MSA RW17L: 9300

MISSED APCH: Climb to 5900′ then climbing LEFT turn to 10000′ direct LIMEX and hold.

Alt Set: INCHES Trans level: FL 180 Trans alt: 18000′

1. AUTHORIZATION REQUIRED. 2. GPS required. 3. Radar required.
4. For uncompensated Baro-VNAV systems, procedure not authorized below -25°C (-13°F) or above 48°C (118°F). 5. Simultaneous approach authorized.
6. Use of Flight Director or Autopilot providing RNAV track guidance required during simultaneous operations. 7. VGSI and RNAV glidepath not coincident.

GWENS (IF)

SBAS ARCHITECTURE
SATELLITE BASED AUGMENTATION SYSTEM

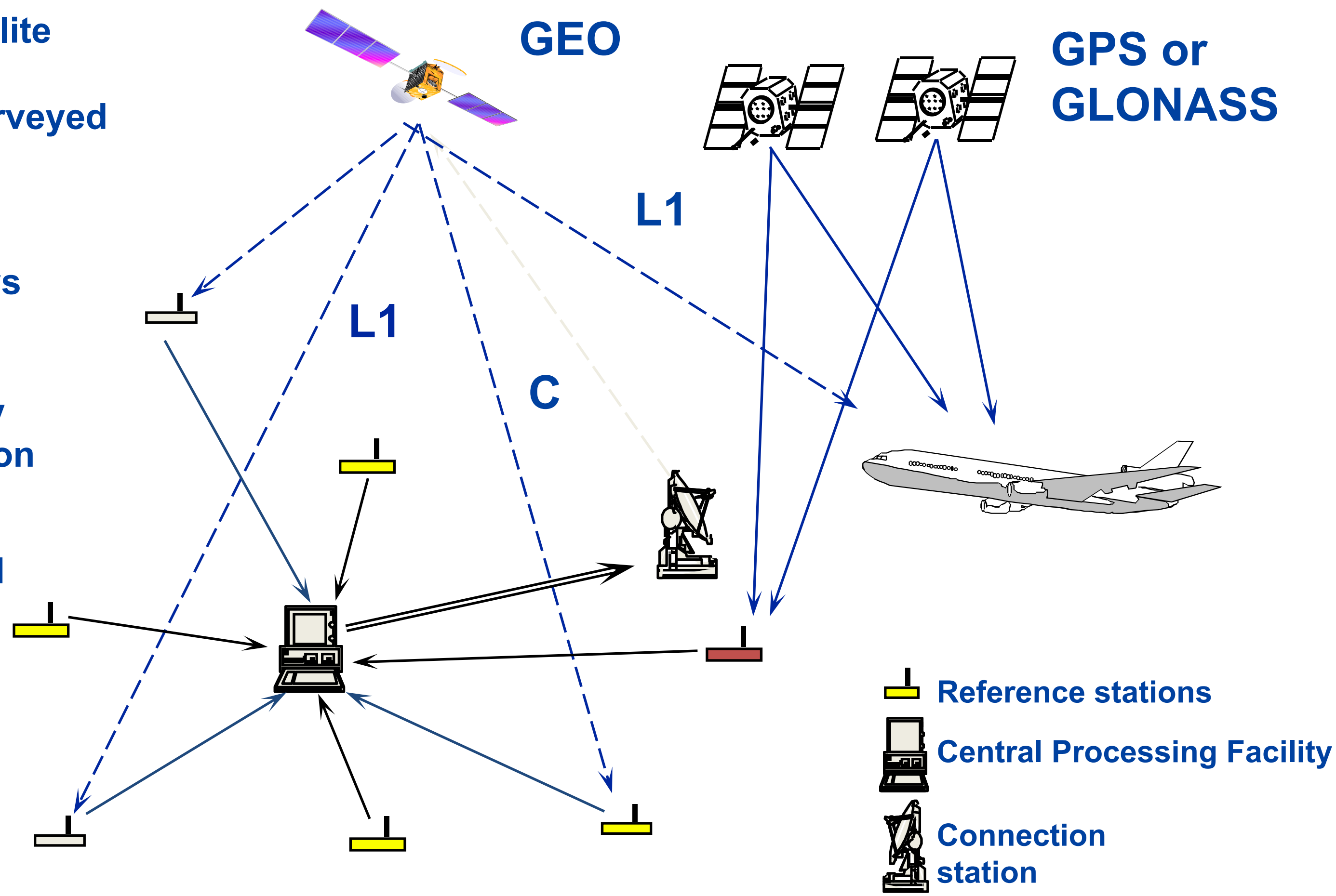
1. Signals from GPS and GEO satellite are received by the reference stations.Each of them precisely surveyed determine if any errors exist

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



SBAS
Charting

KDEN/DEN
DENVER INTL

JEPPESEN
1 DEC 17 (12-1)

DENVER, COLO
RNAV (GPS) Y Rwy 7

D-ATIS Arrival	DENVER Approach (R) North	DENVER Approach (R) South	DENVER Tower	Ground
125.6	119.3	120.35	128.75	127.5

BRIEFING STRIP TM

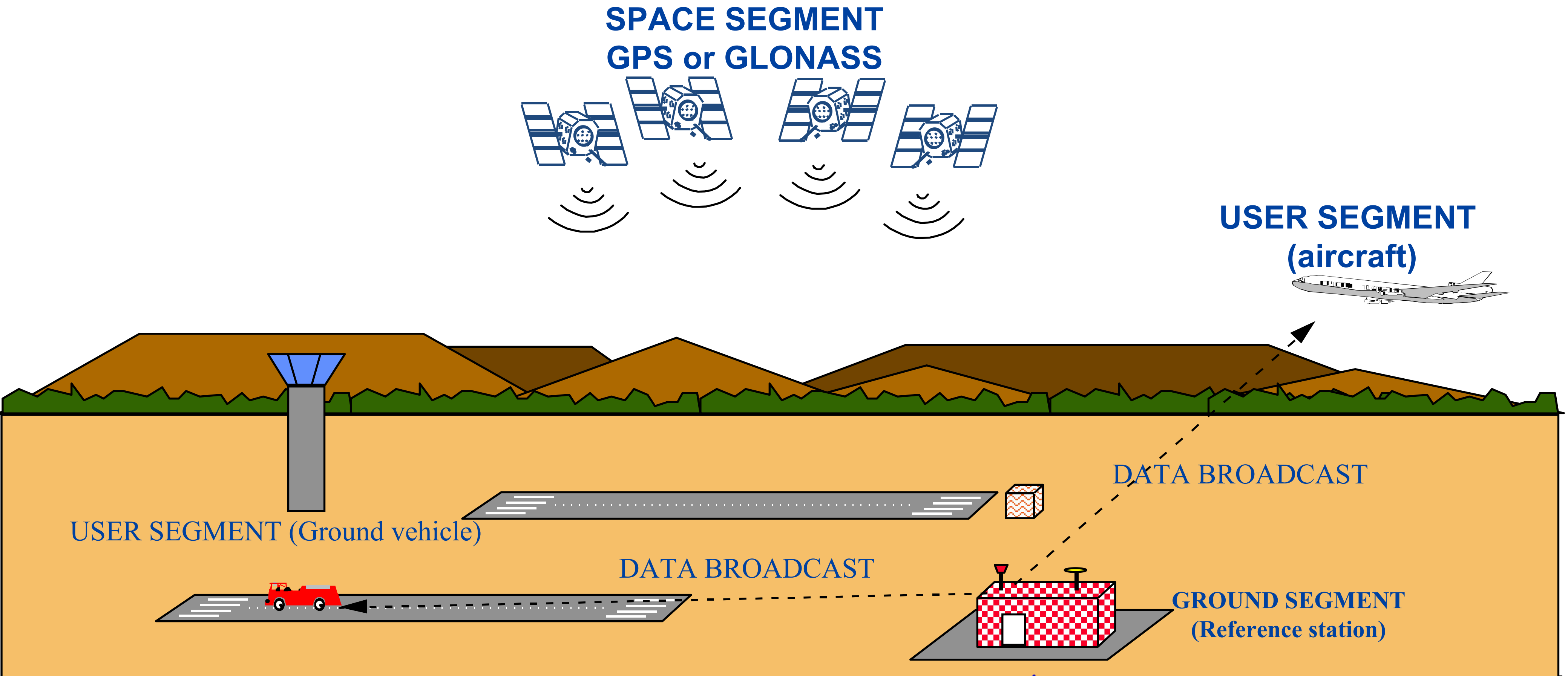
WAAS	Final Apch Crs	Minimum Alt	LPV DA(H)	
Ch 87128 W-07A	082°	TAILR 7000′ (1648′)	5552′ (200′)	Apt Elev 5434′ TDZE 5352′

MISSED APCH: Climb to 5900′ then climbing RIGHT turn to 10000′ direct CIDMU and on track 081° to LIMEX and hold.

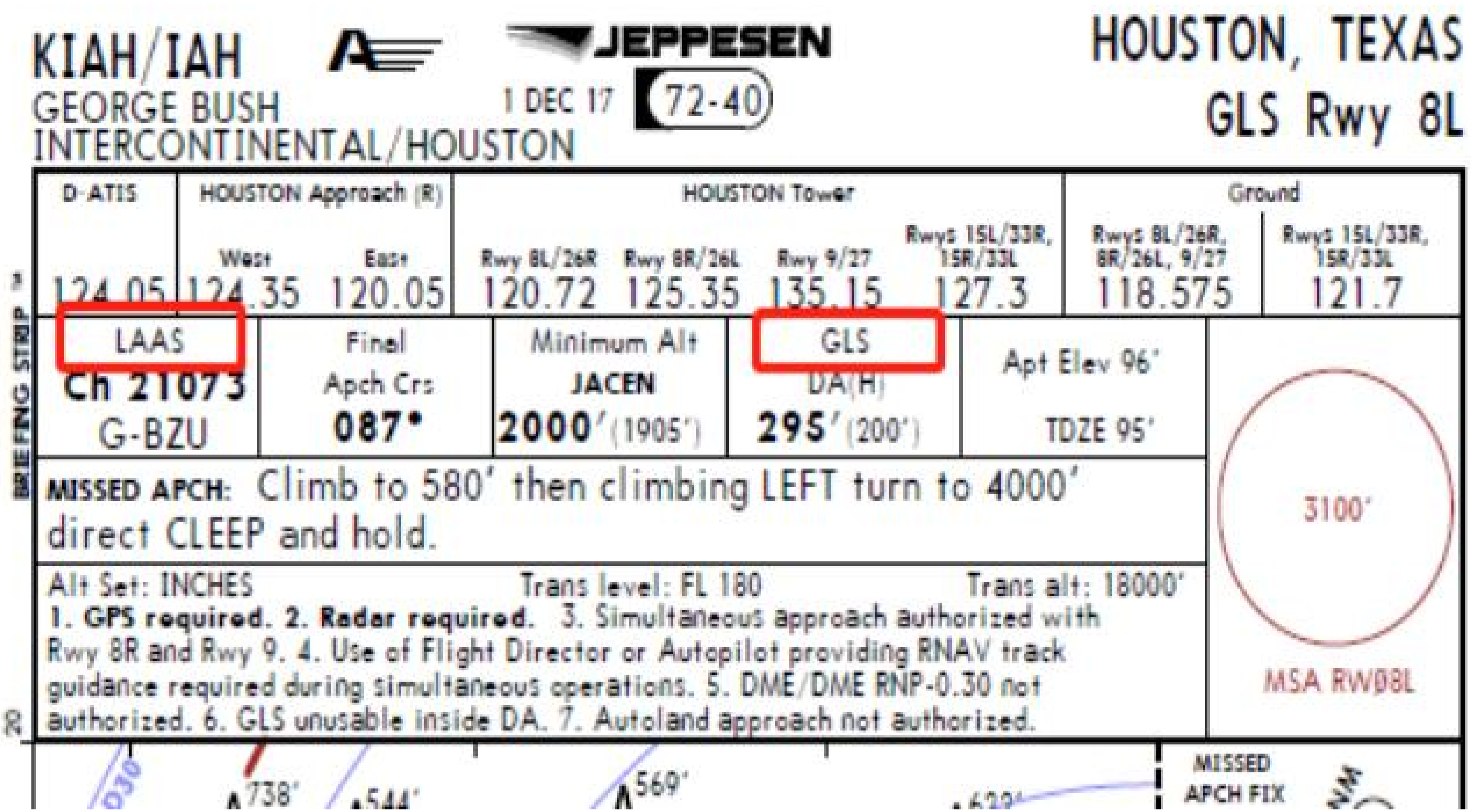
Alt Set: INCHES Trans level: FL 180 Trans alt: 18000′
1. Simultaneous approach authorized with Rwy 8. 2. Use of Flight Director or Autopilot providing RNAV track guidance required during simultaneous operations. 3. LNAV procedure not authorized during simultaneous operations. 4. For uncompensated Baro-VNAV systems, LNAV/VNAV not authorized below -25°C (-13°F) or above 46°C (116°F). 5. DME/DME RNP-0.30 not authorized. 6. VGSI and RNAV glidepath not coincident.

10,900
MSA RWØ7

GBAS ARCHITECTURE
GROUND BASED AUGMENTATION SYSTEM



GBAS Charting



THANKS