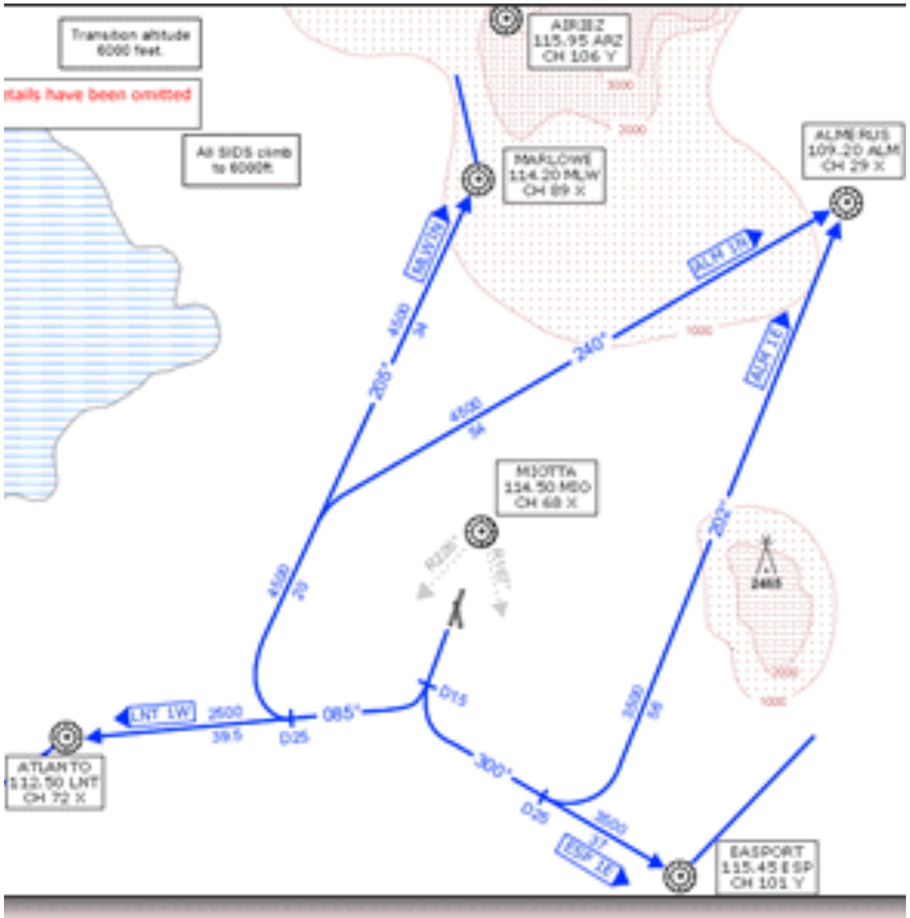
Designing Routes

Learning Objectives

- By the end of this presentation you should understand:
  - Benefits of RNAV
  - Considerations when designing airspace routes
  - The basic principles behind route spacing
  - The current nav specs and their phase of flight
  - Matching fleet capabilities to operational requirements

Benefits of RNAV

Conventional SID



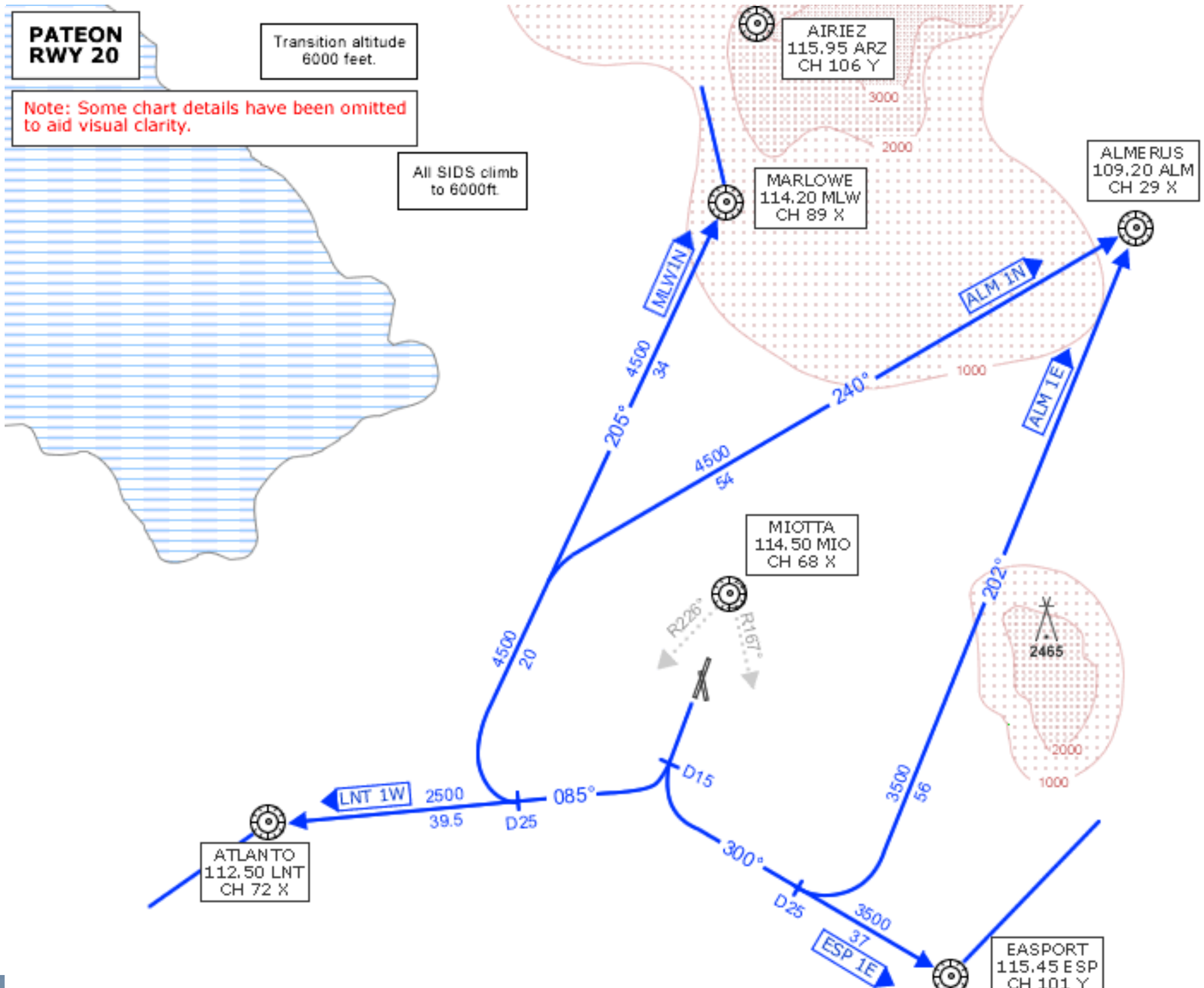
Limitations:

- Inflexible SID/STAR design: a constraint to airspace optimisation.
- Inconsistent track-keeping performance
- Requires use of VOR/DME and/or NDB

Advantages:

- All aircraft operating under IFR are suitably equipped

The Benefits of RNAV

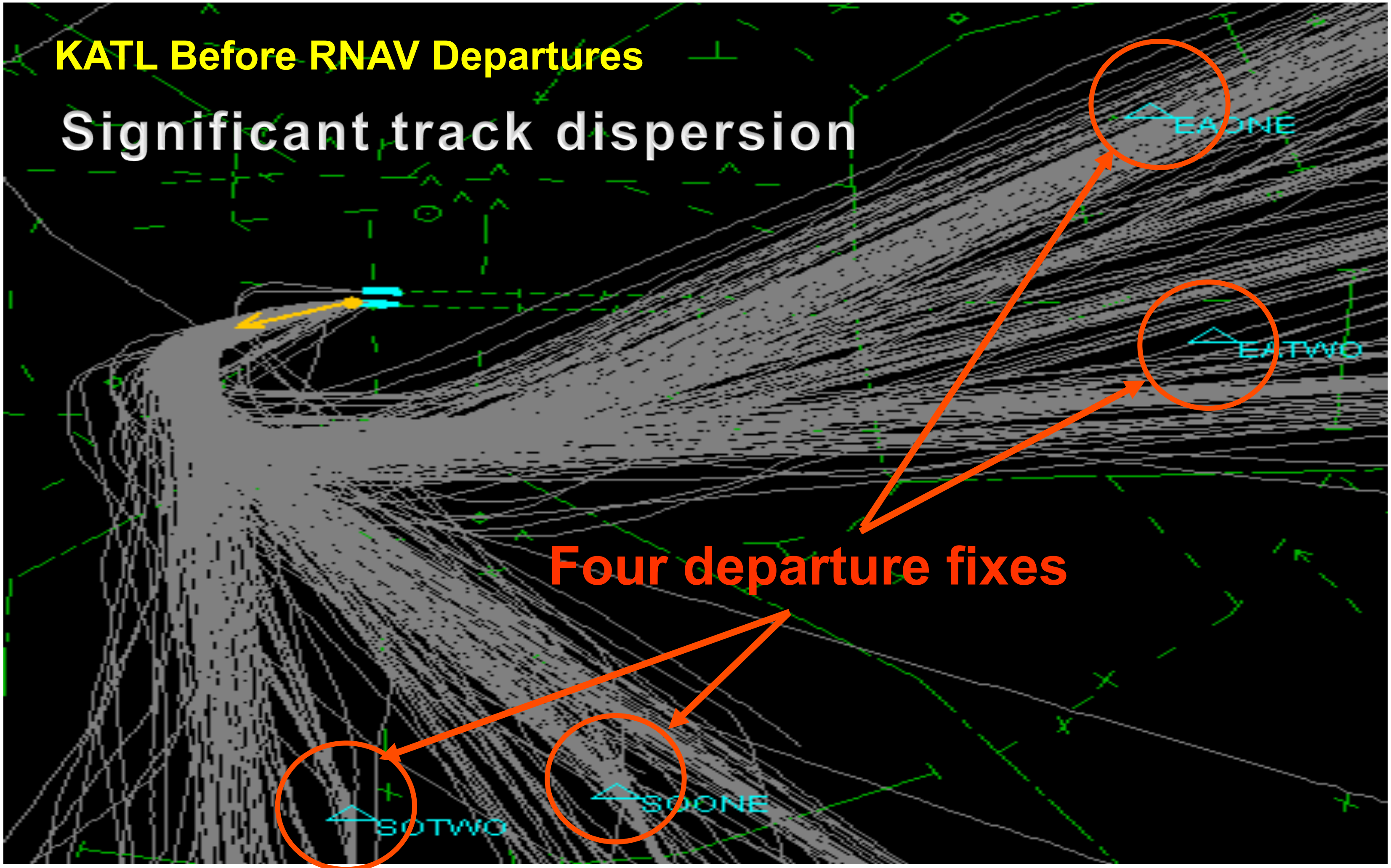


STANDARD INSTRUMENT DEPARTURES

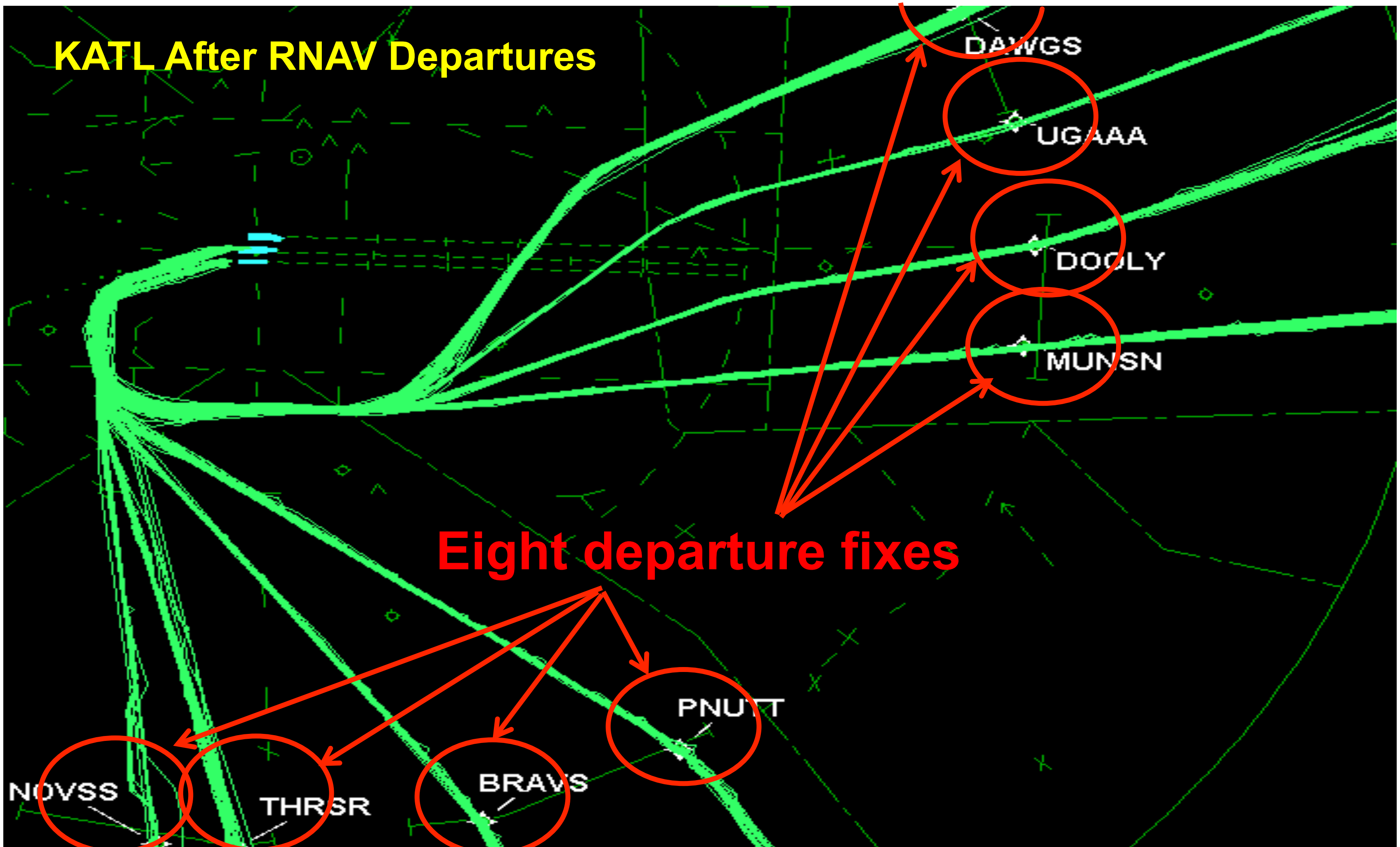
MSA ARP 25 NM	VOR/DME	Latitude	Longitude
150°, 4500', 240°, 2000', 3500', 360°	AIRIEZ	N54º 01'	E003º 03.1'
	ALMERUS	N53º 48.9'	E003º 25.1'
	ATLANTO	N53º 14.3'	E002º 34.8'
	EASPORT	N53º 05.2'	E003º 14.2'
	MARLOWE	N53º 50.5'	E003º 01.2'
	MIOTTA	N53º 27.7'	E003º 01.6'
Bearings and tracks are magnetic. Tracks in brackets are true. Altitudes in feet AMSL.			

DEPARTURES	ROUTEING
ALM 1E	Climb on track 203, at 15D MIO turn left to intercept ESP R300. At 25D MIO turn left to intercept ALM R202 to ALM.
ALM 1N	Climb on track 203, at 15D MIO turn right to intercept LNT R085. At 25D MIO turn right to intercept MLW R205. Intercept ALM R240 to ALM.
ESP 1E	Climb on track 203, at 15D MIO turn left to intercept ESP R300 to ESP.
LNT 1W	Climb on track 203, at 15D MIO turn right to intercept LNT R085 to LNT.
MLW 1N	Climb on track 203, at 15D MIO turn right to intercept LNT R085. At 25D MIO turn right to intercept MLW R205 to MLW.

RNAV Departures at Atlanta USA

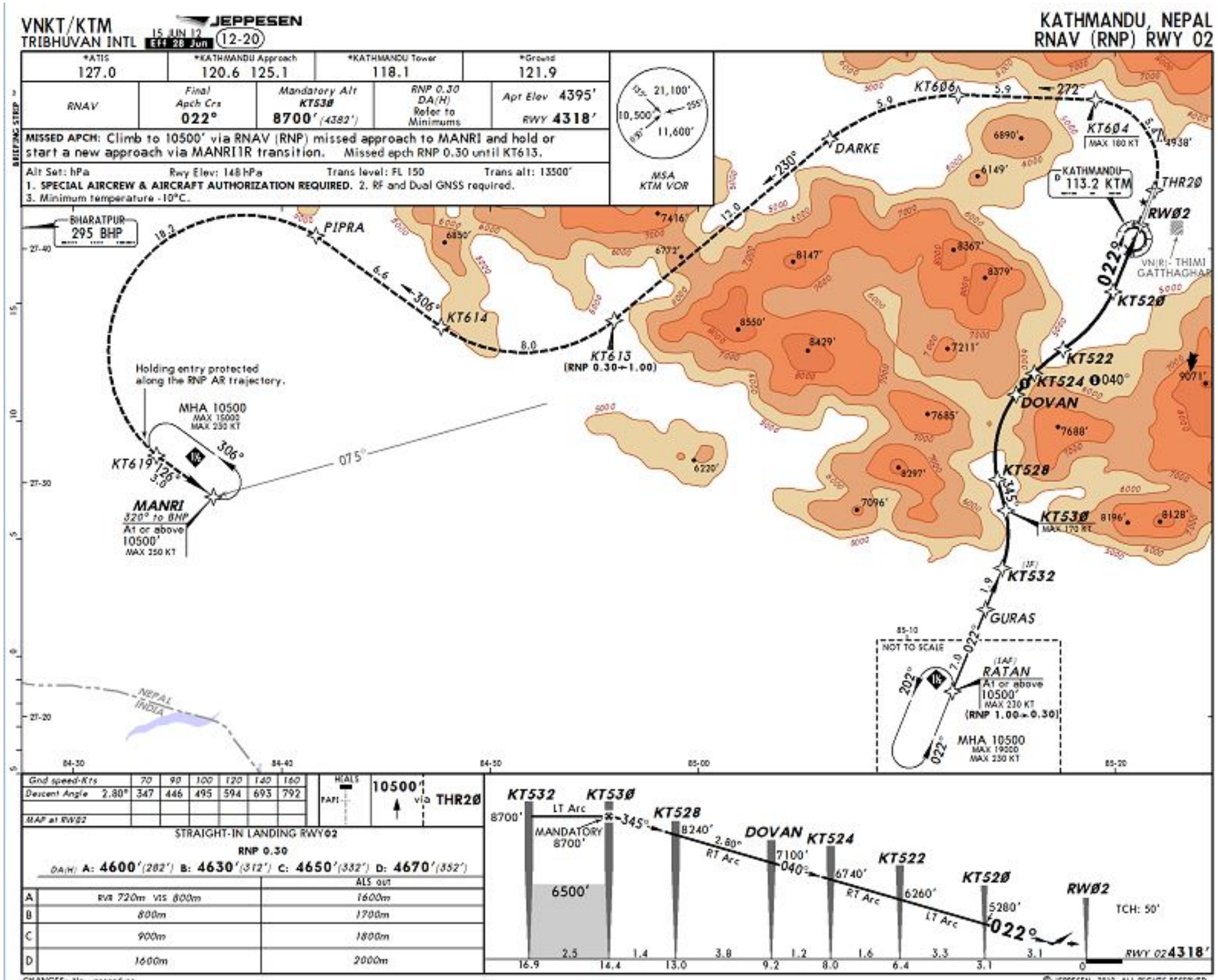


RNAV Departures at Atlanta USA

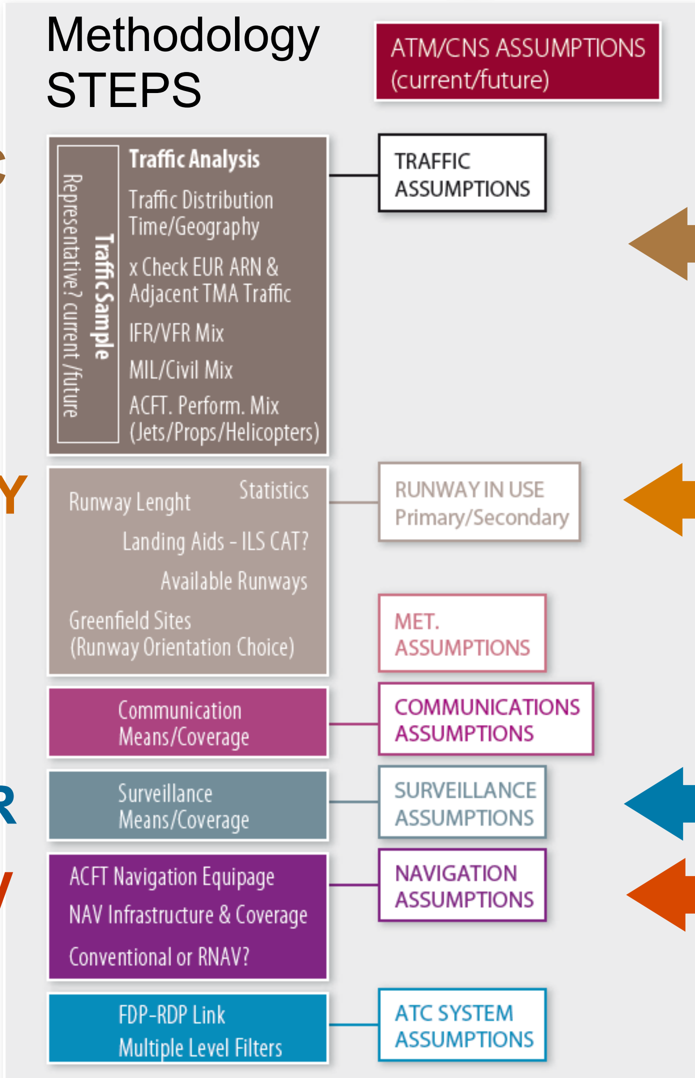


Slide from ICAO PBN Seminar

Kathmandu Arrival



Design in context



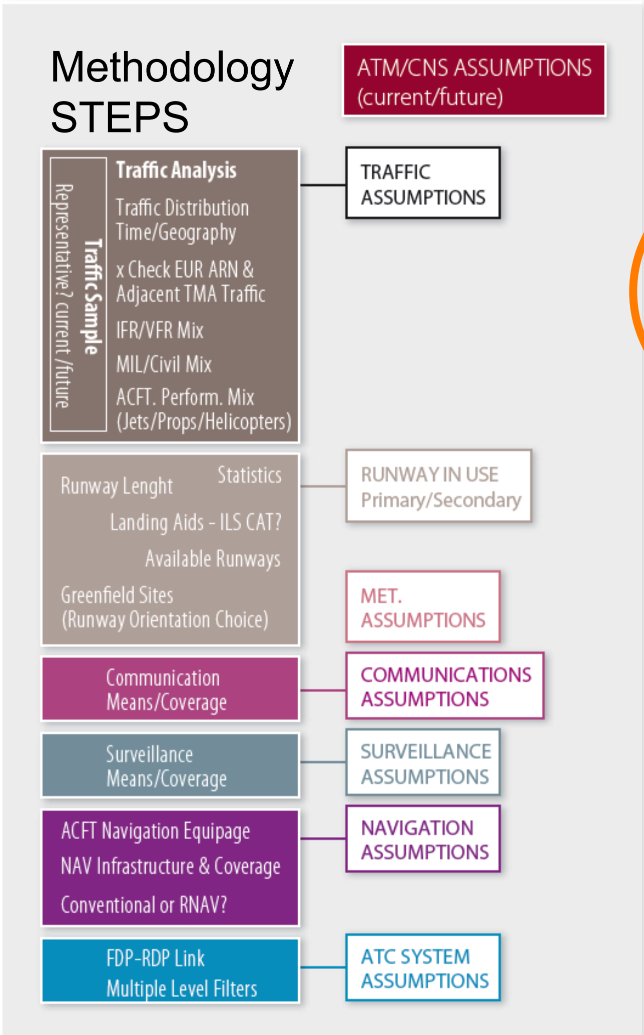
TFC — **Where does the traffic come from? And when?**

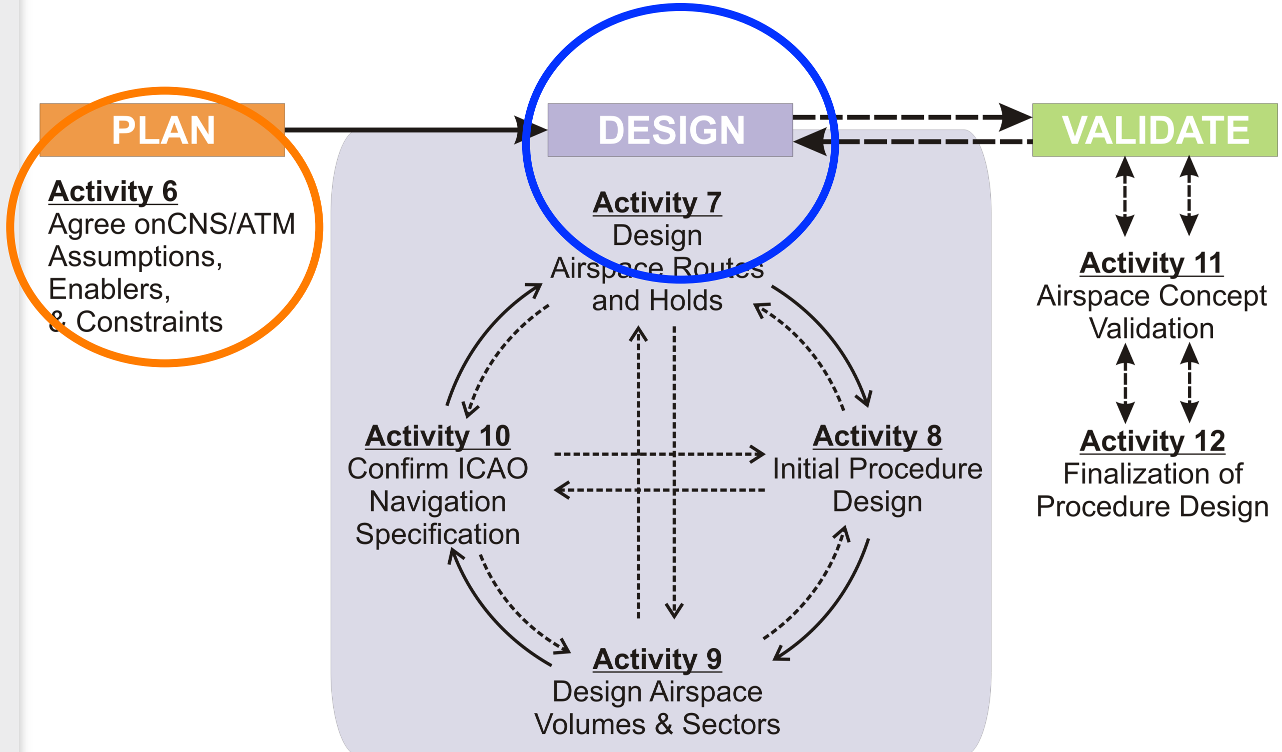
RWY — **Which Runway(s)?**

SUR — **Is there Radar?**

NAV — **Which equipage? How many aircraft ?**

Design in context

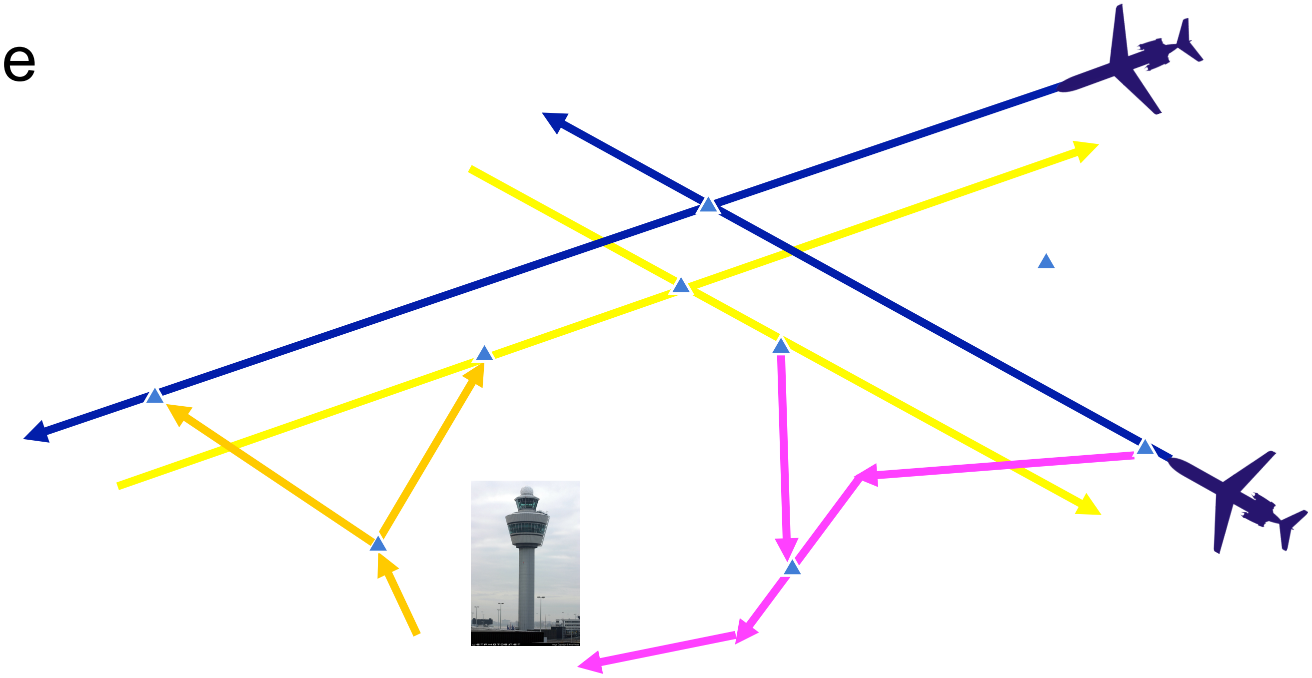




Terminal Routes

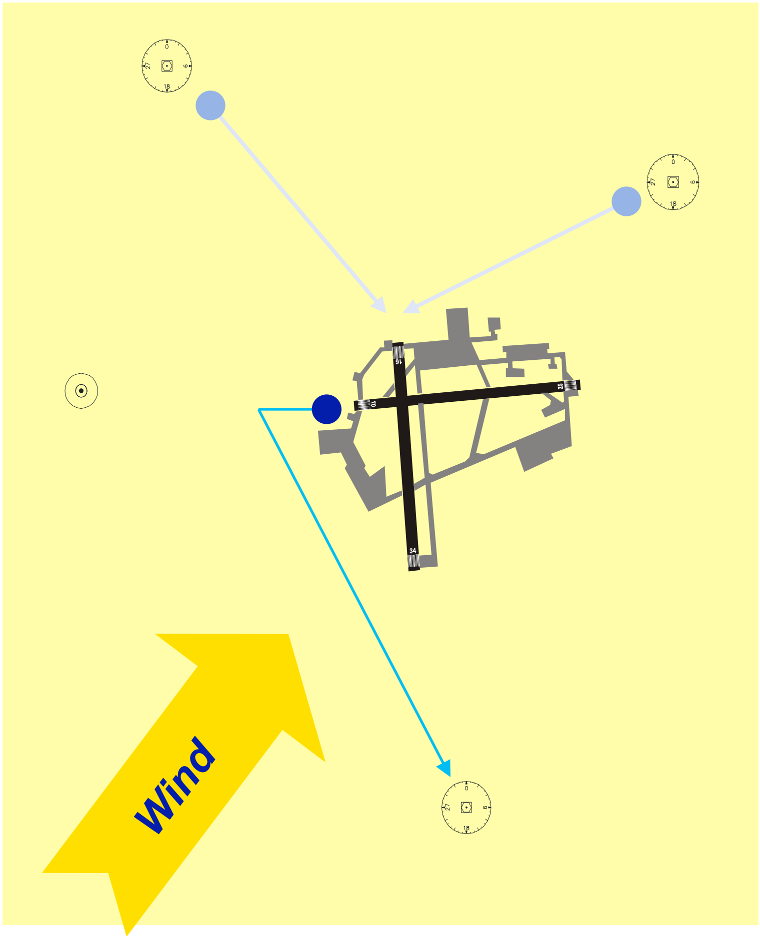
Routes in Terminal Airspace link…

- Changing demand
- Runway in use
- ATS Routes



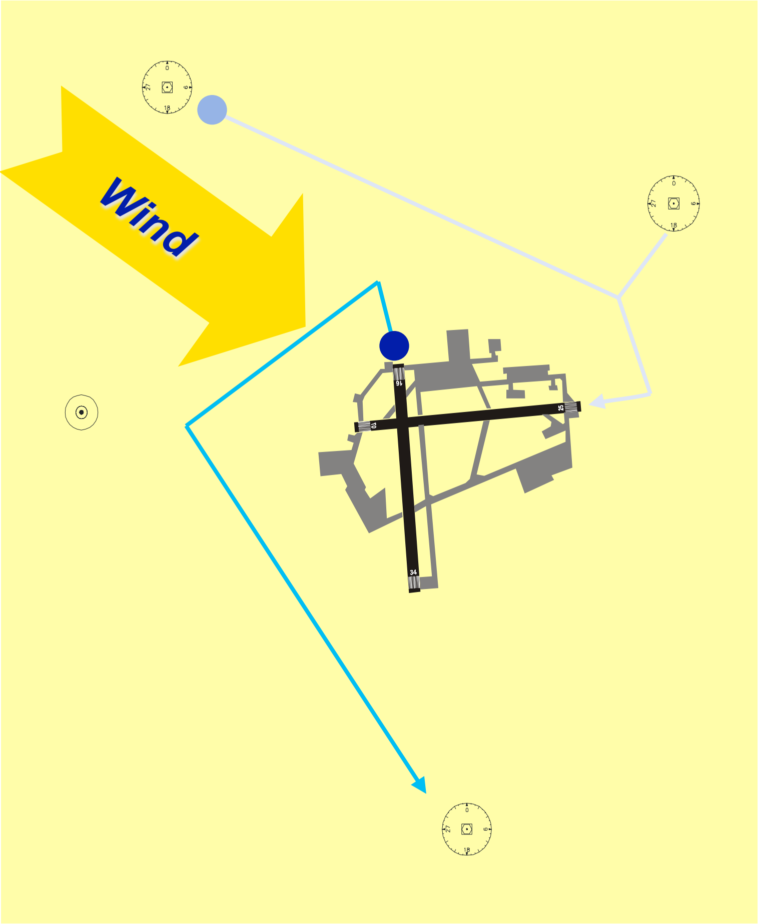
Dependence on RWY (1)

- RWY orientation is given
- Direction of RWY in use depends on wind



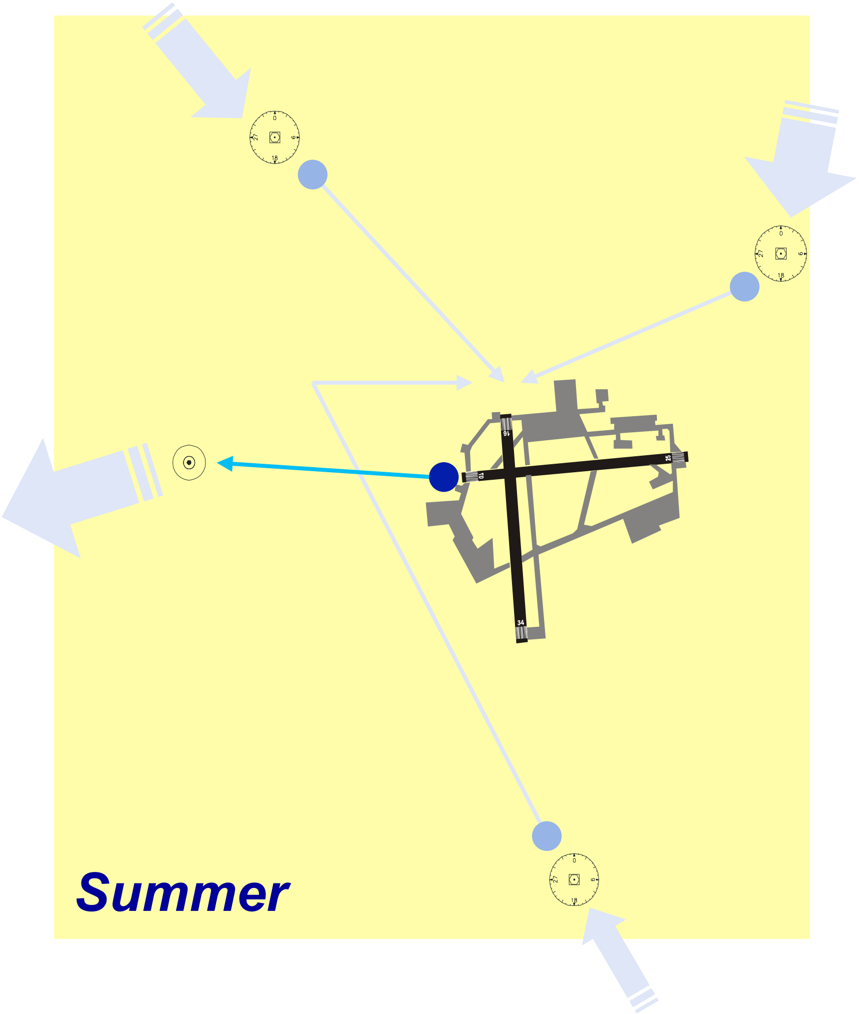
Dependence on RWY (2)

- Different set of SIDs and STARs for different runway in use



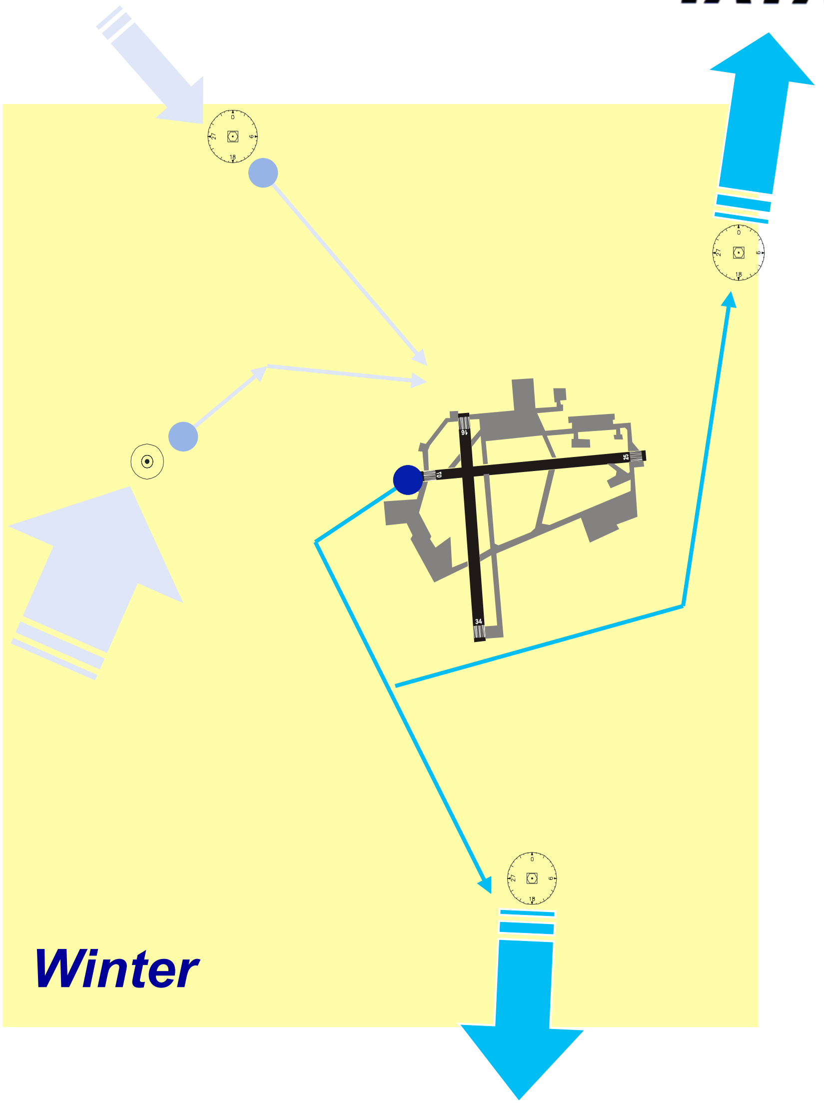
Seasonal Effect (1)

- Demand and route placement can vary for different seasons



Seasonal Effect (2)

- Different set of SIDs and STARs per season



Selecting a Navigation Specification

What Navigation Specification is needed?

- Which phase of flight?
- How much confidence is needed in track keeping?
- Various requirements identified by Airspace Concept
  - Vertical
  - Lateral
  - Longitudinal
- Is there a need for on-board performance monitoring and alerting?

On Board Performance Monitoring and Alerting

- **The PBN concept uses the term "on-board performance monitoring and alerting (OPMA)"**
- **The associated ICAO terms were previously *containment area, contained airspace, containment value, containment distance, obstacle clearance containment***
- **'*Navigation accuracy*' now used instead of 'containment'**

Role of OPMA

- Allows flight crew to determine whether the airborne system meets the navigation performance required
- Relates to lateral and longitudinal performance but not vertical
- Provides greater assurance of lateral track keeping

Navigation Specification by Flight Phase

Doc 9613 Part / Chapter	Navigation Specification	Flight phase							
		En-route oceanic/remote	En-route continental	Arrival	Approach				DEP
					Initial	Intermediate	Final	Missed[1]	
B Ch.1	RNAV 10	10							
B Ch.2	RNAV 5[2]		5	5					
B Ch.3	RNAV 2		2	2					2
B Ch.3	RNAV 1		1	1	1	1		1	1
C Ch.1	RNP 4	4							
C Ch.2	RNP 2	2	2						
C Ch.3	RNP 1[3]			1	1	1		1	1
C Ch.4	Advanced RNP[4]	2[5]	2 or 1	1	1	1	0.3	1	1
C Ch.5	RNP APCH[6]				1	1	0.3[7]	1	
C Ch.6	RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	
C Ch.7	RNP 0.3[8]		0.3	0.3	0.3	0.3		0.3	0.3

Use and Scope of Navigation Specifications

- **Navigation specifications do not address all airspace requirements (e.g., comm, sur, ATM) necessary for operation in a particular airspace, route or area**
  - These will be listed in AIP and ICAO Regional Supplementary Procedures
  - States must undertake a safety assessment in accordance with Annex 11 and PANS-ATM, Chapter 2
- **PBN Manual provides a standardized set of criteria, but is not a stand-alone certification document**
  - Examples: RNP 4, RNAV 1, RNP AR APCH

What kind of Navigation Specification?

- For Approach/Terminal/En-route/Oceanic?
- RNAV or RNP
- Influencing factors
  - Airspace available
  - Navigation infrastructure available
  - Aircraft available
  - Airspace requirements

Aircraft Types you cater for

Local fast regionals

Occasional older visitors – lack of functionality

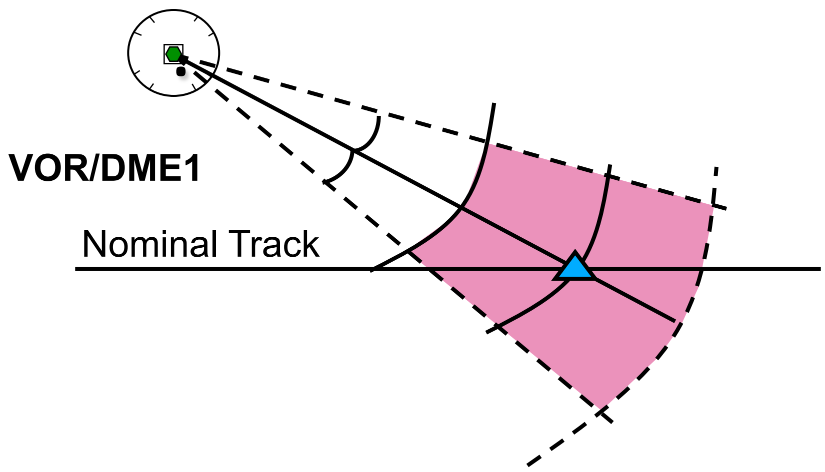
Heavy slow long-hauls

NAVAID Coverage

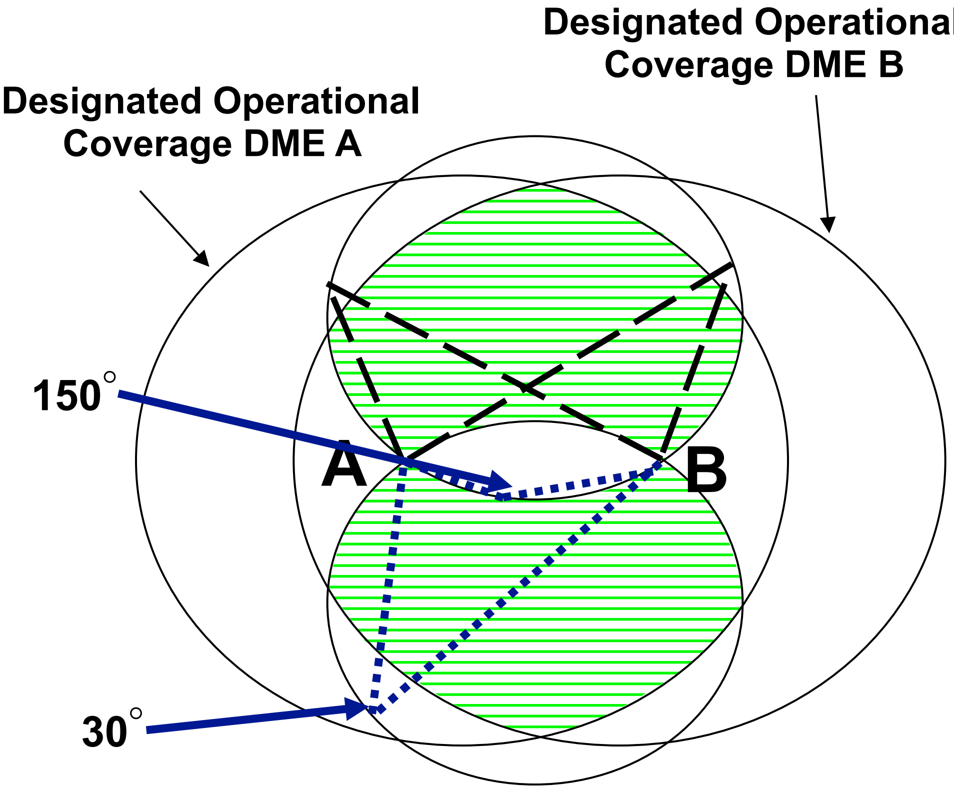
- Geographical Distribution of Navaids
- Accuracy
- Continuity of Service
- Availability
- Redundancy

Geographical Distribution of Navaids

VOR/DME

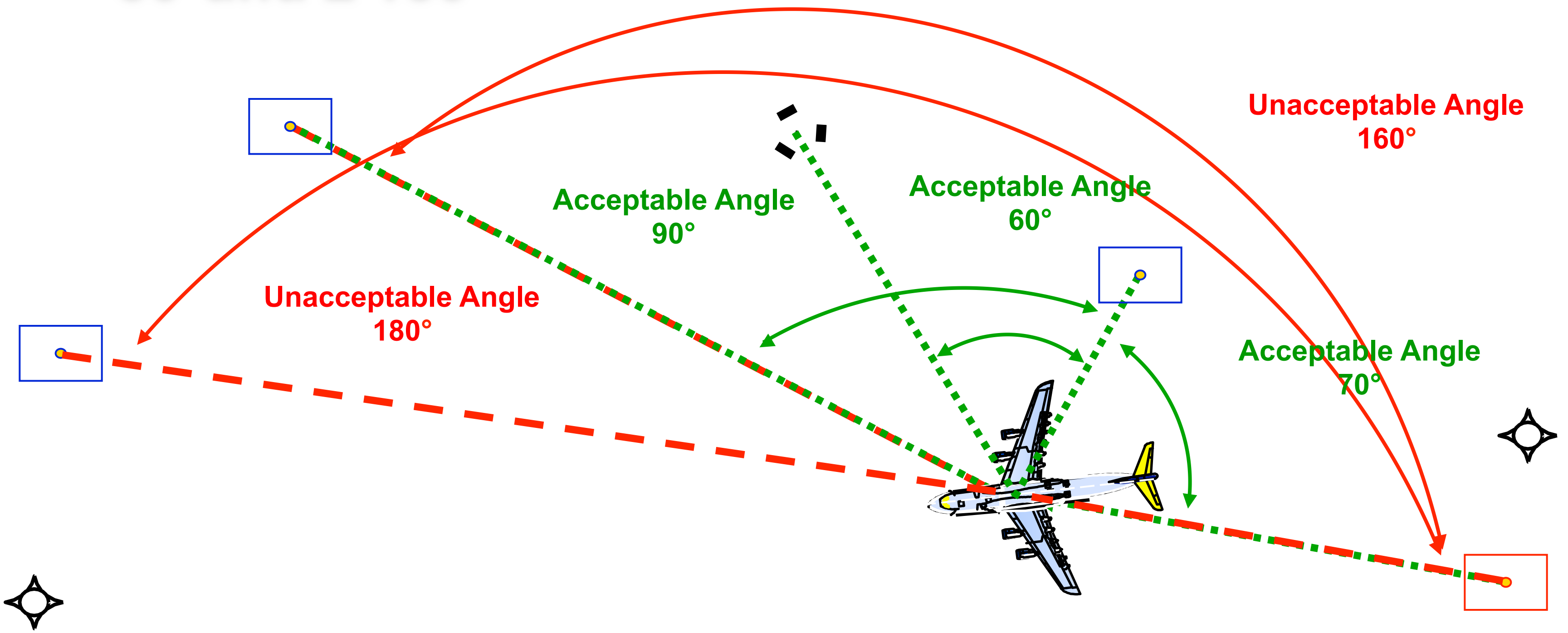


DME/DME



DME/DME Geometry

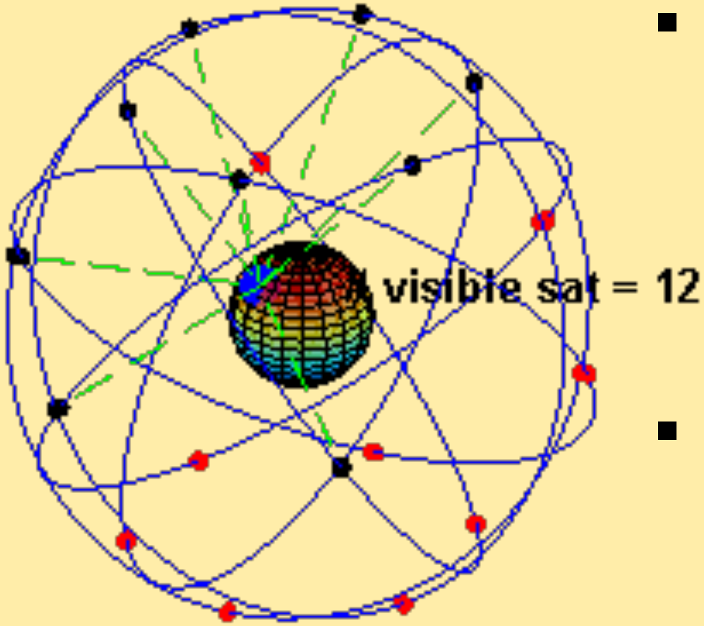
- For DME/DME systems using DME facility pairs, geometry solutions require two DMEs to be ≥ 30°and ≤ 150°



RNAV GNSS: GPS (Global Positioning System)

A 24 satellite constellation

- Position computed in WGS84
- Accuracy of 10 meters or better



- Worldwide coverage
- Database navigation

More GNSS

- BeiDou-2 (COMPASS)

  2020 with 35 satellites

- Galileo

  2019 with 30 satellites

- India

  Regional IRNSS 2014

  with 7 satellites

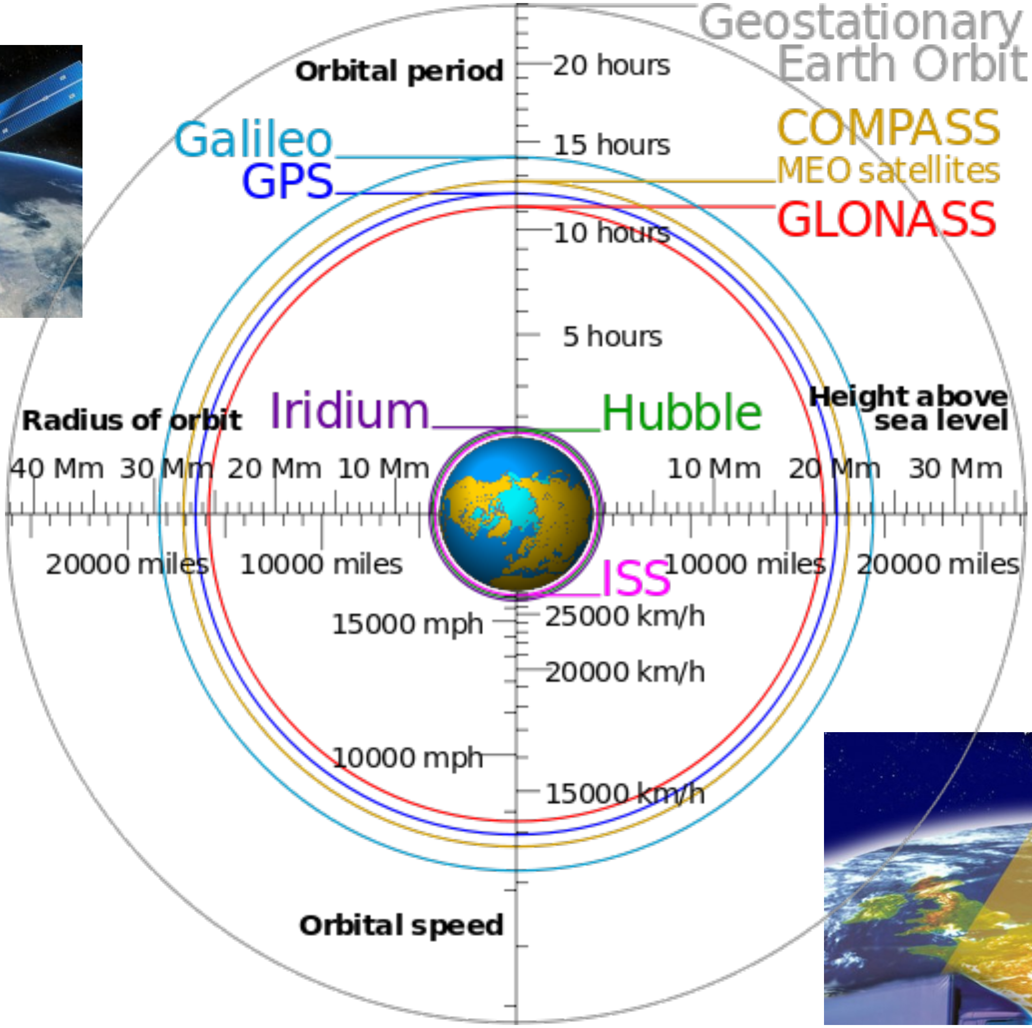
- GLONASS

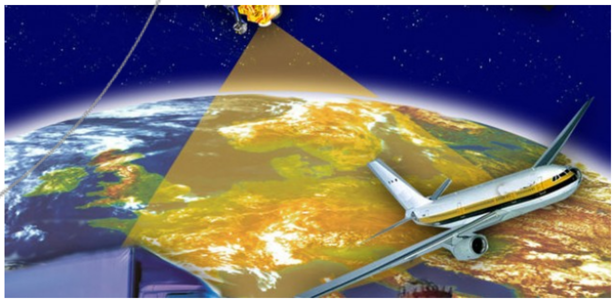
  2013 with 24 satellites.

Quad-Constellation Receiver: GPS, GLONASS, Galileo, BeiDou

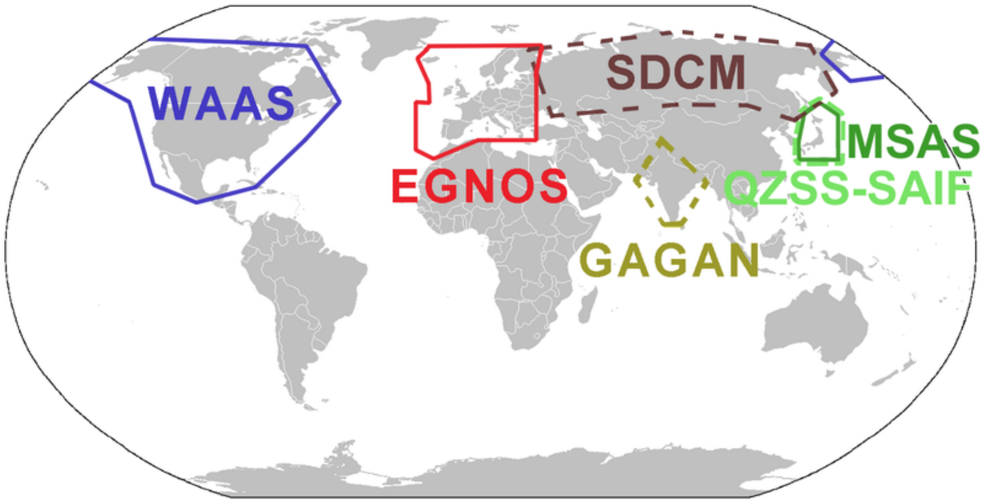
The implementation changes and first live tests of BeiDou and Galileo on Teseo-3 GNSS chips developed in 2013 are covered, bringing it to a four-constellation machine. By 2020, we expect to have four global constellations all on the same band, giving us more than 100 satellites – under clear sky, as many as 30 or 40 simultaneously.

More GNSS


Geostationary
Earth Orbit
Orbital period
20 hours
15 hours
10 hours
5 hours
Galileo
GPS
COMPASS
MEO satellites
GLONASS
Iridium
Hubble
ISS
Radius of orbit
Height above
sea level
40 Mm
30 Mm
20 Mm
10 Mm
10 Mm
20 Mm
30 Mm
20000 miles
10000 miles
10000 miles
20000 miles
15000 mph
25000 km/h
20000 km/h
10000 mph
15000 km/h
Orbital speed

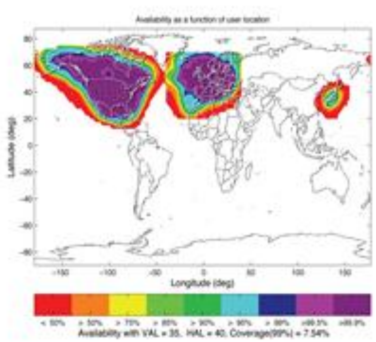


More GNSS – SBAS

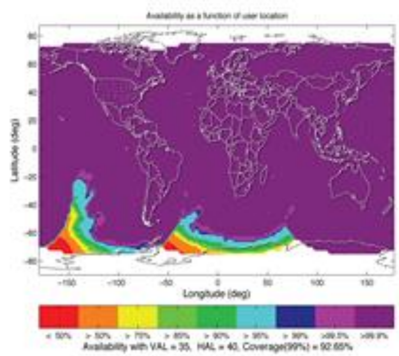


Long term (2020-2025) plan
Extract of joint presentation
IWG23

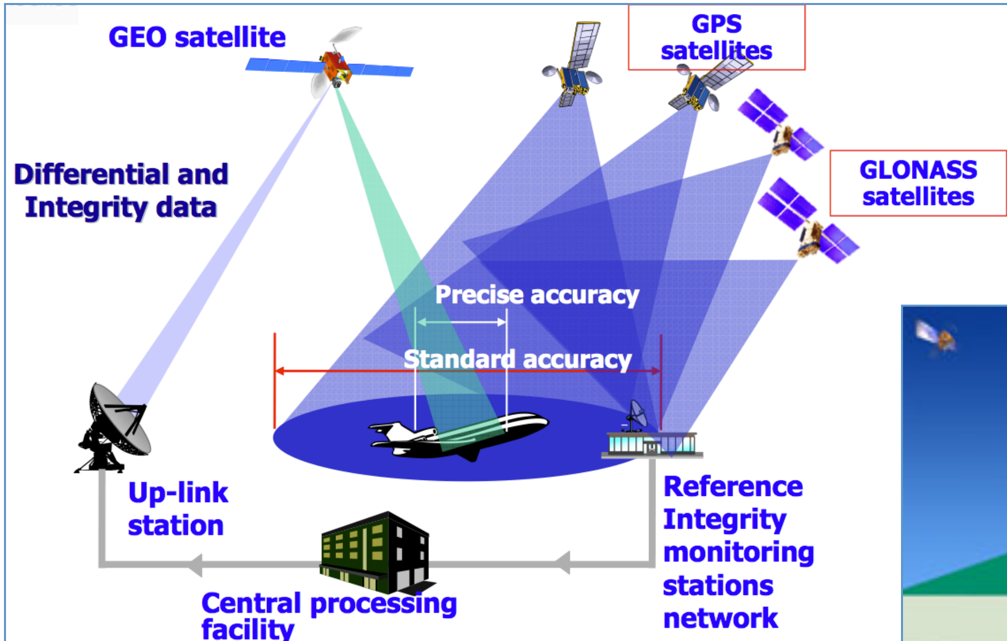
Current Coverage WAAS-EGNOS-MSAS

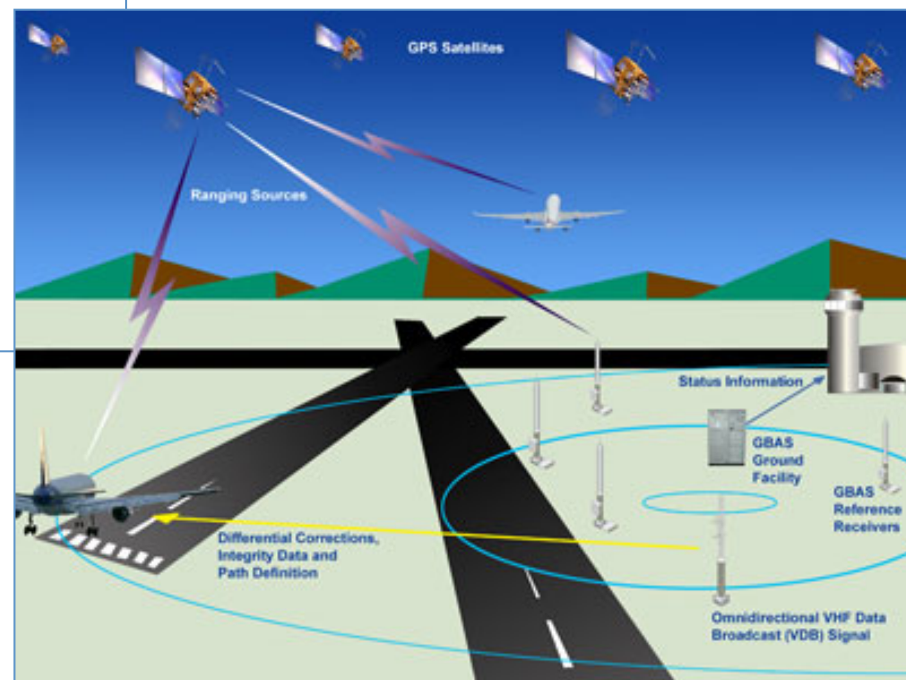


Dual Frequency / dual GNSS WAAS-EGNOS-MSAS-SDCM-GAGAN with expanded network of stations in South hemisphere

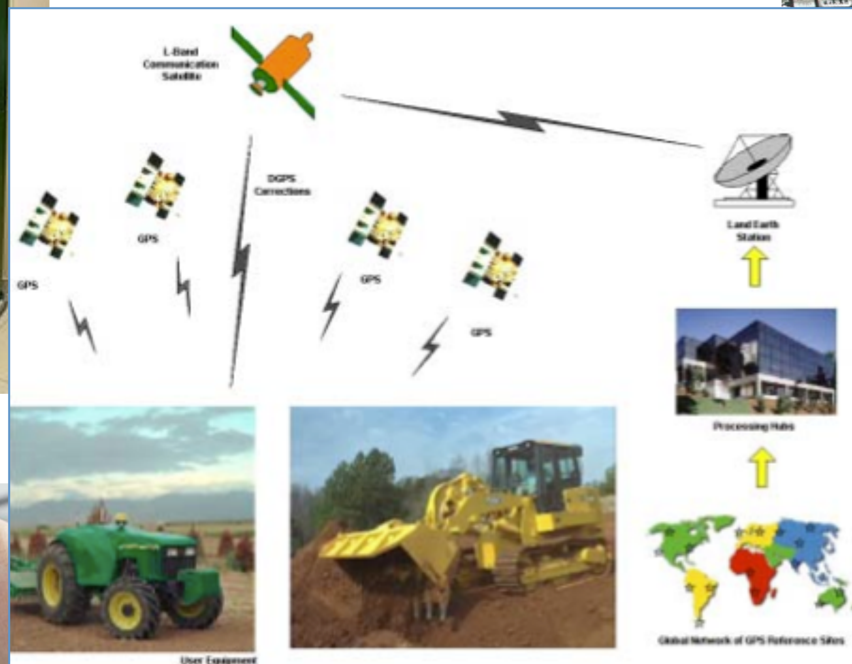


More GNSS – SBAS / GBAS

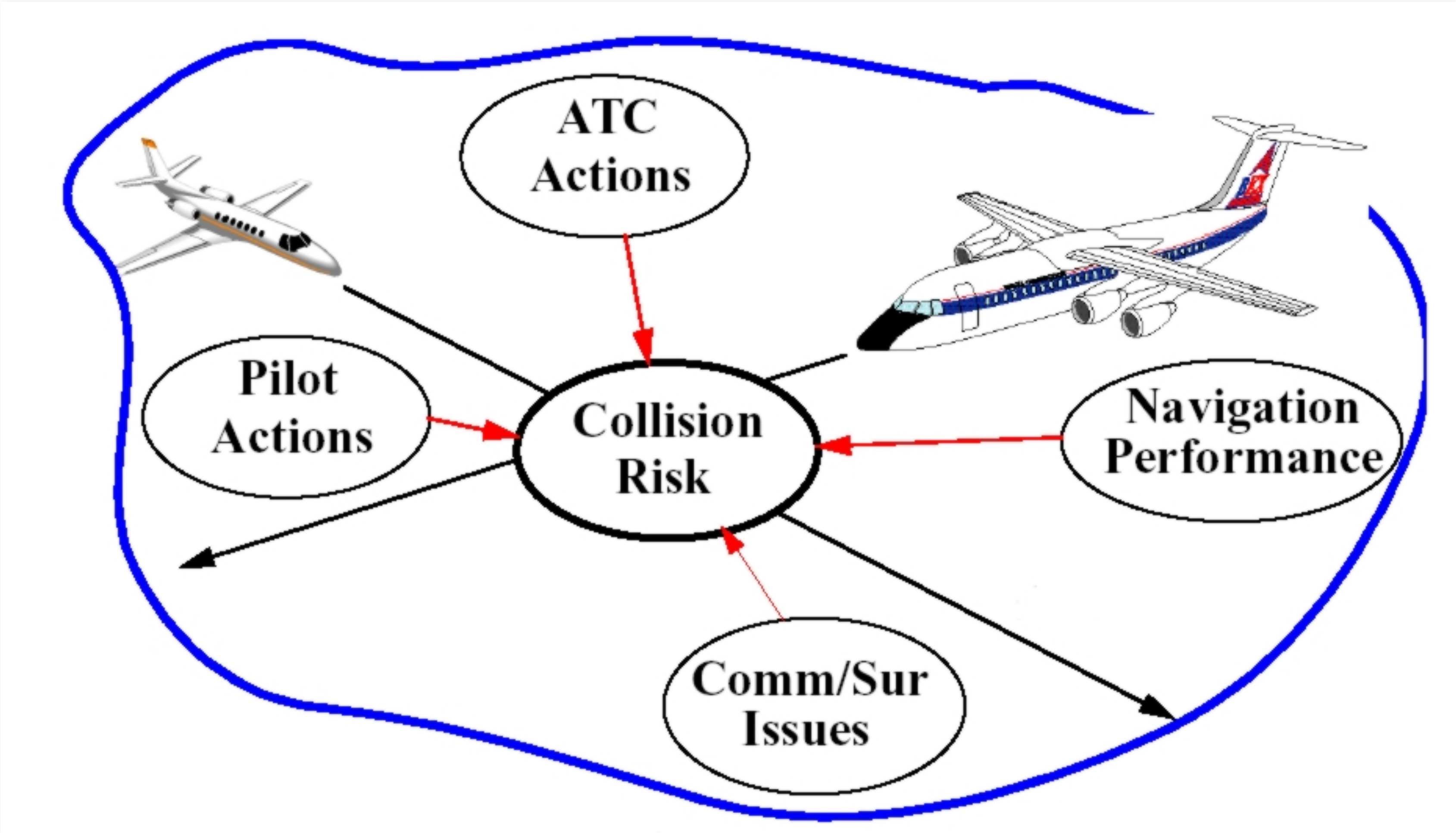




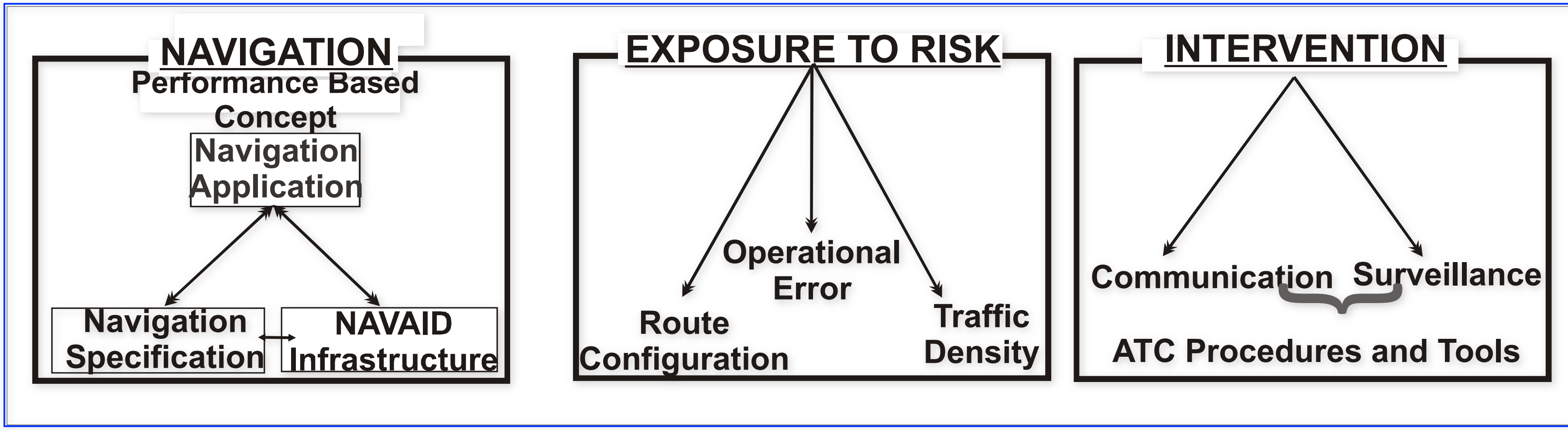
GNSS – Uses / Continuity



Route Spacing



Route Spacing



Generic model used to determine separation and ATS Route spacing

Route Spacing

The spacing between ATS routes may be determined, in part, by the navigation performance of the aircraft that are expected to use them, by anticipated aircraft density, and by the communication and ATS surveillance services that are available to those aircraft.

Route Spacing – ICAO 4444

5.4.1.2.1.3 *By use of different navigation aids or methods*. Lateral separation between aircraft using different navigation aids, or when one aircraft is using RNAV equipment, shall be established by ensuring that the derived protected airspaces for the navigation aid(s) or RNP do not overlap.

Route Spacing – ICAO 4444

5.4.1.2.1.4 *Lateral separation of aircraft on published adjacent instrument flight procedures for arrivals and Departures*

5.4.1.2.1.4.1 Lateral separation of departing and/or arriving aircraft, using instrument flight procedures, will exist:

a) where the distance between RNAV 1, Basic RNP 1, RNP APCH and/or RNP AR APCH tracks is not less than 13 km (7 NM); or

b) where the protected areas of tracks designed using obstacle clearance criteria do not overlap and provided operational error is considered.

Route Spacing – ICAO 4444

Note 1.*— The 13 km (7 NM) value was determined by collision risk analysis using multiple navigation specifications. Information on this analysis is contained in Circular 324,* Guidelines for Lateral Separation of Arriving and Departing Aircraft on Published Adjacent Instrument Flight Procedures.

Note 2.*— Circular 324 also contains information on separation of arrival and departure tracks using non-overlapping protected areas based on obstacle clearance criteria, as provided for in the* Procedures for Air Navigation Services — Aircraft Operations, *Volume II* — Construction of Visual and Instrument Flight Procedures *(PANS-OPS, Doc 8168).*

Note 3.*— Provisions concerning reductions in separation minima are contained in Chapter 2, ATS Safety Management, and Chapter 5, Separation Methods and Minima, Section 5.11.*

Note 4.*— Guidance concerning the navigation specifications is contained in the* Performance-based Navigation (PBN) Manual *(Doc 9613).*

Route Spacing – ICAO 4444

5.4.1.2.1.5 *RNAV operations where RNP is specified on parallel tracks or ATS routes*.

Within designated airspace or on designated routes, where RNP is specified, lateral separation between RNAV-equipped aircraft may be obtained by requiring aircraft to be established on the centre lines of parallel tracks or ATS routes spaced at a distance which ensures that the protected airspace of the tracks or ATS routes does not overlap.

RNP Lateral Separation

- PANS OPS Doc 8168, Vol II, Part III, Section 7.5
  - RNP area semi-width is determined by the formula: 2(XTT) + BV
  - Where: BV = buffer value (see Table III-1-7-1)
- The calculation for a RNP 1 arrival is shown below:

XTT = 1.00 NM; BV= 0.50 NM

area semi-width = 2(1.00) + 0.50 = **2.50 NM**

Table III-1-7-1. RNP buffer values

Segment	*Buffer value (BV)*
Departure	0.93 km (0.50 NM)
En route[1] and arrival[2]	1.85 km (1.00 NM)
Arrival[3]/initial/intermediate approach	0.93 km (0.50 NM)
Final	0.37 km (0.20 NM)
Missed approach	0.56 km (0.30 NM)
Holding[4]	

1. For all RNP types equal to or exceeding RNP 1.
2. Arrival up to 46 km (25 NM) before the IAF.
3. Arrival closer than 46 km (25 NM) to the IAF.
4. Holding areas use different principles.

Route Spacing – Example
EN ROUTE Continental Airspace

- 16.5 NM route spacing for straight unidirectional tracks operated with ATS radar surveillance, and;
- 18 NM route spacing for straight bi-directional tracks operated with ATS radar surveillance, have been derived for European continental airspace by comparison to a reference system (VOR Spacing)

Minimum ATS requirements:

- NAV —All aircraft need an RNAV 5 operational approval valid for the routes or tracks to be flown, and the NAVAID infrastructure must be sufficient to support RNAV 5 operations.
- COM — Direct VHF controller/pilot voice communications
- SUR — with radar surveillance

Notes:

1. *This spacing is not applicable to remote or oceanic airspaces, which lack VOR infrastructure.*
2. *For general ECAC application, spacing of 16.5 NM for same-direction routes, and of 18 NM for opposite-direction routes, was shown to produce an acceptable intervention rate. Moreover, route spacing could be safely reduced to as little as 10 NM provided the resultant intervention rate was considered acceptable. In the event that ATS radar surveillance was not available, route spacing needed to be increased, and could be as great as 30 NM in a high-traffic-density environment. (Also note that route spacing needs to be increased at turning points because of the variability of aircraft turn performance. The extent of the increase depends on the turn angle).*

Route Spacing – Example

European RNAV

4.3 The table below indicates the route spacing achievable with current specifications and Advanced-RNP based on a lateral navigation accuracy of 1 NM in a Radar Surveillance environment. A 2012 study shows that there are no gains in route spacing when the lateral navigation accuracy is 0.5 NM.

↓Parallel Routes / based on ➔	**Advanced-RNP***		**RNAV 1***		**RNAV 5**
	En Route	Terminal	***En Route***	***Terminal***	***En Route***
Same Direction					16.5 NM
Opposite Direction	7 NM	7 NM	9 NM	8 NM	18 NM
Other					10-15 NM with increased ATC intervention rates
Spacing on turning segments	As above		Larger than above because no FRT		Much Larger than above because no FRT
**Note: The Advanced-RNP and RNAV 1 route spacings are the result of collision risk modelling; the spacings achieved at local implementation could be different following a local implementation safety case.*					

Source: ICAO 12th ANC, Montreal, 19-30 NOV 2012

Route Spacing – Example
EN ROUTE Continental Airspace

- Eight to nine nautical mile (8 to 9 NM) route spacing for straight tracks in a high-density continental en route system using ATS radar surveillance, has been derived by independent collision risk analyses undertaken separately by the Federal Aviation Administration of the United States of America

Minimum ATS requirements:

- NAV — All aircraft need an RNAV-2 operational approval valid for the routes or tracks to be flown, and the NAVAID infrastructure must be sufficient to support RNAV-2 operations
- COM — Direct VHF controller/pilot voice communication
- SUR — Radar surveillance

Thank You