



Global ATM System

~Technology and Operations~

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**Workshop on the Development of Business Case
for the Implementation of CNS/ATM Systems
(Antigua, 25-29 May 2009)**

Presentation outline

- Strategic vision and current practices in ATM
- Need to change over
- Development of concept – FANS to CNS/ATM
- System description – CNS/ATM
- Maturity of concept – CNS/ATM to a Global ATM system
- Spectrum issues
- SARPs development and its status

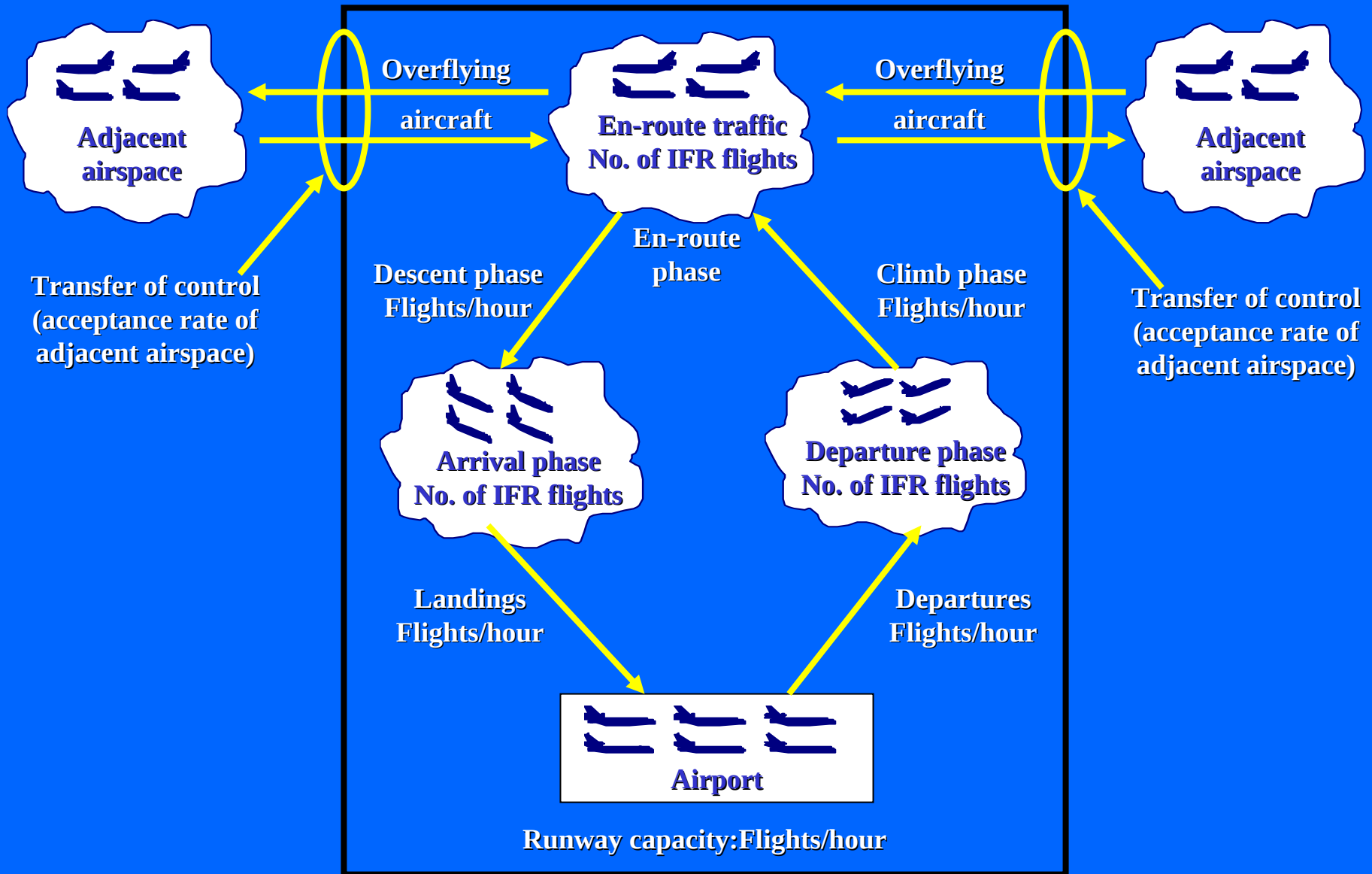
ICAO and World Civil Aviation Community

~ Strategic vision ~

To foster the implementation of an interoperable global air traffic management system for all users during all phases of flight that:

- meets agreed levels of safety**
- provides for optimum economic operations**
- is environmentally sustainable**
- meets national security requirements**

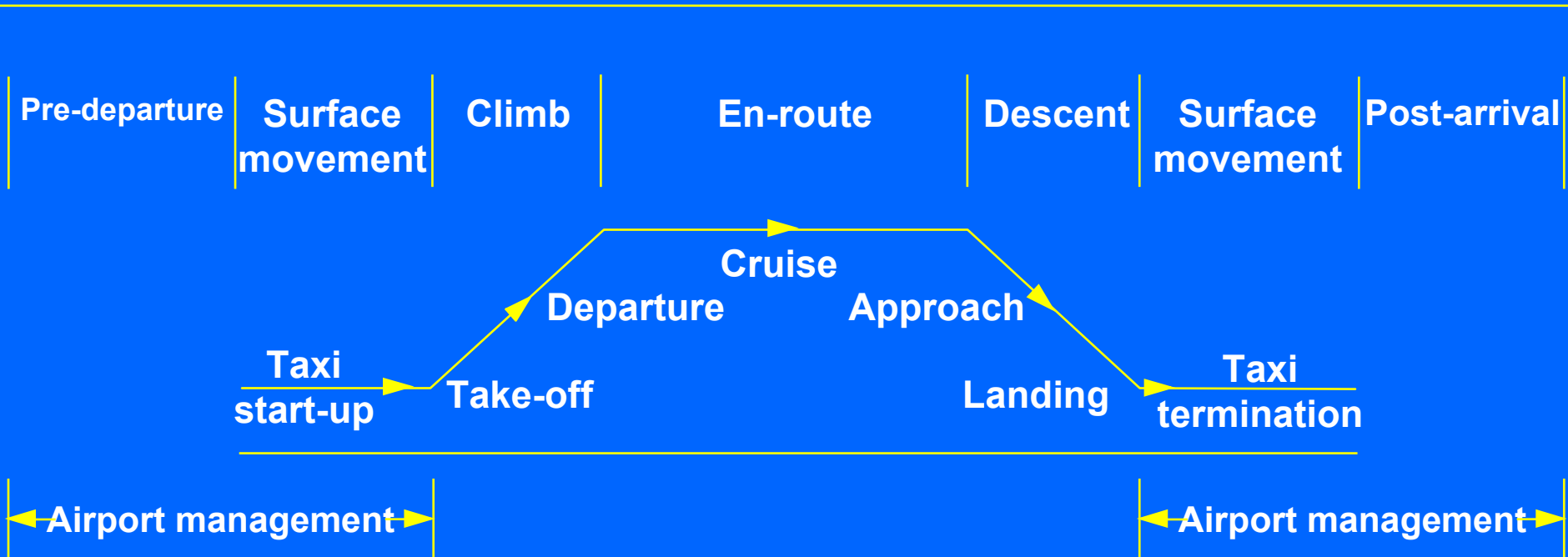
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Capacity assessment for ATM

Air traffic management

Gate to Gate Operation



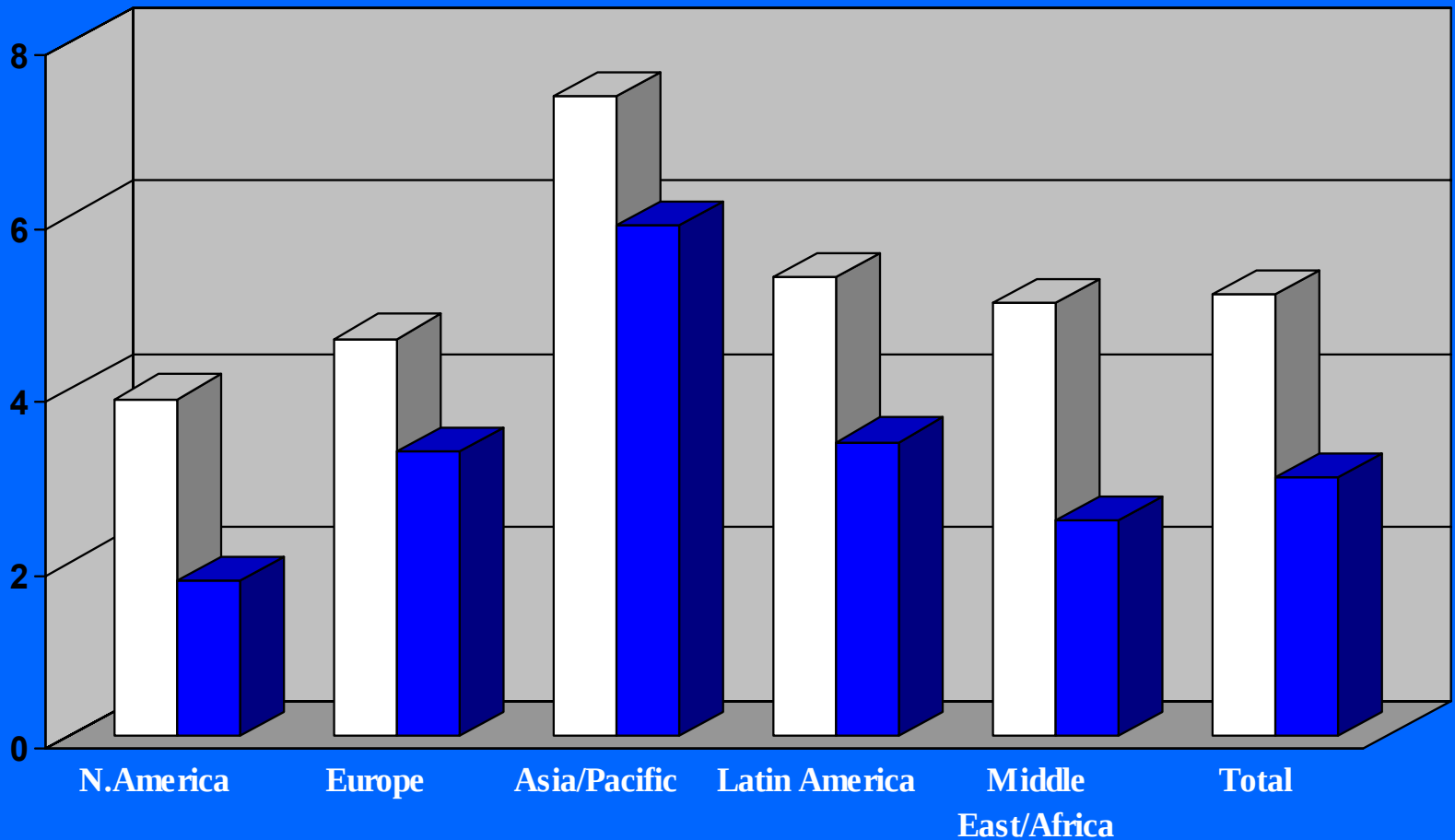
Different phases of flight

Current limitations

- **Line-of-sight propagation of current CNS facilities**
- **Difficulty in implementation of present CNS systems in large parts of the world**
- **Lack of Digital Air Ground Data interchange Systems**

Projected Growth in Air Traffic Demand

Average Annual Increases in Traffic Movements 1992 – 2010



Need for change

- Increased growth in air traffic
- Limitations of current systems
- New technologies provide solutions
- Requirement for global consistency



- **FANS (Future Air Navigation Systems) Committee was established to address the above issues**

FANS milestones ...

- FANS phase I committee: **July 84 – Dec. 88**
(Development of systems concept)
- FANS phase II committee: **July 89 - Oct. 93**
(Planning for transition to new technologies)
- 10th Air Navigation Conference accepted FANS concept: **Sept. 91**

FANS milestones

- ICAO Assembly endorses
FANS concept: **Sept. 92**
- ICAO CNS/ATM systems
implementation task force
addressed funding, cost recovery
& promotion of the concept: **Dec. 94**

CNS/ATM distinct features ...

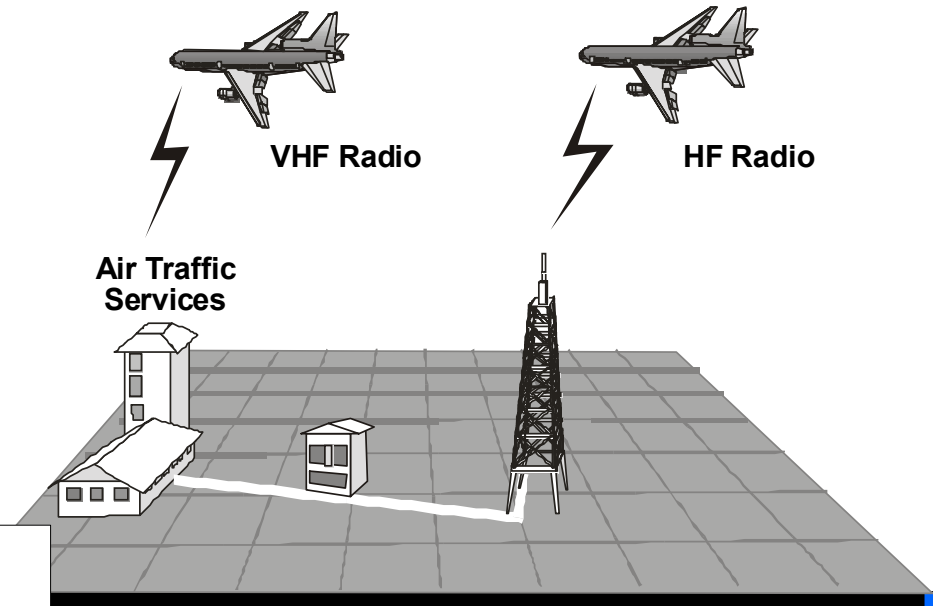
- a) have a mix of satellite and ground-based systems**
- b) provides global coverage**
- c) uses interoperable systems**

CNS/ATM distinct features

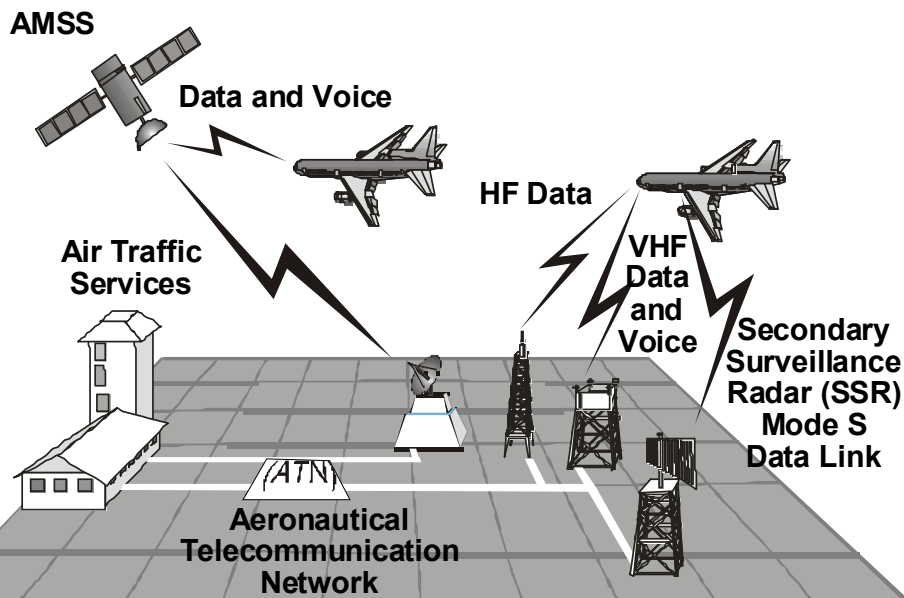
- d) provides seamlessness**
- e) employs air/ground data link**
- f) employs digital technologies**
- g) comprises various levels of automation**

Communications

Communications: Current Environment

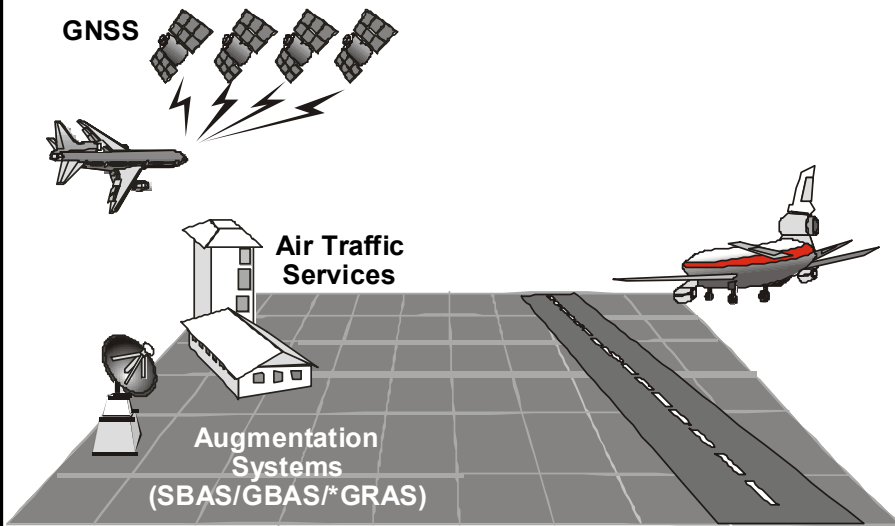


Communications: Future Environment

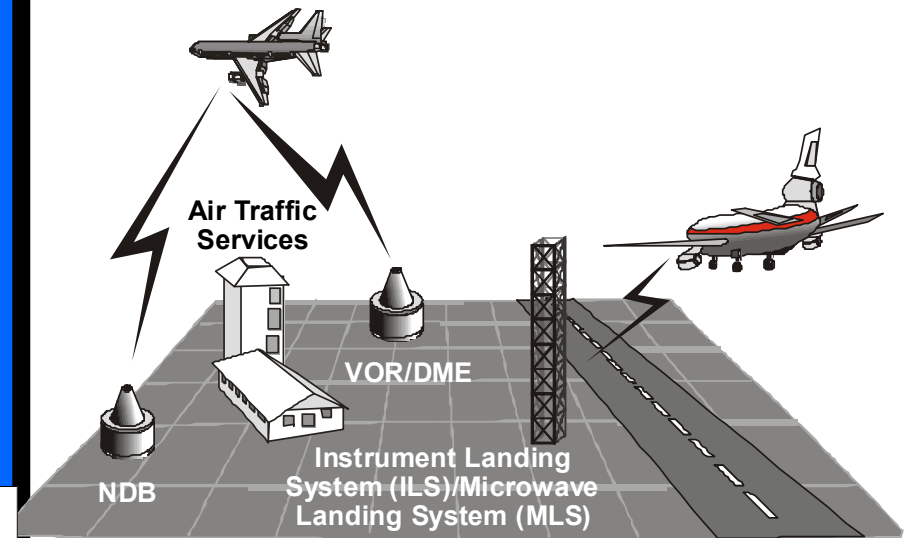


Navigation

Navigation: Future Environment

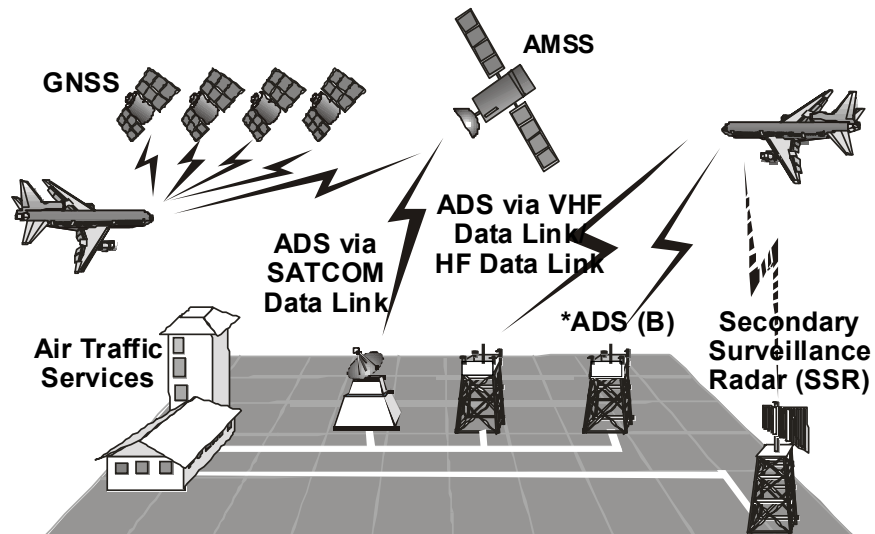


Navigation: Current Environment

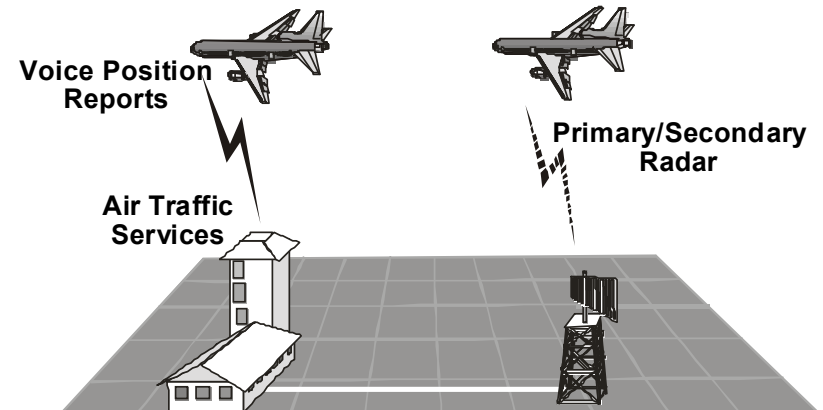


Surveillance

Surveillance: Future Environment



Surveillance: Current Environment



CNS/ATM systems elements – leading to a global ATM system

Communication	Navigation	Surveillance	Air Traffic Management
Data • VHF • HF • Mode S • Satellite • ATN	GNSS • GPS • GLONASS • *GALILEO	SSR • Modes A/C • Mode S	ASM • ATS Route structure • PBN (RNP and RNAV) • Airspace utilization
Voice • VHF • Satellite • HF VOIP	Augmentation • ABAS • GBAS • SBAS	ADS-C • VHF • HF • Satellite	ATS • Air Traffic Control • RHSM and RVSM • Search and Rescue • Decision support systems
	DME/DME	ADS-B	
		MLAT	ATFM • Planning • Coordination

**emerging systems*

Global ATM system

Global ATM system can be understood as a worldwide system which facilitates:

- interoperability of different technologies,
- accommodates different procedures, and
- provides harmonization leading to seamlessness across regions

This is achieved through progressive, cost effective and cooperative implementation of air navigation systems worldwide .

Air traffic management

~ Operational concept ~

- **The operational concept**
 - **describes how an integrated global ATM system should operate**
 - **provides PIRGs, States and industry with clearer objectives for designing and implementing air navigation systems**
- **The concept has been approved by AN-Conf/11 and the Council of ICAO**
- **The ATM System Requirement document has been developed to ensure that all ATM related standards-making and industry work will be in support of the operational concept.**

Performance requirements

~ RCP ~ ...

- Required communication performance (RCP) is a statement of the performance requirements for operational communication in support of specific ATM functions
- ICAO has completed the development of guidance material (Manual on RCP) and also amendments to Annexes 6 and 11, PANS – ATM and ICAO flight plan form concerning the use of RCP in the provision of air traffic services

Performance requirements

~ RNP-RNAV

- ICAO ANC study group RNPSORSG (RNP and Special Operational Requirements Study Group) now known as PBN SG has addressed the open issues of RNP and RNAV and recommended a new concept – Performance-based Navigation (PBN).
 - a) **RNP specification.** A navigation specification based on area navigation that includes the requirement for performance monitoring and alerting, designated by the prefix RNP (e.g. RNP 4, RNP APCH)
 - b) **RNAV specification.** A navigation specification based on area navigation that does not include the requirement for performance monitoring and alerting, designated by the prefix RNAV (e.g. RNAV 5, RNAV 1)

Performance Requirements

~RSP~

- Required surveillance performance (RSP) will enable transition to new surveillance systems by defining high-level system performance requirements independent of the used technology and architecture. This will allow the implementation of surveillance applications over various surveillance systems with the same level of performance and results in world-wide harmonization.
- RSP is defined as “the set of system performance parameters that are required for a surveillance system to support a surveillance application”
- The RSP concept is under consideration by the Aeronautical Surveillance Panel of ICAO

Performance Requirements

~ RTSP ~

- RTSP would address an internal perception: what functionality of which quality ATM services, infrastructure, procedures, systems and resources should have and/or aircraft and crews should meet
- RTSP would incorporate all system capability aspects. It has been historically seen as a compound of required communication, surveillance or navigation performance, for the communication, surveillance and navigation parts, but the proposed definition differs significantly from that view
- The RTSP concept is under development by ICAO ATMRP Panel (Air Traffic Management Requirements and Performance Panel)

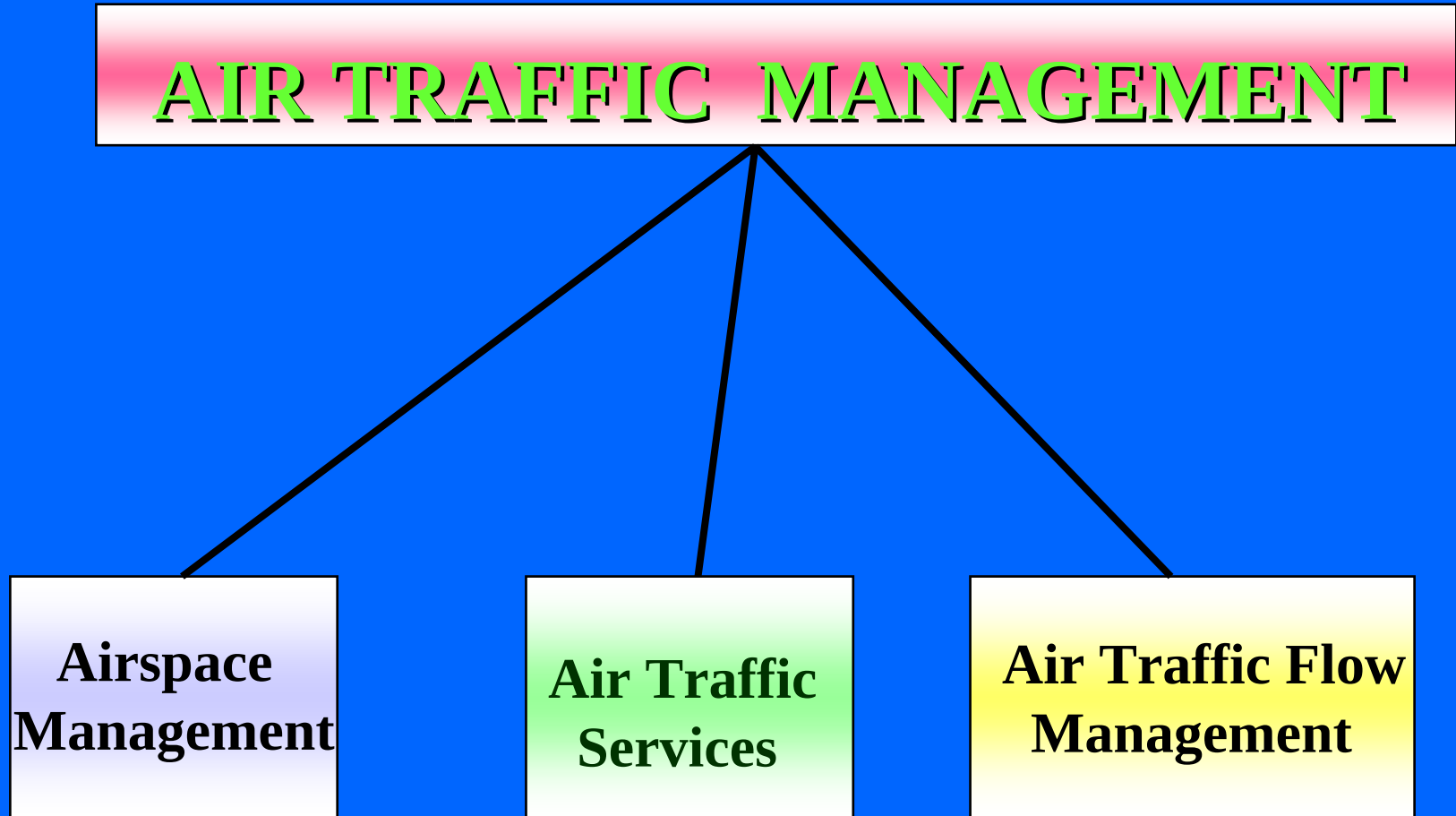


Air Traffic Management

~ Definition (March 2007)~

Air traffic management is the dynamic, integrated management of air traffic and airspace (including ATS, ASM and ATFM)—safely, economically, and efficiently — through the provision of facilities and seamless services in collaboration with all parties and involving airborne and ground based functions

Elements of ATM



Airspace management

- **ATS route structure**
 - **fixed routes**
 - **RNAV fixed/random/mixed routes**
- **Airspace organization**
 - **fixed and flexible use of airspace**
 - **civil/military coordination**
 - **application of RCP/RNP/RSP/RTSP**
 - **optimized sectorization**

Air traffic services ...

➤ Air Traffic Control

- flight information service
- area control
- approach control
- aerodrome control
- surface movement control

➤ Search and Rescue

- Emergency locator transmitter (ELT) of COSPAS and SARSAT(406 MHz from 1 Feb 2009) and no satellite coverage for 121.5 MHz

Air traffic services ...

- **Decision support systems**
 - conformance monitoring; MTCA/STCA; MSAW
 - PRM for independent IFR approaches to closely spaced runways
 - arrival metering and sequencing system
 - AIDC
- **Separation standards**
 - Reduced Horizontal Separation Minimum (RHSM) and Reduced Vertical Separation Minimum (RVSM)

Air traffic services

➤ Applications

- data link
- use of curved and segmented approaches
- PBN
- A-SMGCS

Air traffic flow management (ATFM) ...

➤ ATFM Objective

- to ensure an optimum flow of air traffic through areas during times when demand exceeds or is expected to exceed the available ATC capacity

➤ Application of ATFM

- re-routing; and
- allocation of slots

ATFM ...

~ Phases of ATFM activity ~

- **Strategic phase:** Strategic activities are research, planning and coordination activities carried out in the period from two days to several months in advance of the day of operation
- **Pre-tactical phase:** Pre-tactical activities are planning and coordination activities carried out within the two days prior to the day of operation
- **Tactical phase:** Tactical activities are ATFM activities carried out on the day of operation
- **Airborne flights:** ATFM shall take action on individual flights before their departure and shall not normally intervene in the progress of airborne flights which are the responsibility of the appropriate ATC unit. However, airborne flights may be subject to additional tactical ATFM measures

ATM evolution

	PAST/CURRENT	CURRENT/ NEW
ATM	➤ Fixed sectorization ➤ Fixed routes ➤ MNPS ➤ Airspace segregation ➤ RHSM ➤ Search and Rescue	➤ Optimized/dynamic sectorization ➤ RNAV routes ➤ MNPS/PBN ➤ Airspace desegregation ➤ RHSM and RVSM ➤ Search and Rescue ➤ Application of RCP/RNP/RNAV/RSP & RTSP ➤ Application of data link ➤ Decision support systems ➤ User-preferred flight profiles ➤ A-SMGCS ➤ ATFM (databases, strategic and tactical planning & coordination)

Communications

Communication systems

- **Ground- ground communication**
 - **Data**
 - **Voice**
- **Air – ground communication**
 - **Data**
 - **Voice**

Ground-ground data links

➤ Current

- AFTN (Aeronautical Fixed Telecommunications Network) (between communication centres)
 - low/medium speed
 - store and forward
- OLDI (On Line Data Interchange) (between ATS centres)
 - not compatible with ATN

➤ New

- AMHS (Aeronautical Message Handling System) an ATN application (between communication centers)
- AIDC (ATS Interfacility Data Communication) an ATN application (between ATS centers)

➤ Ground/ground data & voice communications network

The first step in planning for the transition to CNS/ATM systems

It is essential to have ground/ground networking to transport textual data, radar data, graphics and voice. The selected network platform can be either terrestrial (Radio links/coaxial) or satellite, or a mix of terrestrial/satellite, depending on economic and technical factors

Services (current & future) to be considered when establishing ground/ground networking (such as VSATs)

Data: AFTN, FDPS, FAX, RDPS, SBAS, GRAS, VHF, HF, AMSS, AMHS, AIDC

Voice: VHF, PABX, VCCS, DSC

Remote operations: NAVAIDS monitoring

Graphics: Weather maps

Video

Ground-ground voice links

- Voice communication between ATS units (direct speech circuits)
 - Will remain the principle means of communication with AIDC for routine work
- Private Integrated Service Network Exchange (PINX)
 - VCCS/VCS
 - New digital voice switching systems are expected to bring more extensive integration and improved controller interface
- Ground/ground data and voice communications network

Data link functions

~ Basic principles ~

- **It will supplement and support voice communications, not replace them**
- **The initial service is for routine events**
- **Messaging should be simple**
- **Procedures should be consistent with current voice systems**
- **En route, terminal and tower ATC facilities require different data link capabilities**

Air-ground data links

➤ Current

- ACARS (Aircraft Communications Addressing and Reporting System)

➤ New

- VHF digital data link
- Mode-S data link
- AMSS data link
- HF data link

ACARS (VHF) and VDL

Mode	Modulation	Modulation Rate Kbits/sec	Access Control	Application
ACARS	AM MSK	2.4	CSMA	A/G Data
VDL 1 (not in use)	AM MSK	2.4	CSMA	A/G Data
VDL 2	D8PSK	31.5	CSMA	A/G Data
VDL 3 (not in use)	D8PSK	31.5	TDMA	A/G Data & voice
VDL 4	GFSK	19.2	STDMA	A/G Data

ACARS

- **ACARS (Aircraft Communications Addressing and Reporting System)**
 - initially developed for airlines operations communications
 - operates in VHF/HF/Satellite modes
 - supports FANS-1/A
 - does not support ATN

VHF digital link ...

- VHF digital link is compatible with ATN
- Mode 2 has higher capacity; successor to Mode 1
- Mode 3 not in use
- Mode 4 is capable of transmitting time-critical messages and can accept prioritization of messages

VHF digital link

- Mode 4 – allocation of time slot without external unit
- Single VHF radio to operate all the modes with a minimum addition of PCBs
- With VDL, aircraft is not involved in any manual frequency tuning for any station change
- Mode 4 is a data link option for ADS-B operations

Mode S data link

- Uplink :1030 MHz
- Downlink: 1090 MHz
- Types of messaging:
 - Level 1 – Receive 56 Standard Length Message (SLM)
 - Level 2 – Level 1 + Send SLM
 - Level 3 – Level 2 + Receive 112 bit ELM
 - Level 4 – Level 3 + Send ELM
 - Level 5 – Level 4 + Multiple Stations

Aeronautical Mobile Satellite Service (AMSS) data link ...

- **GEOS (Geo-stationary Earth Orbit Satellites)**
 - **36 000 km altitude, 24 hours/orbit**
 - **INMARSAT is now migrating from I-3 (3rd generation) to I-4 satellites**
 - **I-4 Satellites are already in commercial operation.**

AMSS data link ...

- **Current service available (by Inmarsat- 3 and 4)**
 - **Aero-H/H+** (high gain, voice and data, global coverage, suited for long-/medium-haul aircraft) + **SwiftBroadband** (for voice, data, internet access available through mobile phones for passengers).
 - **Aero-I** (intermediate gain, voice and data, regional coverage, suited for short-/medium-haul aircraft)
 - **Aero-L** (low gain, data only, global coverage, suited for aircraft that do not need voice or high-speed data communications)
 - **BGAN** (Broadband Global Area Network) is a new mobile voice and broad band data transfer product, based on I-4 satellites and can be used any where on the planet.

AMSS data link

- **LEOS (Low Earth Orbit Satellites)**
 - **1 000 km altitude, 100 minutes/orbit**
 - **66 satellites for global coverage needed**
 - **SARPs have been developed by ICAO**
 - **Service available with Iridium**

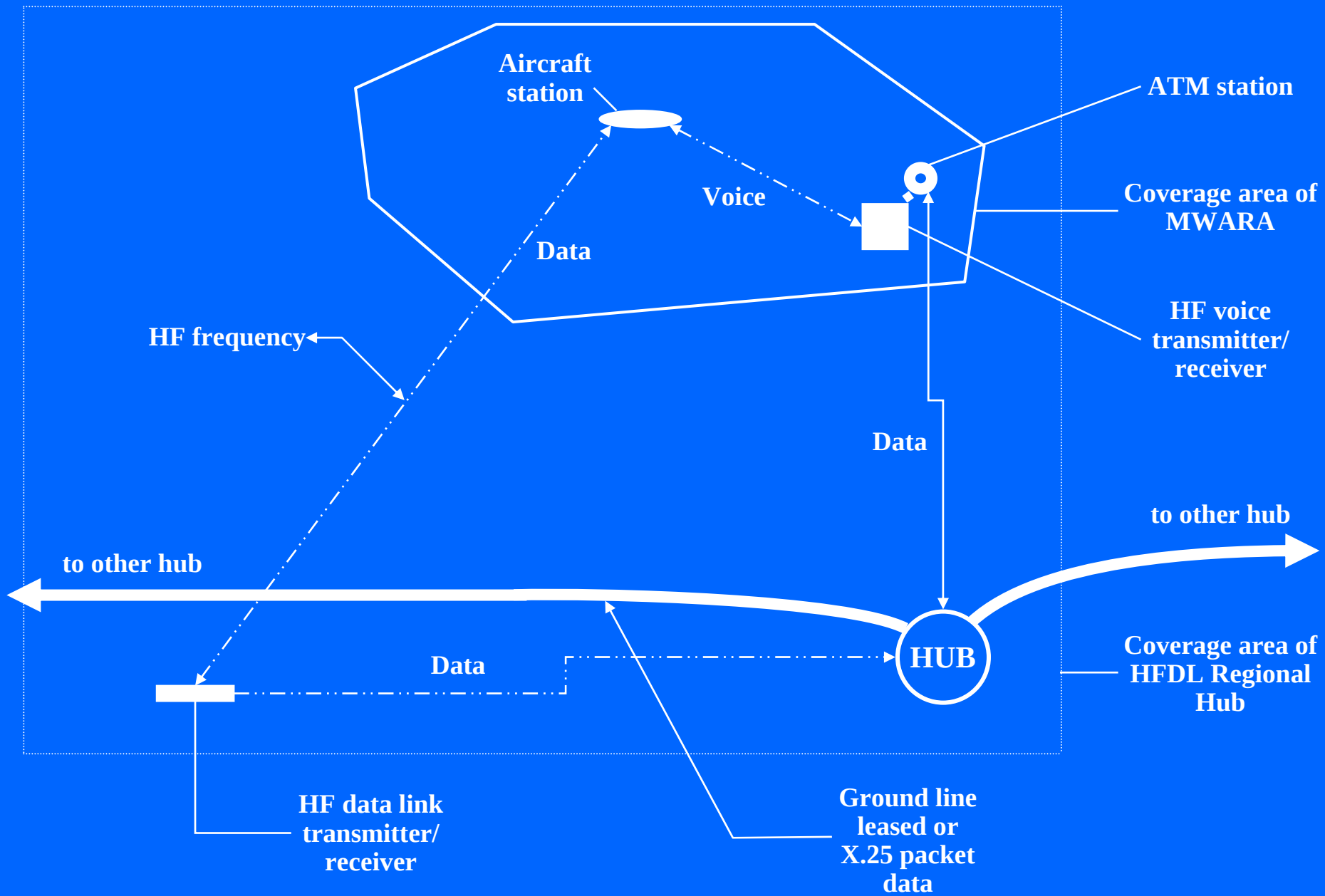
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HF data link – Concept ...

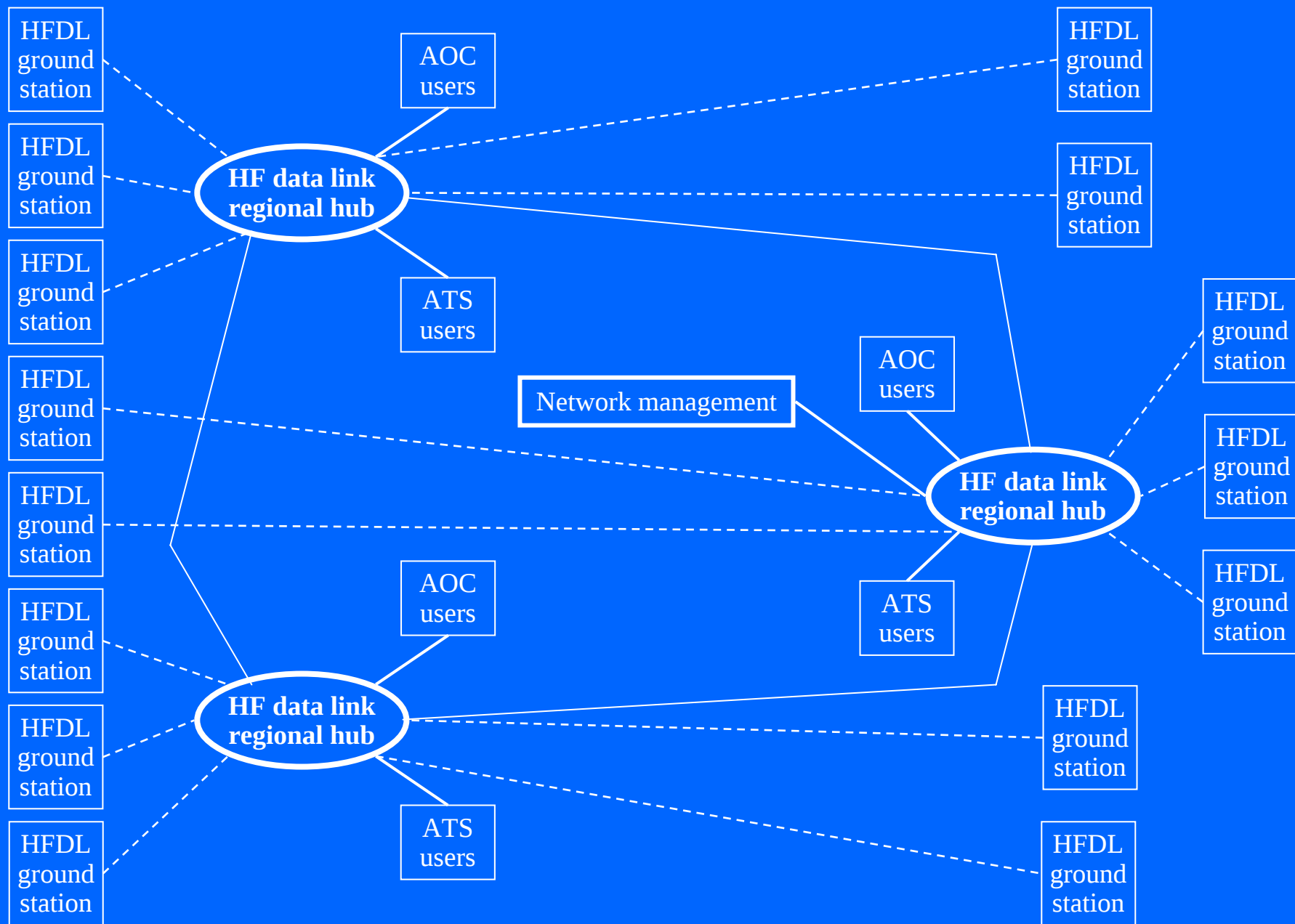
- Network of 14 HFDDL ground stations required for global coverage
- 3 regional hubs, each having 4 to 5 ground stations
- HFDDL is different from current HF voice network
- Ground stations are separated by a distance of 3 000 to 5 000 kms

HF data link – Concept

- System capacity is 2 000 aircraft simultaneously
- Pool of 40 to 60 HF frequencies required
- Aircraft can contact 3 or more HF DL ground stations constantly
- Hubs can become ATN routers
- ARINC currently operates 14 stations worldwide



Data link versus voice link



Possible scenario for a global network

Controller Pilot data link communications (CPDLC) ...

- CPDLC is a data link application that allows for the direct exchange of text-based messages between a controller and a pilot
- The CPDLC allows:
 - the flight crew to print messages
 - the auto load of specific uplink messages into the FMS thus reducing crew-input errors.Also the crew could downlink a complex route clearance request, which the controller can re-send when approved without having to type a long string of coordinates

ATN ...

- It is the OSI architecture that has been chosen for use within the aviation industry

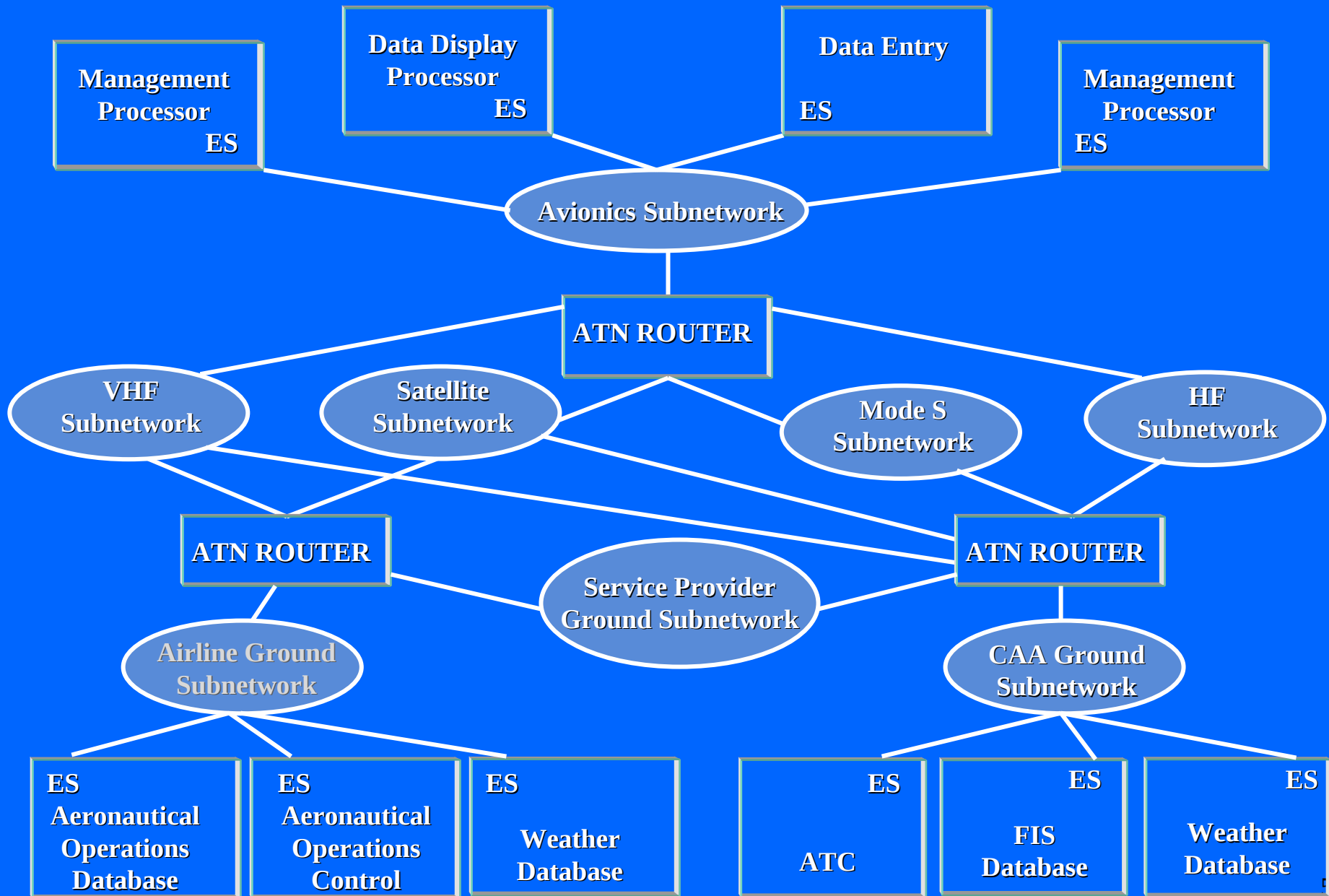
It will:

- allow the interconnection of various air/ground administrations such as
 - civil aviation authorities
 - airlines
 - telecommunications service providers

ATN ...

- allow interoperability of different types of data links:
 - VHF
 - AMSS
 - Mode S
 - HF
- allow communications between a wide variety of users
- use the standard set of ISO protocols

ATN architecture



Aviation use of public Internet ...

- Widespread availability, speed, ease of use and low cost of public Internet has been appealing to aviation community
- Several States are already using the public Internet for exchange of aeronautical data for ground-ground applications

Aviation use of public Internet

- ICAO has published in June 2005 a Manual on guidelines for the use of public Internet for Aeronautical applications (ICAO Doc 9855)
- The ICAO Document 9855 will be amended to reflect recent Internet – related developments and comments received by states and International organizations

ATN update — use of IPS

- Aeronautical Communication Panel (ACP) of ICAO has agreed to the use of TCP/IP or the Internet protocol suite (IPS) in the provision of aeronautical internetworking for ground-ground and air-ground to replace the ATN/OSI Internet for the following reasons:
 - X-25 technology is obsolete;
 - IPS infrastructure is available and flexible; and
 - ATN/OSI Internet protocols are not maintained
- SARPS and guidance material on the use of IPS aeronautical data communications are available now. Manual on ATN/IPS also been completed.
- The feasibility of using IPS for air-ground data applications has been demonstrated. Future air/ground data link system will be based on already existing IPS SARPs.

Air-ground voice links

➤ Current

- HF voice
- VHF voice (Analogue) channel spacing 25 KHz and 8.33 kHz

➤ New

- VHF digital voice (VDL Mode 3)
- Satellite (AMSS) voice

Air-ground voice communications ...

➤ HF voice

- SSB in the band of 2.85 MHz to 22 MHz is used
- widely available in Oceanic and remote regions
- propagation characteristics vary with time of day and other conditions
- audio quality is not good
- HFRT (RDARA) is still employed in en route continental airspace of some States due to lack of continued coverage of VHF RT

Air-ground voice communications ...

➤ VHF voice

- DSB-AM analog voice with 25 kHz is widely used for TMA and en route continental airspace
- to overcome the congestion, channel spacing has been reduced from 25 KHz to 8.33 kHz so as to increase the number of available channels (e.g.: in European Region)
- VDL Mode 3 provides both voice and data communications. However, this technology is not implemented by any State.

Air-ground voice communications

- **Satellite (AMSS) voice**
 - application in oceanic and remote areas for non-routine and emergency use only
 - Security concerns still to be resolved
 - no coverage near polar regions
 - Services available from INMARSAT using GEO satellites
 - Service under test for using low earth orbits by Iridium

SATCOM voice

- **There are no major issues for airborne initiated calls and it should be accepted**
- **Ground initiated calls could be accepted if the proper security measures are implemented.**
- **There are two main issues related with the use of SATCOM for routine ATS purposes: Security and costs**

Voice communications (Ground-ground and Air- ground) – use of VoIP

- **The feasibility of using Voice over Internet protocol (VoIP) for ground –ground application on the basis of available standards has been demonstrated; SARPs and guidance material will be completed by 2010**
- **The feasibility study of using VoIP in air-ground communications is part of the future communications study in ICAO**

Future communications- study – a vision

- A single technology in the C- band (5.091-5.150 GHz) has been agreed to support airport surface operations, especially in high density areas.
- Two technologies are currently under consideration for the L-band (960-1164 MHz) as the main terrestrial component of the Future Communication Infrastructure (FCI) for all phases of flight. Until such time as the spectrum compatibility between the proposed systems and the legacy systems has been proven it would not be possible to complete this activity. This will require the development of prototypes in order that testing in a real environment against operational legacy equipment can be carried out.
- A Satellite component is required to support the oceanic and remote areas, and possibly provide complementary support to TMA and enroute phases.
- Due to the current spectrum congestion in some regions in the VHF communications band (117.975 MHz-137MHz), the potential use of the VHF band for new technologies was not considered viable within the same timeframe as the bands mentioned above.

Navigation

Navigation systems

- **Current systems (ground-based)**
 - **Navigational aids for en route**
 - **Navigational aids for precision approach/landing**
- **New systems (satellite-based)**
 - **GNSS for all phases**

Nav aids for enroute

- **NDB**
 - **Compass direction to beacon**
- **VOR**
 - **bearing from beacon**
- **DME**
 - **distance from beacon**

Non-directional beacon (NDB)

➤ Ground station

- radiates equally in all directions
- transmits at 200-500 kHz
- range 400 NM depending on power
- usually located at airports/en route

➤ Aircraft

- rotates antenna for maximum signal strength

VHF Omni-Range (VOR)

- Two types: CVOR and DVOR
- Ground station
 - radiates reference and rotating beam
 - transmit at 112–118 MHz
 - rotating beam at 30 Hz
 - reference beam at 30 Hz modulated onto sub-carrier at 9.6 kHz
- Aircraft
 - compares phase of the 30 Hz signals
 - in-phase when due North of beacon
 - Range – 200NM

Distance measuring equipment (DME)

➤ Aircraft

- radiates & receives return
- measures time of travel
- frequency band at 960–1215 MHz
- range 200 NM

➤ Ground

- triggered response at DME station

Inertial navigation system (INS)

- Current sole means NAVAID for aircraft
 - triple redundancy
 - passive – no interference
 - dependent on on-board electronic & electro-mechanical devices
 - error increased with time
 - drift rates better than 1 nm/flight hour

Navigation aids for precision approach/landing

➤ ILS

- instrument landing system
- provides bearing in elevation and azimuth
- Currently widely used worldwide

➤ MLS

- microwave landing system
- Provides bearing in elevation & azimuth
- Available at number of airports in Europe such as London Heathrow, Munich, Frankfurt and Paris airports)

ILS

- **Primary landing aid**
- **Localizer beam (azimuth) at runway end**
 - two overlapping beams aligned along runway centre frequency at 108 – 118 MHz
- **Glide slope beam (vertical) at runway side**
 - two beams intersect at 3° glideslope approach
 - frequency at 328.6 – 335.4 MHz or IDME
- **Markers (inner, middle & outer)**
 - frequency at 74.8 – 75.2 MHz (VHF)
- **DME co-located with Localizer in lieu of Markers**

MLS

- Scanning beams
 - coverage to 20,000 ft. altitude & 15 miles width
 - frequency at 5 GHz
- Curved and segmented approaches feasible
- Less vulnerable to interference

**RNP/RNAV concept
leading to
Performance-based
Navigation**

ICAO RNP concept - Background

- FANS identified need for performance based navigation and developed *Required Navigation Performance* capability concept to avoid selection between competing systems
- Manual on Required Navigation Performance (doc 9613)
- Emphasized on the en-route phase of flight (RNP-10 and RNP-4) for oceanic and remote applications
- No ICAO RNP requirements for continental enroute and terminal applications.
 - Proliferation of national standards
 - Wide variety of functional requirements
 - Variety of required navigation sensors
 - Differing air crew requirements
 - Lack of global harmonization

What needs to be done

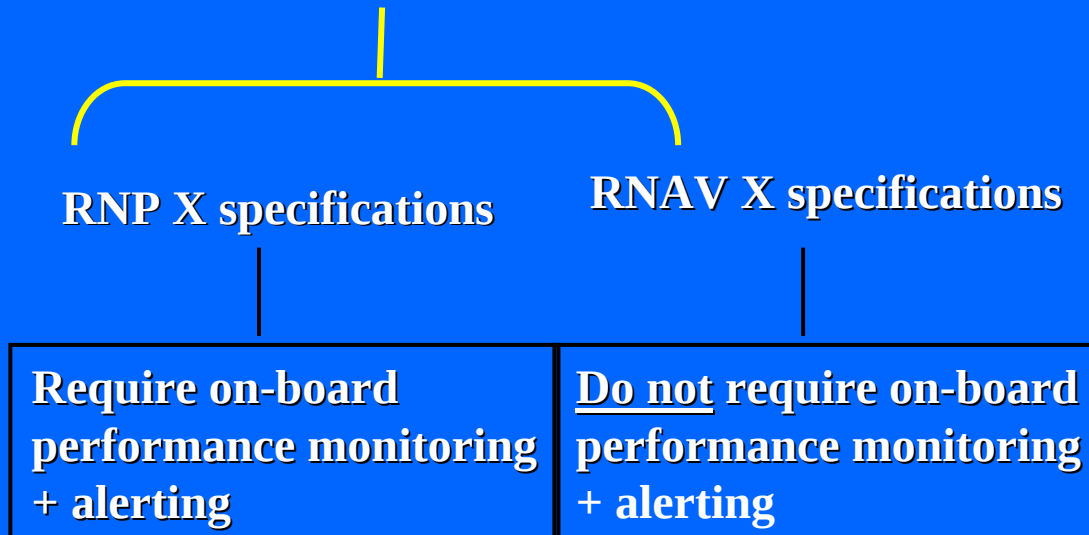
- Original RNP concept in principle good, however...
- Adjustment to the RNP concept required.
 - Clear distinction between operations that require performance monitoring and alerting and operations that don't require
 - Harmonization of current RNAV and RNP operations
 - Development of new navigation specification to meet operational demand.
 - Need for clear operational approval requirements
 - Clear implementation guidance

Performance-based Navigation (PBN)

- ICAO established a study group “*Required Navigation Performance Special Operational Requirements Study Group (RNPSORSG)*” now known as PBN SG to review open issues of RNP concept
- The revised RNP Concept leading to PBN distinguishes between navigation standards that do not require containment integrity, which are to be designated as “X-RNAV” where “X” is a letter of the Roman alphabet, and those navigation standards requiring containment integrity, which are to be designated as “RNP-x”, where “x” corresponds to the navigation accuracy.
- The revised concept allows for an expansion of the designation for 3-D and 4-D capabilities, as potential future applications in the period beyond 2015.
- The PBN Manual is now available on ICAONET.

PBN

- PBN specifies RNAV system performance i.e. accuracy, integrity, continuity, availability + functionality; – written up in **navigation specifications**



This is different to the RNP concept which stressed navigation accuracy and ‘stopped’ at *required performance*. However, PBN is anchored in detailed navigation specifications which contain performance and functionality requirements.

PBN CONCEPT

Navigation specifications
without performance
monitoring and alerting
(existing)

Navigation specifications
requiring performance
monitoring and alerting
(new)

RNP 10

RNAV 5
RNAV 2
RNAV 1

Available (RNP 4)
To be developed
(RNP 2,
RNP 1, RNP 0.3,
RNP 0.1)

RNP with additional
requirements (e.g.
3D/4D) to be determined

Operations under current and proposed PBN concept ...

Area of application	NAV accuracy	Designation of navigation standard: Current situation	Designation of navigation standard: PBN concept
Oceanic/Remote	10	RNP 10	RNAV 10 (RNP 10 label)
	4	RNP 4	RNP 4
En Route – Continental	5	RNP 5 Basic RNAV	RNAV 5
En Route – Continental and Terminal	2	USRNAV type A	RNAV 2
Terminal	1	USRNAV type B and P-RNAV	RNAV 1

Operations under current and proposed PBN concept

Area of application	NAV accuracy	Designation of navigation standard: Current situation	Designation of navigation standard: PBN concept
Terminal	1	Basic GNSS SBAS	Basic RNP 1
Approach	1-0.3	Basic GNSS (Baro-VNAV) SBA	RNP APCH
Approach	1-0.1	RNP SAAAR (US)	RNP AR APCH

Area Navigation (RNAV)

New definition as of 19 June 2007

- A method of navigation which permits aircraft operation on any desired flight path within the coverage of ground- or spaced-based navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

Note — Area navigation includes performance-based navigation as well as other operations that do not meet the definition of performance-based navigation.

Performance-based navigation (PBN)

New definition as of 19 June 2007

- Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

Note — Performance requirements are expressed defined in navigation specifications in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

Navigation specification ...

New definition as of 19 June 2007

- **A set of aircraft and air crew requirements needed to support performance-based navigation operations within a defined airspace.**

There are two kinds of navigation specifications ...

Navigation specification

- a) ***RNP specification.*** A navigation specification based on area navigation that includes the requirement for performance monitoring and alerting, designated by the prefix RNP (e.g. RNP 4, RNP APCH)
- b) ***RNAV specification.*** A navigation specification based on area navigation that does not include the requirement for performance monitoring and alerting, designated by the prefix RNAV (e.g. RNAV 5, RNAV 1)

New systems

GNSS

Satellite orbits

➤ GEO (Geostationary Earth Orbit)

- 36,000 KM; 3 Satellites for global coverage; 24 hours per orbit
 - e.g.: INMARSAT

➤ MEO (Medium Earth Orbit)

- 20,000 KM; 24 Satellites for global coverage; 12 hours per orbit
 - e.g.: GPS

➤ LEO (Low Earth Orbit)

- 800KM; 66 Satellites for global coverage; 100 minutes per orbit
 - e.g.: Iridium system

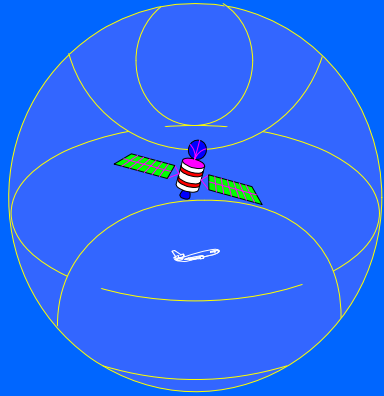
GNSS

~ Definition ~

A worldwide position and time determination system, that includes one or more satellite constellations, aircraft receivers, and augmentations as necessary to support the required navigation performance for the actual phase of operation

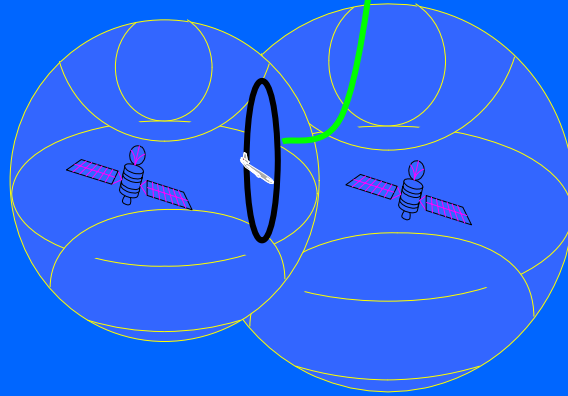
Satellite navigation – Basics

Aircraft is somewhere on the surface of this sphere



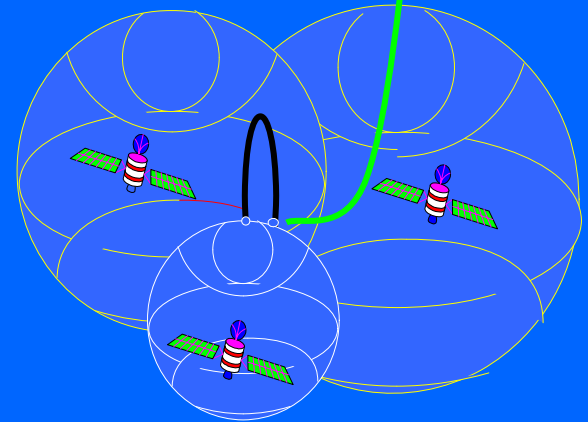
1-satellite
position

Aircraft is somewhere on this circle



2-satellite
position

Aircraft is at one of these two points



3-satellite
position

**reference to a fourth satellite eliminates clock errors*

GNSS

Satellite Constellation + Augmentations + Aircraft Receivers

Satellite Constellations: GPS/GLONASS/
GALILEO

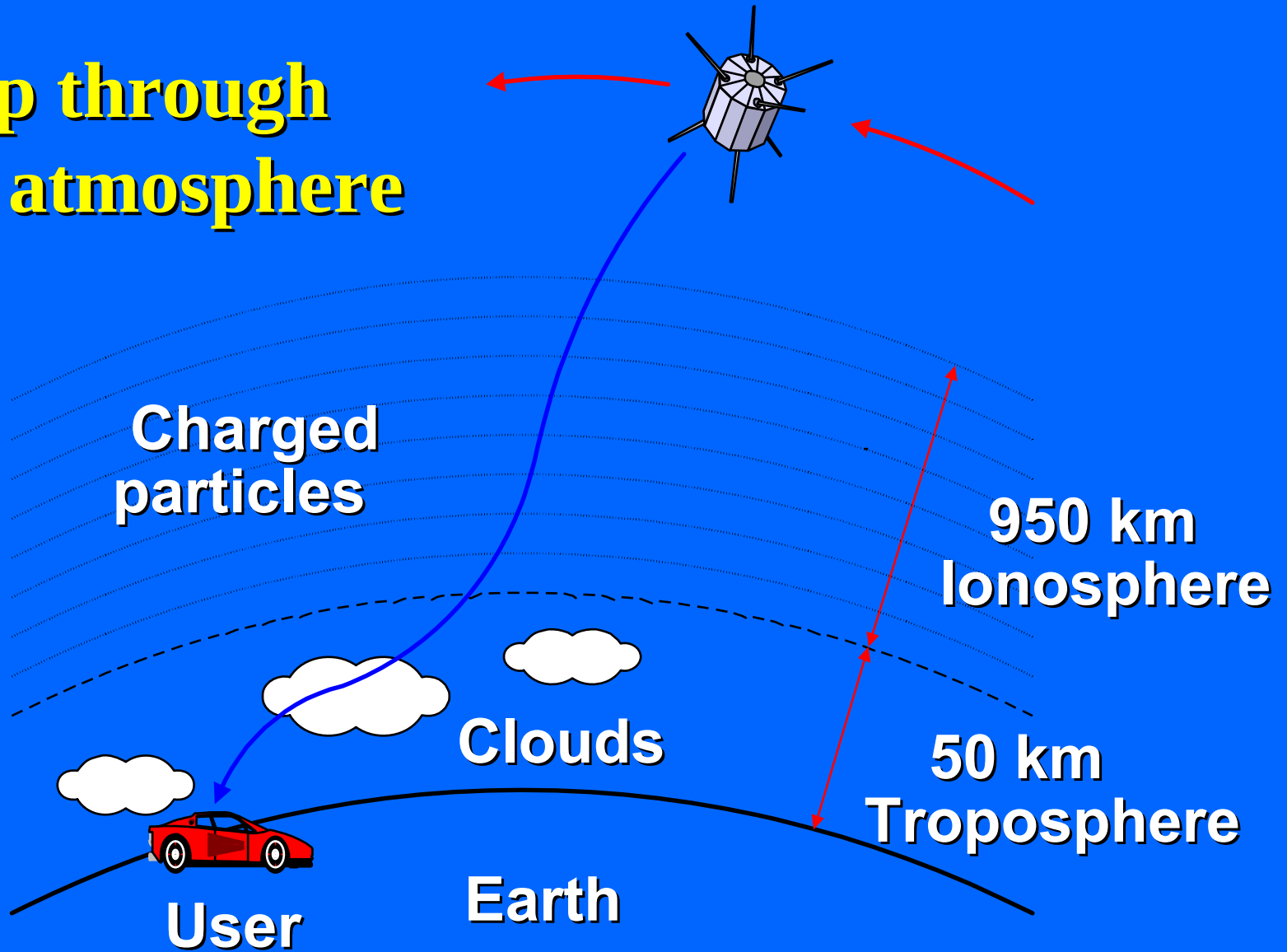
Augmentations: ABAS/SBAS/GBAS

Aircraft Receivers: On board Aircraft receivers

GNSS – error sources

- **Ionospheric delays:** 20 to 30 meters during the day and 3-6 meters during night
- **Tropospheric errors:** 1 to 3 meters
- **Ephemeris errors:** 3 to 4 meters
- **Satellite clock errors:** 3 to 4 meters
- **Multipath errors:** 1 to 2 meters
- **Receiver Noise:** up to 1 meter

Trip through the atmosphere



Ionospheric impacts

- Propagation errors can be corrected by:
 - application of ionospheric models (averaged estimates)
 - application of reference station corrections
 - direct measurements on two frequencies (when available)

Why augment GNSS?

- Both GPS and GLONASS require varying degrees of augmentation to meet operational performance requirements (accuracy, integrity, availability and continuity) for all phases of flight
- To overcome inherent system limitations, augmentations have been proposed in three broad categories:
 - on-board
 - ground-based
 - satellite-based

Types of augmentation systems for GNSS

- **ABAS** (aircraft-based augmentation systems)
 - RAIM and AAIM
- **SBAS** (satellite-based augmentation system)
 - WAAS, EGNOS, MSAS, GAGAN
- **GBAS** (ground-based augmentation system)
 - LAAS

Aircraft-based augmentation system

- **Receiver Autonomous Integrity Monitoring (RAIM)**
A technique whereby an airborne GNSS receiver/processor autonomously monitors the integrity of the navigation signals from GNSS
- **Aircraft Autonomous Integrity Monitoring (AAIM)**
A technique whereby an airborne sensor such as INS/altimetry-aiding is used to augment GNSS. This is particularly employed during short periods when the satellite navigation antennae are shadowed by the aircraft during maneuvers or during periods when insufficient satellites are in view

Receiver autonomous integrity monitoring

- **requires redundant satellite measurements**
- **5 satellites allow to detect the faulty satellite**
- **6 satellites allow to exclude the faulty satellite from position determination**

Radius of the alarm circle is usually 200 m for stand-alone GPS

Satellite-based augmentation system (SBAS) – Service providers ...

1. Wide Area Augmentation System (WAAS)
 - Developed by USA and Initial operating capability commissioned on 10 July 2003.
2. European Geo-stationary Navigation Overlay Service (EGNOS)
 - Developed by European States. The full operational capability of EGNOS is planned for 2010. Certification is in progress.

SBAS – Service providers ...

3. MTSAT Satellite-based Augmentation System (MSAS)

- **Provided by Japan for the Asia Pacific Region. MSAS commissioned in early 2008 after various certification activities as a highly reliable system with two MTSATs.**

4. GPS/GLONASS and geostationary augmented navigation (GAGAN)

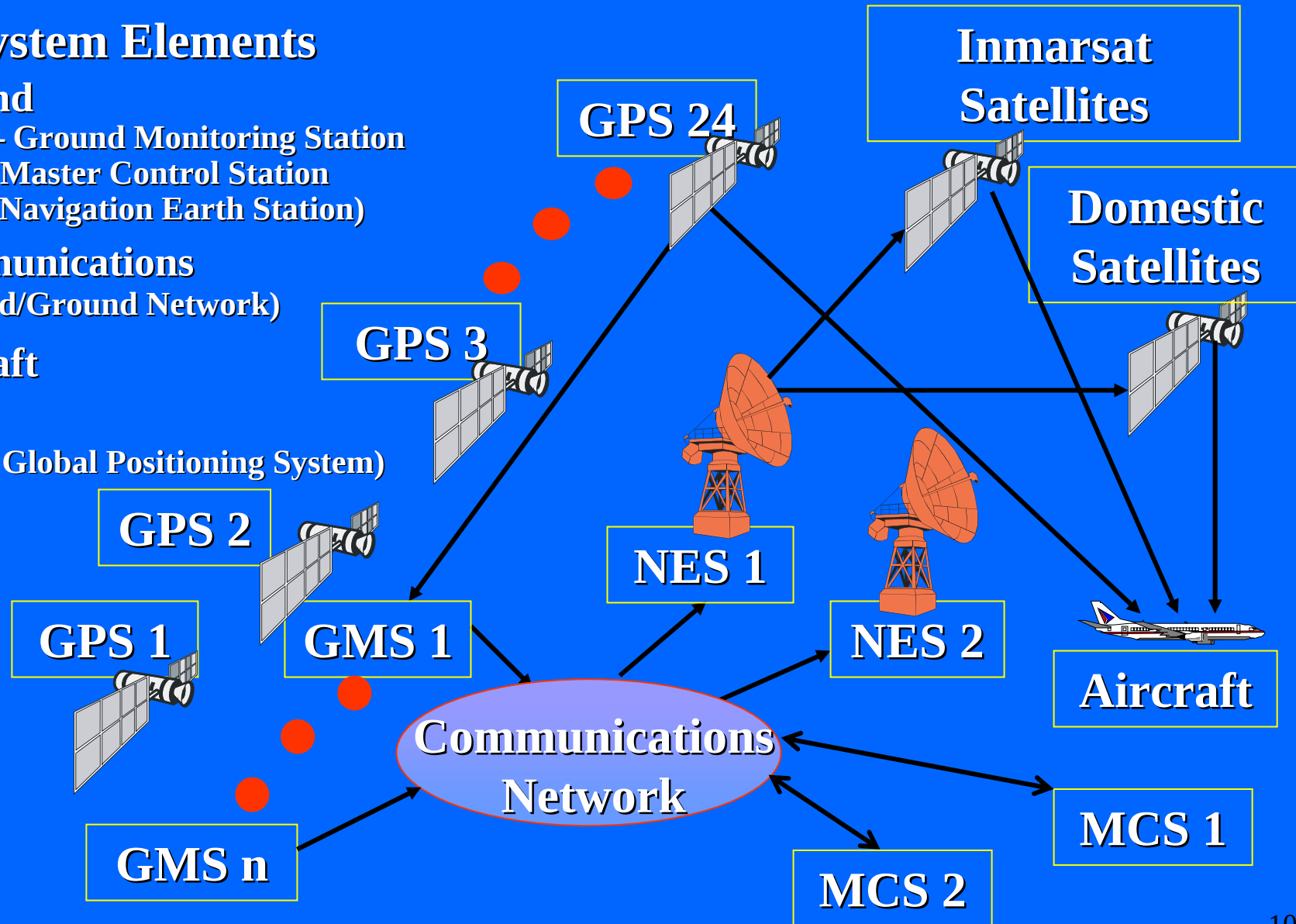
- **Being developed by India to meet the needs of the States of Indian subcontinent and expected to be available in 2010**

SBAS architecture



System Elements

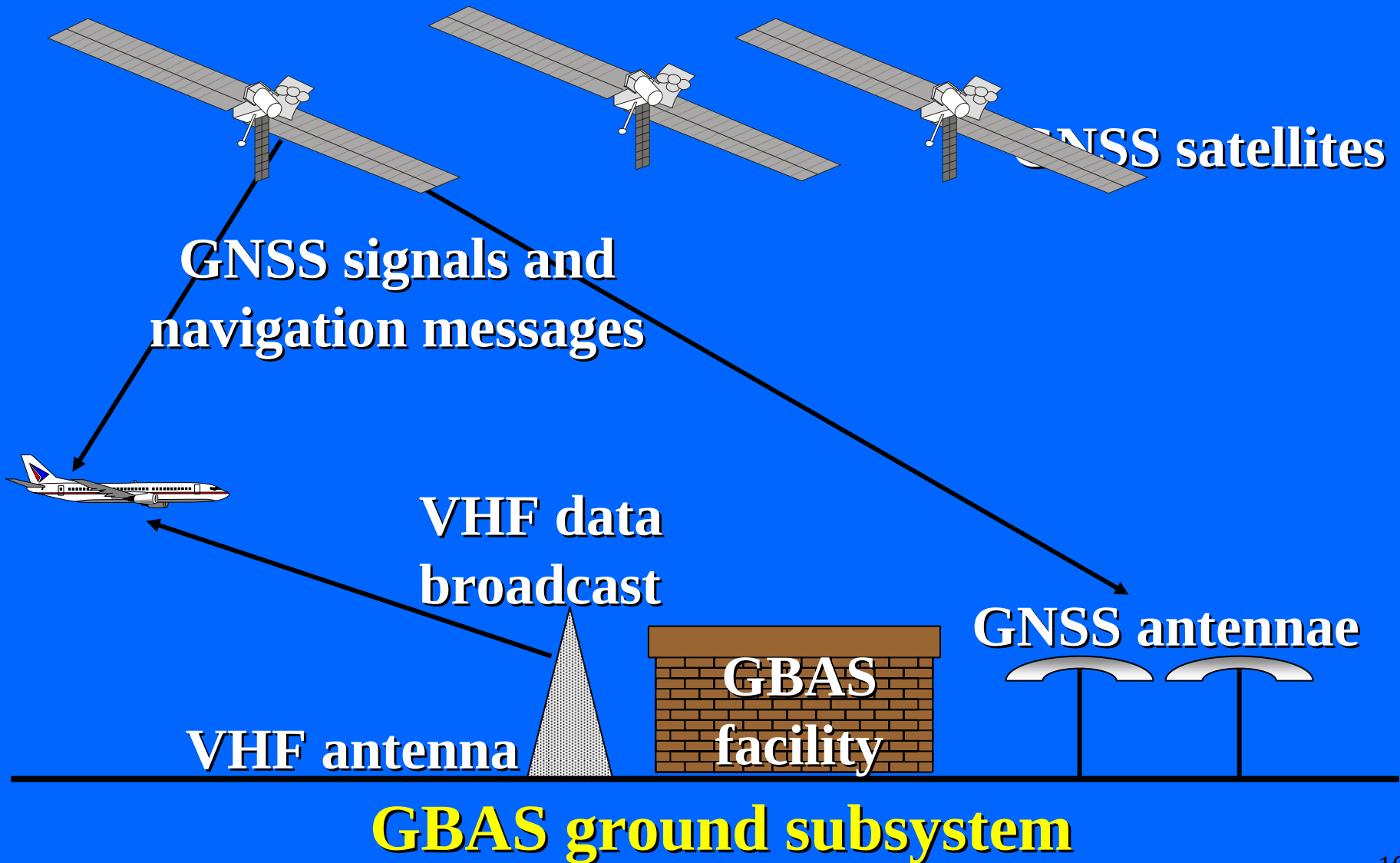
- **Ground**
(GMS – Ground Monitoring Station
MCS – Master Control Station
NES – Navigation Earth Station)
- **Communications**
(Ground/Ground Network)
- **Aircraft**
- **Space**
(GPS – Global Positioning System)



GBAS

- Provides integrity information and differential corrections
- Range limited to a radius of 20 NM
- Requires a VHF data link
- Meets PA Cat. I, Cat. II and Cat. III requirements

GBAS system



Comparison of SBAS and GBAS

Parameters	SBAS	GBAS
Integrity broadcast	Available	Available
Additional ranging	Available	Not available
Differential corrections	Available	Available
Platform	Satellite-based	Ground-based
Service area	Wide area - Depends on number and position of monitoring stations	Each GBAS station having radius of 20 NM
Operations supported	Up to Cat I	All operation including Cat. I–II–III
Data link	Satellite	VHF

GNSS Database

Ephemeris

- Data about itself
- Identification, orbit parameters and time
- Used for navigation

Almanac

- Data about other satellites
- Orbit parameter and health statement
- Used to predict available satellites and select good satellite constellation

GNSS SARPs completed

➤ New standard aid to:

- navigation, approach and landing

➤ System elements:

- satellite constellation – GPS, GLONASS
- augmentation systems – ABAS, GBAS;
GRAS and SBAS
- receivers

PANS-OPS requirements for GNSS-based IFR operations

- **Installation certified and approved for intended operation**
- **Equipment is serviceable**
- **Equipment operated in accordance with aircraft operating manual**
- **NOTAM reviewed prior to operation**
- **Pilot/crew has knowledge of equipment operation**
- **RAIM prediction available**
- **Back-up procedures in place**
- **Database correct and current**

WGS-84 issues ...

- Accurate satellite navigation is only possible when the ground-derived coordinates, calculated coordinates, and the satellite system-derived coordinates use the same geodetic reference system
- In support of evolving satellite-based technology, ICAO adopted WGS-84 as the common geodetic reference datum for civil aviation with an applicability date of 1 January 1998 (Annex 15)

WGS-84 issues ...

- The responsible agency for geographic coordinates of a State is usually the national mapping or surveying agency
- The geodetic datums referred to various stations are horizontal datums
- The world's vertical datum is considered to be mean sea level (MSL), to which all elevations are referenced
- There are in excess of 150 different geodetic datums in use throughout the world

WGS-84 issues ...

- Transition path to WGS-84
 - transformation
 - surveys
- Conversion of current coordinates to WGS-84 format can be carried out by the software programme such as MADTRAN (US) or DATUM (Europe)
- ICAO has prepared detailed guidance material on establishing WGS-84 (Doc 9674)

WGS-84 issues

(Appendix 5 to Annex 11 — Accuracy requirements)

- Outside control area
 - FIR, prohibited areas
 - 2 km
- Inside control area
 - navigational aids/fixes
 - holding SID/STAR
 - 100 m
- Final approach fixes/final approach points
 - 3 m

WGS-84 issues – Airline concerns

- Airlines are concerned not only with the availability of coordinates to support GNSS operators but also the quality of the coordinates
- Use of GNSS in mixed datum, e.g. the difference between latitude and longitude of a point as referred to local datum and WGS-84 in the Asia/Pacific area ranges from approximately less than 1 – 11 seconds in latitude and from 4 – 11 seconds in longitude
- States should provide the WGS-84 coordinates to preclude an operator from having to make transformation

GNSS satellite constellations

– Update ...

➤ GPS enhancements

- additions of new signals on L2 at 1227 MHz was first launched in Sep 2005 and L5 at 1176.45 MHz was launched in February 2009 for civil use (improves accuracy, Ionospheric corrections, availability and interference)
- increased constellation from present 30 to 36 satellites (improves availability, accuracy and geometry)
- increased satellite power (improves availability).
- anti-jam capability (improves availability)

GNSS satellite constellations

– Update ...

- GLONASS modernization
 - Total number of GLONASS- M satellites in operation (in April 2009) is 18. Full operation of GLONASS with 24 satellites is scheduled for 2010.
 - enhanced data structure for combined use of GPS/GLONASS
 - improved stability of space segment
 - new signal on L2 for civil use
 - additional signal power on L2
 - plans for GLONASS-K after 2010

GNSS satellite constellations

– Update

- **GALILEO (an emerging system)**
 - **proposed 30 MEO satellites**
 - **GEO satellite as a complement to regional enhancement**
 - **development and validation completed**
 - **deployment 2007-2013; FOC: 2013**
 - **civil controlled: liability and certification issues being addressed**

Need for multi-modal airborne landing capability

- **For the foreseeable future, a number of landing systems will be in service:**
 - **ILS**
 - **GNSS**
 - **MLS**
- **To meet the precision approach requirements globally, airlines are required to carry both current and new systems**
- **MMR (Multi-mode receiver) is the solution to interface all the systems**

GNSS & RNAV operations

- In the future, when GNSS meets requirements concerning reliability, integrity and accuracy, it will be used as sole mean of navigation
- RNAV, based on GNSS and established RNP values, will allow increased capacity through reduced separation minima

Benefits of GNSS

- Improved accuracy and high integrity
- Four-dimensional navigation
- Single set of avionics
- Improved runway utilization
- Increased airspace capacity
- Reduced separation minima
- Reduced ground-based NAVAIDS
- Precision common time reference

Trends in implementation

- GPS-based operations spreading (en route, NPA)
- Augmentations development in progresses but with delays
- GNSS (GPS) vulnerability recognized
- “Sole means” concept no longer advocated
- Development of new GNSS elements advances (GPS L5, Galileo)
- Marginal user support for SBAS services

Navigation – the future ...

- Transition to satellite navigation is a long-term commitment
 - ICAO and industry standards available to support near-term and mid-term applications
 - SBAS service, GBAS stations and respective avionics will be generally available in the near term
 - Near-term focus to continue on approvals for en route (oceanic and remote), terminal and NPA operations using basic GPS avionics
- (1/2)¹²¹

Navigation – the future

- Mid-term focus on SBAS-based APV and GBAS-based PA Category I
- Two core satellite systems and dual frequency operations to begin beyond 2010
- User community commitment to transition is crucial factor

Surveillance

Types of surveillance

- Independent surveillance
 - PSR (Primary Surveillance Radar)
- Cooperative independent surveillance
 - SSR (Secondary Surveillance Radar)
 - Conventional SSR
 - Monopulse SSR
 - Mode S SSR
- Automatic Dependent Surveillance(ADS)
 - ADS-C (Contract) also known as ADS-A (Addressed)
 - ADS-B (Broadcast)

Primary radar

- Received signal = echo + noise + clutter
- PSR offers: range, azimuth
- PSR limitations: identification? FL?
- Solution: SSR
- No airborne equipment required
- Enroute PSR range is 200 NM and Terminal PSR is 60 NM
- Use of PSR for en route airspace is declining

Secondary radar

- **SSR characteristics:**
 - **line of sight**
 - **need for airborne transponder**
 - **position information: range and azimuth**
 - **ID (Mode A) and FL (Mode C)**
- **Types of SSR**
 - **conventional SSR (No longer in use)**
 - **monopulse SSR**
 - **SSR Mode S**

Monopulse SSR

- Very widely used world over
- Uses Mode A and C
- **FRUIT**-False replies unsynchronized in time (ie replies coming from interrogations generated by other ground stations giving rise to false targets) and **Garbling** (two closely spaced aircraft replying to same interrogation) not eliminated entirely
- Shortage of Mode A codes
- Very limited downlink data link
- Can be upgraded to Mode S

SSR Mode S ...

- Improved version of SSR
- Selective addressing – individual interrogation to reduce problems of garbling experienced in M SSR
- Elimination of Mode A code shortages
- Compatible with SSR Mode A/C
- Altitude data in 25-foot increments

SSR Mode S ...

- Improved accuracy
- Supports air/ground data link for enhanced surveillance
- Short squitter of Mode S supports ACAS II implementation
- Extended squitter of Mode S supports ADS-B application

SSR Mode S

➤ Elementary surveillance

- Downlinks only the aircraft identification parameter (call sign/registration number)
- Eliminates shortage of Mode A codes thus increasing airspace capacity
- ACAS RA available
- Requires level 2 Mode S transponder

➤ Enhanced Surveillance

- Downlinks all airborne parameters (DAPs) in addition to classical surveillance data such as position, aircraft identification, Mode C derived altitude, computed ground speed
- Requires level 4 Mode S transponder

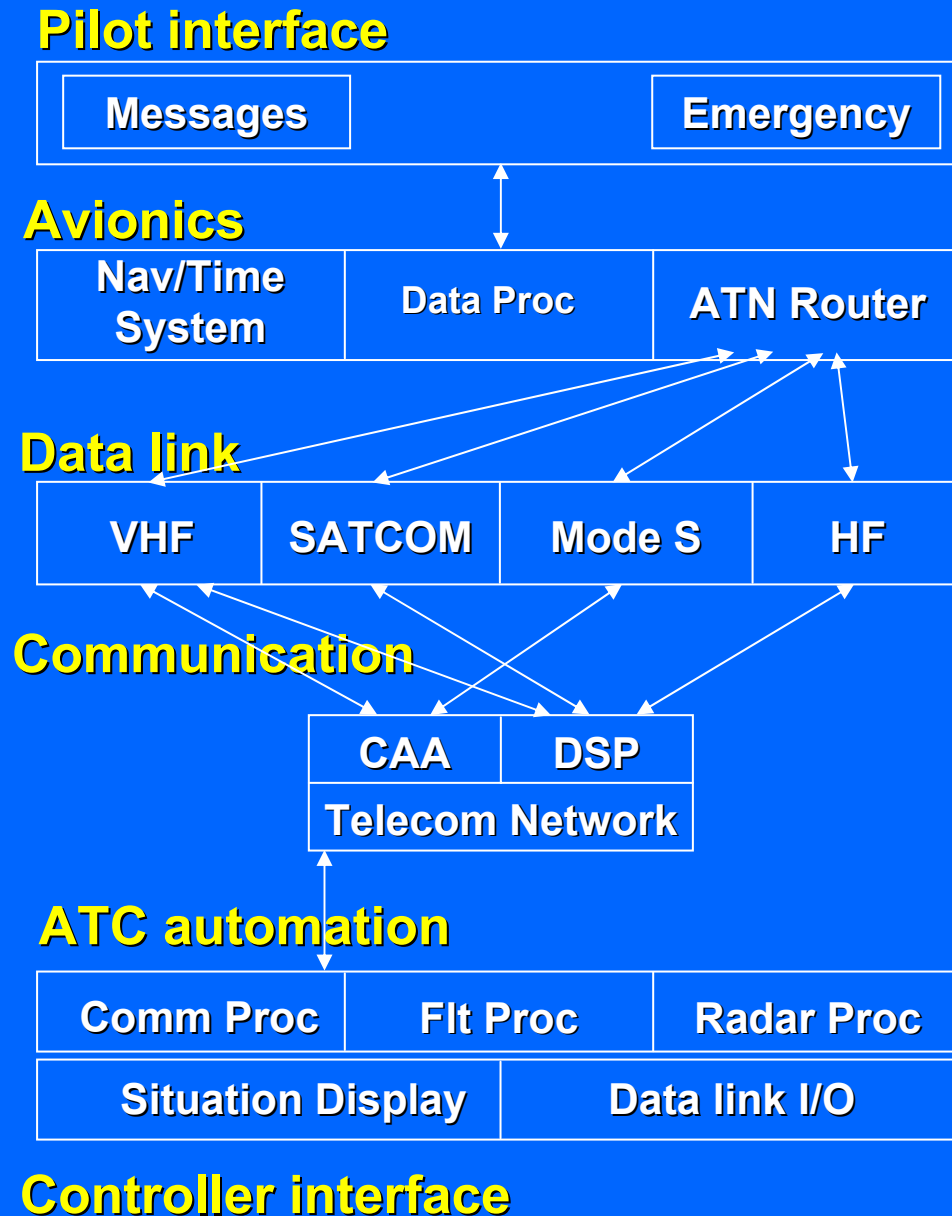
Comparison of SSR characteristics

OPERATIONS	Convention al SSR	Monopulse SSR	SSR Mode S
Replies per scan	20 – 30	4 – 8	1
Range accuracy (rms)	230 m	13 m	7 m
Bearing accuracy (rms)	0.08°	0.04°	0.04°
Height resolution	100 ft	100 ft	25 ft
Garble resistance	Poor	Good	Best
Data capacity (uplink)	0	0	56 – 1 280 bits
Data capacity (downlink)	23 bits	23 bits	56 – 1 280 bits
Number of codes/ Addresses available	4 096	4 096	> 16 million

Automatic dependent surveillance – Contract (ADS-C)

- **A surveillance technique for aircraft**
- **Requires a data link, on-board navigation and a position-fixing system**
- **Provides aircraft identification, 4-D position and additional data as appropriate on a one-to-one basis**
- **ATC will get a radar-like picture**
- **Also known as ADS-A (addressed)**

ADS-C functions



Automatic dependent surveillance

– Broadcast (ADS-B) ...

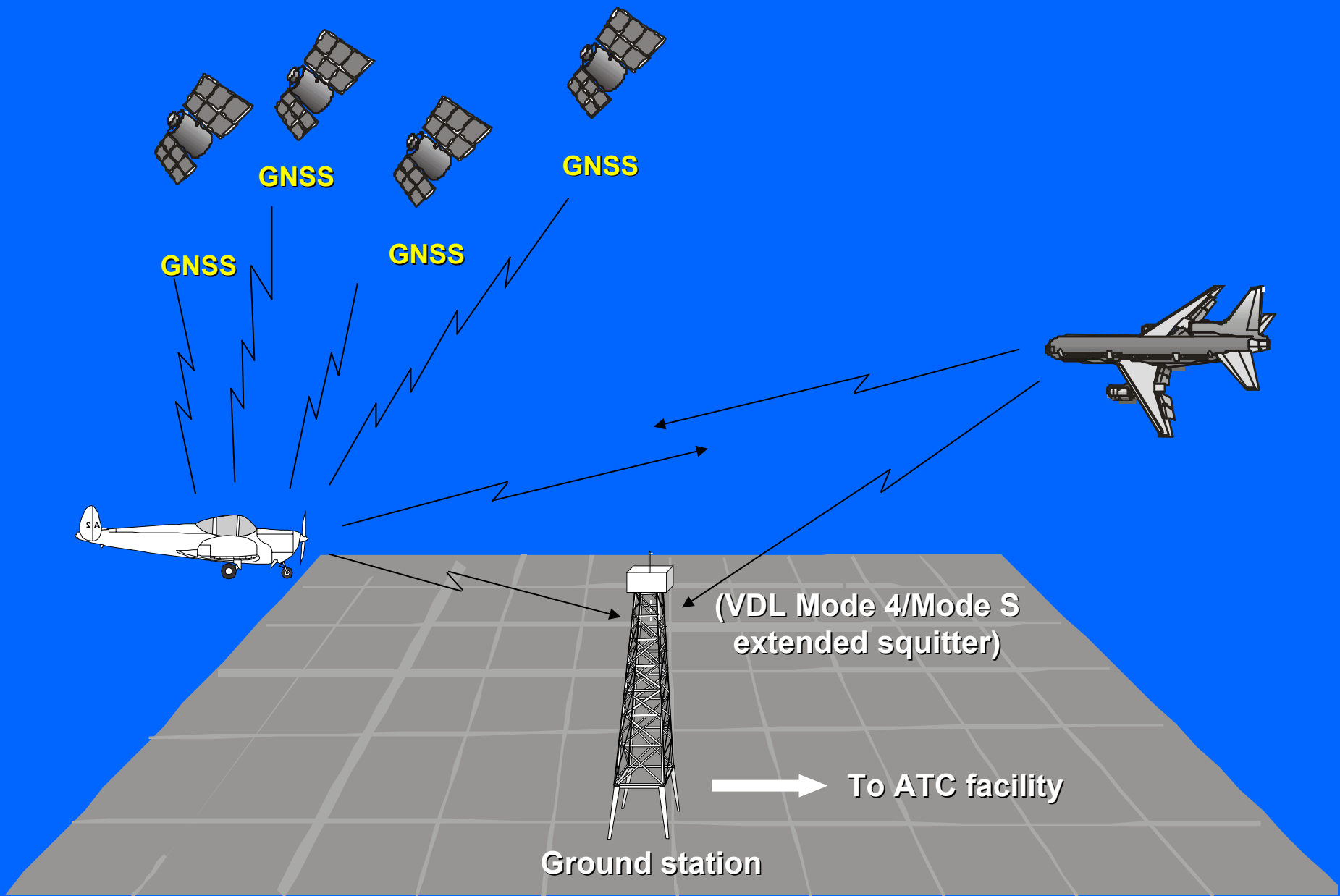
A means by which aircraft, aerodrome vehicles and other objects can automatically transmit and/or receive data such as identification, position and additional data, as appropriate, in a broadcast mode via data link

ADS-B...

- A surveillance technique for aircraft and ground users (like vehicles)
- Requires a data link and on-board navigation system
- Provides parameters such as position, track and ground speed via a broadcast mode at specified intervals
- Applications for air/ground, ground/ground and air/air surveillance
- Mode S extended squitter, Universal Access Transceiver and VDL Mode 4 (STDMA) are three technologies for ADS-B

ADS-B

- Aircraft broadcasts position (based on GPS or INS) to all listeners, to both ground ATC and other aircraft
- Ground-based receiver stations collect position information
- Position information can be used to simulate radar-type surveillance for ATC use
- Aircraft operators can use position data for more precision aircraft dispatching
- Other aircraft use position information for traffic display/collision avoidance



Automatic dependent surveillance – Broadcast

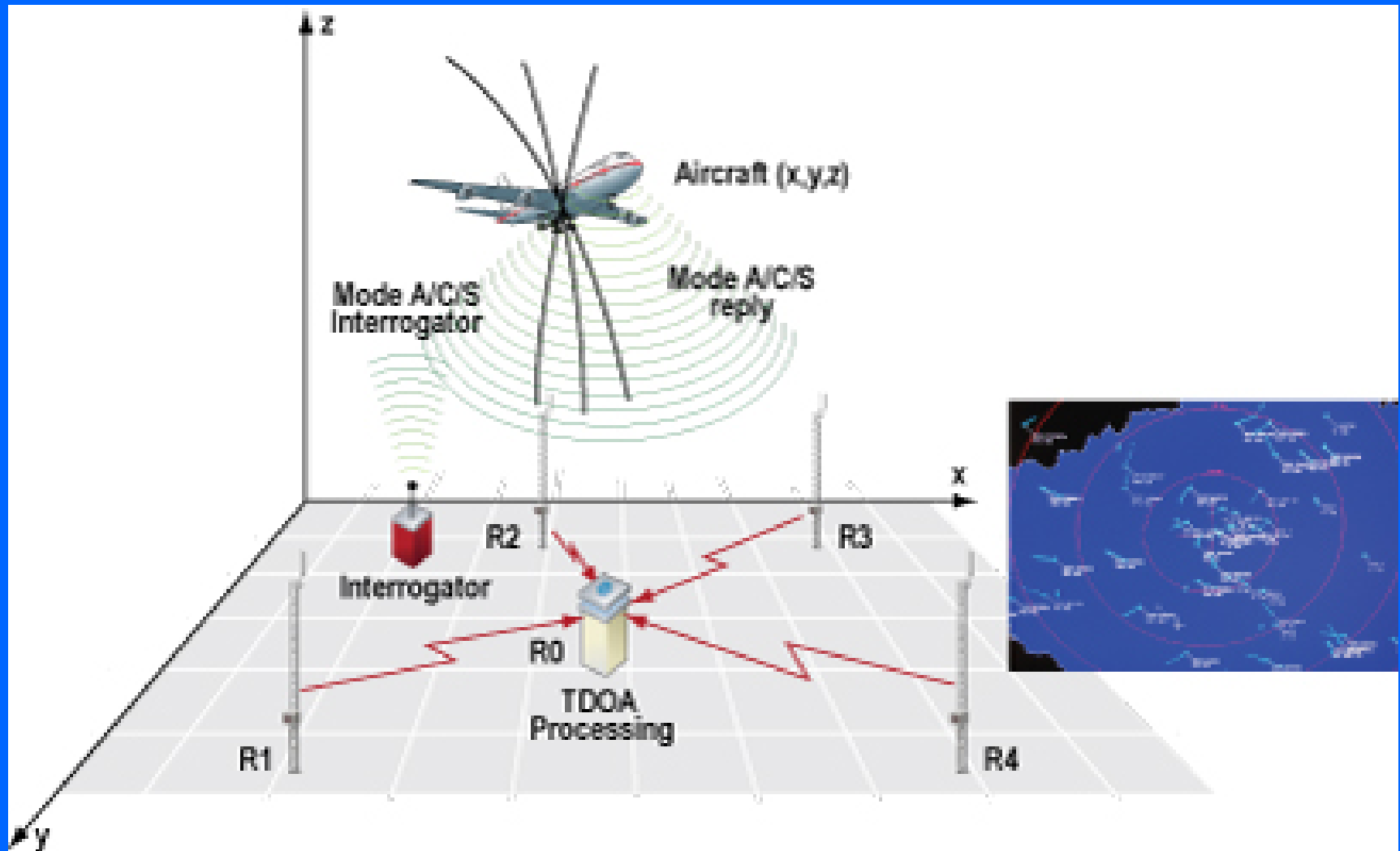
ADS-B capability

- The transponder pseudo-randomly “squirts” (broadcasts):
 - ADS airborne position report (Lat, Lon, Alt, Time)
 - approximately twice per second
 - Flight identification report (8 characters, alphanumeric)
 - approximately once every 5 seconds
 - ICAO aircraft address (24-bit aircraft ID)
 - approximately once per second

Multilateration (1/3)

- It is a system whereby multiple ground stations use triangulation to work out the position of an aircraft. At least 3 stations need to receive a signal from the aircraft. The signal used is Mode S squitter, ADS-B transmission or mode C reply.
- It can provide surveillance on aircraft not equipped with ADS-B. In short, before ADS-B equipage, multilateration is an alternative to radar.

Multilateration (2/3)



Multilateration (3/3)

Features

- Significantly lower in cost than traditional radar
- Easier and less costly to maintain and operate
- requires no additional avionics equipment.
- Air traffic controllers see MLAT targets on their screens much the same as conventional targets
- It monitors Mode A, C and S transponders, as well as military IFF and ADS-B transponders. MLAT's small, unmanned sensor stations are more accurate and less expensive than traditional SSRs and can be added to meet a wide range of coverage requirements and future surveillance needs.

A-SMGCS

- An advanced surface movement guidance and control system (A-SMGCS) is a fusion of radar and air field lighting technologies
- Used for routing, guidance, surveillance and control of aircraft and vehicles on the ground
- Maintain acceptable movement rates under all weather conditions, while improving the required level of safety

CNS evolution

CURRENT SYSTEMS		→	NEW SYSTEMS
Communication	➤ VHF voice ➤ HF voice		➤ VHF voice and data ➤ HF voice and data ➤ AMSS voice and data ➤ SSR Mode S data ➤ ATN (IPS)
Navigation	➤ MNPS ➤ Barometric altimetry ➤ INS/IRS ➤ ILS/MLS ➤ OMEGA/LORAN- C ➤ NDB ➤ VOR/DME		➤ PBN ➤ Barometric altimetry ➤ INS/IRS ➤ GNSS
Surveillance	➤ PSR (ASDE/ASR/ARSR) ➤ SSR Mode A/C ➤ Voice position reports on oceanic & remote areas		➤ ADS – C (VHF); ADS-B ➤ SSR Mode A/C; SSR Mode S ➤ ADS –C (HF/satellite) ➤ Multilateration

Spectrum issues

ICAO's role

- Analyze the agenda of WRC's (World Radio Communication conferences)
- Develop the ICAO position
- Work with ITU and Regional Telecommunications Organizations (APT, CEPT, CITELE, ...)
- Submit the position (approved by the Council) to States and ITU
- Participate in WRCs

What is expected from States?

- Assist in the development of the ICAO position
- Participate with aviation experts in the work of ITU and Regional Telecommunications Organizations
- Send aviation experts to WRC's (A32-13)
- Support ICAO position (Assembly Resolution A32-13)
- Next WRC is scheduled in 2011

What is the ICAO Position for WRCs – Main Goals

- a) Spectrum requirements for unmanned aircraft systems**
- b) Regulatory measures to facilitate introduction of new aeronautical mobile (R) services in a number of frequency bands**
- c) Long term spectrum availability and access to spectrum to meet the requirements of the aeronautical mobile satellite (R) services.**

Future work on spectrum issues

- **Prepare ICAO position for WRC-11**
- **Protection of aeronautical radio systems from harmful interference**
- **Participate in ITU activities**
- **Participate in work of regional telecommunication organizations (CEPT, CITELE, APT, ATU etc.**

Status of SARPs development for CNS/ATM systems

Development of SARPs for complex systems

- **1st level:** “Core” SARPs in Annexes consisting of broad, mature and stable provisions specifying system-level, functional and performance requirements that provide for the requisite safety levels and interoperability;
- **2nd level:** Any technical specifications in appendices to Annexes necessary to achieve requirements of core SARPs; and
- **3rd level:** Related detailed technical specifications in separate documents, published by ICAO or other organizations, and referenced in Annexes by means of notes.

Panels and study groups directly involved in air navigation activities...

Panels of the ANC

ACP	Aeronautical Communications Panel
ATMRPP	Air Traffic Management Requirements and Performance Panel
NSP	Navigation Systems Panel
IFPP	Instrument Flight Procedure Panel
OPSP	Operations Panel
SASP	Separation and Airspace Safety Panel
ASP	Aeronautical Surveillance Panel
AP	Aerodrome Panel

Panels and study groups directly involved in air navigation activities

AN Study Groups

AISAIMSG

**Aeronautical Information service and
Aeronautical information Management
Study Group**

UASSG

Unmanned Aircraft Systems Study Group

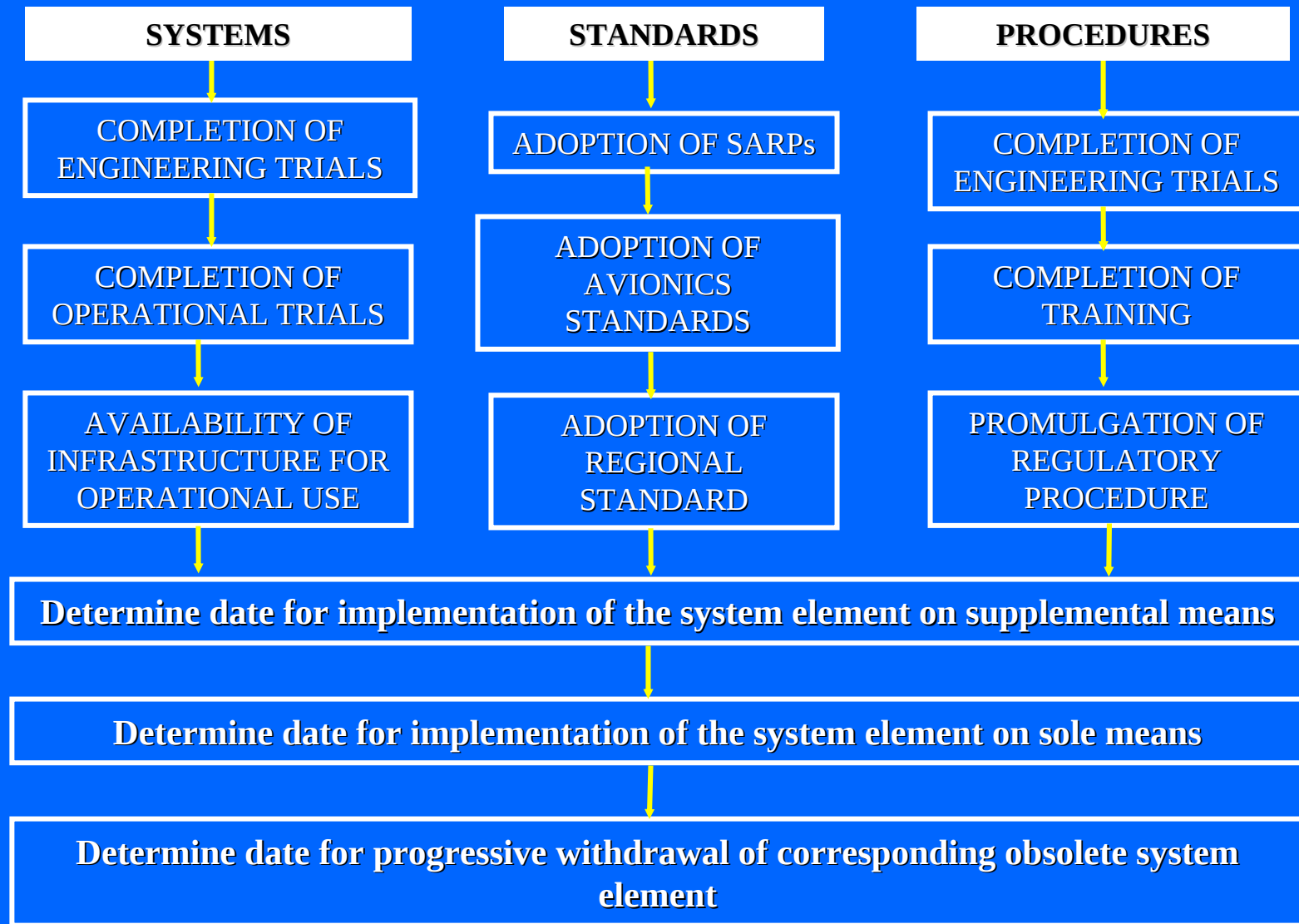
METWSG

Meteorological Warnings Study Group

PBNG

Performance based navigation Study Group

Element of CNS/ATM



Milestone determination

SUMMARY

- **Transition from FANS to Global ATM is ongoing to achieve a seamless sky**
- **Discussed current system elements**
- **Recognized what are the new elements of global ATM**
- **Migration to the concept of PBN**
- **Highlighted Spectrum requirements**
- **Became familiar with SARPs development**

— END —