Regional Workshop on SSR Mode S II Code and 24 Bits Addresses assignment
Accra, Ghana, 24-27 October 2023

MODULE 0: Introduction

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Introduction

Your Facilitators:

Introduction

Your Name and State/Organization

Your Current Title

Your Expertise

Your Expectations



Module 0 Headlines

I. Objectives of the Workshop

II. Overview on Aeronautical surveillance systems

III. Overview on ongoing development in the Surveillance Panel

Objectives of the Workshop

- **Provide States and the industry with best practices for the assignment of 24-bit addresses;**

- **contribute to harmonize practices in Mode S addressing;**

- **Present the regional procedure set for the assignment of SSR Mode S II Codes by the ICAO ROs;**

- **Prevent dysfunctions due to conflicting assignments of II Codes to stations with overlapping radio coverages;**

- **Discus Surveillance data sharing will and experiences in the field**

Overview on Aeronautical surveillance systems

Surveillance definition

provision of data and information

with quality required for :

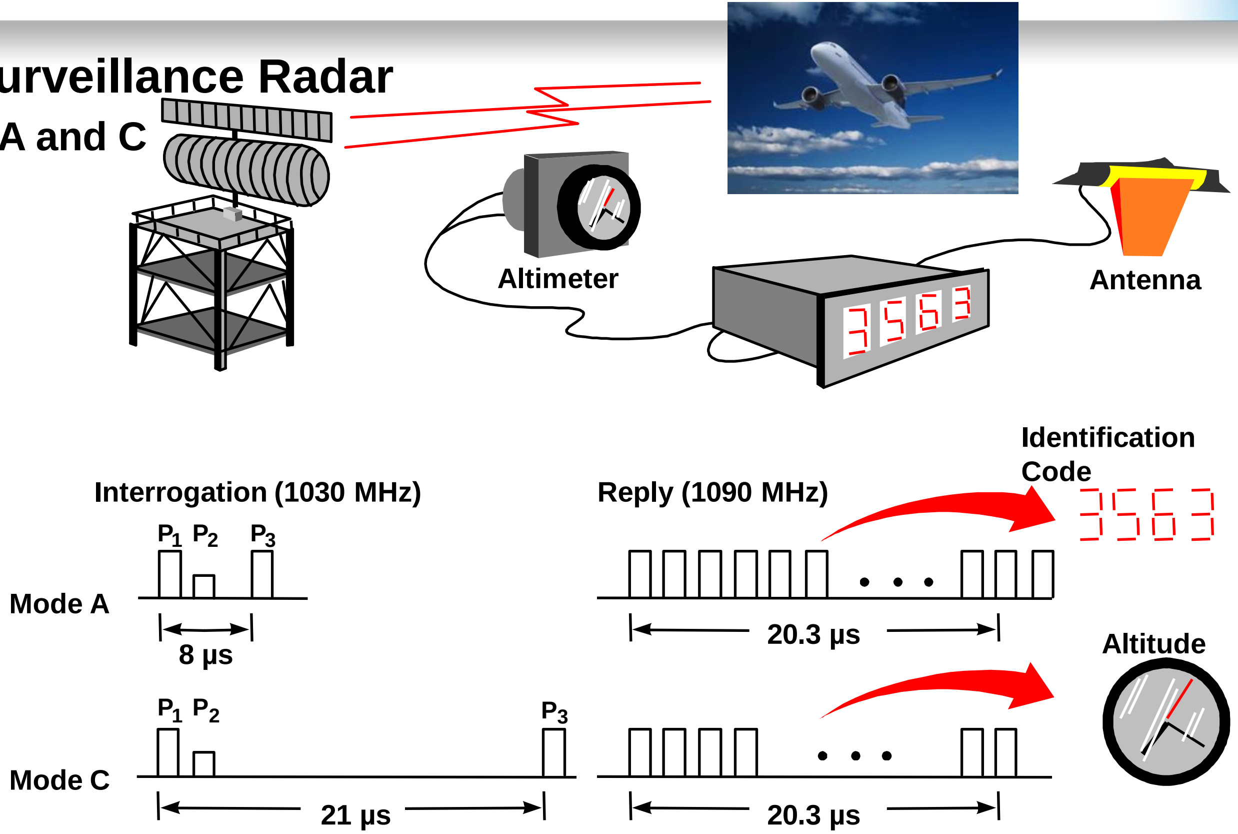
- identification of all aircraft
- representation of their accurate position and kinetic characteristics

as needed for Air Traffic Management.

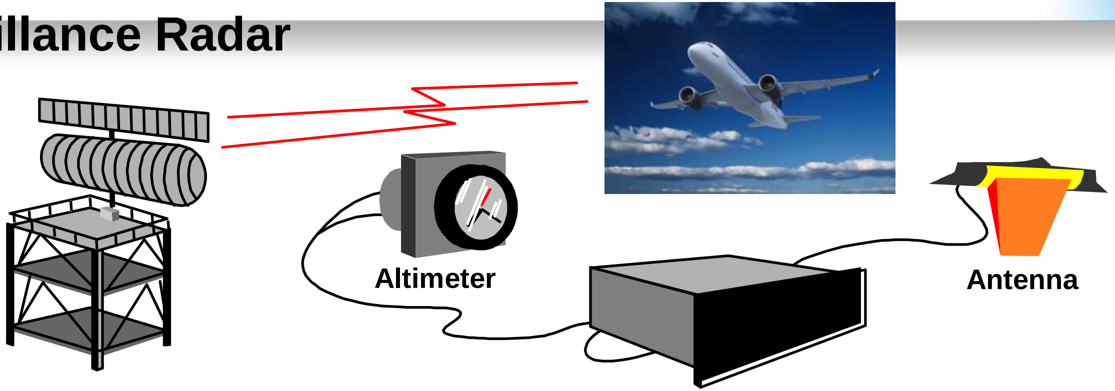
Secondary Surveilance Radar

Presented by FX SALAMBANGA
Regional Officer, CNS WACAF

Secondary Surveillance Radar (SSR) Modes A and C

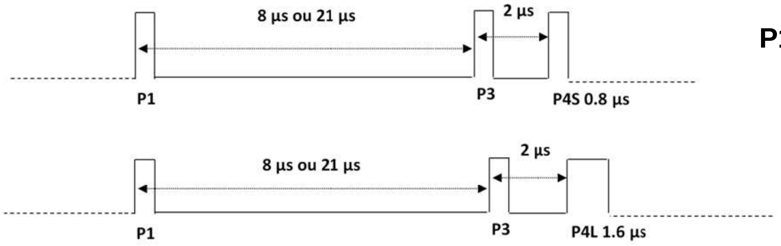


Secondary Surveillance Radar (SSR) Modes S



Interrogation (1030 MHz)

Mode S All Call-AC

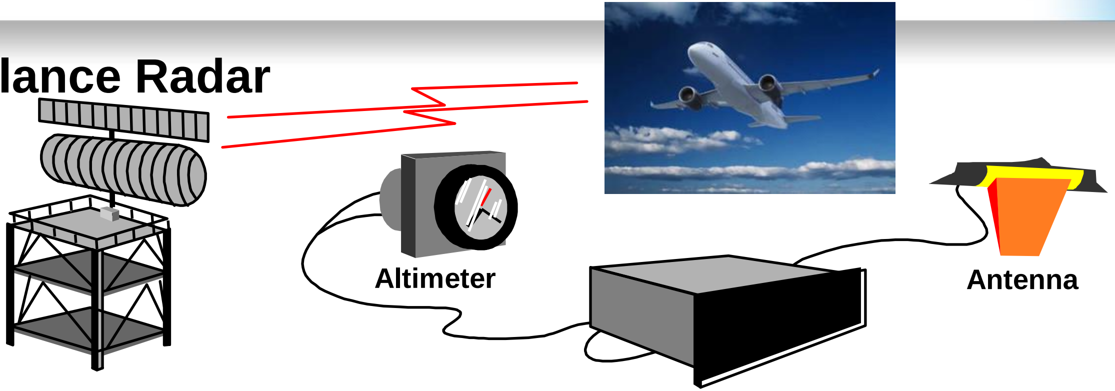


P1-P3-P4S SSR only

P4 is not used in practice

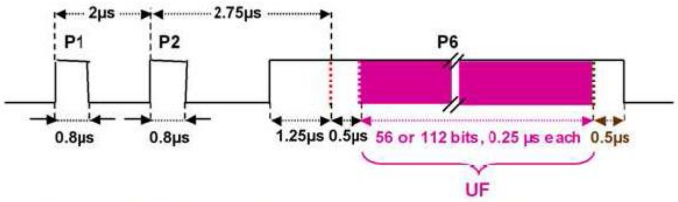
P1-P3-P4L SSR & Mode S

Secondary Surveillance Radar (SSR) Modes S



Interrogation (1030 MHz)

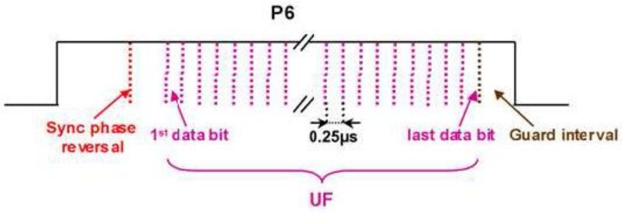
Mode S All Call & Roll Call-AC/RC



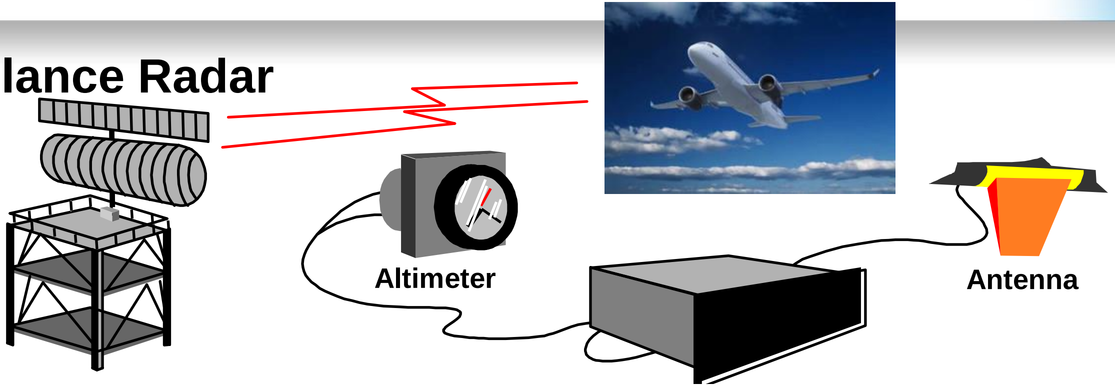
P6 (56 bits) = 16.25µs

P6 (112 bits) = 30.25µs

Note : P2 inhibe les transpondeurs SSR

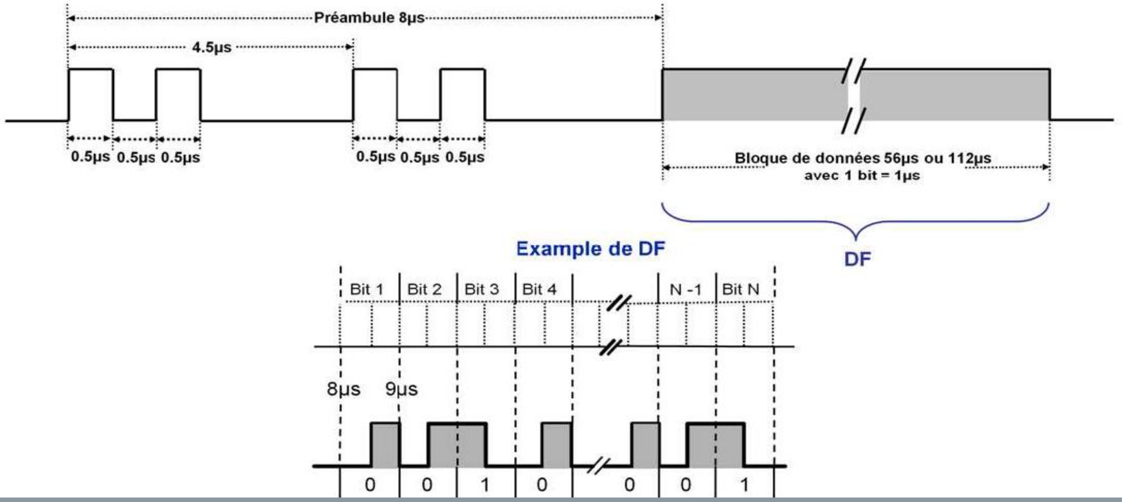


Secondary Surveillance Radar (SSR) Mode S



Response (1090 MHz)

Mode S



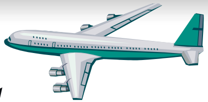
Advantages of SSR Mode S (over Mode A/C)

- **Better overall performance and in high density areas, improves the safety of air navigation**

- **However, Mode S is rather complicated (mainly for the technical personnel). So its use in not-so-high density areas should be carefully considered**

- **Many parameters need to be properly set/adjusted and often in coordination with adjacent Radars:**

-
  *** Pulse repetition frequency (PRF)**
  *** Mode interlace pattern (A/C, All-Call A/C/S, All-Call Mode S only, Roll-calls)**
  *** Interrogator Code (IC)**
  *** Use of lockout (coverage and protocol)**
  *** Use of datalink capability**
  *** Types of transponders in the airspace**



Benefits of Mode S

* Immunity to garbling/Less RF pollution

* Selective (addressed interrogations) based on 24-bits aircraft addresses

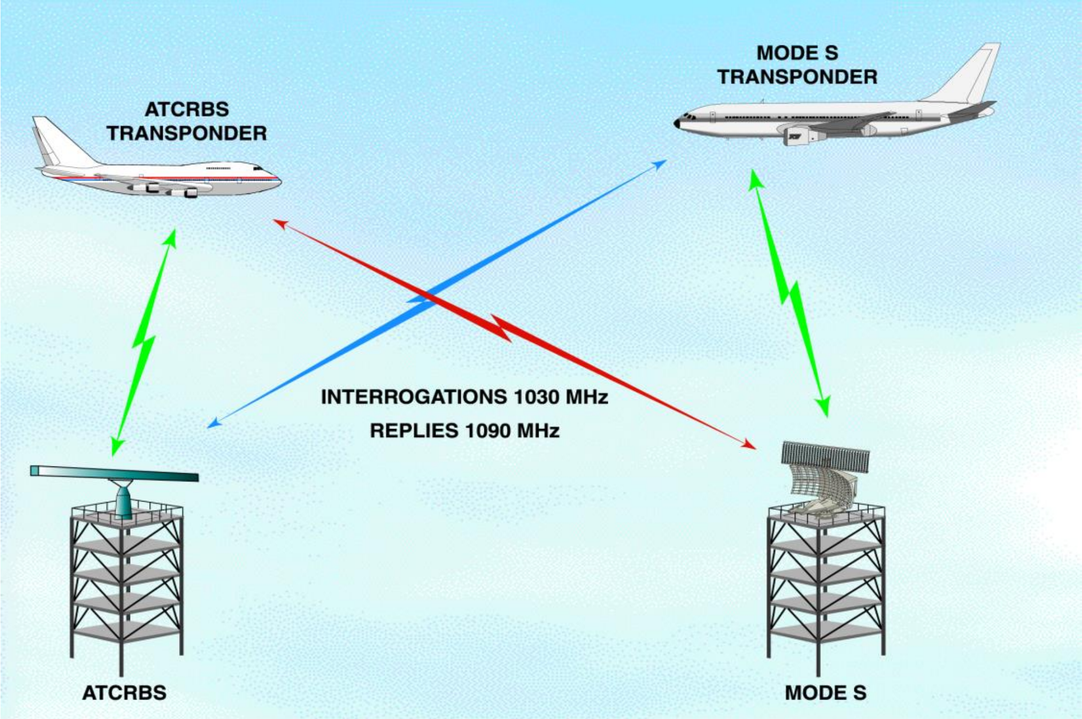
* Relief from Mode A code shortage-4096 possibilities (when Aircraft Identification is used)

* Additional information (e.g. identity and pressure altitude in 25 ft increments)

* Uses error detection so data is accurate

* Offers an A-G data link medium (up to 112 bits in every signal)

Compatibility Between Mode A/C and Mode S



Summary

- Nowadays, a modern SSR comes with Mode S
- Mode S has many features, not all are needed everywhere
- According to Annex 10, decisions on PRF, lockout coverage and use of interrogator codes must be based on regional agreements:
- Regional Offices may be asked by some States to assist with assigning interrogator codes
- They therefore need to know the locations of all such radars in the given geographic area, any existing IC used and the documented use of lockout operations if any
- Then, if only a handful of radars exit, the assignment can be better be done manually
- If however many sites are involved, a computer tool (such as the Frequency Finder Module developed by ICAO) could be helpful.

ADS
Automatic Dependant Survillance

- Automatic → ✓ Aircraft Reports without intervention
- Dependent → ✓ Position communicated is determined onboard aircraft
- Surveillance → ✓ Purpose is to allow the observer to know the position of specific aircraft on the ground

Automatic Dependent Surveillance -ADS-B

Presented by FX SALAMBANGA
Regional Officer, CNS WACAF

Headlines

I – Definition

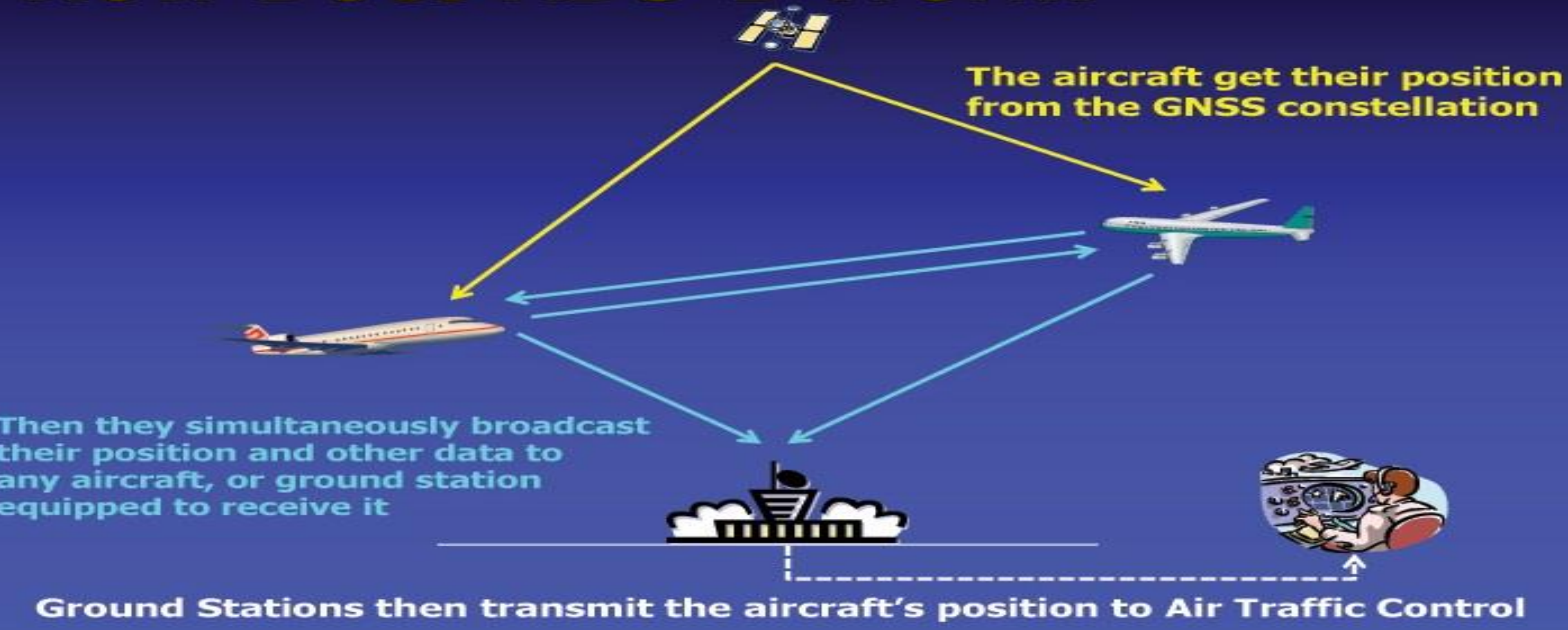
II –Principles

III –Architecture

IV - ADS Functional objectives and services

V - Conclusions

How Does ADS-B Work?



ADS-B characteristics (1)

Unlike Radar ADS-B :

- accuracy does not seriously degrade with range, atmospheric conditions, or target altitude
- update intervals do not depend on the rotational speed or reliability of mechanical antennas.
- Aircraft precise position is broadcasted in space via a digital datalink with other data (airspeed, altitude..), and whether the aircraft is turning, climbing, or descending.
- Receivers provide users (Pilots/ATCs) with the same real-time information and accurate depiction of aviation traffic, both in the air and on the ground

ADS-B characteristics (2)

Also, unlike Radar ADS-B :

- **Works at low altitudes and on the ground therefore, can be used for taxiways and runways traffic monitoring.**
- **Is also effective in remote areas or in mountainous terrain where there is no radar coverage, or where radar coverage is limited**
- **Is now Satellite based providing global coverage as relief to ground based sensors for surveillance provision in remote and oceanic areas**

ADS-B characteristics (3)

ADS-B OUT

- Aircraft to report position information to ATC and to other aircraft;
- Aircraft must have:
  - An IFR certified GPS receiver as the position source, and;
  - A data link Mode S Extended Squitter to send the ADS-B data
- UAT data link specific to US airspace –not approved elsewhere may only be used on GA aircraft at lower altitudes in the USA.

Advantages of ADS-B

- Aircraft to be able to hear position reports from all the other nearby aircraft – independently of ATC;
- Such a facility would drive “Cockpit Display of Traffic Information”(CDTI);
- In practice this kind of display often integrated with a Multi-Function Display or moving map GPS display
- Requires a data link receiver, in addition to the ADS-B “Out” data link transmitter ;

Advantages of ADS-B

- ADS-B gives pilots in the cockpit and controllers on the ground reliable, accurate, real-time information about air traffic;
- By using existing, proven, digital communications technology, ADS-B can be implemented rapidly for a relatively low cost;
- Effective range of more than 100 miles of ADS-B provides a much greater margin in which to implement conflict detection and resolution
- Pilots and controllers using ADS-B data will be able to determine not only the position of conflicting traffic, but will clearly see the traffic's direction, speed, and relative altitude;

Advantages of ADS-B

- As the conflicting traffic turns, accelerates, climbs, or descends, ADS-B will indicate the changes clearly and immediately;
- ADS-B systems can further enhance aviation safety through features such as automatic traffic call-outs or warnings of imminent runway incursion
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Advantages of ADS-B

- ADS-B can be scaled and adapted for use in general aviation and in ground vehicles;
- This will provide affordable, effective surveillance of all air and ground traffic, even on:
  - Airport taxiways and runways, and in
  - Airspace where radar is ineffective or unavailable;
- General aviation aircraft can use ADS-B data links to receive flight information services such as graphical weather depiction and textual flight advisories;
- In the past, these services have been unavailable or too expensive for widespread use in general aviation.

Automatic Dependent Surveillance -ADS-C

Presented by FX SALAMBANGA
Regional Officer, CNS WACAF

Headlines

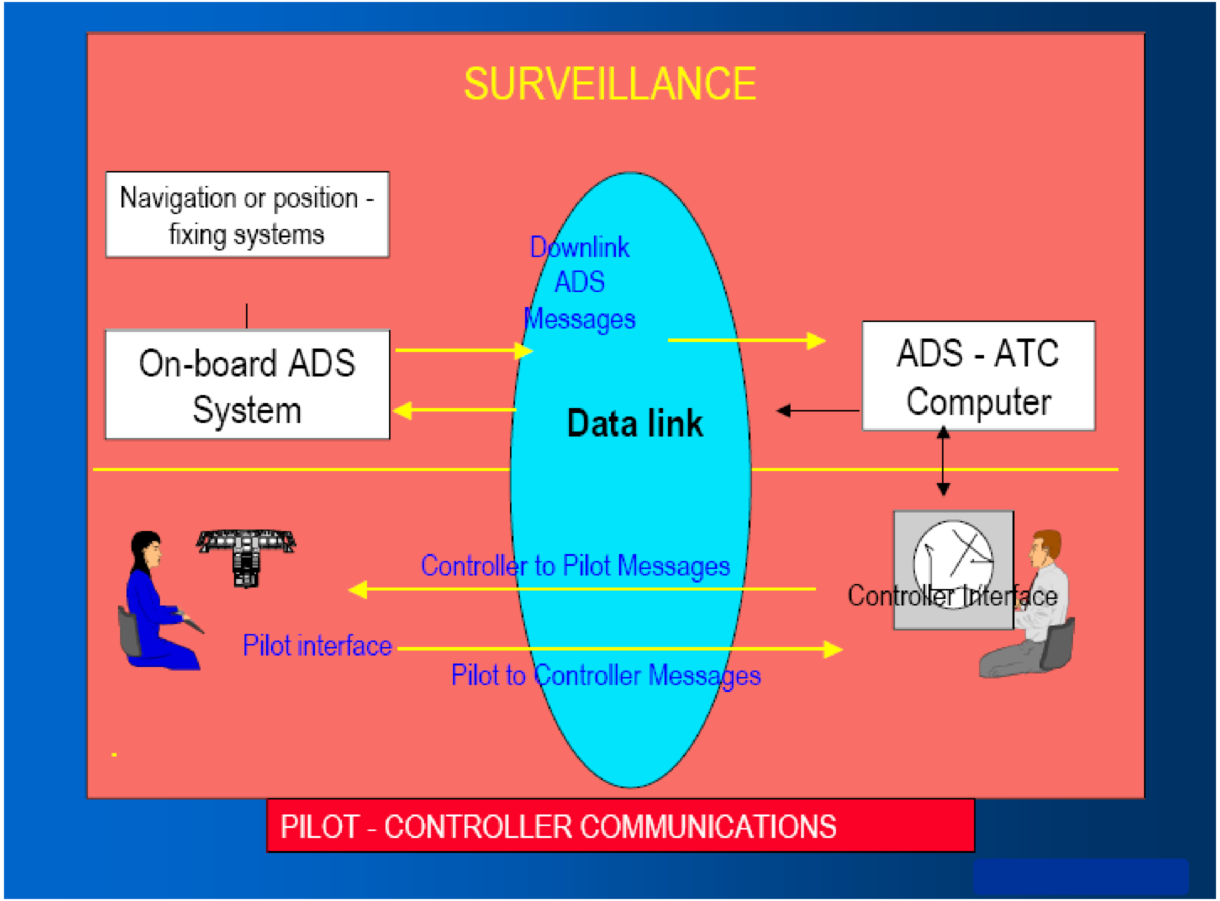
I – Overview

II –Contract

III –Architecture

IV - ADS Functional objectives and services

V - Conclusions


SURVEILLANCE
Navigation or position - fixing systems
On-board ADS System
Downlink ADS Messages
Data link
ADS - ATC Computer
Controller to Pilot Messages
Controller Interface
Pilot interface
Pilot to Controller Messages
PILOT - CONTROLLER COMMUNICATIONS

SURVEILLANCE - ADS Contracts

A contract = agreement between air and ground on information to transmit to the ground.

Three types of contract defined :

A- Periodic Contract
ADS basic group (interval T) +
a set of additional groups with for each group a reporting rate defined as multiple of the basic reporting

B- Demand Contract
Basic group + a set of additional groups

C- Event Contract
Basic Group with a flag to indicate the event triggering the report

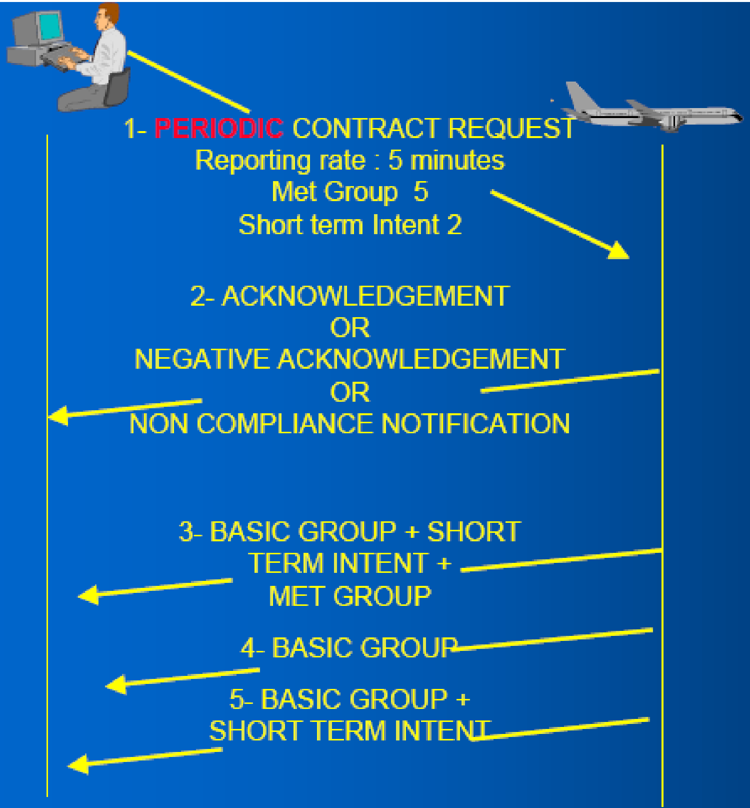
ADS Contracts - Specifics

In addition an Urgent Mode can be initiated by the pilot :
Transmission of basic group with a pre-defined reporting interval + aircraft Identification

An aircraft can support up to 4 contracts with 4 ATS different ground systems ✪ *access control*

Theoretical reporting rate can vary from 1s to 30 minutes ✪ *avionics specs (64 sec typical)*

Details on Periodic Contract



Details on EVENT contract

When this contract is set up reports containing
the basic group are sent when the event defined occurs

Pre-defined Events are :

-Passing of :

- a WPT
- a specified altitude
- a specified longitude
- a specified latitude

- Change of :

- next or next + 1 WPT
- heading
- altitude
- speed (grond/air/vertical rate)
- F.O.M.

- Deviation from the cleared route or altitude

SURVEILLANCE - ADS Reports

A- Basic ADS report
- Latitude, Longitude
- Altitude, Time
- Figure Of Merit (F.O.M)

B- Ground Vector
- True Heading
- Ground Speed
- Vertical rate

C- Air Vector
- Heading
- Mach number
- Vertical rate

D-Meteorological report
- Wind speed
- Wind direction
- Temperature
- turbulence

E- Flight identification

SURVEILLANCE - ADS Reports

E- Flight identification

F- Projected Profile

Next Waypoint (WPT)
Estimated altitude at next WPT
Estimated time at next WPT
Next + 1 WPT
Estimated altitude at next + 1 WPT

G- Short -term intent

Latitude at projected position
Longitude at projected position
Altitude at projected position
Time of projection

SURVEILLANCE - ADS Reports

I- Extended projected profile

Next WPT + Altitude + Estimated time
Next +1 WPT , Altitude + Estimated time
etc...
Next + 128 WPT, altitude + Estimated time

SURVEILLANCE-ADS Reports

H-Extended projected profile

Next WPT+ Altitude+ Estimated Time

Next+1 WPT+ Altitude+ Estimated Time

……….

………

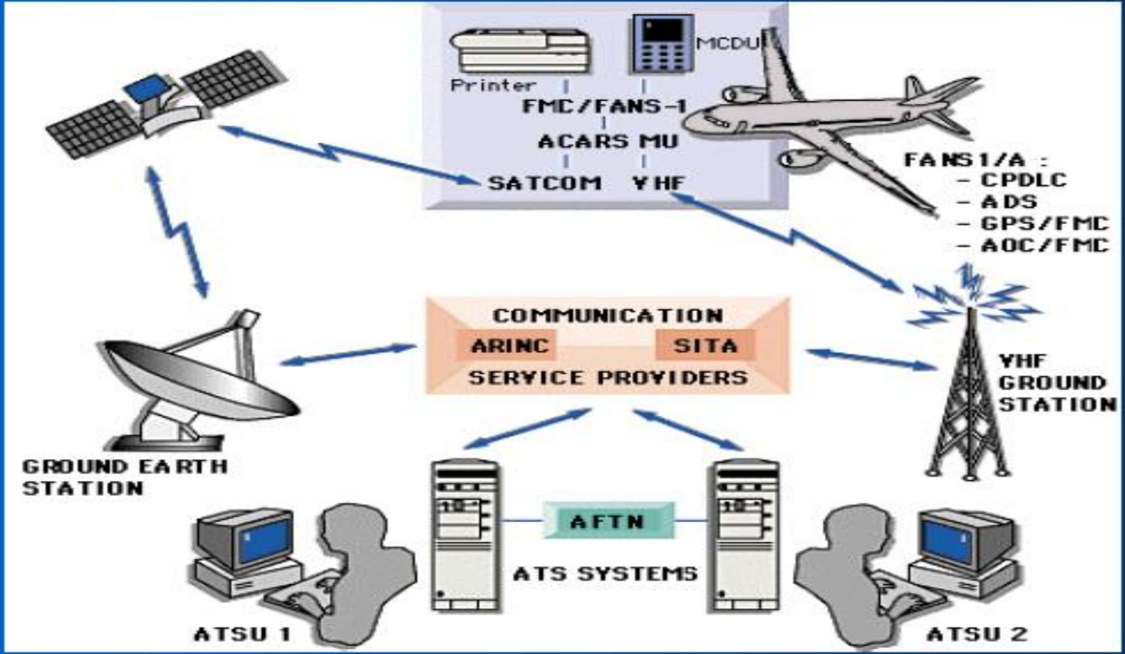
Next+128 WPT+ Altitude+ Estimated Time

ADS connection establishment

- Identification of the ADS capability of the aircraft by ground system
- Establishment of a data link between aircraft and ground system
- Comparison of the aircraft 3D profile with ground flight plan
- Identification and allocation of the appropriate ADS contract

ADS technical architecture and context

ADS end to end technical architecture



FANS-1 /A combined CPDLC/ADS operational concept expected benefits

- **Safety** : Improve pilot-controller communications
- **Economy** : Optimum routes "Flextracks" based on wind forecast
  Single and then multiple re-routings per day
- **Capacity / Economy** : Reduction of separation standards

15 minutes longitudinal → 50NM → 30NM
100NM lateral

Functional objectives

- Data Link Application= toolbox

The notion of "Data-Link Application" has been defined by ICAO Manual of ATS datalink applications doc 9694-ed1-99

as: "the implementation of datalink technology to achieve specific Air Traffic Management operational functionalities".

ADS FUNCTIONAL OBJECTIVES

a) Increase flight safety, through the capability to provide surveillance services to aircraft outside radar coverage.

Oceanic -remote areas

b) Better notification and increased accuracy of the aircraft position in emergency situations.

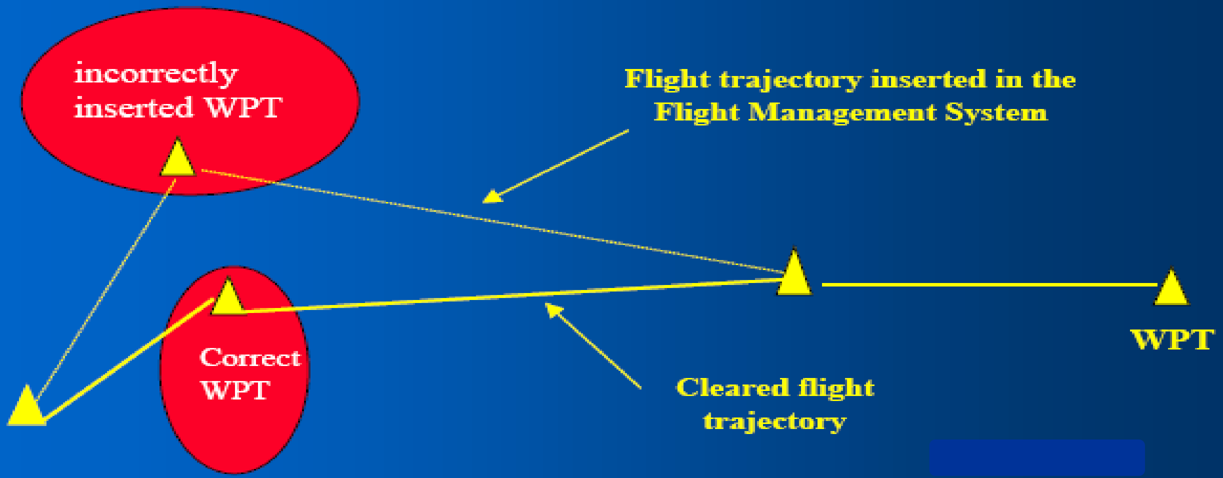
Search and Rescue operations eased

c) Complement to radar (low altitudes, radar failure)

Not an alternate to radar, just a complement

ADS FUNCTIONAL OBJECTIVES

d) Early detection of waypoint insertion errors



ADS FUNCTIONAL OBJECTIVES

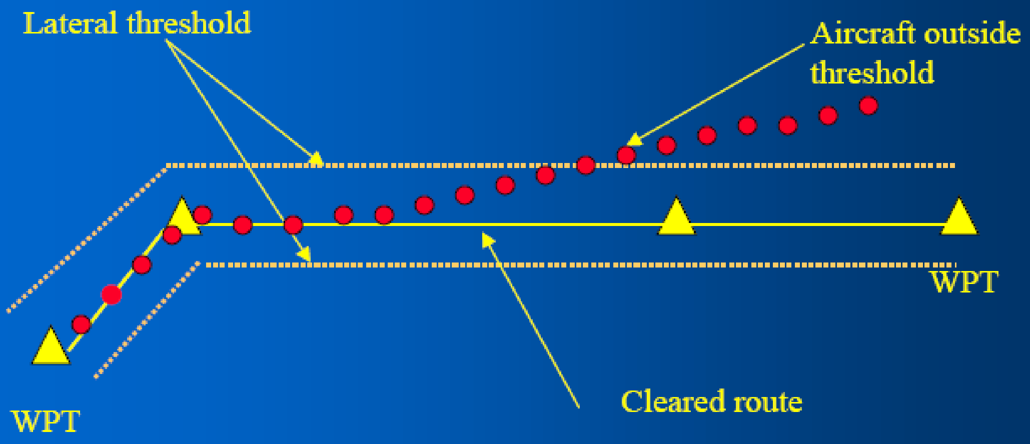
e) Reduction of separation minima in procedural airspace (still argued for FANS)

f) Enhanced conflict detection and resolution capabilities

g) More flexible use of airspace due to the increased level of tactical control

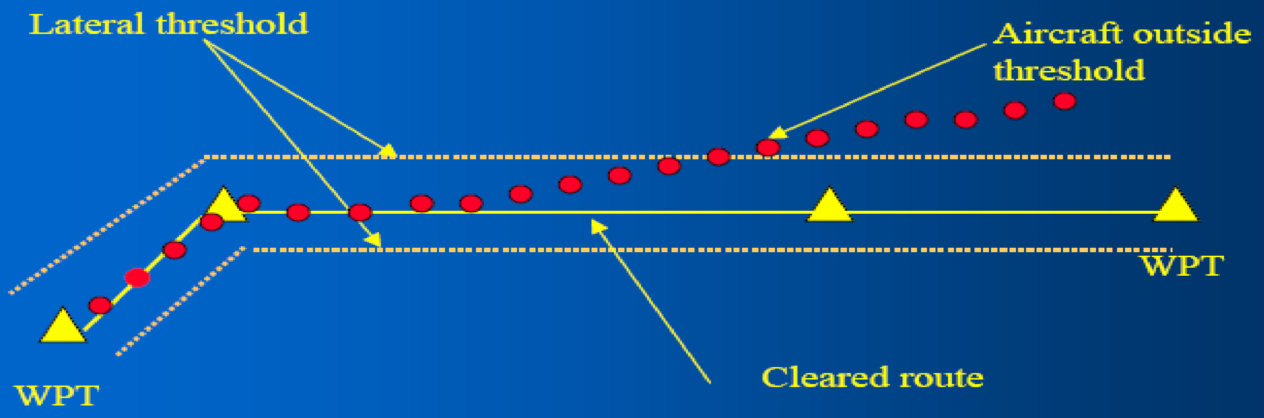
ADS FUNCTIONAL OBJECTIVES

h) Flight path monitoring and early detection of deviation from the cleared route



ADS FUNCTIONAL OBJECTIVES

h) Flight path monitoring and early detection of deviation from the cleared route



CAP functional objectives

CAP Controller Access Parameters is the *service*

DAP Downlink of Aircraft Parameters is the *sub-application*

- High level objectives :
  - Increasing traffic **capacity** per sector
  - Increasing **safety** by reducing both controllers' and pilots' workload
  - Decrease of R/T channel **congestion**
  - Better controllers' traffic and meteorological **situation awareness**

- 3 main DAP-enhanced tools envisioned:
  - Enhanced controller tools in en-route airspace
  - Enhanced surveillance in non-radar, low-density airspace; and
  - Enhanced support tools for arrival management at major airports.

CAP benefits & constraints

- **Expected Benefits**
- direct provision of up-to-date aircraft parameters to the Controller,
- reduction of the risk of error,
- extension of the domain of common reference for Aircrew and Controller,
- improvement of the capacity of pre-regulation (e.g. sequencing) in terminal sectors,
- reduction of the Controller workload by reducing uncertainty concerning expected behaviour of the aircraft,
- **Anticipated Constraints**
- transmission delay (air-ground and airborne).
- **Associated Human Factors**
- An appropriate Controller Human Machine Interface
- Impact on cockpit Aircrew procedures with regard to Aircrew selected altitude.

MULTILATERATION

Presented by François-Xavier Salambanga
RO/CNS, WACAF Office

Headlines

I – Principles of MLAT

II –Aircraft Signal

III –Multilateration on Airports

IV - ADS Functional objectives and services

V - Conclusions

Principles of Multilateration

Basic Principles of Multilateration

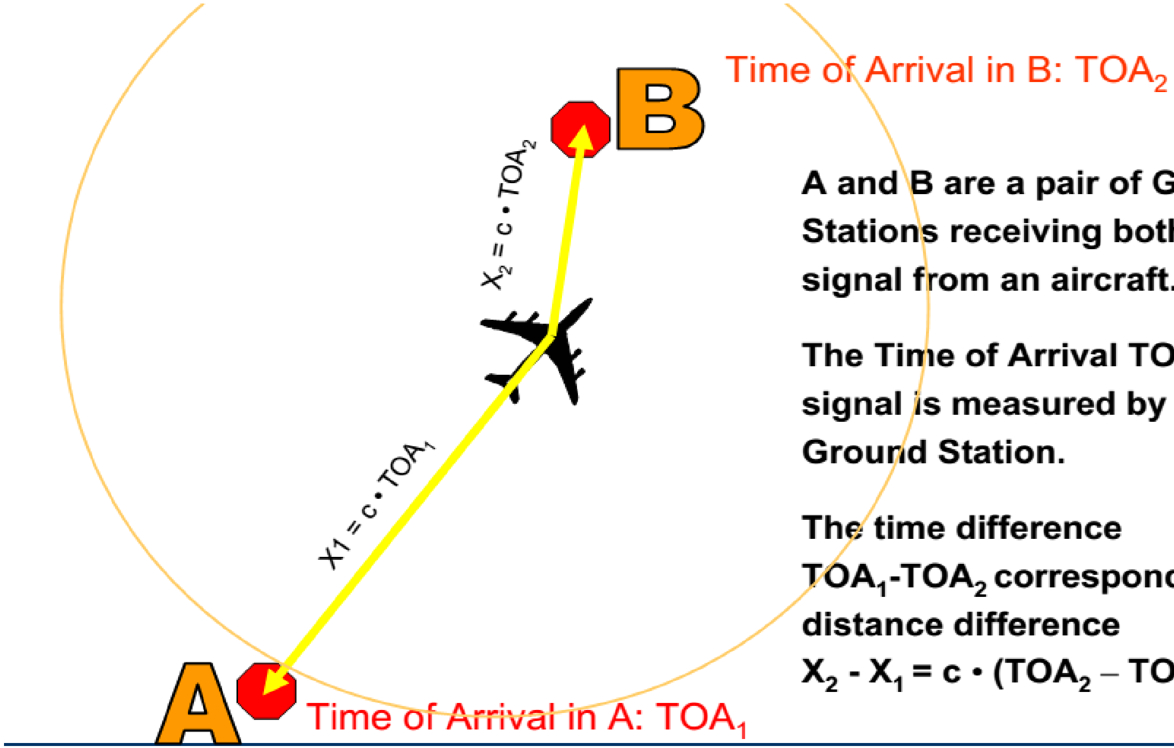
Multilateration (MLAT) is a technique initially developed for military applications, which allows to passively locate co-operative targets by multistatic measurements.

- Passive: **no interrogation from the surveillance system are required (i.e. receive only), provided the aircraft transmits a signal**
- Co-operative: **the principle requires appropriate onboard equipment (e.g. a transponder)**
- Multistatic: **The same signal needs to be received simultaneously by several ground stations**

Comparison with other Surveillance Principles

Surveillance Principle	Onboard equipment required?	Interrog. required?	Data measured by surveillance system?
Primary Radar	**No** non-co-operative	**Yes** active	**Yes** independent surveillance
Secondary Surveillance Radar	**Yes** co-operative	**Yes** active	**Yes (partly)** partly independent surveillance
Mode A/C Multilateration	**Yes** co-operative	**Yes** active	**Yes (partly)** partly independent surveillance
Mode S Multilateration	**Yes** co-operative	**No** passive	**Yes (partly)** partly independent surveillance
ADS-B	***Yes*** *co-operative*	***No*** *passive*	***No*** *dependent surveillance*

Principles of Multilateration systems (1)

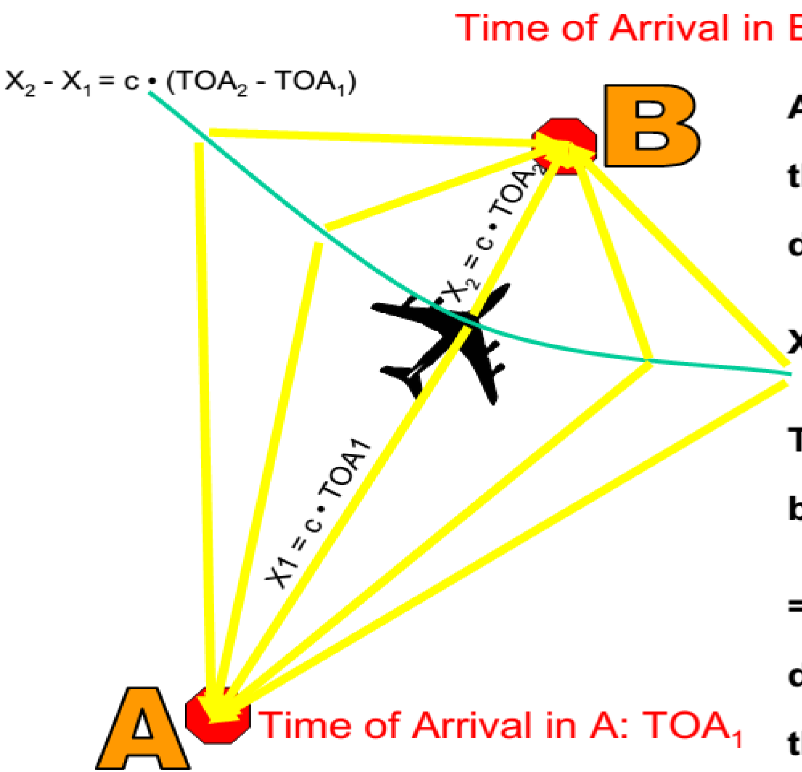


A and B are a pair of Ground Stations receiving both a signal from an aircraft.

The Time of Arrival TOA of the signal is measured by each Ground Station.

The time difference TOA_1-TOA_2 corresponds to the distance difference
$X_2 - X_1 = c \cdot (TOA_2 - TOA_1)$

Principles of Multilateration Systems (2)



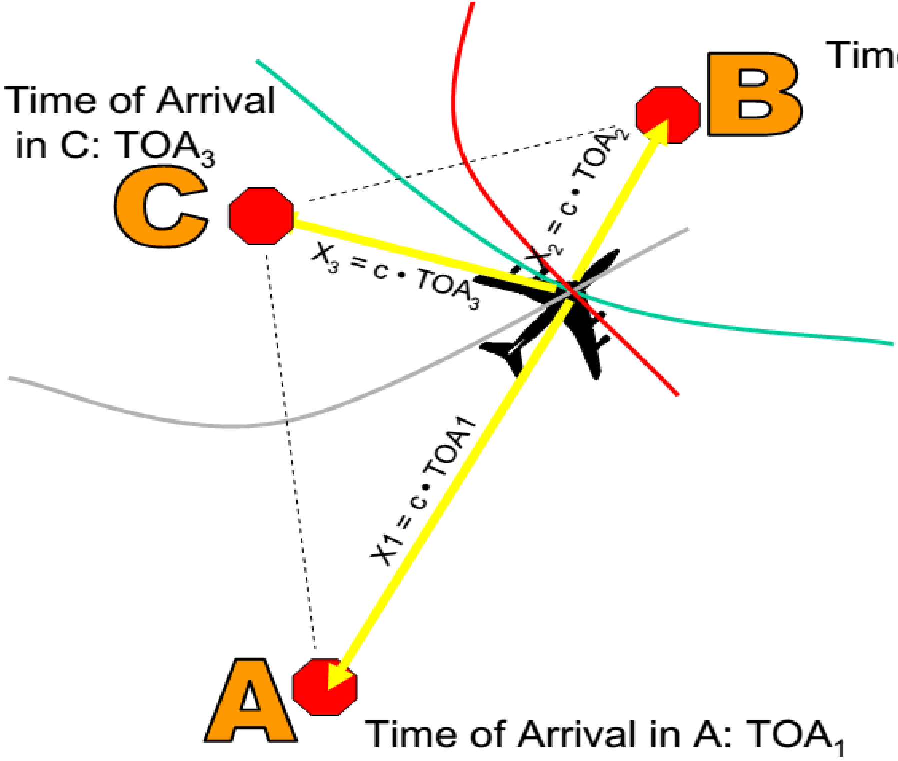
At a given time, the Aircraft is on the locus of points having the distance X2 - X1 constant:

$$X_2 - X_1 = c \cdot (TOA_2 - TOA_1)$$

This is a hyperbola (curve in blue)

=> Two ground stations allow to determine one hyperbola where the aircraft is located

Principles of Multilateration Systems (3)



A third station in C gives two more differences

$$X_2 - X_1 = c \cdot (TOA_2 - TOA_1)$$
$$X_2 - X_3 = c \cdot (TOA_2 - TOA_3)$$
$$X_1 - X_3 = c \cdot (TOA_1 - TOA_3)$$

and thus allows to determine two more hyperbolas

=> The aircraft is located at the intersection of the three hyperbolas

Principles of Multilateration Summary

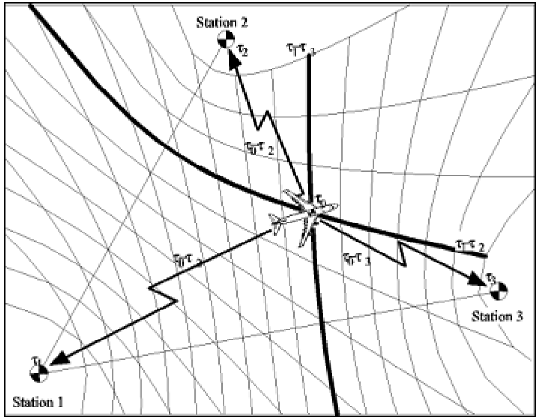
Signal transmitted by aircraft transponder is received by several ground stations (a minimum of 3 for 2D position) in the vicinity

Ground stations determine the precise time of arrival (TOA) of received signals

TOA difference is calculated for each pair of ground stations

Knowing the speed of wave propagation, a hyperbolic line of position results

Intersection of several hyperbolas is the target position



This principle can be extended to measure 3D positions : a 4th ground station is then required

Generic System Architecture

To implement the principle of multilateration system, the generic system architecture consists of:

- A sufficient Number of Ground Stations (GS) capable of:
  - receiving the signal(s) from aircraft located in the service area,
  - measuring the time of arrival and forwarding the TOA to a central station,
  - being synced to the same timebase
- A Central Processing Station (CPS):
  - to receive the TOAs from the Ground Stations and
  - to compute the aircraft position from the set of measurement.
  - In addition the CS has to manage the fact that several aircraft can be located in the service area,
- A communication network to link all the GS to the CS

Constraints on the principle of multilateration systems

The measurement of time of arrival must be very accurate

- As an inaccurate measurement will degrade the accuracy of the position calculation
- This can be achieved by high frequency sampling of incoming signals

The clocks of the ground stations must be very well synchronised

- As a bias between GS clocks will imply a measurement error
- This can be achieved by several means :
  - transmission of a calibration signal
  - use of an universal common time reference signal (regional time signal transmitter, GPS)

Aircraft Signal

Cooperative Target

Unequipped aircraft will not be seen by the MLAT system.

Only cooperating targets will be detected.

For civil aviation, the signal transmitted by aircraft can be:

- either a Mode A/C or Mode S reply to any interrogator in the neighbourhood (e.g. Radar, ACAS)
- the Short Squitter (acquisition squitter for ACAS) transmitted once per second for aircraft equipped with a Mode S Transponder
- In the next future, the Extended Squitter transmitted twice per second for ADS-B equipped aircraft.

In case the aircraft are not equipped with Mode S transponders, and no MSSR are available in the neighbourhood, a specific interrogator must be implemented to trigger Mode A/C replies.

Aircraft Signal which can be used by multilateration

Transponder transmission	When sent	Original purpose	Data contents	Use today
Mode A/C reply	**Sent in response to interrogation**	**Ground ATC surveillance and ACAS**	**Mode A or Mode C code depending on interrogation**	**Very widespread**
Mode S reply	**Sent in response to interrogation**	**Ground ATC surveillance and ACAS**	**24bit aircraft address. The rest depends on interrogation**	**Expanding (few ground Mode S interrogation)** **Mode S replies widespread due to ACAS mandate**
Acquisition squitter « short squitter »	**Once per second**	**ACAS**	**24bit aircraft address and transponder capability**	**Widespread due to ACAS mandate**
ADS-B Extended Squitter	**Various rates up to 2 per second**	**ADS-B**	**24bit aircraft address and the rest is variable**	**Implementation is just starting**

Difference between processing Mode S and Mode A/C aircraft

With Mode S signals, each ground station receives a signal which is uniquely identified by the ICAO 24 bits address; this allows the MLAT system to unambiguously associate the various messages as belonging to the same aircraft

For Mode A/C signals, the association is easy if the signal is a Mode A signal, but if it is a Mode C signal, the MLAT system must maintain a table of all aircraft in the service area before being sure to associate the replies received by ground stations as belonging to the same aircraft.

Identification of aircraft (1)

In civil applications, identity of the aircraft is required

MLAT extracts aircraft identity information from the transmitted signal (also used to measure aircraft position)

This is obtained by Mode A information when the signal is a reply to MSSR or Mode S interrogation

Identification of Aircraft (2)

The identification sis not straight forward in case of no Mode S or MSSR is implemented in the neigbhourhood

If the aircraft is equiped Mode S transponder it tranmits the short squiter including the 24bits ICAO address of the aircraft

- **The 24bits ICAO address is included in the new Flight Plan Format of the allowing to correlate the signal with the ID**
- **If the aircraft is equiped with a transponder with extended squitter then the Call Sign will be transmitted**
- **If the aircraft is equiped with a MSSR tranponder then the MLAT system must interogate the aircraft to obtain a Mode A reply**

Aircraft Altitude

In the same manner as for identity, aircraft barometric altitude will be obtained by using Mode C.

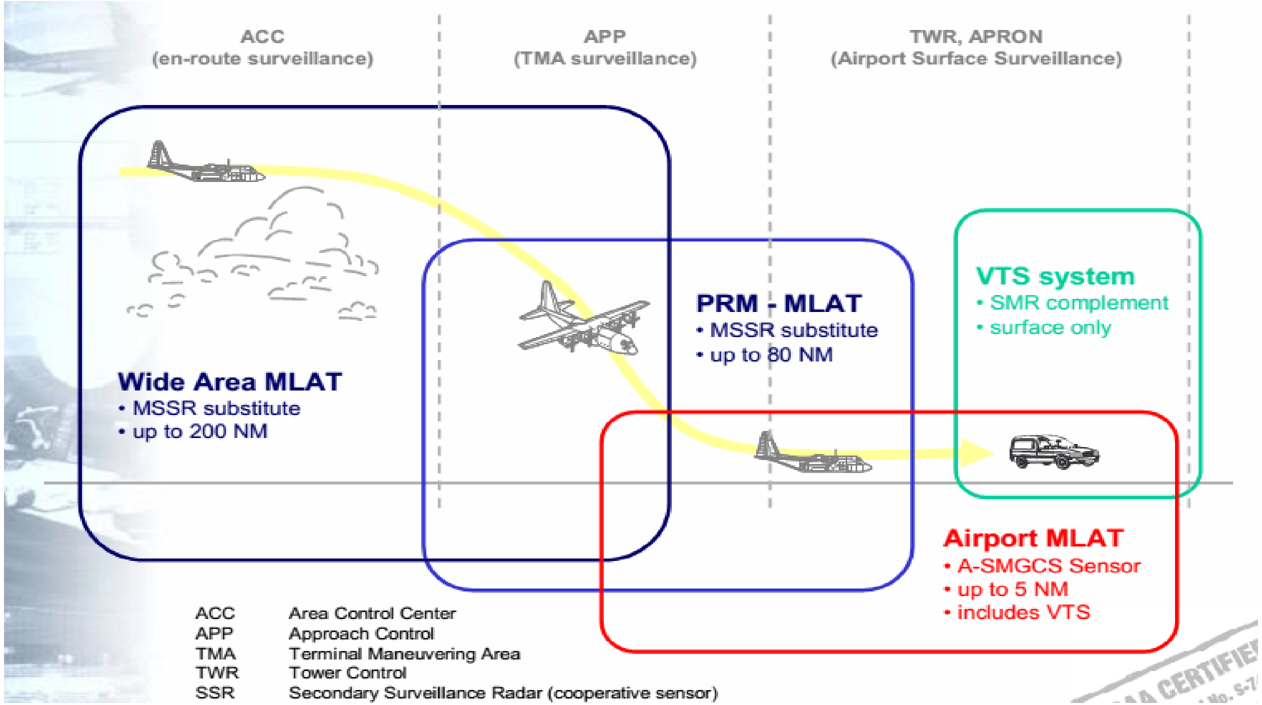
In the case of 3D MLAT system, only the geometric altitude of the aircraft is measured :

- Not used in “normal” surveillance operation
- Used in monitoring of the performance of aircraft altimeters, for example in the case of RVSM implementation. In this case a modelling of the variation of atmospheric pressure with altitude must be established

ADS-B provides barometic and geometric Altitude

Conclusion

MLAT Systems Applications



Airport Multilateration Summary

Strengths

- High performance
  - For airports, it exceeds present SMR performance
- No additional aircraft equipage required
  - Aircraft widely equipped with SSR transponders
  - More and more aircraft are equipped with Mode S Transponders
- Lifecycle cost lower than Radar
  - no rotating machinery, essentially maintenance-free

Weaknesses

- Performance affected by ground effects (multipath, shadowing, etc)
- Change in installations and procedures may be required
  - So transponder is not disabled on the ground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