INTERNATIONAL CIVIL AVIATION ORGANIZATION
ASIA AND PACIFIC

Guidance Material on Comparison of Surveillance Technologies (GMST)

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GUIDANCE MATERIAL ON COMPARISON OF SURVEILLANCE TECHNOLOGIES (GMST)

1 Introduction

A number of surveillance technologies suitable for the delivery of ATC services to separate aircraft are currently available.

This paper will concentrate on enroute, and terminal applications rather than airport surface surveillance. It will consider the sensor component of the ATC system only – and will ignore the ATC display system. These sensors can support simple display systems or sophisticated automation systems.

2 The need for ATC Surveillance

Surveillance plays an important role in Air Traffic Control (ATC). The ability to accurately and reliably determine the location of aircraft has a direct influence on the separation distances required between aircraft (i.e. separation standards), and therefore on how efficiently a given airspace may be utilised.

In areas without electronic surveillance, where ATC is reliant on pilots to verbally report their position, aircraft have to be separated by relatively large distances to account for the uncertainty in the estimated position of aircraft and the timeliness of the information.

Conversely in terminal areas where accurate and reliable surveillance systems are used and aircraft positions are updated more frequently, the airspace can be used more efficiently to safely accommodate a higher density of aircraft. It also allows aircraft vectoring for efficiency, capacity and safety reasons.

ATC surveillance serves to close the gap between ATC expectations of aircraft movements based on clearances or instructions issued to pilots, and the actual trajectories of these aircraft. In this way it indicates to ATC when expectations are not matched, providing an important safety function. Surveillance provides “blunder” detection.

The demand for increased flexibility to airspace users by reducing restrictions associated with flying along fixed routes requires improved navigation capability on board the aircraft. Equally, accurate surveillance is required to assist in the detection and resolution of any potential conflicts associated with the flexible use of the airspace which is likely to result in a more dynamic environment.

Accurate surveillance can be used as the basis of automated alerting systems. The ability to actively track aircraft enables ATC to be alerted when an aircraft is detected to deviate from its assigned altitude or route, or when the predicted future positions of two or more aircraft conflict. It also supports minimum safe altitude warnings, danger area warnings and other similar alerts.

Surveillance is used to update flight plans, improving estimates at future waypoints and also removing the workload for pilots in providing voice reports on reaching waypoints.

3 General Requirements of an Air - Ground Surveillance System

The most basic function of a surveillance system is to periodically provide an accurate estimate of the position, altitude and identity of aircraft. Depending on the ATC application that a surveillance system is intended to support, there will be other requirements of the system.

A surveillance system may be characterised in terms of the parameters listed below:

1. Coverage volume – the volume of airspace in which the system operates to specification.

2. Accuracy – a measure of the difference between the estimated and true position of an aircraft.

3. Integrity – an indication that the aircraft's estimated position is within a stated containment volume of its true position. Integrity includes the concept of an alarm being generated if this ceases to be the case, within a defined time to alarm. Integrity can be used to indicate whether the system is operating normally.

4. Update rate – the rate at which the aircraft's position is updated to users.

5. Reliability – the probability that the system will continue operating to specification within a defined period. Sometimes this is called continuity.

6. Availability – the percentage of the total operating time during which the system is performing to specification.

Other issues which need to be considered when designing a surveillance system for ATC are:

1. The ability to uniquely identify targets.

2. The impact of the loss of surveillance of individual aircraft both in the short (few seconds) and long term

3. The impact of the loss of surveillance over an extended area.

4. Backup or emergency procedures to be applied in the event of aircraft or ground system failure.

5. The ability to operate to specification with the expected traffic density.

6. The ability to operate in harmony with other systems such as the Airborne Collision Avoidance Systems (ACAS) and Airborne Separation Assistance Systems (ASAS).

7. The ability to obtain Aircraft Derived Data (ADD).

8. The interaction between communication, navigation, and surveillance functions.

4 A Surveillance Sensor is One Part of a Surveillance System

Whilst this paper concentrates on the possible surveillance sensors, they are just one part of an overall system that provides data for use in ATC. A complete system includes:

- Position and altitude sensors. Some of these sensors may be ground based (e.g. radars) or may be airborne (e.g. altitude sensors). Datalinks are used to transmit data from airborne sensors to the ground,
    - The Fundamental Data provided to the air traffic controller is aircraft position, aircraft identity and altitude. Further information such as aircraft direction, speed, the rate of climb may also be provided.

- A system to transmit the data from the reception point on the ground to the ATC centre,
- A display system or ATC automation system
    - Data from a sensor system may be presented on a standalone display or combined with data from other sensor(s) and/or other data in an automation system and then presented on a plan view situation display.
    - The situation display provides Air Traffic Controllers with plan view of the position of aircraft relative to each other and to geographic features. This supports controllers in providing Separation and other services to aircraft.
    - Automation systems may use surveillance data to implement automated safety net functions such as Route Adherence Monitoring, Cleared Level Alarm, Conflict Alert, Lowest Safe Altitude and Danger Area Infringement Warning. These facilities increase overall safety.
- Suitably trained air traffic controllers, aircrew and
- Suitable standards and procedures to use the system including separation minima
    - ICAO PANS-ATM (Doc.4444, Chapter 8) details radar separation minima of five (5) and three (3) nautical miles. These minima allow for a considerable increase in airspace utilisation compared to procedural control. Changes to ICAO documents are about to be published (2007) recognising ADS-B use to support 5 nautical mile separation standards. ICAO's Separation & Airspace Safety Panel (SASP) is working on proposals to allow 3 nautical mile separation standards using ADS-B and also on the use of multilateration to support both 3 and 5 nautical mile separation standards.
    - Due to the low update rate, ACARS based ADS-C is unlikely to ever support 3 and 5 nautical mile separation standards. However it is used to support 30/30 and 50/50 nautical mile procedures used in some regions. ATN and VDL2 based ADS-C may reduce the achievable separation standards in some regions.

5 The Technologies

Knowledge of the position of aircraft is essential to an Air Traffic Controller in the provision of most air traffic services. Certainly knowledge of aircraft position is required to provide separation services. The provision of knowledge regarding aircraft position is referred to as surveillance. Position reports from pilots can provide knowledge of aircraft position to a controller. However the inherent inaccuracy, infrequent updates and scope for error due to misunderstandings requires very large spacing between aircraft to maintain safety. This technique is known as procedural separation.

Today there are primarily four classes of surveillance technology available to support air traffic control services;

1. Radar
2. ADS-B alone
3. Wide Area Multilateration (typically with ADS-B but may be supplied without)
4. ADS-C

5.1 Radar

Radar provides the controller with an accurate, trustworthy on-screen plan view of the aircraft position in real-time. The required separation between aircraft for safe operation can be greatly reduced compared to procedural separation. It also allows vectoring, ATC directed terrain avoidance and the provision of safety nets.

Radar is a technology which detects the range and azimuth of an aircraft based upon the difference in time between transmission of pulses to the aircraft and the receipt of energy from the aircraft. Typically the technology uses a large rotating antenna and associated machinery.

A radar system requires a number of racks of equipment (normally on a plinth) normally in an air-conditioned shelter. A typical site consumes between 10 and 20 kWof electricity and this needs to be backed up by generators and battery backup Uninterruptible Power Supplies (UPS). A specialised tower installation is required.

A radar typically takes a number of months for site preparation and deployment unless special, transportable systems are deployed.

5.1.1 Primary Radar

Primary Surveillance Radar (PSR) transmits a high power signal, some of which is reflected by the aircraft back to the radar. The radar determines the aircraft's position in range from the elapsed time between transmission and reception of the reflection. The direction of the aircraft is the direction in which the narrow beam radar antenna is facing.

PSR does not provide the identity or the altitude of the aircraft. However, PSR does not require any specific equipment on the aircraft.

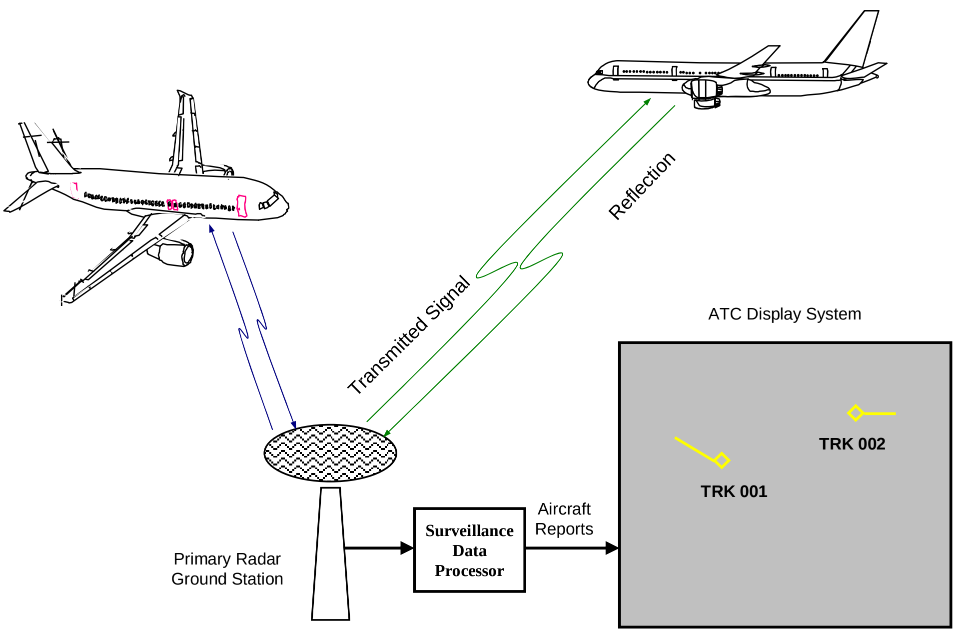

Figure 1 - Primary Radar

Strengths

- PSR does not require a transponder to be installed or operating on aircraft thus allowing the detection and management of non equipped/faulty aircraft or non co-operative aircraft[1]
- Can provide a weather channel output if display of weather is required.
- Well suited for aerodrome surface surveillance

Weaknesses

- PSR does not provide identity
- Does not provide altitude[2]
- Position is based on slant range measurement rather than true range (which presents some difficulties for multi-radar tracking systems)
- Can often report false targets (ground vehicles, weather, birds etc)
- Poor detection performance in the presence of ground and weather clutter especially for flight tangential to the radar
- Expensive compared to Secondary Surveillance Radar (SSR)
- A update rate between 4 and 12 seconds (longer than typical multilateration or ADS-B)
- High transmitter power required for long range performance – brings interference and environmental concerns
- Systems are very expensive to install and maintain
- Systems require optimum site with unobstructed view to aircraft, and with the minimum of ground clutter visible to the radar
- Cannot resolve two aircraft at a similar location at the same range, due to poor azimuth resolution performance.

5.1.2 Secondary Surveillance Radar

Secondary Surveillance Radar (SSR) systems consist of two main elements, a ground based interrogator/receiver and an aircraft transponder. The aircraft's transponder responds to interrogations from the ground station, enabling the aircraft's range and bearing from the ground station to be determined.

Refer to the ICAO Manual of Secondary Surveillance Radar (SSR) Systems (Doc 9684) for a detailed study of the subject.

The development of SSR evolved from military Identification Friend or Foe (IFF) systems and allows the use of the Mode A/C service for civil aviation. Since then it has been significantly developed to include the Mode S service. SSR frequencies of 1030 and 1090 MHz remain shared with the military.

In many cases SSR is co-located with a PSR, usually with the SSR mounted on the top of the PSR antenna.

Mode A/C transponders provide identification (Mode A code) and altitude (Mode C) data with 100 foot resolution information in reply to interrogations. Therefore in addition

[1] ICAO Annex 6 says at para 6.13.1 "From 1 January 2003, unless exempted by the appropriate authorities, all aeroplanes shall be equipped with a pressure-altitude reporting transponder which operates in accordance with the relevant provisions of Annex 10,Volume IV". A number of authorities provide exemptions.

[2] Some primary radars have height finder capabilities although these are normally too expensive for ATC use and have poor altitude accuracy with respect to civil aviation needs.

to being able to measure the aircraft's range and bearing, the Mode A/C system is also able to request the aircraft to provide its identity and altitude.

Mode S is an improvement of Mode A/C. It contains all the functions of Mode A/C, and also allows selective addressing of targets by the use of unique 24 bit aircraft addresses, and a two-way data link between the ground station and aircraft for the exchange of information. It provides the transponder capability to report altitude data with 25 foot resolution although accuracy and resolution also depend on the altitude sensor systems on board the aircraft.
SSR determines the aircraft's position in range from the elapsed time between the Interrogation and reception of the Reply. The direction of the aircraft is determined from the direction in which the narrow beam radar antenna is facing. The Reply contains the aircraft Identity and/or Altitude. The Identity information is able to be input by the pilot and the altitude information comes from a barometric encoder or air data computer on the aircraft. SSR will only detect an aircraft fitted with a functioning transponder. SSR with Mode S may also data-link many aircraft parameters such as heading, track, bank angle and selected altitude to the Radar.

Whilst SSR independently calculates geographical position, pressure altitude data, flight identity (4 digit octal code) and other data such as emergency flags are provided by airborne sensors or systems and datalinked to the ground.
SSRs transmit pulses on 1030 MHz to trigger transponders installed in aircraft to respond on 1090 MHz. This datalink can theoretically support 4 Mbits/second uplink and 1Mbits/second downlink.

There are two classes of SSR used today:

Classical SSR: typically uses a hog-trough antenna. This SSR system relies on the presence or absence of SSR transponder replies within the beamwidth. Performance can be quite poor, particularly azimuth accuracy and resolution. This type of system is also subject to significant multipath anomalies due to the poor antenna pattern. Range accuracy depends on variability of the fixed delay in the ATC transponder[3].

Monopulse SSR: Monopulse SSR systems measure the azimuth position of an aircraft within the horizontal antenna pattern using diffraction techniques. These techniques improve azimuth accuracy and resolution. In addition, these radars typically have large vertical aperture antennas and hence are less subject to multipath effects.

[3] Time allowed for transponder to reply : 3 uS +- 0.5 us as per SARPS

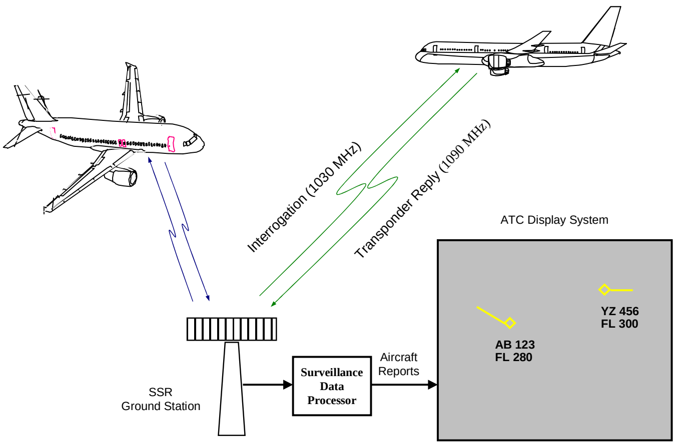

Figure 2 - Secondary Surveillance Radar

Strengths

- o SSR allows communication of identity (4 digit octal codes) when matched with flight plan data held by the ground system
- o Allows communication of altitude and emergency states to ground system
- o Provides good detection capability independent of clutter and weather.
- o Provides moderately high update rate.
- o Provision of altitude allows correction for slant range error

Weakness

- o Poor azimuth accuracy and resolution (particularly for classical SSR)
- o Can sometimes report false targets or position (reflections, multipath)
- o Can sometimes confuse Mode A replies as Mode C and vice versa
- o Can sometimes report false altitude or 4 digit code
- o No error detection provided in downlinked 4 digit code and altitude from Mode C transponders
- o Systems are expensive to install and maintain
- o Systems require optimum site with unobstructed view to aircraft
- o Cannot resolve two aircraft at the same location (garbling/ resolution performance)
- o Dependent on aircraft avionics
- o Not accurate enough for aerodrome surface applications due to transponder delay uncertainty

5.1.3 Mode S Secondary Surveillance Radar

Mode S radars typically use monopulse techniques to measure the azimuth position of an aircraft and have large vertical aperture antennas and hence are less subject to multipath effects. In addition, they are able to discretely interrogate single aircraft transponders and hence can discriminate between two aircraft at the same geographical position.

Mode S has additional capabilities which provide:

- improved ability to distinguish between Mode S equipped aircraft (resolution performance)
- error detection and correction of downlinked data
- improved tracking relying on Mode S 24 bit address (reduced tracking ambiguity)
- improved altitude quantisation

- ability to downlink a wide variety of information from Mode S equipped aircraft

A Mode S radar is backwards compatible with a conventional SSR Mode A/C radar and the detection and processing of Mode A/C transponder replies is essentially identical. To achieve Mode S benefits, the aircraft transponders must be Mode S capable transponders.

All ACAS II (v6.04 or v7.0) equipped aircraft have mode S transponders.

Europe has issued Mode S mandates requiring all aircraft in certain airspace to be Mode S equipped. Some exemptions will exist.

The European mandate also requires support of

Elementary surveillance (ELS) which requires the aircraft to be able to downlink callsign in response to Mode S interrogations and

Enhanced surveillance (EHS) which requires the aircraft to be able to downlink

- Selected Altitude
- Roll Angle
- Track Angle Rate
- Track Angle
- Ground Speed
- Magnetic Heading
- Indicated Airspeed/Mach No
- Vertical Rate

Strengths

- Altitude and identity is protected and the downlink is error free (of course flight identity could have been entered incorrectly)
- Can resolve two aircraft at the same location
- Provides 25 foot altitude quantisation (instead of conventional 100 foot resolution)
- Operates with Mode A/C aircraft albeit with no advantages compared to a Mode A/C radar

Weakness

- Benefits apply only to Mode S equipped aircraft
- More complex to set up than SSR
- Some currently deployed Mode A/C transponders are non compliant with the standards and fail to respond to Mode S interrogations properly – whilst these transponders are tolerated by Mode A/C radars
- Dependent on aircraft avionics – but most **airliners** are equipped with Mode S as a result of ACAS mandates
- Systems require optimum site with unobstructed view to aircraft

5.1.4 Secondary Radar Alone

SSR alone is used for en route radar control in many States where intruder detection is not required. An SSR only installation is less expensive than a combined primary plus secondary radar, but involves a significant outlay for buildings, access roads, mains electrical power, standby generators, towers and turning gear to rotate a large elevated antenna etc.

ICAO Document 4444, Procedures for Air Traffic Services – Air Traffic Management, sets out the requirements for Radar Services in Chapter 8. An extract is copied at Attachment 1. In particular, Section 8.1.9 states:

"SSR systems, especially those with monopulse technique or Mode S capability, may be used alone, including in the provision of separation between aircraft, provided:

a) The carriage of SSR transponders is mandatory within the area; and

b) Aircraft identification is established and maintained by use of assigned discrete SSR codes"

5.1.5 Combined Primary plus Secondary Radar

Combined Primary & Secondary Radar makes use of the advantages of the two types of radar in one installation. Typically, the PSR antenna and the SSR antenna are mounted on the same turning gear and the associated processing performs filtering, combines the SSR and primary data and tracks the radar reports. One track message is output per aircraft each antenna rotation.

The primary radar provides detection of intruder aircraft and the SSR performs detection of co-operative aircraft as well as providing altitude and identity information.

Digital tracking systems gain significantly benefits from having SSR and PSR installed on the same rotating antenna. SSR can resolve tracking ambiguities that would exist in a PSR only solution and vice versa.

Some States choose to mount PSR and SSR systems at separate locations thus providing separate antenna platforms. This has the advantage of a level of redundancy since one antenna stops, a level of service can be provided from the other. However, in this case, the advantages of improved tracking performance are forgone – unless the antennas are nearby and antenna rotation is synchronised[4].

Combined PSR/SSR systems are usually provided to support approach departure ATC in terminal manoeuvring area airspace. It is in the busy terminal area airspace that the probability of general aviation aircraft straying into controlled airspace is higher – and therefore some States prefer to have PSR in these environments.

Often such systems are backed up by offsite SSR only systems.

5.2 ADS-B alone

ADS-B is a system that uses transmissions from aircraft to provide geographical position, pressure altitude data, positional integrity measures, flight identity, 24 bit aircraft address, velocity and other data which have been determined by airborne sensors.

Typically, the airborne position sensor is a GPS receiver, or the GPS output of a Multi-Mode Receiver (MMR). This sensor must provide integrity data that indicates the containment bound on positional errors. The altitude sensor is typically the same barometric source / air data computer source used for SSR. Integrated GPS and inertial systems are also used. Currently inertial only sensors do not provide the required integrity data although these are likely to be provided in the future.

[4] Mechanical slaving brings another degree of complexity and failure modes and is rarely implemented (for good reasons)

An ADS-B ground system uses a non-rotating antenna positioned within a coverage area, to receive messages transmitted by aircraft. Typically a simple pole (DME like) antenna can be used.

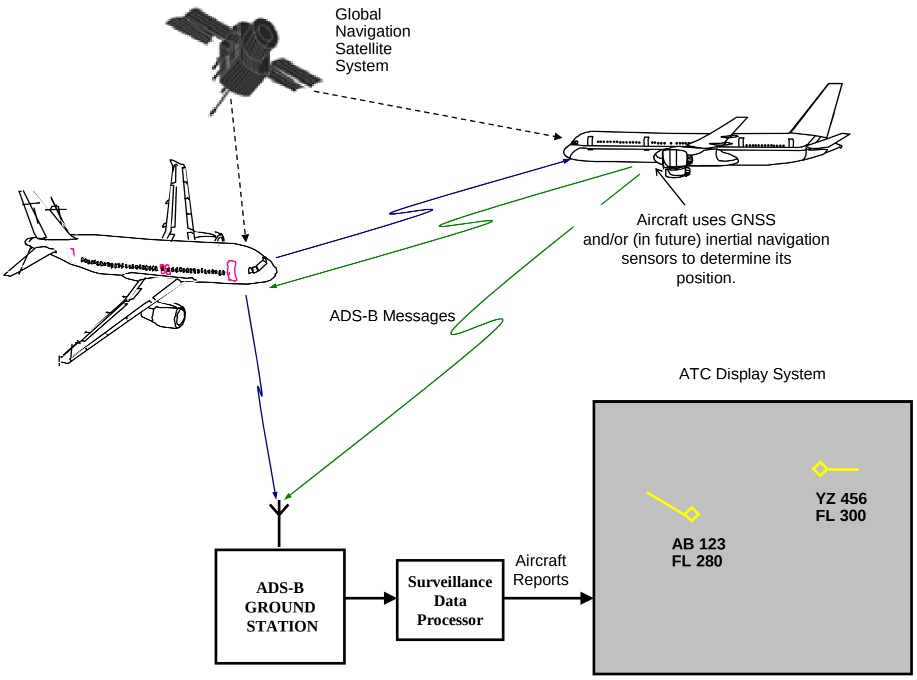

Figure 3 - Automatic Dependent Surveillance - Broadcast

The ADS-B ground system does not necessarily transmit anything. ADS-B receiver ground stations are the simplest and lowest cost installations of all options to provide air-ground surveillance, although costs may increase if ADS-B transmitter (to broadcast or rebroadcast ADS-B data e.g. TIS-B, ADS-R or FIS-B) capabilities are deemed necessary.

An ADS-B receiver is typically less than six inches high by nineteen inches wide and a duplicated site consumes less than 200 watts of electricity. An ADS-B ground station can normally be installed in an existing VHF communications facility.

The installed cost of a duplicated ADS-B ground station is lower than other alternatives. If it can be housed in an existing communications facility, installation can be as short as one week after delivery of equipment from the manufacturer.

While ADS-B has the advantage of quite low ground station cost, it has the disadvantage of requiring aircraft to equip with ADS-B transponders, which will take time. Voluntary equipage among jet airline fleets is still expected to be high, and ADS-B remains very attractive in the longer term.

Many avionics vendors have included ADS-B capability in the software release that supports ELS and EHS.

Some ATC systems can support ADS-B use, including delivery of separation services, when there is partial aircraft ADS-B equipage. Other ATC systems require complete equipage for ADS-B use to be viable.

The use of ADS-B along the Flight Information Region (FIR) boundary may be easily shared by the boundary States. ADS-B technology is generally not sensitive to military authorities because it is co-operative in nature and hence such authorities are less likely to block data sharing.

The low marginal cost of ground stations encourages FIR boundary data sharing where large parts of coverage benefit the adjacent FIR. This data sharing can be considered similar to the sharing of ADS-C data when adjacent Air Navigation Service Providers (ANSPs) use service providers to deliver ADS-C data.

Strengths

- Simple ground station design without transmitter
- Can be installed at sites shared with other users
- Very low ground station cost (but highly variable ADS-B avionics fitment cost)
- Very high update rate
- Almost perfect resolution
- High accuracy and integrity (airborne measurements)
- Higher performance velocity vector measured by avionics and then broadcast, rather than determined from positional data received on the ground
- Accuracy not dependent on range from ground station
- Facilitates exchange of surveillance data across FIR boundaries
- Can be easily deployed for temporary use (emergency, special events etc)
- Can support the display of callsigns on simple display systems without interfaces to flight planning systems since callsign is provided directly from the aircraft
- Facilitates future provision of innovative ATM services based on air-to-air ADS-B.

Weakness

- Dependent on aircraft avionics. This can be a major issue in some environments.
- Equipage rates are relatively low at this stage (2007)
- Systems require optimum site with unobstructed view to aircraft
- Some outages expected due to poor GPS geometry when satellites out of service, although exposure expected to reduce in the future with use of GNSS augmentation & internal support[5]
- ADS-B has the capacity to evolve towards the broadcast and use of other data, such as Trajectory Change Point (TCP) or others, already defined in the standard

ADS-B Critical issue

The critical issue for ADS-B is that it requires ADS-B avionics including GPS or similar in participating aircraft. Whilst many airliner manufacturers produce aircraft with ADS-B out avionics a large legacy fleet remains to be equipped.

The situation is different in different regions of the world. Some States have new airliner fleets which are growing rapidly – and the new aircraft are fitting with ADS-B. In other States very large numbers of legacy aircraft remain unequipped.

The situation is also different in different aviation segments.

[5] Analysis of 37 million ADS-B samples by one State over a 4 month period indicated that 99.8% of samples were acceptable for ATC 5 nautical mile separation. See ADS-B SITF/5-IP/8

Whilst large aircraft are equipping, few regional airliners are equipped.

General Aviation (GA) is another area that can be problematic. In some States the cost to equip the GA fleet is small. In others with a large fleet it can be very expensive. Some States envisage subsidies to assist GA equipage so that all aviation segments benefit. Some States also envisage the mandatory fitment of ADS-B with and without subsidies.

Timing of transition to match aircraft equipage of ADS-B will be critical for many States.

At the same time, the benefits of ADS-B equipage are significant and may allow other surveillance systems to be decommissioned and supports delivery of air-air surveillance applications. ADS-B avionics support the ADS-B application in all locations to which the aircraft travels.

5.3 Multilateration

Multilateration is a system that uses aircraft transponder transmissions (Mode A/C, Mode S or ADS-B) to calculate a 2D or 3D position.

Multilateration relies on signals from an aircraft's transponder being detected at a number of receiving stations to locate the aircraft. It uses a technique known as Time Difference of Arrival (TDOA) to establish surfaces which represent constant differences in distance between the target and pairs of receiving stations, and determines the position of the aircraft by the intersection of these surfaces.

The accuracy of a multilateration system is dependent on the geometry of the target in relation to the receiving stations, and the accuracy to which the relative time of receipt of the signal at each station can be determined.

Multilateration is mainly used for airport surface and terminal area surveillance, although with careful design and deployment it may be used in segments of enroute airspace.

Multilateration independently calculates geographical position in 2D, or in 3D if more sensors are installed.

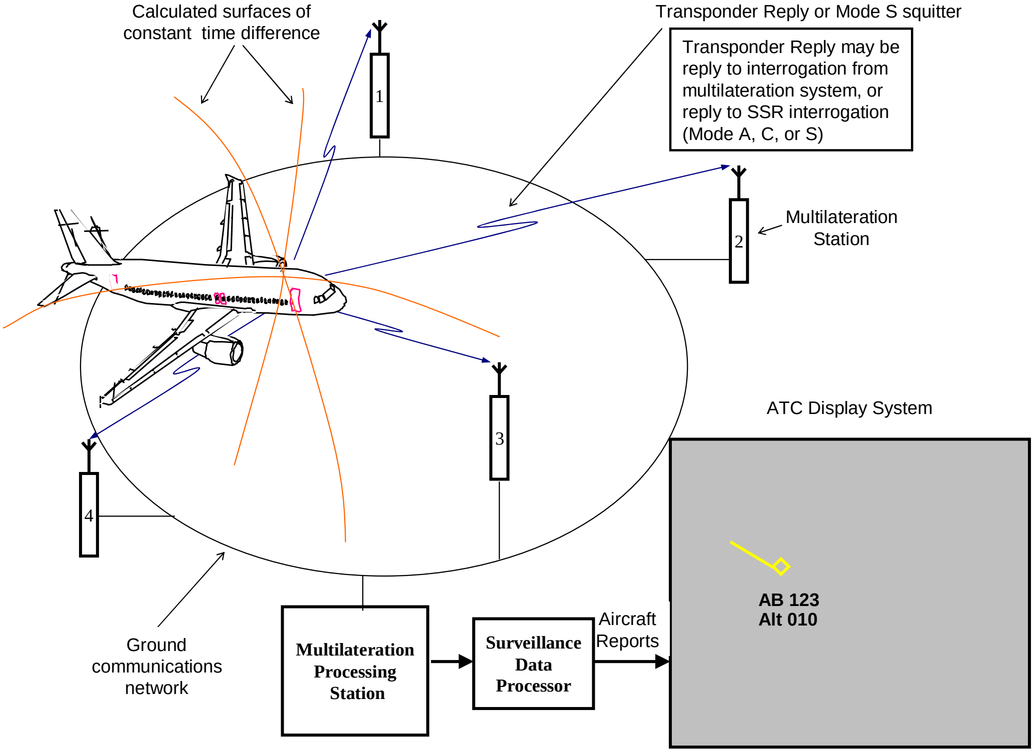

Figure 4 - Transponder Multilateration

Multilateration systems can be defined as being either passive or active. Passive systems require only ground receivers. An active system requires ground receivers and at least one interrogator. Multiple interrogators may be required to meet coverage requirements. The latter enables the system to be independent from other sources to trigger transmissions from aircraft. In most practical ATM applications multilateration systems are active and must interrogate aircraft to obtain altitude and identity data. Passive systems usually rely on nearby radars to perform interrogation[6]. They could operate on ADS-B signals which do not require interrogators.

Multilateration systems will provide a range of fundamental data items relative to a specific target depending on the airborne derivation of the data and if they are transmitted within the aircraft signal used by the multilateration system, i.e. MSSR Mode A or MSSR Mode C or 1090 MHz Extended Squitter (ADS-B). Derived data can include:

- Pressure altitude data derived from decoding ADS-B transmissions or replies to Mode C interrogations.

- Flight identity obtained by decoding ADS-B transmissions or replies to Mode A interrogations.

- 24-bit aircraft address obtained by decoding ADS-B transmissions, DF11 Mode S autonomous transmissions[7] or replies to Mode S interrogations.

[6] Difficulties in distinguishing between Mode A and Mode C replies will be experienced unless the interrogator pulses are available.

[7] DF11 is an autonomous transmission from a Mode S transponder which provides aircraft 24 bit code only. It was primarily designed to support self announcement to TCAS systems. Multilateration systems can

Additionally, multilateration systems can make use of position messages provided by ADS-B systems, i.e. each multilateration receiver can usually be configured to operate as an ADS-B receiver. These can be used as standalone ADS-B sensors.

Initially multilateration systems have been used for surface surveillance. More recently States have begun deploying multilateration for wide area applications of terminal area size. These wide areas tend to be smaller than the area covered by radars.

System performance in the service volume is determined primarily by the geometry of the ground station deployment. Therefore the number of sites and the geographical disposition of those sites (site selection) are the critical factors in achieved performance. The availability of such sites and reliable, high performance communications to the central processing system is required.

One requirement of multilateration systems is that the central processing must be able to determine the time DIFFERENCE of arrival of signals from aircraft. This requires a synchronisation of the ground stations typically using either:

a) A reference transmitter visible to multiple receiver stations, or
b) Use of common clock (GPS or other) to time synchronise the receptions, or
c) The transmission of the received signals by wideband datalink to the central processing system, or
d) Very accurate clocks at each sensor (atomic standard).

Mutilateration systems require a number of ground stations to detect each aircraft transmission.

- For surveillance of airborne aircraft a minimum of four ground stations must receive each message to determine a position.
  - Three ground stations can be used if pressure altitude is also used but the position accuracy will be adversely affected due to 100 foot barometric pressure altitude quantisation and because this altitude varies[8] and does not match the WGS84 geoid.
  - An additional ground station may be necessary to support the ability to continue operations with one ground station failed.
  - One less ground station is required if a ground station uses "radar ranging" to measure the distance of the aircraft from the interrogating station.

- For surface movement applications a minimum of three ground stations must receive each message to determine a position.

- "Ranging" via interrogation of SSR transponders can be used in some cases to improve accuracy.

Strengths

- Provides aircraft identification using 4 digit octal codes, 24 bit Mode S codes or Flight Identity (ADS-B or Mode S based) to ground system
- Allows communication of identity, altitude and emergency states downlinked from aircraft

determine position from DF11 transmissions. These transmissions do not provide altitude or flight ID data. Mode A/C transponders need to be interrogated to determine position.

[8] Due to atmospheric pressure

- Provides good detection capability independent of clutter and weather
- Is able to provide a high update rate
- Can resolve two aircraft at the same location (garbling / resolution performance) if aircraft are Mode S capable using selective address interrogation
- Can operate as a set of multiple ADS-B ground stations
- Can be installed at sites shared with other users
- Is an attractive transition path before widescale ADS-B equipage occurs in some States
- Lower cost than radar[9]
- Data feed can be made to resemble radar data (and hence can be used in some ATC automation systems that are not adapted to support native multilateration data)[10]
- In some locations, when existing infrastructure is available, the systems can be inexpensive to install and maintain compared to alternative systems.

Weakness

- Requires multiple sites
- Requires multiple communication links
- Sometimes reports false targets (reflections, multipath)
- No error detection provided in downlinked 4 digit code and altitude from Mode C transponders
- Systems can be moderately expensive to install and maintain because of the costs associated with the provision and maintenance of multiple sites especially if existing infrastructure is not available.
- Systems require multiple sites with unobstructed view to aircraft. This can be a significant problem in some environments
- Requires a transmitter to trigger aircraft to transmit the data required for ATC applications
- Not yet endorsed by ICAO
- Requires multiple transmitter sites for large coverage, due to the poor uplink antenna gain when omni-antenna used (compared to high gain radar antenna).

5.4 ADS-C

ADS-C (Contract) is also known as Automatic Dependent Surveillance – Addressed (ADS-A) or simply Automatic Dependent Surveillance (ADS). With ADS-C the aircraft uses on-board navigation systems to determine its position, velocity, and other data, and reports this information to the responsible air traffic control centre.

Information that may be sent in ADS-C reports includes:

a. Present position (latitude, longitude, altitude, time stamp, and FOM)
b. Predicted route in terms of next and (next + 1) waypoints
c. Velocity (ground or air referenced)
d. Meteorological data (wind speed, wind direction, and temperature)

ADS-C reports are sent by point to point satellite or VHF data links. The data links are typically provided by service providers. Typically fees are charged for the transmission of each message; as most of these costs are borne by the airlines, there is a reluctance to use ADS-C at

[9] There is a wide variability of the costs for multilateration since site costs typically dominate the total costs. In some environments multilat costs could approach those of radar

[10] Usually brings some additional inaccuracies that are tolerable.

higher rates than 10-15 minutes between messages]. Sometimes HF datalink is used, but with reduced performance.

With ADS-C the airborne and ground systems negotiate the conditions (the Contract) under which the aircraft submits reports (i.e. periodic reports, event reports, demand reports, and emergency reports). Reports received by the ground system are processed to track the aircraft on ATC displays in a similar way to surveillance data obtained from SSR.

ADS-C is typically used in oceanic and remote areas where there is no radar, and hence it is mainly fitted to long range air transport aircraft. The aircraft avionics chooses VHF communication when in coverage of the VHF network to lower costs and improve performance. Satellite data-communications is used at other times such as when the aircraft is over the ocean.

Typically messages are transmitted infrequently (~ each 15 minutes). The positional data is accompanied by a “figure of merit” value which indicates the accuracy. It is not an integrity value.

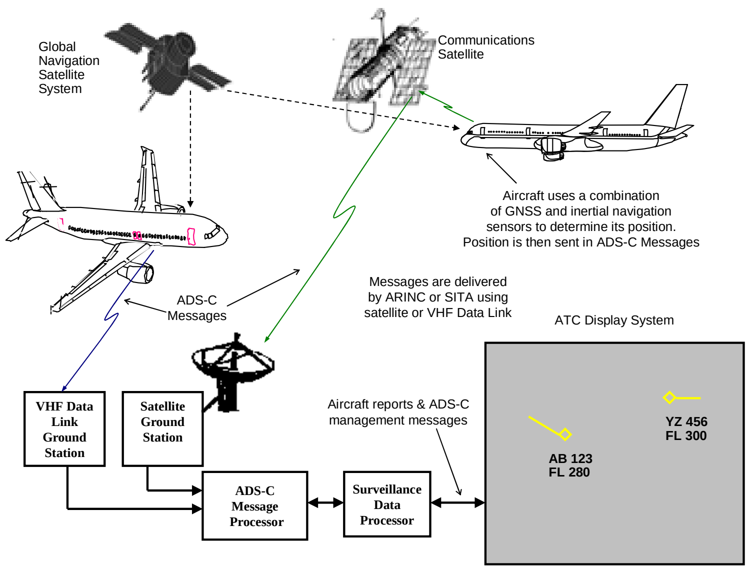

Figure 5 - Automatic Dependent Surveillance - Contract

Strengths

- Provides surveillance coverage over very remote regions and oceans except in the polar regions
- Supports a subset of the safety net applications (Cleared Level Adherence Monitoring : CLAM, Route adherence monitoring : RAM , and ADS Route conformance warning : ARCW[11]) but unable to support more tactical alerts like STCA
- Low capital cost for ANSP
- Minimal maintenance costs

Weakness

- High costs per report (service provider)
- Low reporting rates
- No ability to offer radar like separation services (vectoring etc)
- Expensive avionics fitment
- FANS-1/A is not ICAO-compliant, but has been accepted as a transition step
- ATN variant is not mature but will support higher reporting rates [12]
- Long latency when satellite communication link is used
- Availability not as high as other systems (not all elements are duplicated)
- Susceptibility to failure/overload at satellite earth stations
- Relatively low message delivery reliability

[11] This is the same as "FLIPCY" in the European context

[12] FANS1 standards limit reporting rates so that contracts can be supported over ACARS satellite (amongst other reasons)

6 COMPARISON

This section compares the various technologies

6.1 APPLICATIONS

PSR	**Enroute surveillance**: In the 1960s & 1970s PSR was widely used for ATC surveillance including in enroute airspace. In the late 1970s and following years many ANSPs have decided to discontinue the use of PSR in this application due to the high cost and due to mandatory requirements for SSR transponders in a lot of airspace. In many countries the use of PSR is retained for defence purposes rather than for provision of civil ATC services. The use of PSR for enroute ATS is expected to continue to decrease. **Terminal area surveillance**: PSR remains a useful tool in busy terminal areas to detect non transponder equipped aircraft and provide intruder protection of the terminal area airspace. Typically primary radars have co-mounted SSR to improve tracking performance and provide identity/altitude. In the next decades the use of primary radar is expected to commence to decrease. **Surface movement radar** application: PSR remains a significant tool in surveillance of airport surfaces. Its purpose is to detect vehicles and aircraft which are not detected by other cooperative surveillance means (eg aircraft and vehicles not equipped with transponder or equivalent). **Airborne:** no civil application.
SSR	**Enroute surveillance**: SSR only sensors often provide surveillance in enroute airspace when financially justified. In some States enroute radars rotate slowly (typically 5 rpm) and in others rotate at 16 rpm. In some regions (Europe) two SSR sensors are required to cover the airspace. In other regions, single SSR surveillance is used. **Terminal area surveillance**: SSR radars are currently critical to the effective provision of terminal area surveillance because they provide a moderate update rate of position (typically 15 rpm), identity (4 digit octal codes) and altitude. Typically a terminal area radar includes primary radar and SSR. **Precision Runway Monitor (PRM) - electronic scan**: Special SSR ground stations are used by a number of States to support precision runway approach monitoring to parallel runways. Typically these electronic scan sensors provide an update every 1 second, with an azimuth accuracy exceeding 1 milliradian. The objective of these radars is to detect divergence from the defined final approach path.

	Airborne: ACAS systems including TCAS 1, TCAS 2 and other products such as TCAD rely on SSR transmissions.
Mode S	**Terminal area & enroute surveillance** Mode S SSR sensors are being commissioned around the world to support both enroute and terminal area operations. Whilst the surveillance performance benefits (eg: resolution) of Mode S will be delivered to all Mode S equipped aircraft in the coverage of a Mode S radar, only ANSPs with updated ATC systems will be able to take advantage of many capabilities such as downlink of airborne parameters (DAP). The move away from the use of 4 digit SSR codes will be slow and driven by ATC automation changes as well as fitment of Mode S radar ground stations and transponders in aircraft. Europe's ELS/EHS mandate will speed this process in Europe and hence worldwide. Legacy ATC automation in other States will slow progress. **Airborne:** ACAS systems including TCAS 1, TCAS 2 and other products such as TCAD rely on SSR transmissions.
Multilateration	**Advanced Surface Movement Guidance and Control Systems (ASMGCS)**: Multilateration has been deployed at numerous locations for surface surveillance. Typically it supports a surface movement radar and provides highly accurate position and identity to these systems. Typically 10-20 ground stations are used to provide multilateration coverage over the whole airport surface. High update and high integrity positional data is provided for Mode S capable aircraft and for ADS-B equipped surface vehicles. Implementation requires new "transponder on" procedures to be followed by flight crew whilst taxing. Careful site selection and tuning of these systems has been found to be necessary to account for multipath, coverage obstructions and for aircraft that are not Mode S capable. Multilateration systems operate more efficiently the higher the Mode S transponder fitment rate. **Terminal area surveillance**: Multilateration shows promise for "wide area" application and a number of States have projects to deploy multilateration for this purpose. However, at this time, no ICAO approval has been obtained to use multilateration for this application. SASP is working on a proposal to use multilateration for 3 nautical mile separation. Austria is using multilateration in a specific terminal area application (Innsbruck) monitoring approaches and has authorised a 5 nautical mile separation standard. **Enroute surveillance**: Multilateration is likely to be able to be used in some "very wide area" applications. At this time, no ICAO approval has been obtained to use multilateration for this application. The Czech Republic has been using a specific type of multilateration for very wide area surveillance for some time in a search & rescue support role. "Very wide area" multilateration requires that multiple ground stations have the ability to "see" the aircraft over large areas.

	Typically this requires a high number of sites and hence makes multilateration a higher cost that anticipated because of site and data communication costs. A comprehensive site survey would be required to ensure that adequate coverage, geometry and site availability exists to meet the requirement. In States with particular requirements, a highly developed communications infrastructure, the cost of site development and data communication may be low enough for this to be preferred. Typically this may occur when terrain would prohibit cost effective radar coverage. **PRM**: Multilateration shows promise for use in PRM applications when sufficient aircraft are equipped because multilateration meets the accuracy and update requirements of PRM. However, at this time, no safety case or ICAO approval has been obtained to use Multilateration for this application. The USA and Australia envisage using multilateration for this purpose. **Airborne:** no application.
ADS-B	**Enroute surveillance**: ADS-B may be used in enroute airspace. Some States will require full ADS-B equipage whilst others will allow separation services without all aircraft being equipped largely dependent on their ATC automation system capabilities and traffic environment. ADS-B will bring safety improvements and automated safety nets where there is no surveillance today. ADS-B will be more readily used in ATC systems which can support low performance surveillance (eg voice reports) and high performance surveillance (eg radar or ADS-B) within a sector. Clearly benefits rise the higher the percentage of equipage. In many States, ADS-B will be used enroute in remote areas which have no radar surveillance. Other States will decommission enroute radars in lieu of ADS-B because of ADS-B's cost effectiveness. ICAO's SASP and OPLINK panels have agreed to the use of ADS-B to provide 5 nautical mile separation standards. The associated changes to PANS ATM doc 4444 are soon to be published. ADS-B may also be used in parallel with radar, improving overall performance by improving detection (coverage holes), improving tracking (using 24 bit code, using velocity vector), reducing latency and increasing update rate. **Terminal area surveillance**: ADS-B may be used in terminal area airspace to provide high quality surveillance data. The application of ADS-B in this domain is currently hindered by lack of equipage of ADS-B avionics. Comprehensive use in busy terminal areas will require a relatively high percentage of equipage because of the difficulties and workload associated with procedural terminal areas. However, in some States mixed equipage may be possible. ADS-B positional data accuracy and ADS-B's high integrity are major advantages as well as the better velocity vector performance of ADS-B compared to radar. No ICAO approval yet exists for the use of a 3 nautical mile separation standard using ADS-B although work is currently being progressed by SASP. **Surface movement**: ADS-B has potential for surveillance on airport surfaces. No States have yet deployed ADS-B alone for this application. However surface surveillance systems have been commissioned to provide identity and emergency flag data to

	surface movement displays. **PRM**: ADS-B shows promise for use in PRM applications when sufficient aircraft are equipped because ADS-B meets the accuracy, velocity vector performance and update requirements of PRM. However, at this time, no safety case nor ICAO approval has been obtained to use ADS-B for this application. **Air-Air Applications**: ADS-B shows promise for use a large number of air to air applications. A number of States are examining strategies to improve safety, efficiency and increase capacity using these applications. This feature has significant strategic impact on the choice of technology for some States. Applications include In Trail Procedure, Airborne situational awareness, Merging & Spacing etc **Airborne:** A significant number of airborne applications of ADS-B are envisaged by the international community including Air Traffic Situational awareness, In trail procedures, Merging & spacing etc. Airbourne applications are seen by FAA and Europe as key elements of the next generation of Air Traffic Management and are critical to provision of future capacity.
ADS-C	Enroute surveillance in remote or oceanic areas Due to the low update rate, the cost of ADS-C avionics and service provision, it will not be preferred when other technologies can support surveillance. However, over the ocean or remote areas, where other technologies cannot be used, ADS-C will remain as the preferred surveillance tool. ADS-B may compete in cases where ground stations can be installed, for example on islands, oil rigs etc. ADS-C does not support 3 nautical mile or 5 nautical mile separation standards. ADS-C does not support tactical ATC nor vectoring. **Airborne:** airborne equipment may be used for airline-specific communications such as systems monitoring, crew and airframe scheduling and customer care requirements.

6.2 PERFORMANCE CHARACTERISTICS

Since this document is aimed at discussing alternative technologies to be deployed in the future, the performance of new generation radars shall be assumed. This is in contrast to many comparative documents that compare existing (old) radar performance with new surveillance technologies to demonstrate that the new technology is safe.

	Range	Accuracy	Integrity	Resolution	Update period
Primary radar	S-band typically 60-80 NM L-band 160-220 NM	In range : 0.1 NM rms or 0.2 NM 2 σ In azimuth : 0.15 degrees rms or 0.3 degrees 2 σ .	No "message by message" integrity report provided. Range/Azimuth alignment can be assured through statistical comparison of SSR & primary radar reports. Alternatively special primary test units may operate like a SSR site monitor.	1 to 3 degrees in azimuth	Between 4 & 15 seconds
SSR	200 NM-250 NM	For a monopulse radar In range : 0.03 NM rms In azimuth : 0.07 degrees rms or 0.14 degrees 2 σ for random errors. [13]At 50 NM range the 0.14 degree error results in a position error of 0.12 NM. At 100 NM range : 0.24NM, At 200 NM : 0. 48 NM At 250 NM : 0.60 NM	No message by message integrity. Testing of site monitor provides integrity check in general. Downlinked data such as altitude & 4 digit identity is subject to transmission errors which are passed to controllers. Subject to mode A/C code garbling.Subject to confusion between mode A and Mode C data.	0.5 to 1 degree in azimuth	Between 4 & 15 seconds

[13] The range noise errors are 0.03 NM (1σ) and the noise errors in azimuth are 0.07 degrees (1σ). For comparison purposes, and since GPS (ADS-B) errors are expressed with respect to a positional error with 95% confidence, this paper will use 2 σ (95% assuming Gaussian distribution of errors) - namely a 0.14 degree error.
Taking into account the random noise errors only: At 50 NM the 0.14 degree error results in a position error of 0.12Nm. At 100 NM this error becomes 0. 24NM, 0.48 at 200 NM and 0.60Nm at 250 NM. In addition to these errors one must consider systematic errors of alignment. Radars can be maintained aligned accurate to +-0.05 degrees in azimuth. Azimuth errors are clearly the dominant error as range increases, and can be translated into positional errors as follows: Systematic errors of +- 0.2Nm at 250Nm from the radar also need to be considered when using Multi Radar to separate aircraft and when separating aircraft from terrain or geographical boundary.

	Range	Accuracy	Integrity	Resolution	Update period
ModeS	200 NM-250 NM	Same as SSR	No message-by-message positional data integrity. Testing of site monitor provides integrity check in general. Mode S downlinked data is subject to stringent transmission error detection algorithms virtually eliminating the risk of undetected false data.	Perfect for mode S avionics due to ability to uniquely interrogate one aircraft 1 degree in azimuth for mode A/C transponders	Between 4 & 15 seconds
ADS-B	200 NM-250 NM	Determined by the aircraft avionics and independent of range from sensor. For GPS, typically : 95% less than 0.1 NM	Position integrity guaranteed to $1*10^{-7}$ [14]due to RAIM algorithm in avionics. Integrity value is downlinked in the ADS-B message. A site monitor typically augments the integrity monitoring and often also supports GPS constellation monitoring. ADS-B downlinked data is subject to stringent transmission error detection algorithms virtually eliminating the risk of errors in the transmission medium	Perfect due to Mode S avionics unique 24 bit code and random transmission requirements	0.5 seconds from aircraft. Typically 1 second from ground station. In high density environments with significant 1090 Mhz FRUIT, the update rate may be reduced

[14] Sometimes limited to 10^{-5} to account for software assurance level

	Range	Accuracy	Integrity	Resolution	Update period
Multilateration	Determined by the geometry of the ground stations.	Determined by geometry of ground stations with respect to the aircraft. Therefore each multilateration system is designed to achieve a defined accuracy for the particular operational requirements of the service volume. Higher accuracy requires better geometry and typically more ground stations. Very high accuracy in some areas and low accuracy in others. A requirement for multilateration accuracy < 0.1 NM rms is reasonable for such a system. ie 0.2 NM at 2 σ The number and position of ground stations required to achieve this accuracy can then be determined. Processing systems need to filter received information based on geographical area and DOP of receiver system when accuracy of the report is less than that required for the operation.	Position integrity could in theory be guaranteed by reception algorithm if an overdetermined solution is available. This could operate like the RAIM algorithm in GPS. Current implementations do not require an overdetermined solution. Insistence on such a solution would require multilat systems to flag to downstream users whether or not an overdetermined solution is provided. It would also require additional ground stations and costs. Downlinked data from Mode S transponders (but not A/C transponders) is subject to stringent transmission error detection algorithms significantly reducing the risk of false data. Provision of a site monitor can provide a general system integrity check but does not provide integrity data relating to each aircraft.	Perfect for Mode S avionics due to unique 24 bit code and independence of transmission times. For Mode A/C transponders, position resolution is good due to multilateration technique. With Mode A/C avionics, aircraft at same range (and hence possibly garbled) from one ground station are not at the same range from other ground stations. Some multilateration implementations use whisper-shout techniques to resolve Mode A/C transponders.	Typically 1 second for Mode S aircraft. Typically 2.5 to 5 seconds for Mode C transponder aircraft.

	Range	Accuracy	Integrity	Resolution	Update period
ADS-C	200 NM from VHF ground station or via satellite (unrestricted except for polar regions)	Determined by the aircraft avionics. Typically 99% less than 0.2 NM	An Actual Navigation Performance (ANP) value is provided by avionics and generates FOM value to ATC. This is an "accuracy" value and no integrity measure is conveyed to the ATC centre. Downlinked data is subject to stringent transmission error detection algorithms (CRC) virtually eliminating the risk of false data.		Typically a report each 14 minutes. However, also supports event contracts which initiates unscheduled reports on occurrence of defined events.

	Availability	Typical Reliability – MTBF (Continuity) & Major factors	Maturity	Anomalies
		Reliability and availability are very specific to the deployment of concern because they depend on organisational factors, maintenance, telecoms infrastructure as well as hardware and software. Therefore the values shown are very generic.		
Primary radar	> 99% NB: Outages for routine antenna maintenance required	For duplicated system > 20,000 hours Modular and fail soft transmitter & reliance on single antenna. Relies on mechanical machinery for antenna rotation Duplicated receiver/processing	Very mature. Thousands of systems installed. Separation standards and procedures are established in PANS ATM Doc 4444	Affected by weather, "road traffic", multipath, and ground clutter
SSR	> 99 %[15] NB: Outages for	For duplicated system	Very mature. Thousands of systems installed	Affected by multipath, reflections, second time around replies, plot splits, garbling, resolution loss & data corruption

[15] Eurocontrol standard document for radar surveillance in enroute airspace and major terminal areas para 7.4 : <9 hours/ year = 99.9%
Australia : Planned outages over 10 years (inc major bearing refurbishment) 52 hours/pa average plus unplanned 9 hours = 99.3%

	Availability	Typical Reliability – MTBF (Continuity) & Major factors	Maturity	Anomalies
	routine antenna maintenance required	> 20,000 hours Reliance on single antenna. Relies on mechanical machinery for antenna rotation. Duplicated transmitter/ receiver	Separation standards and procedures are established in PANS ATM Doc 4444	
ModeS	> 99% NB: Outages for routine antenna maintenance required	Same as SSR For duplicated system > 20,000 hours	Reasonably mature. Deployments have occurred in Europe, UK & New Zealand although few are operating in purely ModeS modes. Most interrogate A/C as well. Few ATC systems are operationally using Mode S downliked parameters (DAPs). Separation standards and procedures are established in PANS ATM Doc 4444 since Mode S is treated in the same way as SSR. Operational procedures are still being developed for operational use of DAPs.	Similar to SSR for processing of Mode C transponders. Significantly less impact with Mode S transponders. Some new anomalies (loss of detection) associated with some older mode C transponders.

	Availability (of Service inc GPS & avionics)	Typical Reliability – MTBF (Continuity) & Major factors	Maturity	Anomalies
ADS-B	> 99 % NB: Some outages as a result of pre-alerted poor GPS geometry	Duplicated system >20,000 Hours Receiver only Dependence on GPS Duplicated receiver	Maturing. Operational in at least 1 State. SASP and OPLINK panels have agreed with proposed ADS-B separation standards. Procedures have been defined for PANS ATM Doc 4444 and are expected to be published soon.	Some avionics "bugs" identified.
Multilat	>99%	Duplicated system >20,000 Hours Requires multiple sites & multiple communication links Failure of 1 receiver has geography related impact on performance. However, assume that extra ground stations provided to support any one failure	Maturing. Operational in ASMGCS (airport surface) applications worldwide. Operational as WAM in at least 1 State. SASP has development of separation standards on the work program.	Some "teething" problems identified. Careful tuning of each site used to overcome these.
ADS-C	>99% Also constrained by service guarantee by service providers.	2,000 Hours (Low reliability due non duplicated system)	Mature. Used worldwide as FANS1A. Is not an "ICAO system". Yet to mature for ICAO/ATN variants.	FANS1A anomalies documented and managed by FANS1A Central reporting agencies (CRAs) on behalf of States in regions.

6.3 DATA PROVIDED BY EACH TECHNOLOGY

The following provides a brief overview of the information that may be received and processed by the relevant surveillance technologies

	No transponder	Mode A/C transponder	Mode S transponder with DAPs
Primary radar	Position, calculated velocity vector from these position reports	No data is able to be provided by this sensor	No data is able to be provided by this sensor
SSR	No data is able to be provided by this sensor	Position, flight level (barometric), 4 digit octal identity, calculated velocity vector	Position, flight level (barometric), 4 digit octal identity, calculated velocity vector
Mode S	No data is able to be provided by this sensor	Position, flight level (barometric), 4 digit octal identity, calculated velocity vector	Position, flight level (barometric), 4 digit octal identity, 24 bit unique code, selected altitude, Flight ID, Selected Altitude, Roll Angle, Track Angle Rate, Track Angle, Ground Speed, Magnetic Heading, Indicated Airspeed/Mach No, Vertical Rate, calculated velocity vector[16]
Mulitlat	No data is able to be provided by this sensor	Position, flight level (barometric), calculated altitude, 4 digit octal identity, calculated velocity vector	Position, flight level (barometric), 4 digit octal identity, 24 bit unique code, selected altitude, Flight ID, Selected Altitude, Roll Angle, Track Angle Rate, Track Angle, Ground Speed, Magnetic Heading, Indicated Airspeed/Mach No, Vertical Rate, calculated velocity vector

[16] Based on European Mode S mandate for Elementary & Enhanced surveillance. Additional data block have been defined in Mode S standards and could be used in the future.

ADS-B	ADS-B Requires the aircraft to be equipped with either : - A Mode S transponder capable of ADS-B message transmission (appropriate transponder product and software version), plus appropriate data to be fed to this transponder, typically a GNSS receiver or - A standalone ADS-B transmitter device (perhaps independent of the transponder) able to transmit ADS-B messages according to the standards or - A Mode C transponder able to transmit ADS-B messages according to the standards.
	If ADS-B equipped : Current aircraft : Position, flight level (barometric), position integrity, geometric altitude (GPS altitude), 24 bit unique code, Flight ID, velocity vector, vertical rate, emergency flags, aircraft type category. Fully compliant DO260A[17] will add a number of data fields.

ADS-C	ADS-C Requires the aircraft to be equipped with either a) The FANS1/A package. This includes processing, GPS, ACARS VHF and satellite datalinks b) An ICAO ATN ADS-C avionics package
	If ADS-C FANS1/A equipped : Position, altitude, flight ID, emergency flags, waypoint events, waypoint estimates, limited “intent data”, limited wind speed data If ADS-C FANS1/A equipped : There are currently no aircraft providing ATN ADS-C

[17] RTCA DO260 : Minimum Operational Performance Standards for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)

6.4 COST

The cost to deploy and maintain surveillance systems is high. The total cost includes much more than the ground based electronic equipment itself. Consideration of the following points is required when examining the total cost of various systems.

6.4.1 Aircraft owner/operator costs

In comparing the total cost of surveillance systems, some consideration must be given to airborne equipment requirements, which may be considerable for some technologies.

The total lifecycle cost should be considered. The timing of transition to new avionics is governed by numerous factors including the expected life of the aircraft, the cost, the benefit that can be obtained, available products and mandatory avionics requirements.

In considering the various ground based surveillance technologies it can be noted that:

- Primary radar surveillance does not require avionics deployed in aircraft.
- Multilateration surveillance can operate with Mode C, Mode S or ADS-B avionics. It operates better when aircraft are Mode S or ADS-B equipped.
- Mode C based surveillance requires either Mode S or Mode C transponders on board aircraft.
- Mode S based surveillance requires Mode S transponders supporting Elementary and/or Enhanced surveillance parameters if the DAPs benefits are to be realised.
- ADS-B surveillance requires either
    - A suitable Mode S transponder (hardware/software), or
    - A mode C transponder with capability to transmit ADS-B messages, or
    - A standalone avionics package able to transmit ADS-B messages.
    - In addition it requires the transmitter to be connected to appropriate GNSS receiver (or equivalent performance position source)

The costs associated with any aircraft equipage program (for new production aircraft, as well as for retrofit) are highly variable and airframe dependent. Hundredfold cost variations to fit the same avionics to different aircraft types are not uncommon. Operating costs are also highly dependent on aircraft type, fleet size and nature of operation but include

- Engineering support costs
- Scheduled & unscheduled Maintenance
- Flight crew training costs
- Costs associated with aircraft simulator upgrades

For these reasons avionics costs associated with each surveillance technology will be very FIR (or ANSP) specific. However, the nature of the aviation industry (in particular cross FIR and international operations, fleet turnover and the prevalence of aircraft leasing) mean that it is impossible – and unhelpful – to attribute the total cost of avionics equipage to any one FIR, ANSP or surveillance system. It must be noted that some of the avionics required to support surveillance – in particular ADS-B and ADS-C – have other applications and hence benefits to operators.

The current status (2007) of avionics equipage is :

	Mode S	**Mode C**	**ADS-B**
International air transport	Almost all aircraft are equipped with Mode S; ACAS equipped aircraft have Mode S transponders. A large percentage of aircraft that operate in and transit Europe are also equipped with DAP capability	Almost all are equipped with Mode C capability Most new aircraft delivered in the last 5 to10 years are equipped with GPS and most of these have the capability to output HPL integrity data for ADS-B. This is particularly true in Asia Pacific region with its new fleets.	A large percentage of new aircraft manufactured in the last 2 years are equipped. Many legacy aircraft are being equipped at the same time as the European Mode S mandate is implemented.
Domestic major airline air transport	Almost all aircraft are equipped with Mode S; ACAS equipped aircraft have Mode S transponders	Almost all are equipped with Mode C capability. Many aircraft are equipped with GPS and most of these have the capability to output HPL integrity data for ADS-B	New aircraft from Boeing & Airbus are equipped. Many legacy aircraft are not equipped.
Regional aircraft	Many regional aircraft are equipped with Mode S	Almost all are equipped with Mode C capability Many aircraft are equipped with GPS but only some have the capability to output HPL integrity data for ADS-B	Very few are equipped with ADS-B capability because Regional Airliner OEMs have not embraced ADS-B
General aviation	Few general aviation aircraft are equipped with Mode S	Many are equipped with Mode C capability. Many aircraft are equipped with GPS but few with capability to output HPL integrity data for ADS-B	A few are equipped with ADS-B capability using a single GA product. There is insufficient choice in ADS-B products available today for this market.

Taking the above into account, it is very difficult to allocate a cost to equip with any avionics type. Clearly the transition to ADS-B equipage is the most significant and expensive of the alternatives in terms of aircraft equipage).

The APANPIRG meeting report of 2006 states that

> *"IATA noted that much of the business case is complicated by the problems of quantifying the cost of ADS-B avionics fitment by airlines. In this regard, IATA recommended that APANPIRG should simply assume that all aircraft will be equipped as a consequence of the worldwide move towards ADS-B OUT and Mode S Enhanced Surveillance."*

6.4.2 ANSP costs

ANSP costs include:

- Equipment purchase
- Installation costs and system testing
- Project costs including planning, procurement activities etc
- Site costs including
  - land
  - environment impact statement preparation
  - power provision
  - UPS and batteries
  - airconditioning
  - roads
  - shelters
  - racks in which to install main and ancillary equipment
  - towers
  - fencing
  - land clearing
  - security
  - telecommunication lines
- Operating costs
  - Engineering support costs
  - Scheduled and unscheduled Maintenance
  - Power and airconditioning running costs
  - Telecommunication operating costs

Taking the above factors into account and using experience of the technologies to date, the cost of surveillance to support enroute and TMA airspace is shown in the following table.

This table assumes that the selected sites are **NOT** "Greenfield" sites and hence do not include land purchase, environmental clearance, shelter and road building costs.

The table does NOT include avionics costs.

	Major cost factors	**Cost for TMA (60NM radius) $ Australian**	**Cost for Enroute (200NM radius) $ Australian**
Primary radar	Site costs, capital cost, ongoing maintenance & management costs, large UPS & power supply especially for antenna. No avionics required.	$8M	$10-14M

	Major cost factors	**Cost for TMA (60NM radius) $ Australian**	**Cost for Enroute (200NM radius) $ Australian**
SSR	Site costs, capital cost, large UPS & power supply especially for antenna, ongoing maintenance & management costs. SSR Mode C avionics required. In some regions the majority are required to be Mode C equipped.	$6M	$6M
Mode S	Same as SSR. Most vendors offer ModeS radars as "standard" at a similar price to SSR. Mode S avionics required.. Air transport already have Mode S to support ACAS in most parts of the world.	$6M	$6M
ADS-B	Apart from avionics installation, major items are site related costs and ongoing telecommunication costs. ADS-B avionics fitment is not included in estimate here because of difficulty in attribution of cost especially for international aircraft where the fitment supports surveillance in all ADS-B capable FIRs/ANSPs. Major airframe manufacturers fit ADS-B in the factory. IATA has recommended at APANPIRG that APANPIRG members ignore fitment costs be ignored in business case development.	$380K	$380K
Mulitlat	Major items are site related costs and ongoing telecommunication costs. If the operational requirement does not demand coverage extended range coverage (eg say coverage is only required to 40 nautical miles) then multilateration is a stronger competitor. Ie: it may not be warranted paying the extra costs for long range performance provided by radar . Of course each individual case must be considered because the costs are highly dependent on the environment, cost and infrastructure in the country of deployment. Multilateration is a stronger competitor against radar when the required area of coverage is small. Use of Greenfield sites could dramatically increase costs due to development and possibly the number of sites required. Site development costs can easily exceed equipment costs. At least SSR Mode C avionics are required but Mode S avionics are required for best performance.	>$1-$3 M	$2M - $5M

	Major cost factors	Cost for TMA (60NM radius) $ Australian	Cost for Enroute (200NM radius) $ Australian
ADS-C	No sensor cost. Minimal setup cost for ANSP. Large cost of FANS1/A avionics and associated equipment for new aircraft (and very large for retrofit)..	N/A	N/A

Some further details are provided in **Appendix A**

7 ISSUES IN CHOICE OF SURVEILLANCE TECHNOLOGY

In the deployment of ATC surveillance technologies care is required to match the chosen technology to the operational need and environment. In some cases a clear choice will emerge for a particular State. In other cases a mixed solution may be best.

Some factors to consider are as follows :

7.1 COST

The cost of surveillance systems can be a major determinant of whether surveillance is deployed, and if it is deployed, which technology is chosen. In many States the availability of lower cost surveillance (compared to radar) has allowed surveillance to be provided in areas where surveillance was previously uneconomical.

In States where there is significant traffic, the operational need and the ability to use funds from airways charges will determine the deployment of surveillance.

The lowest cost surveillance to meet the particular operational needs in the particular environment will be chosen.

The issue of who bears the cost and who benefits also needs to be considered.

> For example : Safety benefits may be provided to the whole community. Efficiency benefits may be provided to the airlines and their customers. Costs of surveillance system delivery are usually borne by the ANSP and sometimes passed to airspace users in charges. If new avionics are needed to be fitted to aircraft consideration of who pays for that equipment is required. In some cases the ANSP may be able to subsidise some segments of the industry to equip their fleet. In other cases airlines and aircraft owners bear the entire equipment cost.

Cost is further examined in Paragraph 6.4 as well as in Appendix 1.

7.2 MARKET SEGMENT MIX

The nature of the aircraft to be subject to surveillance is a determinant of the best technology to use

- non cooperative aircraft (targets) can only be detected by primary radar

- cooperative air transport aircraft can be expected to have Mode S or ADS-B equipment and hence ADS-B or SSR/Mode S may be the most appropriate technology

- If general aviation aircraft are to be detected, SSR or ADS-B avionics may need to be installed in those aircraft. This issue can become problematic if a large general aviation fleet operates in the State. If the general aviation fleet is small, it may be cost effective to use ADS-B and pay to fit the small number of aircraft with ADS-B.

In some States the market mix, and which part of the market would pay for avionics fitment is a critical issue.

Equipage of military aircraft can be problematic. However, each State needs to consider the role of the ANSP in the provision of surveillance facilities to support the military.

7.3 AIRSPACE SEGREGATION

In some States, airspace can be segregated so that equipped aircraft are able to access defined airspace whilst non equipped aircraft are permitted to operate in different airspace.

7.4 GEOGRAPHY

The decision making needs to consider the obstacles to radio propagation for all relevant technologies. In some cases the geography may favour radar, in other cases it may favour multilateration.

SSR/Mode S radar has a long range capability from a single site due to its high gain antenna. It is well tailored for upper airspace detection up to 250 NM if the geographical location is free from close obstacles.

Multilateration is particularly effective in areas of constrained line of sight situations, due to its ability and adaptability to fill smaller specific area of surveillance. Ie: in places where the benefits of long range radar performance cannot be realised.

The choice of ADS-B is not really affected by geographic considerations because it achieves coverage as good as either multilateration or radar from fewer sites.

In the case of very remote or oceanic regions, there may be no choice apart from ADS-C.

7.5 EXISTING TELECOMMUNICATIONS INFRASTRUCTURE

In cases where there is comprehensive telecommunications infrastructure it will be more easy (and hence less expensive) to install ADS-B and multilateration ground station sites. When telecommunications infrastructure does not exist it can be costly to establish.

7.6 EXISTING SURVEILLANCE & ATC AUTOMATION INFRASTRUCTURE

There are significant benefits of a homogeneous surveillance infrastructure. If one technology (and one vendor) is chosen there are savings in engineering support, training, documentation management and system planning. This can impact on the choice to support additional or new technologies.

The ATC system used by a State may need to be upgraded to support any or all of the technologies listed in this paper. The cost of performing these upgrades needs to be considered. There may also be lower overall costs if the ATC automation system only needs to support the one surveillance technology, although there are operational advantages if the ATC system can support multiple surveillance technologies.

Some ATC systems and associated operational procedures can support ADS-B use, including delivery of separation services, when there is partial aircraft ADS-B equipage. Typically such systems support the graphical display of ADS-B, radar and flight plan tracks.

Other ATC systems and/or operational procedures require complete equipage for ADS-B use to be viable.

7.7 REQUIRED FUNCTIONALITY

Depending on the State’s functional needs, different technologies may be chosen. Each technology has different functional capabilities beyond detection and provision of position and altitude data. Eg: Mode S is able to provide readout of selected altitude; some multilateration systems are able to provide a precise position report independent of GPS; ADS-B is able to provide a high update of high accuracy velocity vector.

Some States require the use of primary radars to support Defence needs rather than Air Traffic Management requirements.

7.8 ABILITY TO MANDATE EQUIPAGE

The choice of SSR, Mode S, multilateration or ADS-B may depend on the State's ability to mandate that aircraft operating in the airspace must be equipped with the required avionics. The State's ability to issue a mandate may depend on many factors.

7.9 AIRSPACE CAPACITY REQUIREMENTS

The capacity of airspace can be increased through the provision of high quality surveillance. This is achieved through the application of reduced separation standards.

At this time ICAO recognises that 3 nautical mile and 5 nautical mile separation standards may be used using primary radar, SSR, and Mode S radar. Changes to ICAO documents are about to be published recognising ADS-B use to support 5 nautical mile separation standards. SASP is working on proposals to allow 3 nautical mile separation standards using ADS-B and also on the use of multilateration to support both 3 and 5 nautical mile separation standards.

ADS-C is unlikely to ever support 3 and 5 nautical mile separation standards. However it is used to support 30/30 and 50/50 nautical mile procedures used in some regions.

7.10 STRATEGIC NATURE OF TRANSITION TO ADS-B

It is widely recognised that ADS-B will eventually become the preferred surveillance technology worldwide, although this will take time.

ICAO, at ANC11 resolved that

"*ICAO and States recognize ADS-B as an enabler of the global ATM operational concept bringing substantial safety and capacity benefits*"

Therefore decision making by States will consider the long term enabling of ADS-B balanced against short term requirements.

For some States it may be too difficult to fit enough aircraft with ADS-B avionics and radar or multilateration may be necessary until ADS-B fitment occurs.

Some States may view the benefits of ADS-B as so large that strategically they move to this technology as soon as possible. Typically this is because in the long term, once aircraft are equipped, ADS-B has strong performance in numerous areas :

- lowest cost of additional surveillance coverage
- **allows air-air surveillance benefits**
- allows low cost surveillance for 3rd party applications (flying schools, Search & Rescue…)

The issue of enabling air-air surveillance is significant since it has the potential to change the way in which ATM is performed. The ability for aircraft pilots to electronically "see" nearby aircraft changes the risks encountered in certain airspace compared to today's practice where pilots use the human eye. ADS-B technology has the potential to significantly influence airspace classification, ATC procedures and system efficiency.

For the airline community, the future air-air applications promise increased capacity, functionality, reduced cost. Some see that they will only be able to cope with future air traffic needs by using aircraft centric – network enabled aircraft. ADS-B is a key component of such a vision. The airline UPS is pioneering considerable work in this area along with the work of the FAA-Eurocontrol Requirements Focus Group.

It is interesting to review the views of a major ANSP customer IATA. The meeting report of APANPIRG 2006 states :

> *"IATA noted that much of the business case is complicated by the problems of quantifying the cost of ADS-B avionics fitment by airlines. In this regard, IATA recommended that APANPIRG should simply assume that all aircraft will be equipped as a consequence of the worldwide move towards ADS-B OUT and Mode S Enhanced Surveillance."*
>
> *It was also informed that as indicated in its CNS/ATM road map published in 2005, IATA supported to mandate the use of ADS-B OUT from 2010 and simultaneously avoid the installation of new or replacement ATC radar facilities where there are demonstrated operational and cost benefits"*

7.11 VERIFICATION OF ADS-B

Some commentators have promoted the use of multilateration as a means of ensuring the validity of received ADS-B data. Technically this is possible. Radar could also be used to verify the integrity of ADS-B data. If radar and/or multilateration in **all** areas of ADS-B coverage is required, then the most advantages of ADS-B are significantly diminished and the ADS-B deployment becomes unlikely. Verification could perhaps be achieved at major airport hubs aimed at detecting non compliant avionics and triggering corrective action – perhaps in the same manner as Mode S and RVSM monitoring stations.

Periodic verification could perhaps be performed by ramp check units in the same manner as SSR transponder verification.

It must be recognised that integrity monitoring of ADS-B positional data is performed by the GPS integrity monitoring function within the aircraft avionics. This is the same monitoring function used to ensure that aircraft may safely conduct non precision landings with GPS – and associated “separation” from terrain.

The only envisaged integrity check for ADS-B air to air applications will be to monitor the ADS-B integrity data transmitted with the ADS-B message.

Regulations can require that aircraft owners provide high quality ADS-B data together with the appropriate integrity qualifiers. In the same way that airworthiness authorities ensure that Mode C data is trustworthy, authorities need to ensure that ADS-B data is trustworthy. Verification of ADS-B data using radar or multilateration is neither required nor justified in most States.

7.12 ADS-B MULTILATERATION MIXED SOLUTION

In some environments a mixed solution may be appropriate whereby multilateration is used to provide coverage in a “central” area, typically at an airport, for both equipped and non ADS-B equipped aircraft. In addition, each multilateration ground station supports ADS-B only coverage to a larger coverage volume surrounding the “central” area.

In this environment. the central area could be a Terminal Manoeuvring Area (TMA) where both airlines and general aviation co-exist at lower flight levels. Outside this area, services are only provided to ADS-B equipped aircraft outside coverage of multilateration.

A number of existing ASMGCS systems using multilateration are able to support this mixed technology solution.

8 SURVEILLANCE INTEGRATION

There are a number of ways that surveillance data from different sensors can be incorporated into an ATC system. Typically these can be :

- A separate display for each technology, although this approach is not desireable it has been used in a number of cases for demonstration or to build operational experience before further integration is performed.

- A priority system whereby one technology (or data from a particular site) is displayed and other data sources discarded whilst the priority source provides useable data

- A fully fused position calculation whereby data from different technologies are used to calculate a best estimate of aircraft position,

All solutions need to consider how best to present the data including consideration of the following :

- What position symbols will be presented?

- Will different symbols be used to indicate data quality or data source

- Will the data be used for situational awareness or for execution of ATC separation services?
- Will a prediction system advise users of potential radar, multilateration or ADS-B outages
- Will coasting of positional data be used? Will “smoothed” data be presented?
- What update rate is displayed to the user ? Is the update synchronised to a particular sensor or is independent of any sensor input?
- How is alignment maintained and monitored between various position sensors?
- Does the controller have the ability to select/deselect a sensor or technology?

9 SURVEILLANCE TECHNOLOGY SELECTION

This section outlines some indicative cases where the environment may suggest particular solutions. It needs to be clear that the total environment including available funding, politics, and numerous other factors also impact on the choice of technology, therefore the solutions presented can only be indicative :

	Solution	Reason
State has a large fleet equipped with Mode C ATC transponders and surveillance is needed in the near term. Intruder protection not required	Multilat (WAM) with ADS-B capability to support future ADS-B equipage	Near term requirement makes it difficult to fit many aircraft with ADS-B
State requires surveillance on a busy airport surface. Detection of vehicles is also required	Multilat and primary radar. ADS-B as part of multilat could used to detect & identify vehicles some of which are itinerant	Effective multilat surveillance with good accuracy and provides identity. Primary radar used for vehicles without transmitters
State has requirement for surveillance of air transport aircraft (small GA fleet) and has an ATC system able to support ADS-B mixed equipage.	ADS-B only with optional fitment.	Percentage of air transport aircraft that are equipped is rising. Could encourage ADS-B equipage by giving improved services & priority to equipped aircraft. Allows non equipped aircraft to operate. ANSP could purchase ADS-B avionics for small fleet.
State has requirement for surveillance of air transport aircraft (minimal GA aircraft) and does not have an ATC system able to support ADS-B mixed equipage.	ADS-B only but equipage mandatory in designated airspace	Percentage of air transport aircraft that are equipped is rising. Can mandate ADS-B in relevant airspace to provide surveillance at minimum cost to ANSP
State provides ATM services to a large number of operators that are unable to fit ADS-B, but already have SSR transponders – surveillance is required enroute	SSR only sensors	Cost of equipping a large number of air transport carriers may be cost prohibitive to Industry
Surveillance needed in relatively small geographical area – without concern of non transponder equipped	Multilat (WAM) with ADS-B capability	Multilat can serve the small area with the benefits of ADS-B delivered for air transport

intruder aircraft, but Air transport also operate into area with ADS-B. GA aircraft that may operate into area not able to be fitted with ADS-B		operating in a larger area of coverage.
High density airport with need for airspace intruder protection (ie: to detect violations of controller airspace)	Primary & co-mounted Mode S radar	Primary radar for intruder protection. Mode S to maximise resolution and position display performance and to maximise benefits of investment in SSR – even if ATC system cannot yet process Mode S DAPS
Surveillance needed for small GA domestic fleet plus some international carriers. Limited funds available.	ADS-B only but perhaps subsidise fitment of GA if required. Mandate ADS-B equipage	Subsidy cost may be less than cost of multilat or radar
State requires surveillance for a very large airspace and has minimal funds available and there is no surveillance today	ADS-B only	Most effective solution.
State requires surveillance over an ocean without islands for radar or ADS-B stations.	ADS-C	Only alternative
State requires surveillance at an FIR boundary but has no site for radar or ADS-B – and has limited capital funds – typically for FIR boundary safety.	Service provider provision of ADS-B surveillance or If adjacent FIR has surveillance negotiate an agreement for data sharing	Cost effective surveillance without capital cost
State has coverage requirements that are complicated by terrain restrictions that would have previously required multiple radars to solve – and has good physical and telecommunications infrastructure	WAM multilat with ADS-B support	Cost of site preparation and installation and support of radars would be cost prohibitive. Multilat and/or ADS-B offers the only cost effective solution to meet the requirement. Good infrastructure allows multilateration to be deployed cost effectively.

10 CONCLUSION

The optimum choice of surveillance technology depends on the operational requirements and environment.

As recognised by ICAO at ANC11, ADS-B is a technology of the future. States will work towards its deployment but will consider alternative technology, when cost effective.

ADS-B is the only technology which supports future applications of air to air surveillance. Some states see this as a decisive strategic factor in moving towards ADS-B.

1 APPENDIX A : Cost comparison multilateration and radar

The following examines the costs of radar and multilateration in two scenarios; one where surveillance coverage is needed in an area of radius of 200 NM and another when coverage is needed for a 40 MN radius.

Case 1 : Area of 200 NM radius

In this short analysis it is **assumed** that only 9 multilateration ground stations are required to achieve a coverage of 200 NM in accord with a NLR report[18]

The NLR report presented a 9 ground station multilateration solution designed to provide 200NM coverage (125,663 sq NM) to approximate a 250 NM (196,349 sq NM) coverage of a radar.

It is far from clear whether a realistic multilateration system can be built to support a 200 NM radius area with 9 ground stations. Such a "paper design" does not examine the issues of terrain, site availability and product availability with high power interrogators. Of course the operational coverage needs would also need to be considered, and it is likely that coverage at lower flight levels would bring the need for additional multilateration sites.

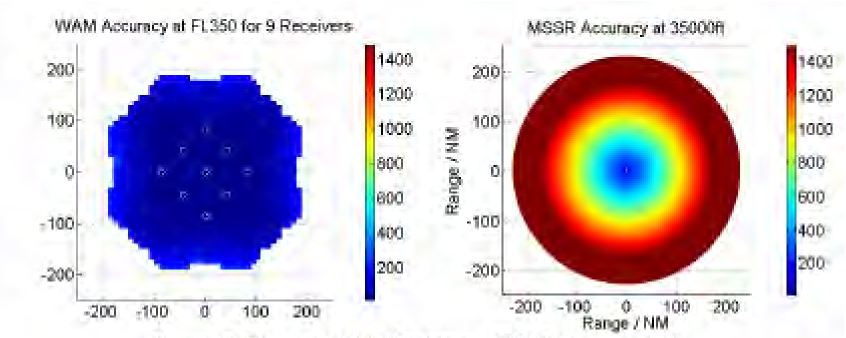

Figure 27 Extended WAM System vs. MSSR (accuracy in ft)

Figure 27 of NLR report

This analysis has been conducted using very approximate estimates of costs.

	Multilat system Assume 9 sites (4 tx/rx, 5 rx)	Radar
Equipment cost	$1.05M	$6M
Tower and antenna mounting[19]	$0.36M	included
Power supply and backup if required	$180K	included
Telecommunications establishment	$90K	$10K
Telecommunications ongoing costs	$1.35M	$150K

18 National Aerospace Laboratory NLR report prepared for Eurocontrol : NLR-CR-2004-472 "Wide Area Multilateration Report on EATMP TRS 131/04 Version 1.1 August 2005 available at http://www.eurocontrol.int/surveillance/gallery/content/public/documents/WAM_study_report_1_1.pdf Used with permission of Eurocontrol.

19 Tower expected to achieve maximum line of sight and minimise number of sites

($15K/pa = assume 10 years)		
Installation activity (planning, travel, testing)	$90K	$20K
TOTALS	**$3,120K**	**$6,190K**
For maximum range radius of	200 NM	250NM

If one assumes that an enroute WAM is based on a set of 9 ground stations using existing sites (as described above) then the cost per square nautical mile of coverage is

C(mlat) = $3,120/125,663 = $24.82 per square NM

C(radar) = $6,190,000 / 196,349 = $31.52 per square NM

It must be remembered that these estimates are highly dependent on the environment, cost and infrastructure in the country of deployment. However, these figures indicate that multilat could approach or even exceed the cost of radar in some environments.

If "greenfield sites"[20] are assumed the comparison moves in favour of radar.

	Multilat system(9*)	Radar
Land purchase or lease	$90K	
Environmental impact study/ statement/clearances	$720K	$200K
Shelters or building including fencing & security	$450K	$50K
New road cost if required (very site dependent).	9 * M$x	M$x
TOTAL	**$1260K + road**	**$250K + road**

[20] sites that do not have a building, road, shelter or other infrastructure

Case 2 : Area of 200 NM radius

If the coverage requirement is for a terminal area of say 40 Nautical miles radius then less multilateration ground stations would be required. Lower power interrogation units would be required.

Assuming a more realistic 7 sites (in a location without terrain issues) and the analysis could look like

	Multilat system Assume 7 sites (3 tx/rx, 4 rx)	Radar
Equipment cost	$0.86M	$6M
Tower and antenna mounting[21]	$0.28M	included
Power supply and backup if required	$140K	included
Telecommunications establishment	$70K	$10K
Telecommunications ongoing costs ($15K/pa = assume 10 years)	$1.05M	$150K
Installation activity (planning, travel, testing)	$70K	$20K
TOTALS	**$2,426K**	**$6,190K**
For maximum range radius of	40 NM	250NM

In this case, if the operational requirement does not demand coverage beyond 40 nautical miles it does not warrant paying the extra costs for a radar (even if it provides 250 NM.

Of course each individual case must be considered because the costs are highly dependent on the environment, cost and infrastructure in the country of deployment. Multilateration is a stronger competitor against radar when the required area of coverage is small.

21 Tower expected to achieve maximum line of sight and minimise number of sites