# Air Traffic Surveillance – Building Capacity and Enhancing Safety

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## *Abstract*

*Surveillance of aircraft is a key requirement of any effective air traffic control system. Classical methods of surveillance, both ground to air and air to air, have their limitations depending upon the environment in which they are used. These limitations primarily manifest themselves in terms of cost and capacity, with surveillance capability already being a limiting factor in the growth of air traffic in certain regions.*

*Various methods and applications are being developed to overcome surveillance limitations on air traffic growth, the primary objective of which is to enable increased traffic flows whilst enhancing the existing levels of safety. Developments underway in various regions of the world are considering both near term and longer term enhancements to surveillance capability as part of a more effective air traffic management system.*

*One of the prime focus of these developments is a shift away from classical 'active' surveillance to a 'passive' surveillance based system where the aircraft is responsible for providing the necessary surveillance data rather than the interrogating system. Such an approach can provide significant enhancements in terms of cost and capacity but also brings potential safety risks that need to be effectively managed, particularly during the transition.*

*This objective of this paper is to outline the benefits that such a transition could provide whilst highlighting some of the key safety issues and how they could be addressed. The paper concludes with a vision of a future air traffic surveillance system and a safe transition towards it.*

## Background

For the safe and effective management of air traffic, surveillance is a key tool that enables those responsible for separation to maximise the use of airspace and maintain safety. Surveillance methods in use widely today vary from the high accuracy radar surveillance used in busy airspace and terminal areas, to the procedural verbal position reporting used in remote or oceanic areas where there is low traffic density.

In the radar environment there are three types of radar surveillance in use around the world, often in combinations and with multiple radar coverage:

### Primary Surveillance Radar (PSR)

Primary radar is the oldest form of radar surveillance and operates independently of an airborne equipage on the aircraft. The rotating radar antenna determines azimuth and range of an aircraft based purely on the reflection of RF power of the aircraft fuselage. The azimuth is determined from where the antenna is pointing and the range is a function of the time taken for the signal to travel to the aircraft and back.

The scenario could be likened to people moving around in a darkened room where the controller stands in one corner with a search light. As the searchlight is scanned across the room the controller becomes aware of the location of each person by the reflection of light off them.

The advantage of PSR is that it is completely independent of the aircraft so will always detect an aircraft (assuming it is large enough and not of a stealth design). Its significant limitation is that it provides no identification of the aircraft and the radar cannot determine the aircraft's altitude. The other major drawback of PSR is the cost to install and maintain a large rotating radar antenna.

## Secondary Surveillance Radar (SSR)

To overcome the limitations of primary radar, secondary radar was introduced. SSR is no longer an entirely independent system as it requires equipment to be fitted to an aircraft to enable it to be tracked, but the actual surveillance function (determination of range and azimuth) is still carried out by the radar so it is a co-operative surveillance system. In an SSR system a rotating antenna (significantly smaller than and often mounted on top of a Primary radar - see *Figure 1*) actively interrogates the transponder fitted to the aircraft. The aircraft transponder replies to the ground station within a controlled time so the radar can again determine range from the time taken for reply to be received.

SSR is implemented in a number of different modes, the most common being Mode A-C. In a Mode A-C scenario the transponder reply contains two pieces of information: An identity code (Mode A code) and the aircraft altitude (Mode C). In this system the Mode A code is a four digit code assigned to the aircraft by the controller and entered by the crew. This code is not globally unique, as there are only 4096 codes available, but must be managed in each airspace so they are always different.

Using the same analogy of people in a room, the use of Mode A-C SSR could be equated to each person holding a sign that states a number they were provided when they arrived and what floor of the building they are on. As the beam of light shines on them the controller can read the information so knows who they are and what their altitude is. This analogy also demonstrates one of the major limitations of a Mode A-C system. If when the light shines in one direction there are several people all together or one behind the other, the controller would have difficulty reading the information of each of them, both because of time limitations and some being obscured.

This limitation is known as 'Garble' where the responses overlap and become garbled. Another technical limitation is 'Fruit' where replies are received from an aircraft but not based on an interrogation from that radar, these replies cannot be used to determine range. The reply by every aircraft in the radar beam also creates significant RF congestion in the frequency band (1030MHz interrogations, 1090MHz replies) so that not all replies get through leading to the loss of aircraft tracks from the controllers screen.

Although Mode A-C provides an identification code associated to each aircraft tracked by the radar, the numbers of codes available are limited and they act only as a tag which can be translated on the ground to correlate to a particular aircraft and flight plan. In high density operations such as Europe the number of codes available is becoming a significant limitation and in an air to air scenario the Mode A code is of little value.

To overcome the primary limitations of Mode A-C SSR, Mode S (Mode Select) was developed. This mode allows each aircraft to be uniquely identified and individually interrogated. The individual interrogation capability allows the removal, or at least significant reduction, of garble from overlapping replies and frees up the 1090MHz band to allow more information than just altitude and identity to be transmitted to the ground.

Mode S in its simplest form has been implemented in the USA but not widely elsewhere. Within Europe it is planned for introduction from 2003 in a number of key states. In the European implementation, aircraft will also be required to transmit their flight identity or call sign that is used for ATC voice communications, so allowing a reduction in use of and reliance on Mode A codes.

Returning to the analogy; now each person also holds up a card with their full name on and they will only hold it up if specifically asked to when the light passes them.

Such an implementation of Mode S overcomes many of the problems associated with RF congestion, overlapping interrogations and unique aircraft identification.

The drawbacks to SSR that still remain are the high cost of rotating interrogators and their range and accuracy. Although SSR has traditionally been recognised as being a highly accurate source of surveillance information, which it is, as traffic density increases this accuracy could potentially become a limiting factor in effective use of airspace. Although accuracy of individual interrogations and replies may be high, an interrogator would usually be rotating at between 10 and 15 revolutions per minute, giving an effective update rate of between four and six seconds. In a radar network scenario, where there is multiple radar coverage, the update rate could be improved but the real time accuracy of the surveillance position will always be limited. The cost of interrogators and their range and update rate in many ways trade off against one another, to increase coverage and update rate more interrogators are needed requiring sites and significant capital investment. These drawbacks aside, Mode S is likely to become the major means for air traffic surveillance for some time to come.

## Air to Air traffic Surveillance

All the discussion so far has focused on the air to ground aspect of air traffic surveillance for the provision of ground based air traffic control. A number of mid air collisions in the USA in the late 1980’s lead to the development of an airborne collision avoidance system known as TCAS (Traffic Alerting and Collision Avoidance System), now standardised by the International Civil Aviation Organisation (ICAO) as an Airborne Collision Avoidance System (ACAS).

ACAS utilises the capability of the Mode S transponder to perform an air to air surveillance function in a similar way to that used by ground interrogators.

It would be impractical to fit rotating interrogators to aircraft so a four sector antenna is used and azimuth is then determined by either phase or amplitude comparison between the sectors. As for the ground the relative altitude is determined from the Mode C information from both aircraft.

The traffic information determined by ACAS is both provided to the flight crew on a display to provide them situational awareness and also used to determine collision risk. ACAS doesn’t as yet use the call sign data so the situational awareness display only shows unidentified traffic symbols. ACAS uses the effective closure rate between the two aircraft to determine the time within which safe separation will be lost and if the time is within a threshold, which varies with altitude, the ACAS declares that a collision risk exists. *Figure 2* shows they typical boundaries for the triggering of a ACAS warning. Once the ACAS determines this risk it will initially alert the crew to the other aircraft with a traffic advisory and then, if necessary, will issue an avoidance command to the flight crew, called a resolution advisory, which they should follow to reduce the risk of collision. The resolution advisory will always be in the vertical plane (either climb or descent) as that is the most accurate information ACAS has.

In the analogy scenario ACAS could be equated to providing all the participants in the room with their own torches so that they can also determine the location of other aircraft in the vicinity and avoid them if the controller fails to ensure separation.

The limitations of ACAS are similar to those for SSR in general, with the cost of an ACAS installation being high and its accuracy limited such that situational awareness and collision avoidance are the extent of its use. In the airborne case, range is a more significant limitation as the power required for long distance interrogation is high, particularly from a non-rotating antenna. For example a ground SSR would likely achieve a range or 400 Km, where as an ACAS installation may only achieve a maximum of 100-130 Km in good conditions.

## Limitations of existing Surveillance

The most fundamental limitation of all the surveillance means used today is that they are focused on the present and the past positions of the aircraft that they are tracking. None of these surveillance means provide information on the intent of the aircraft, other than the prediction of a trajectory from historical tracks based on the assumption that nothing will change. The lack of intent information in air traffic surveillance is today probably the greatest limitation to providing effective use of airspace.

The implementation of Mode S allows for the use of a protocol for the extraction of information, other than just flight identity and altitude, from the aircraft's systems. This function, often known as Downlinked Aircraft Parameters (DAPs), would allow for aircraft system information, such as aircraft speed, heading and potentially intent, to be stored in the transponder for extraction by the ground. This becomes possible because of the selective interrogation capability of the Mode S and the unique identify transmitted with every reply. This function is being proposed for introduction in Europe from 2005 onwards but focuses primarily on the use of real-time data from the aircraft to improve the controllers situational awareness rather than intent information for flight path prediction and de-confliction. It is however likely to be the largest step for air traffic surveillance that has been taken for many years and will enable intent based data to be built upon the capability as its value and integrity gets proven.

Allowable separation distances between aircraft are defined by a number of factors including the accuracy and reliability of the surveillance means. However the most important factor is how quickly the surveillance means can identify the loss or potential loss of separation, providing time for effective conflict resolution by the controller. For example using a single radar with a six second update rate a controller is unlikely to be able to determine that an aircraft has started a turn for maybe three or four sweeps of the radar, a delay of maybe 20 seconds after a turn has started. Horizontal separation minima are much greater than vertical minima because the vertical surveillance is based on the Mode C data from the aircraft so a change can be picked up in one or two radar sweeps.

From the air to air perspective, although ACAS provides a very significant role in collision avoidance, its effectiveness is limited by the lack of any intent information. Although it doesn't suffer from the same update rate limitations of the ground system (ACAS air to air interrogation rate is once per second), the short ranges involved mean that the predicted trajectories lead to false warnings, particularly for manoeuvring traffic in dense airspace.

The other main limitations, mentioned previously, primarily involve a trade off between cost, range and accuracy. Active rotating interrogators are a significant capital expense and require sites, maintenance etc.  To improve coverage range and update rate requires more interrogators in a particular area.  From an airborne perspective a similar trade off exists and, although short ranges are all that is required for collision avoidance, effective situational awareness for the crew requires greater ranges than are generally available today.

## Alternatives to Active Surveillance

All the surveillance means discussed so far are based on active interrogations to determine the surveillance data.  They also provide an independent means for the interrogator to determine the range an azimuth of the aircraft although are all dependent upon the aircraft to provide its altitude from on-board systems.

An alternative to active independent surveillance is to use passive dependent surveillance where interrogators would not be required to provide the surveillance data. The surveillance information would however be totally dependent upon the aircraft data sources that provided it.

This concept, known as Automatic Dependent Surveillance – Broadcast (ADS-B), is being developed by the aviation community to overcome some of the limitations of the existing surveillance means.  The concept has been accepted by ICAO and international standards have been developed and adopted, although a significant number of issues are yet to be resolved before it can widely implemented.

The basic concept of ADS-B is that each aircraft will transmit, at regular intervals, a message containing a number of pieces of information.  As a minimum this information would include: flight identification, unique aircraft identification, altitude and position (given as latitude and longitude).  Other systems can then receive this information and can use it to build up a traffic surveillance picture by comparison with their own position.  Depending upon the transmission medium used and the variability in signal transmission time, all the transmitters and receivers may also need to be synchronised in time to ensure accurate position determination in four dimensions (i.e. including time). Where the transmission delay is a fixed function of distance such synchronisation is unnecessary as it can be calculated by the receiver.

There are three main transmission mediums proposed for ADS-B (IATA[1]):

**1090MHz (Extended Squitter)**

This is the SSR reply frequency and in effect makes the ADS-B an extension of the Mode S SSR system.  Each Mode S transponder issues a short unsolicited message once per second, known as a squitter, that allows the transponder to be detected without interrogation.  The ICAO standards have been developed to allow an additional 'Extended Squitter' to transmit the ADS-B information.  The squitters are unsolicited and un-synchronised between aircraft so to minimise constant garbling the time period between squitters is varied randomly.

**STDMA (Synchronised Time Division Multiple Access)**

The VHF (Very High Frequency) spectrum is used primarily for voice communications, data link and navigational beacon transmissions.  The application of an STDMA protocol to it would enable it to perform an ADS-B function similar to Mode S.  As its name suggests, it requires synchronisation between all parties to allow the strict sharing of transmission slots and the determination of four dimensional position.  The most likely means to achieve this synchronisation would be through the fitment of a Global Navigation Satellite System receiver on each aircraft and ground station to provide a common time reference. A significant issue regarding the implementation of STDMA is the shortage of VHF frequencies available to accommodate it and its interoperability with other systems using the same band.

**UAT (Universal Access Transponder)**

UAT is a newly developed system purely for the purposes of ADS-B but could coarsely by described as Extended Squitter in a different frequency band. The advantage of such an approach is that the band could be free of the existing Mode A-C interrogations and fruit so would enable more capacity and range. However a new frequency would have to be made available globally which is a significant problem yet to be overcome.

## Advantages and Disadvantages of Passive Surveillance

The primary advantage of passive surveillance is the reduced complexity, and hence cost, of the surveillance receiving equipment. If an independent means of surveillance is not required then active rotating interrogators would not be required. Such a reduction in cost and complexity would allow for wider implementation, increased coverage and redundancy at a potentially reduced cost. This advantage is of particular benefit in remote areas where the cost of a radar infrastructure is prohibitively expensive but where an ADS-B network would offer significant safety and capacity enhancements.

From an air to air viewpoint the introduction of passive surveillance again allows for a potential reduction in cost, but of more benefit is the potential increase in range that could be achieved (Orlando[2]). A highly tuned ADS-B receiver could hear Extended Squitters at far greater ranges than an ACAS interrogation could reach without a significant power increase. Also the range and capacity of existing ACAS installations is severely limited in high density traffic by a mandatory reduction in transmitter power to reduce RF usage and minimise radar drop out, passive tracking will overcome these restrictions.

ADS-B also provides a path on which to include aircraft intent based information although this would be at the expense of bandwidth and hence either capacity or range. The inclusion of some intent information will likely be a useful addition to the squitter but for future intent based air traffic management another means for detailed intent data transmission will likely also be needed.

The biggest disadvantage to ADS-B, or any form of passive surveillance, is the lack of independence of the surveillance system from the aircraft navigation system. It has yet to be proven that widespread implementation of ADS-B on multiple types and standards of aircraft can be done to a standard that provides the accuracy and reliability as good as that of an SSR interrogator. It is likely that in the long term such a status can be achieved but there will need to be a significant transition period to prove the case, particularly in areas of dense traffic such as Europe.

## The Way Forward

There are undoubtedly benefits to the air transport industry to the introduction of passive surveillance and intent based air traffic management. However there are significant risks that must be addressed before widespread reliance on such techniques can be made. As within any major change in the aviation business, that spans the world and has a base of over 40 years worth of aircraft, the transition will be the most critical component to it success. A large step change that involves significant investment and threatens the intrinsic safe measures in use today is not desirable, nor achievable.

Returning to the analogy of the darkened room: ADS-B could be equated to each person regularly calling out where they are in the room (or at least where they think they are) and maybe where they where planning to go next. If you were the controller responsible for ensuring people didn't bump into each other would you turn the search light off and maybe take away the torches? Probably not, but then what happens when the light and the call differ in their information? Who is using which information? What are they doing with it? Such a scenario helps to highlight some of the issues that such a change to surveillance brings. The analogy also helps to demonstrate some of the benefits of ADS-B: You may for example hear the position reports of people before they enter the room, or when they are behind a partition which would be considered a blind spot in a radar scenario. Also if your search light fails at least you can maintain a picture of what is happening.

There are a number of key issues that the transition to any future surveillance system needs to address (Rose[3]), the most important of which is safety. Extensive safety studies will be needed to show that ADS-B is a safe replacement for SSR but these alone may not be enough. With reliability of air traffic surveillance then totally dependent upon the installations and procedures on aircraft from around the world and of very different standards, there is an urgent need for internationally enforceable installation standards. The ICAO standards for ACAS and ADS-B address the functionality of the equipment, not how it is installed, maintained and what procedures and training the crew get to use it. The tragic mid-air collision over Germany in July 2002 demonstrates, among may other things, how the safety of all airspace users can be dependent upon the procedures and training given to other flight crews for surveillance and collision avoidance equipment. In this case the ACAS is used as an exception when all else fails, for ADS-B its use could be the norm so the exposure will be far greater. Even with global standards it is still likely that ADS-B will only become proven by a period of demonstration against existing methods of surveillance.

The other significant issue that must be addressed is the cost of transition. For full use of ADS-B all aircraft must be equipped. However the benefits will not divide, or be seen, equally to all users so their business cases will not be the same. For all users to see a positive case, the cost of implementation must be minimised by building upon equipment already installed in the aircraft. Historically the aviation industry has demonstrated that, without mandatory requirements, it only moves at the pace of the slowest implementation. For passive surveillance to become successful it has to realise benefits with only partial equipage.

The implementation of ADS-B based on 1090MHz Extended Squitter would allow these issues to be addressed:

Safe - 1090MHz is a globally accepted and proven medium for surveillance both air to ground and air to air. The use of a common frequency and equipment for both active and passive surveillance allows for the simple implementation hybrid surveillance, so the benefits of ADS-B can be realised whilst the accuracy is independently verified.

Cost Effective - Mode S transponders are fitted to every aircraft that has ACAS and many could be modified to include Extended Squitter. The implementation of Mode S in Europe would allow many aircraft to install Extended Squitter and many ACAS installations could be modified to be an airborne receiver of the squitters from other aircraft, avoiding the need to add equipment to the aircraft at least in the initial implementation. Mode S ground interrogators could also extract the ADS-B position information and other data to both prove the system accuracy and enhance the controller's situational awareness, again without new infrastructure.

The key steps of such a transition are shown in *figure 3*.

## Conclusion

It is clear than any change to the way air traffic surveillance is performed must be a slow and steady progression, building upon the existing standards of safe operation we have today.  It needs to be built upon the existing infrastructure for surveillance both on the ground and in the air if it is to be financially viable in the fragile finances of air transport.

It is however important, and vitally necessary, that the industry grasps the real benefits that passive surveillance has to offer.  As demand for airspace increases, ways must be found to meet this demand whilst improving further on the level of safety we have today.  Passive surveillance and intent based air traffic management are some of the tools that can, if used effectively, help to deliver that capacity whilst enhancing safety and minimising the risk of mid air collision.

## Reference

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2. Orlando, V.A., *Extended Squitter Range and capacity Performance - SSR Improvements and Collision Avoidance Systems Panel, Working Group*, 1996.

3. Rose, A., *A Smooth Transition from Active to Passive Surveillance - ERA Avionics Conference*, 1998.

**Author Biographical Notes**

Andrew Rose has worked for British Airways for 15 years, starting as an Engineering apprentice before gaining a Masters Degree in Control, Instrumentation and Systems Engineering from City University, London.

From 1992 to 2001 he worked in various roles within the Avionic Standards and Design areas, where he was responsible for the installation design, standards and development of Air Traffic Surveillance Equipment, Satellite Communications and Aircraft Collision Avoidance Systems.  Whilst in the Standards Department Andrew held UK CAA delegated Design Authority for the approval of aircraft modifications and for a number of years chaired the Airlines Electronic Engineering Committee - Airborne Separation Assurance Systems Subcommittee.

Andrew is now an Air Safety Investigator with British Airways part-time and outside runs Llanbury Consulting, which specialises in all areas of transportation surveillance and communications.

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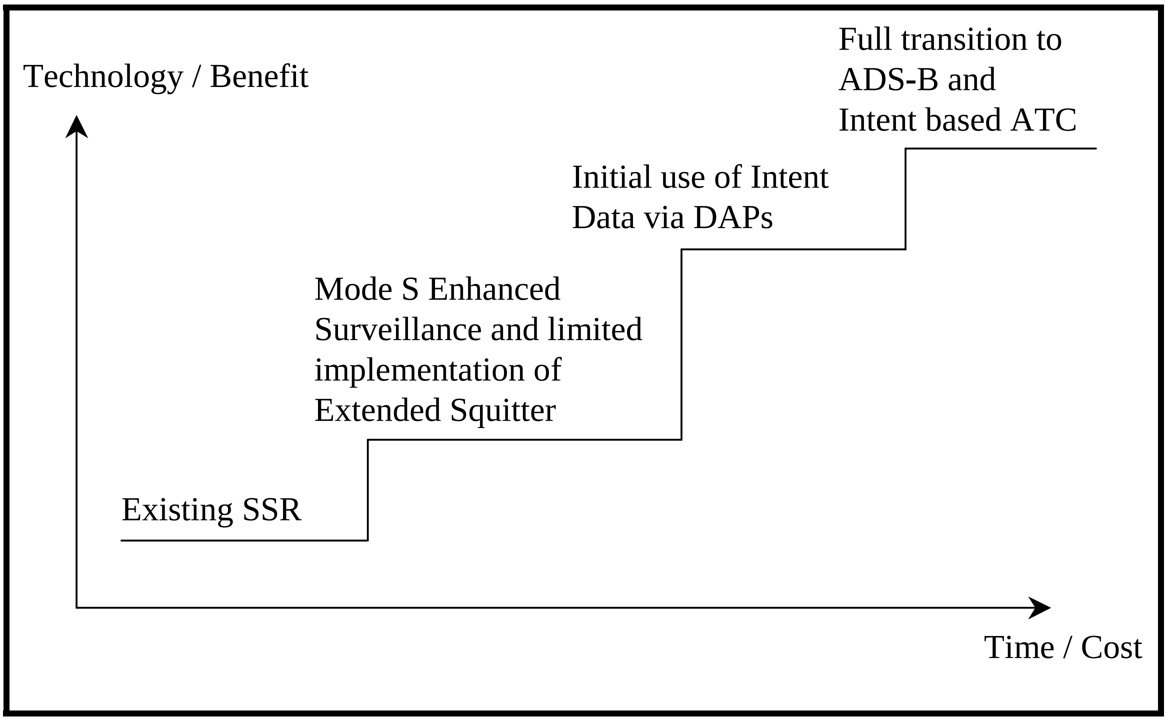


Figure 3:  The transition to future surveillance