A SMOOTH TRANSITION FROM ACTIVE TO PASSIVE AIR TRAFFIC SURVEILLANCE

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Abstract

The key objectives of this paper are to identify the reasons why a smooth transition between the existing air traffic surveillance scenario and any future system or technology is necessary, and to suggest ways of achieving this transition. The paper seeks to explain the background of the existing active surveillance techniques, and identify some of their limitations, before discussing the proposed alternatives and their candidate technologies. The major benefits of any such transition to passive surveillance are investigated to help identify the most cost effective implementation to achieve them.

The main conclusion of the paper is that if any future air traffic surveillance system is to be introduced successfully then it must build upon the existing infrastructure and equipment already in use for the purposes of surveillance. To achieve this, the paper concludes that an implementation of Automatic Dependent Surveillance - Broadcast over the 1090 MHz frequency is the best way forward. The major driver for this conclusion is the uncertainty in the applications and true benefits of the implementation of such a system and when, if ever, it will replace the existing surveillance techniques.

1 Background

Air traffic surveillance is used by Air Traffic Control Authorities to provide separation guidance to aircraft within controlled airspace. This surveillance provides the controller with an awareness of the traffic and its intentions to allow him to maintain safe separation at all times.

This surveillance of air traffic can equally be applied in an airborne scenario to give the pilot an awareness of the traffic and its intentions but at present is only used to provide guidance as a last resort.

1.1 Air Traffic Control Surveillance

The common form of surveillance in the Terminal Manoeuvring Area (TMA) and other busy controlled air traffic locations is a combination of primary and secondary surveillance radar. In locations out of range of traditional radar, such as oceanic regions and other en-route locations, surveillance is based on procedural reporting of traffic positions usually via HF radio. Alternative techniques such as Automatic Dependent Surveillance - Contract (ADS-C) are being developed for these regions but as the primary focus of this paper is areas of radar or possible radar coverage they are not discussed further here.

1.1.1 Primary Surveillance Radar

Primary Surveillance Radar (PSR) operates independently of any airborne equipment and provides ATC with the azimuth and range of aircraft from the reflection of RF power off the aircraft fuselage. This technique, although allowing all aircraft large enough to provide the required level of reflected power to be detected, provides no identification of the aircraft or its altitude.

1.1.2 Secondary Surveillance Radar

Secondary Surveillance Radar (SSR) requires the aircraft to reply to radar interrogations from the ground and therefore requires aircraft to carry an Air Traffic Control Radar Beacon System (ATCRBS) transponder. The ground SSR transmits interrogation pulses which are received by and replied to by the transponders. These replies will provide the same azimuth and range information as PSR but can also contain identification and altitude information.

The identification is via a Mode A code which is a four digit code provided by ATC to the aircraft crew who input it to the ATCRBS control panel. The altitude is provided from the aircraft altimetery system in the ATCRBS Mode C reply.

Mode A-C is the basic level of ATCRBS transponder required for air transport aircraft in controlled airspace. Mode A only transponders are allowable for some general aviation type aircraft but only in certain areas of airspace.

1.1.3 Mode S SSR

The drawback to the traditional Mode A-C transponder system is that the interrogations are received and replied to by all aircraft within the beam regardless of their interest to ATC. An enhancement to this system is the introduction of addressable transponders using a unique twenty-four bit address. This addressable system is known as Mode S and works in tandem with Mode A-C, therefore allowing all aircraft to be tracked with the same equipment. Mode S transponders also perform all the Mode A-C functions so allowing their operation in both Mode S and Mode A-C controlled airspace.

At the time of writing no airspace is actively controlled using Mode S SSR, although the increased burden on the RF environment of the existing Mode A-C interrogations and replies is leading to a number of plans to transfer to Mode S in congested airspace.

1.2 Air to Air Traffic Surveillance

The wide equipage of aircraft with SSR transponders has allowed aircraft to be equipped with the equivalent of a ground SSR interrogator to provide an air to air traffic surveillance functionality. The separation assurance of air transport aircraft in Instrument Flight Rules (IFR) conditions is, by international agreement, provided by the air traffic control authority responsible for the airspace. Therefore any airborne carriage of traffic surveillance equipment is for the purposes of situational awareness and collision avoidance following the failure of the primary means of separation control.

1.2.1 Airborne Collision Avoidance System

The Airborne Collision Avoidance System (ACAS) is the only implementation of an airborne SSR system in regular use. The system actively interrogates aircraft in the vicinity and provides a display of this proximate traffic to the flight crew. The system uses Mode S where aircraft are so equipped, but where not will track Mode A and Mode A-C intruders. The information provided to the crew is similar to that on an ATC radar display except that no aircraft identification is provided.

The primary function of the system is to provide collision avoidance guidance to the aircraft should separation assurance be lost. The function of the traffic display is to assist the crew in visual acquisition of the aircraft should a manoeuvre become necessary.

2 Limitations of existing surveillance techniques

All technologies and procedures have their limitations and the existing methods of air traffic surveillance are not an exception. Consideration is given here to some of the primary limitations before discussing possible alternatives again with their limitations.

Although not specifically discussed in this paper, the main advantage of the present active surveillance techniques is that the position of the aircraft (azimuth and range) is independently determined. This means that although the aircraft is required to carry equipment to reply to interrogations in an SSR environment the accuracy and reliability of the air traffic surveillance is not directly dependent upon the accuracy and reliability of the equipment in the aircraft. It is also to be remembered that the existing systems provide the safe air traffic control that we have today and already identified enhancements such as Mode S provide for significant improvements in the foreseeable future.

2.1 Primary Surveillance Radar

As discussed in 1.1.1 PSR has a significant role to play in ensuring that all aircraft in a particular airspace are known about and, where necessary, are under control. What PSR does not provide is any form of identification and altitude information and is therefore of very limited use in the provision of control instructions in busy airspace.

These limitations are widely recognised and were a fundamental reason for the development of SSR.

2.2 Secondary Surveillance Radar

2.2.1 Range

Secondary Surveillance Radar (SSR) is an extremely effective tool in the control of air traffic but its primary limitation has always been that of range. A rotating SSR could have a reliable range of 250 nautical miles at an altitude of 20,000ft which provides useful coverage for operations such as TMA but for en-route operations a number of radar would therefore be required. The use of multiple radar sites is widely used in continental airspace but is obviously not practical in oceanic or remote continental airspace where other technologies such as ADS-C would be more appropriate.

Apart from this range limitation the other significant drawbacks are those of cost and capacity.

2.2.2 Capacity

The capacity issues revolve around the use of a single frequency (1090 MHz) for the two-way communications between all aircraft and all interrogators. As briefly mentioned in 1.1.3 the use of traditional Mode A-C creates a significant burden on the channel capacity due to the replies generated by all aircraft in the interrogator beam. The implementation of Mode S interrogators and transponders would provide a very significant improvement in this channel utilisation and could likely provide the capacity needed for the foreseeable future.

A further enhancement of capacity in a Mode S environment is the use of electronically scanning antennas which could greatly increase the throughput of the SSR sensor. This enhancement is discussed further in 2.2.3.

2.2.3 Cost

This paper focuses on the issue of cost as that is likely to be the area that the use of passive surveillance will have most impact. The cost of SSR is obviously divided between the ground interrogators and the airborne transponders. Although the cost of the airborne installations is a significant proportion of the system cost, for the purposes of comparison between different methods and technologies there is not a significant variation.

The cost of a ground SSR is significant and obviously multiplies as greater coverage is required. The reason for the high cost is the requirement for a sophisticated rotating antenna to provide the required accuracy in the determination of azimuth and range of the aircraft. This rotating antenna is required both to allow the bearing of the aircraft to be determined from the reply and also to minimise the number of overlapping replies by focusing the interrogation in one particular direction. In addition the rotating antenna allows for increased interrogation range by focusing the antenna power in one particular direction at any one time.

The introduction of Mode S reduces the requirement to focus the interrogation in avoidance of overlapping replies but still requires the ability to rotate the beam to determine the relative bearing of the aircraft. Technology is available to electronically rotate the beam rather than using a mechanically rotated antenna and in a Mode S environment, where the interrogations are directed at particular aircraft, that would allow significant benefit. This benefit would be in cost, but more importantly, in capacity.

2.3 Air to Air Traffic Surveillance

Similar disadvantages to the ground side of SSR could be applied to the airborne implementation of SSR interrogators.

The requirement for the ACAS to be able to determine range and bearing from the RF signal involves complex and relatively costly antenna technology. Although a rotating antenna is not used a sectorised antenna is required to give reasonable estimation of bearing. These antennas, apart from the cost, are sensitive to RF cable quality and length etc. which has an impact on the installation and maintenance of the system. The requirement to focus the interrogation to avoid overlapping replies is greatly reduced in the airborne implementation both because of the use of Mode S and the limited range.

For the airborne implementation of SSR the limitations of range and capacity are inextricably linked. The 1090 MHz frequency is primarily provided for ground-based surveillance and safe separation control and therefore to ensure the ACAS does not over occupy that channel its interrogation power is automatically limited in high traffic density environments. This power limitation has the effect of reducing the ACAS range, sometimes significantly. As stated in 2.2.2 the full implementation of Mode S will provide significantly greater channel availability both for ground based and aircraft based SSR interrogators which could be used to enhance the range of ACAS. In a full Mode S environment it is envisaged that ACAS could have an operating range in excess of 80 nautical miles depending upon the characteristics of the transmitters and receivers.

3 Alternatives to active surveillance

As discussed in section 1, this paper assumes air traffic surveillance of some form is required and therefore no surveillance is not considered as an option to active surveillance. The alternative to active surveillance is passive surveillance where the requirement for a bi-directional flow of data is not required between the aircraft and the ground.

In the existing active methods the interrogator (ground-based or airborne) is required to provide an interrogation that will generate a reply from the aircraft of interest. In the SSR scenario this interrogation is also required to allow the azimuth and range of the aircraft to be calculated using the transmission and reply times of the signal.

If the azimuth and range of the aircraft could be determined from information included in the reply and the reply was provided at regular intervals regardless of interrogation then interrogations would not be required. In this case the replies are no longer replies but broadcasts. These broadcasts would allow for the implementation of passive air traffic surveillance both ground to air and air to air.

3.1 Automatic Dependent Surveillance - Broadcast (ADS-B)

This concept of broadcasting surveillance information automatically has become known as Automatic Dependent Surveillance - Broadcast or more usually ADS-B.

This concept has been taken forward at the International Civil Aviation Organisation (ICAO) and other organisations responsible for the standards and procedures associated with air traffic management. Minimum Aviation System Performance Standards (MASPS) for ADS-B have been produced by the Radio Technical Commission for Aeronautics (RTCA[1]) special committee 186. Within these forums significant discussions are on-going regarding the formats and data content of these broadcast messages. For the purposes of this paper the contents of such broadcasts will be assumed to contain information to allow passive surveillance to be performed and further discussion of parameters and formats used will be limited to a direct comparison of active and passive surveillance.

Although both ground to air and air to air applications have been identified for ADS-B (McCulloch[2]) those most vigorously pursued have mainly been concerned with air to air functions. This can be attributed to a number of reasons including the desire of a number of factions of the aerospace community to transfer the separation control of aircraft from the ground controller to the pilot.

The most simple implementation of ADS-B would be where the aircraft transmits periodically, perhaps twice per second, a position report in three dimensions (i.e. Latitude, Longitude and Altitude) and its identification. Ground stations and other aircraft, that in an active surveillance scenario would have been interrogators, can then receive this broadcast without performing any interrogations. If the 'interrogator' or receiver knows its own position it can easily work out the azimuth and range of the aircraft or broadcaster from the transmitted position information.

Depending upon the transmission medium and other associated transmission delays the broadcaster and receiver may need to be synchronised in time and the broadcaster include the time of transmission within the broadcast. This would allow the surveillance of aircraft in four dimensions to be maintained regardless of any variation is signal delay. In a scenario where the signal delay has a fixed relation to the distance between the two parties, the necessity for time synchronisation is significantly reduced or even eliminated.

3.2 Transmission mediums for ADS-B

One of the international discussions regarding the shape and direction of ADS-B is that of which transmission medium should be used (IATA[3]). It is not the intention of this paper to go into the detail of each of the candidates but the main three will be discussed briefly, particularly focusing on the features most relevant to a smooth transition from active to passive surveillance.

3.2.1 Mode S (1090 MHz)

The Mode S SSR system already includes an unsolicited broadcast called a squitter. This squitter is transmitted for the purposes of allowing the Mode S transponder to be detected, and interrogated by address, by any interrogators within range. This squitter at present just includes aircraft identification information and is transmitted twice per second on the 1090 MHz frequency. There is no synchronisation for the transmission of these squitters so the time between transmissions is randomly varied by the transponder (within limits) to ensure that transponders do not become synchronised causing the signals to become garbled.

The existing ICAO standards for Mode S include data formats for an extended squitter which can be broadcast twice per second from the transponder along with the existing short squitter. This squitter is at present defined to contain position, altitude and basic intent data about the aircraft although will likely be updated as the ADS-B discussions mature. The extended squitter contains all the same information as the short squitter but both are required until all interrogators are capable of using the extended squitter for aircraft acquisition.

3.2.2 VHF - Synchronised Time Division Multiple Access (STDMA)

The VHF is at present used as a medium for voice communications and some limited data link applications. The application of STDMA to the VHF would allow it to provide broadcasts which could be used for the purposes of surveillance. The broadcast data formats could be defined in the same way as the extended squitter has been for Mode S and therefore become the basis for an ADS-B system.

As its name suggests the system is synchronised so a constant time reference is required by all transmitters and receivers. This synchronisation is required to ensure messages do not overlap and also because the time of transmission is not directly related to the distance of transmission. At present the most likely form of time synchronisation would be using Global Navigation Satellite System (GNSS) signals which for many aircraft would necessitate the addition of this equipment along with the STDMA set-up.

3.2.3 Universal Access Transponder (UAT)

This proposed system is basically the same as the Mode S 1090 MHz solution but put on a different frequency. The 1090 MHz frequency is, as discussed in 2.2.2, heavily burdened with the existing Mode A-C surveillance interrogations and replies. In the absence of extensive Mode S use this channel usage significantly affects that capacity to support an ADS-B system in the same frequency. The UAT solution overcomes that problem by shifting the ADS-B into a separate channel.

3.3 Advantages of Passive Surveillance

3.3.1 Cost

The primary advantage of passive surveillance is the reduced complexity and hence cost of the interrogator or, in the passive case, the receiver. As discussed in 2.2.3 the SSR ground radar is a complex and expensive device compared to a simple ADS-B receiver. When making that comparison however it is important to remember that an SSR and an ADS-B receiver are very different devices: the SSR can, independently of any position information from the aircraft, determine the location of that aircraft in azimuth and range to a high degree of accuracy and reliability; the ADS-B receiver is totally dependent upon the transmitted position information from the aircraft to define its location in the airspace and therefore that information is critical in the accuracy and reliability of the surveillance.

This requirement in an ADS-B scenario for the aircraft to accurately determine and transmit its own position for the purposes of a third party's surveillance is the obvious downside of passive surveillance. The aircraft are therefore required to carry more sophisticated equipment than a basic SSR transponder and the air traffic controlling authority has to be certain that the position reports are always to the required accuracy to allow them to maintain safe separation.

In the case of air transport aircraft this required level of position accuracy and reliability may not be difficult or costly to achieve, but in the case of small general aviation aircraft that equipage cost could be significant. Depending upon the technology used for ADS-B and the required accuracy of position determination a common time reference (i.e. GNSS) may also be required further increasing the complexity, costs and reliability of the system.

Until a full safety and cost assessment is carried out it is difficult to know whether an ADS-B type surveillance operation could meet or exceed the same level of safety as the SSR system and at lower cost. What is clear however is that the advantages of passive surveillance in an airspace already satisfactorily controlled by active SSR surveillance are not great enough to discard that SSR before it is due for renewal. Where the cost benefits may become more apparent is in a situation where new or replacement SSR are required, hence the need for a smooth progression towards such a new system.

3.3.2 Range and Capacity

In the Mode S extended squitter implementation of ADS-B both range and capacity are significantly enhanced (Orlando[4]) particularly in the air to air case. One of the prime reasons for this would be that, with a reduction in the number of interrogations, significant extra band width would be available to increase the squitter transmission power. Also the sensitivity of the receivers could be increased with the further use of Mode S.

The use of STDMA for ADS-B would give greater range improvements but at the expense of capacity without the use of multiple channels. The use of multiple channels greatly reduces the 'see all' benefit of ADS-B and may also require interaction from the ground.

4 The Transition to Passive Surveillance

As discussed in 3.3, it is clear that the benefits of passive surveillance are not sufficient to merit a step change from the active surveillance we have today. Any introduction will be in areas and situations where its safety and cost benefit can be proven, which may as time progresses, lead to a complete transition to passive surveillance. Also the aviation industry is, often rightly, in the interests of safety, a conservative one when it comes to the application of new technologies and procedures and the introduction of an entirely new concept to air traffic surveillance would be a prime example.

4.1 Safe transition

Before any consideration can be given to the transition to passive surveillance the safety case has to be proved. In airspace where the passive surveillance is an addition to existing surveillance then that safety case may be relatively easy although each and every application it is used for would need to be demonstrated to be safe. In the scenario where the passive surveillance is to replace or be used for the same functions as active surveillance then the safety case becomes much harder. This paper does not seek to address the safety case of ADS-B but rather addresses the transition issues that will make that case easier to determine. With an easier, more demonstrable safety case, the implementation of any passive surveillance will be more successful.

For example, the easiest way to prove the safety case for ADS-B is to use it alongside of, and in direct comparison with, the existing surveillance techniques. A period of this direct comparison, along with all the necessary hypothetical evaluation, will go a considerable way to proving safety and also convincing the users of its benefits. This direct comparison should also answer the question of whether ADS-B could ever be a complete replacement for SSR.

In an SSR type environment, if the aircraft were equipped to provide a 1090 MHz extended squitter along with the existing SSR replies then the ground radar processing could be modified to directly compare the two position values and provide a qualitative assessment of the extended squitter. A further evaluation could be the use of this data for air traffic control with the active surveillance being used to fill gaps in the coverage (i.e. unequipped aircraft) and monitor the accuracy of position reports received. If then the extended squitter could be proved to be more accurate and reliable this would allow value to be gained with only mixed equipage whilst still maintaining the present level of safety.

A further support for the use of the 1090 MHz frequency in terms of safety is that it is a frequency that is approved and in regular use for surveillance purposes. To introduce another frequency for surveillance in a different part of the RF spectrum would require significant investigation with regard to its safety. This safety assessment may be relatively easy to overcome compared to the significant institutional issues that such a change would generate.

The application of passive surveillance for air to air air traffic surveillance functions would require the air to air datalink to be proven to a level dependent upon the application. The present successful use of 1090 MHz as an air to air datalink in ACAS would add significant weight to this safety case, something no other technology has had much exposure to.

4.2 Cost effective transition

One of the arguments given as a benefit of passive surveillance, as discussed in 3.3, is the possible reduced cost of ground infrastructure. As stated in that discussion this cost benefit will not be enough to merit the decommissioning of the existing ground infrastructure and even less so the full airborne equipage with ADS-B that such actions would require.

The use of the 1090 MHz frequency for the application of ADS-B along with the existing SSR will allow both the existing ground infrastructure and aircraft equipment to provide both functions. This will allow the system to be tested as it is introduced gradually and this introduction can then proceed at the pace that most justifies the benefits in each case. A further, and perhaps more significant, benefit would be that an aircraft equipped with a transponder capable of SSR and ADS-B will be able to freely operate in areas of active or passive surveillance. This fact is further supported by the present use of active surveillance by ACAS which, unless it too was converted to passive surveillance at the same time, would lead to a considerable degradation of the safety backup it provides.

In a similar vain it could be argued that the SSR airborne equipment would have to remain and additional equipment could be added for ADS-B to work alongside. Taking the scenario that perhaps one day a complete transition to passive surveillance will occur this may not be unreasonable. As it is not clear when, if ever, a complete transition could take place that dual equipage would be a significant burden on operators, particularly those of light aircraft.

Despite the accepted high cost of today's ground SSR their replacement and upgrade for the foreseeable future is almost certain. During this process the additional functions to support passive surveillance could probably be included at minimal cost. Comparing this to the case where the ground radar have to be upgraded anyway (to maintain the existing safety case in the transition) and an entire new infrastructure needs to be implemented for ADS-B, the difference in costs is obvious.

The airborne equipage costs can be considered in a similar vain if requirements for the upgrade of SSR transponders become necessary in Europe and world-wide for ACAS and enhanced Mode S surveillance. Where this equipment has to be modified to meet these proposed requirements then the cost of getting the additional functionality into the aircraft is greatly reduced. This modification would not provide the data necessary for the implementation of ADS-B but simply allow the transponder to process and transmit it. The aircraft modifications and equipment additions to provide the data would be the same regardless of ADS-B transmission mediums but obviously need to be considered in a direct comparison with the existing SSR.

4.3 Transition of technology

With the reasonable assumption that SSR transponders are going to be required on all aircraft for at least the foreseeable future it seems sensible to maintain the surveillance functions, both active and passive, in the same device on-board the aircraft. Keeping the functions together in the same box helps considerably to make the transition from one to the other transparent to the crew of the aircraft. This transparency is particularly important as when the aircraft pass from one environment to the other the crew may not and should not need to be aware of this change.

As stated in 4.2 the use of the same ground radar infrastructure for both active and passive surveillance would further aid the success of implementation both financially and in the acceptance of new technology. Again the information provided to the controller could be the same for active or passively acquired aircraft during the transition, slowly introducing the additional benefits to the controller as implementation allowed. This gradual implementation would improve the acceptance of the system and would help to prove, in a controlled fashion, the benefits of the conversion.

4.4 Transition of procedures

The successful transition with regard to procedures falls very much in line with that of the technology discussed in 4.3 above. Where the controllers and pilots are using the same technology interface to the new passive surveillance techniques they should be able to successfully apply the same procedures. Where the new techniques allow the procedures to be enhanced these enhancements can be introduced in a controlled fashion as the transition progresses.

A further significant benefit of a smooth, and perhaps extended, transition is that many of the best suggestions come from the users once the system is operational. With limited operation initially these useful changes could be implemented with the minimum of impact.

The implementation of a new system that required a change in technology and in long established procedures all at the same time would be destined for failure and almost certainly significantly impact the existing level of safety.

5 Conclusion

The benefits of passive surveillance over some of the existing active surveillance techniques are not yet clearly defined or proven but it is a widely held belief that its advantages will emerge in the longer term. Assuming that these advantages do emerge and the safety and cost benefit cases can be proven then some use of passive surveillance such as ADS-B will no doubt occur. With such an unsure case for implementation, particularly to replace the present and proposed implementations of SSR, it is unlikely that a step change or even a quick transition will be justified.

Therefore for any implementation to be successful this transition will have to be as smooth as possible. Prolonged periods of dual equipage on the ground and in the air will be costly and therefore unlikely to be acceptable to the aviation community as a whole but particularly the general aviation contingent. The use of parallel technologies for air traffic surveillance, perhaps divided by region or application, will be extremely difficult to co-ordinate and will effect operators flexibility. The ability of one technology to provide both functions will be extremely attractive and will allow aircraft and ground infrastructure to be upgraded in a progressive and cost effective nature.

The existing SSR surveillance domain is based upon the use of ATCRBS and Mode S on the 1090 MHz frequency. All aircraft operating in busy airspace (excluding the former Soviet regions) are required to be equipped with a 1090 MHz transponder and most actively controlled non-oceanic airspace is controlled using SSR. Where radar are not yet in use or require updating, the use of SSR is still the favoured method. The implementation of ACAS world-wide and proposals to require the carriage of SSR transponders on almost all aircraft will inevitably lead to a significant further equipage of the latest Mode S transponders.

With such wide equipage of SSR transponders the case to transfer across to another technology for passive surveillance will be very difficult to make unless its additional benefits show significant cost benefit over the 1090 MHz solution. An implementation of passive surveillance using that existing SSR equipment will be much easier to justify in both the cost and safety benefit cases and will also allow for a progressive implementation as equipment is replaced and upgraded. With equipage likely, at least to begin with, to be on a voluntary basis this ability to upgrade in a cost effective method or as benefits start to become realised will almost certainly be key to its success.

In conclusion, it is clear that for the implementation of passive surveillance, in the guise of ADS-B, to be successful it is imperative that the transition path be as smooth as possible in all aspects. With the benefits unquantified and the route to implementation unclear, cost will be a very significant factor. The basis of any future method of surveillance should be the safe and effective systems that we are building on today and therefore the 1090 MHz implementation of ADS-B is without doubt the best way forward.

6 Reference

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