Space-based ADS-B

A small step for technology a giant leap for ATM?

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Abstract - **This paper investigates the feasibility and merits of a space-based ADS-B system. The primary concept that will be investigated is the reception of ADS-B transmissions from aircraft in oceanic airspace using satellites and the subsequent relay of the data to end-users on the ground.**

Keywords: ADS-B, space systems, new concepts, applications, oceanic, requirements)

I. The Challenges Facing Air Traffic Management

There are several significant challenges facing Air Traffic Management (ATM) today. These can be summarized as the need for increased capacity to cope with traffic growth whilst at the same time reducing delays. Across Europe these challenges are being strategically addressed through two initiatives. The Single European Sky (SES) is concerned with providing the necessary legislative framework while the SES ATM Research (SESAR) Programme is concerned with the modernization and interoperability of ATM infrastructure across Europe. In particular SESAR has the following performance targets:

- Accommodate a 3 times increase in movements whilst reducing delay.
- Improve safety by a factor of 10.
- Enable a 10% reduction in environmental effects per flight.
- Reduce ATM unit cost to airspace users by at least 50%.

II. The Role Of ADS-B

For SESAR and NextGen (the US equivalent), Automatic Dependent Surveillance Broadcast (ADS-B) is one of the most important underlying technologies in the plan to transform ATM from the current radar-based surveillance to Global Navigation Satellite Systems (GNSS) surveillance. ADS-B is defined by the International Civil Aviation Organization (ICAO) as a surveillance application transmitting parameters, such as position, track and ground speed, via a broadcast mode data link, and at specified intervals, for utilization by any air and/or ground users requiring it. The ADS-B reports are sent periodically by the aircraft with no intervention from the ground function and ADS-B reports may be received by any suitable receiving equipment in range of the transmitting aircraft. The data transmitted is derived from the aircraft systems themselves and in this sense ADS-B is known as a dependent surveillance technology. The transmitting aircraft does not know which, if any, recipients are receiving and processing the position reports as they are not acknowledged. The concept with ADS-B is that position reports are transmitted so frequently that the loss of a small number of position reports is not operationally significant.

ADS-B does not require a specific data link however throughout the rest of this paper when referring to ADS-B we mean the transmission of Extended Squitter messages transmitted over the 1090MHz channel 1090ES. The 1090MHz channel is the downlink channel for Secondary Surveillance Radar (SSR) replies from aircraft and the Extended Squitter messages are compatible with the Mode S radar data link formats. Amongst other data items Extended Squitter messages contain aircraft position information derived from GNSS.

The potential benefits of ADS-B are [1]:

- Faster data update rate than that typically available with radar.
- Lower cost ground infrastructure compared to radar.
- Surveillance data can be directly received in the aircraft cockpit increasing situational awareness.
- Position accuracy is potentially higher than radar and is not range dependent.
- It can display both airborne and ground traffic.
- It can potentially enable new applications and operational procedures resulting in more efficient flight profiles and reduced emissions e.g. allows 5 NM of separation in Non-Radar Airspace (NRA) compared to current procedural separation.

However, in order to realize the full benefits from ADS-B aircraft must be equipped and plans for mandates in both Europe and the US are illustrating the difficulty in achieving universal equipage and the need to ensure that once fitted the avionics are fully utilized. The mandates are currently being put in place in the US and Europe for 1090ES ADS-B (dates 2015-2020) and 1090ES ADS-B is already widely implemented on commercial traffic. In addition ADS-B is being deployed world-wide in places like Australia, Canada, Thailand, Jamaica, United Arab Emirates and South Korea.

Other potential issues related to ADS-B include [2]:

- Incorrectly coded 24-bit (technical) aircraft address used to uniquely identify aircraft.
- Dependent on GNSS for surveillance and navigation, and GNSS position potentially leads to oscillating position quality.
- May need addition surveillance cover provide by independent surveillance technology to provide a separation service in current radar airspace.

III. Surveillance Of Remoter Regions

A. The oceancic problem

Traditionally surveillance has been performed by monitoring on the ground signals received from aircraft, requiring ground infrastructure to do so. However, in oceanic or remote regions it may not be practically possible to install ground infrastructure even with ADS-B.

For long periods of time in oceanic airspace, aircraft are unable to communicate directly with controllers and are therefore issued with strategic clearances between exit and entry points to what is know as procedural airspace. Because of the lack of communication and surveillance information, aircraft in oceanic airspace are required to maintain large separation distances/times, typically 10 minutes longitudinally and 60NM laterally, in order to maintain safety standards [3]. This procedural separation has the undesired effect of limiting airspace capacity and also the flexibility of aircraft to fly efficient routes.

The question therefore arises how can we make use of the ADS-B surveillance data already being transmitted by aircraft to improve oceanic operations?

B. Current oceanic operations and technical solutions

Aircraft with different speeds on the same track in oceanic airspace will gradually get closer or further apart. It is imperative to monitor this change of spacing closely for loss of separation. Pilots are therefore required to report their position verbally at regular intervals along the route, for example at each waypoint or every 45 minutes which ever is shorter [3]. Typically this is using High Frequency (HF) or satellite communications.

However, the advent of data link communications has already removed the need for voice reporting and enabled higher rates of position reporting in oceanic regions for suitably equipped aircraft. This type of position reporting is known as Automatic Dependent Surveillance Contract (ADS-C). It is based on setting up a point-to-point communications contract between the aircraft and the ground where position reports are acknowledged and are either made at an agreed regular rate, are event driven or are made on demand.

The only operational implementation of ADS-C in oceanic airspace is the Future Air Navigation System (FANS) 1/A equipment on Boeing and Airbus aircraft. Nearly all long haul aircraft are now equipped with FANS 1/A. FANS 1/A makes use of the Aircraft Communication Addressing and Reporting System (ACARS) and sub-networks used by many aircraft to communicate aircraft information to the Airline Operations Centre (AOC).

The increased monitoring provided by FANS 1/A ADS-C services potentially enable the following benefits in oceanic airspace [4]:

- reduced separation (typically 30NM longitudinally and laterally);
- more direct routes;
- more optimal climb and descend profiles;
- increased access to cruise altitudes or closer to optimal;
- reduced controller and pilot workload;
- increased level of safety.

However, it is unlikely that ADS-C data will ever be used operationally to provide a radar-like separation service in oceanic airspace. The application of ADS-C based separations would require extensive evaluations and agreements with adjacent Area Control Centers (ACC) [4].

C. Future oceanic operations and technical solutions

A potential future ADS-B enabled application for oceanic airspace is the In-Trail Procedure (ITP). It was originally envisaged that this could be provided by ADS-C. However, it was decided that this was an impractical solution, and that any airborne surveillance application used in the oceanic airspace should be feasible without ground surveillance [5]. Therefore, the application is now either Airborne Traffic Situational Awareness (ATSA) with similar procedural limits to today or Airborne Separation (ASEP) with new airborne separation standards (yet to be defined).

ATSA-ITP has some of the most noticeable benefits for a relatively small investment and is therefore likely to be one of the first airborne applications to be implemented. Although originally a spacing application, ATSA-ITP has now been re-classified as situational awareness. The ATSA-ITP allows pilots to identify the relative position of other aircraft, and pass this information to the controller to clear the aircraft for a procedural climb. Due to the higher accuracy of surveillance information available to the controller (and flight crew) via the ADS-B reports, lower procedural limits can be applied during the duration of the climb, assuming some geometric constraints. Since the separation limits are lower, there is effectively more airspace within which the aircraft can climb, thus maximizing the fuel efficiency for the given traffic density [5].

ATSA or ASEP applications may also enable additional procedures which are not possible with just ADS-C, such as passing maneuvers, to be implemented in procedural oceanic airspace.

IV. SATELLITE ADS-B

A. Why do satelite ADS-B?

One of the aims of SESAR is to develop a global interoperable ATM system. ADS-B is a significant contributor to a future ATM system capable of providing high accuracy, high update rate position reports with a low cost ground infrastructure. Satellites also play a key role in enabling global communications services and high accuracy positioning and navigation through GNSS. Given that aircraft will be equipped for ADS-B operation over continental regions it is only natural to investigate the feasibility of receiving the ADS-B position reports via satellite to provide cost-effective surveillance coverage in remote regions without current surveillance infrastructure. The potential benefits are the improved monitoring of aircraft in remote areas to increase safety and enabling subsequent changes to current procedures to make more efficient use of the airspace.

B. Assessment of a potential implementation

A key question to answer is whether satellite ADS-B is feasible, or under what conditions is it feasible? To help us answer this question we postulate a possible satellite ADS-B implementation and assess its potential performance characteristics.

The analysis consists of an ADS-B receiver installed on a satellite in a sun synchronous orbit at an altitude of 670km receiving ADS-B reports at 10 locations in the North Atlantic oceanic region. The assumptions used in the analysis are summarized in Table I. A visual representation of the scenario is presented in Fig. 1 where the red crosses represent the 10 analysis points, the blue triangles are aircraft and the purple circles are radar locations [6].

C. Assessment results and analysis

The 1090MHz interference received by the satellite ADS-B receiver at each of the test points was analyzed using a 1090MHz interference model developed by Helios on behalf of Eurocontrol. From the analysis the following observations were noted:

- The highest interference levels are recorded at test points that either have the highest traffic densities or are within range of radar interrogations.
- The level of TCAS interference is generally low as the test point locations are primarily in areas of low or medium traffic density and the probability of an aircraft being close enough to generate TCAS transmissions is low.
- The level of Mode A/C SSR interference is low as most test points are out of range of SSR radars.

TABLE I. ANALYSIS SCENARIO ASSUMPTIONS

Scenario element	Description	
Aircraft	Predicted 2015 oceanic and core Europe traffic levels based on actual Eurocontrol CFMU data and STATFOR growth predocitions	
	Mode S equipage	100%
	Extended Squitter equipage	100% of Mode S equipped aircraft
	TCAS equipage	80%
Aircraft Mode S transponder	Short Squitter trasnmission rte	1Hz
	Extended Squitter transmissions rate	6.2Hz
	Transmission power	57dBm
	Antenna pattern	Omni-directional with 0dB gain
Radar	Predicted Mode S and SSR radar installations in Europe in 2015 based on information gathered from Eurocotnrol and European ANSPs	
	Number of civil SSR	20
	Number of military SSR	340
	Number of civil Mode S	160
	Number of military Mode S	45
Satellite	ADS-B receiver installed on a satellite in a sun synchronous orbit at an altitude of 670km	
	Antenna horn size	5mm
	Antenna peak gain	9.6dB
	Antenna beamwidth	-3dB
	Antenna pattern shape	Elliptical with semi-major aperture of 25 degrees and semi-minor aperture of 22.5 degrees
	Cable losses	0dB
	Minimum signal level for detection	-92dBm

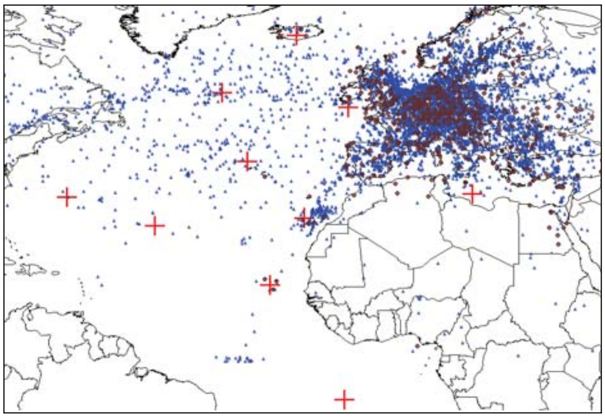

Figure 1. Satellite ADS-B analysis scenario

The figures below show the detailed analysis of a high interference test point in the mid-Atlantic which contains 32 aircraft within the satellite spot beam. Fig. 2 shows the frequency and type of messages received on 1090MHz split into four 90 degree sectors while Fig. 3 shows the cumulative total of messages against the received power [6]. Fig. 4 presents results from a similar analysis to predict interference levels on the ground and in the air in mainland Europe [7].

The interference at the satellite ADS-B receiver is much lower than that expected at an ADS-B ground station in mainland Europe. An ADS-B ground station needs to be able to decode wanted Extended Squitters from aircraft in its operational range in the presence of unwanted transmissions or transmissions from aircraft outside of its operational range. However, the majority of signals received at the satellite will be Extended Squitters which we want to decode. The Extended Squitters also come from aircraft which are at similar distances from the satellite and are therefore likely to have similar received signal powers. Therefore it is highly likely that any overlap between the received transmissions will lead to garbling of the Extended Squitter.

Using the assumption that any overlap between received messages would lead to garbling, and an interference model developed as part of the Eurocontrol ADS-B Coverage Analysis and Planning Tool (CAPT), we further analyzed the potential Update Probability (UP) for receiving ADS-B position updates [8]. Assuming a 2Hz transmission rate for Extended Squitters containing position data the satellite ADS-B receiver could support up to 160 aircraft in the spot beam in an oceanic region whilst still achieving a 95% probability of update within 5 seconds. However, it should be noted that this figure is likely to decrease dramatically as aircraft within the spot beam fall within radar cover and interference levels increase.

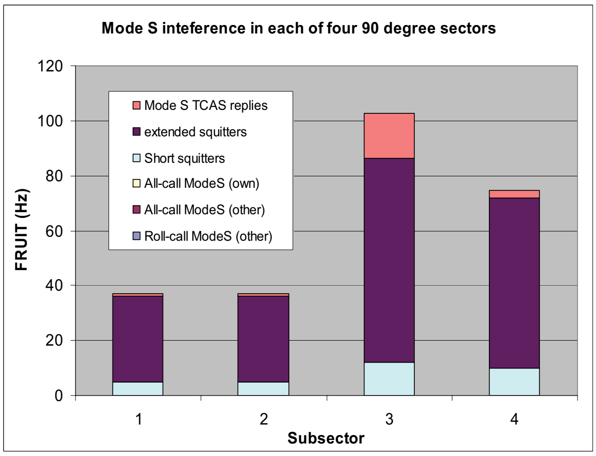

Figure 2. Detailed analusis of interference in mid-Atlantic

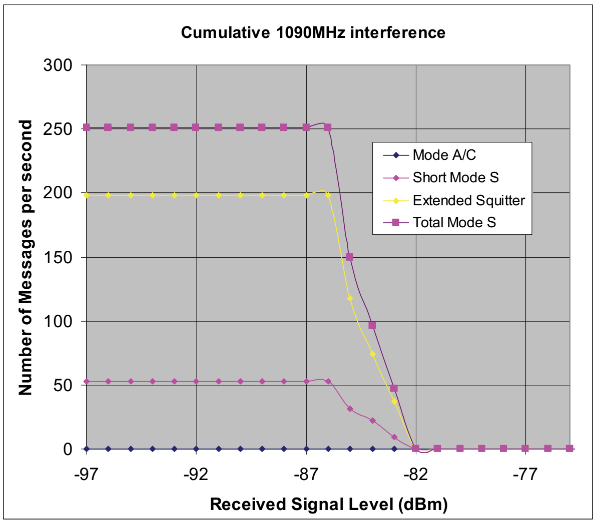

Figure 3. Cumulative interference against receieved signal level

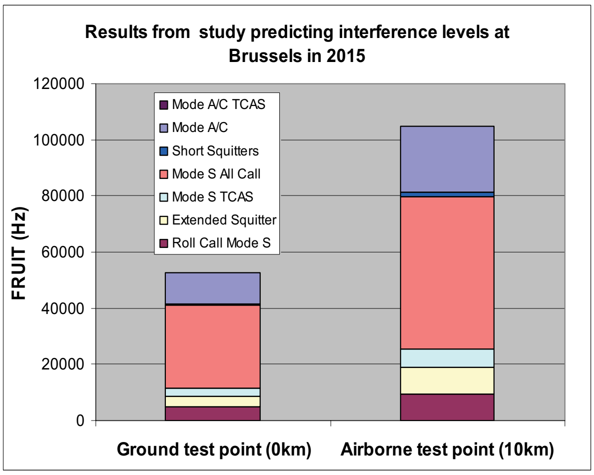

Figure 4. Predicted levels of 1090MHz interference in mainland Europe

Considering the onward transmission of the ADS-B data received by the satellite there are two methods:

- Bent-pipe where the data received by the satellite is forwarded on to the ground with amplification and a shift to the downlink channel frequency.
- Regenerative where the data is decoded by the satellite and then and re-encoded onto the downlink signal.

Table II provides a comparison of these two methods for the onward transmission of the received ADS-B data against the likely ADS-B data rate requirements. Considering this analysis and the analysis above the initial conclusion is that from a technical point of view it is feasible to receive ADS-B data using a satellite.

TABLE II. COMPARISON OF TWO METHODS FOR ONWARD TRANSMISSION OF ADS-B DATA

	1090Mhz ES	Bent-pipe	Regenerative
Channel bandwidth	2.6Mhz (-3dB point)	Typcially 10's of MHz for Ka/Ku band [9]	Typcially 10's of MHz for Ka/Ku band [9]
Data rate	22/111 Kpbs required for decode of Extended Squitters from 32/160 aircraft	Typically 1000's Kbps per sub-channel [9]	Typically 1000's Kbps per sub-channel [9]
Latency		~0.5 seconds	Up to 2 seconds [10]
Pros		Shorter latencies Offers ability ro post process signal on ground for better decode performance	More efficient use of downlink bandwidth Time of applicability of ADS-B report can be adjusted for latency of satellite link
Cons		Time of applicability of ADS-B report ignores latency of satellite link Less efficient use of downlink bandwidth	Longer latencies

D. *Other satellite ADS-B initiatives*

The feasibility and potential benefits of tracking aircraft (and ships) via satellites are now being more and more widely recognized. There are several other recent initiatives investigating the feasibility of providing satellite tracking services and these are summarized below identifying any further lessons that can be learned.

The SESAR project OPTIMI is currently investigating technical solutions including the potential for satellite services to improve monitoring and position tracking of aircraft while in remote or oceanic areas. In particular this is to support Search and Rescue operations and accident investigation in these remote areas. The project aims to deliver recommendations that can be implemented in 2011. ESA has also recently launched an invitation to tender to procure an ADS-B payload for the reception and processing of ADS-B signals on a satellite in-orbit demonstration mission.

This year the satellite service provider Globalstar has signed an agreement with ADS-B Technologies in order to develop a system allowing ADS-B equipped aircraft in remote and oceanic regions to relay information to the ground and other aircraft using the Globalstar network of satellites and ground stations. The proposed Globalstar service is based on a constellation of low-earth-orbit satellites using a bent-pipe architecture which they claim will provide near-real-time data relay.

The Satellite service provider Iridium also announced this year that they plan on monitoring ADS-B transmissions using their next generation of 66 communication satellites. Their current generation of satellites is currently being certified to provide aviation safety services requiring the satellites meet defined levels of robustness, reliability and latency. The next generation of satellites will be fully operational by 2017 providing global coverage. The main technical challenge being investigated is the need to blank out ADS-B reports received from high density areas as these could saturate the ADS-B receiver.

Similar initiatives exist, and in many cases are further advanced, in the maritime domain for tracking ships using satellites and AIS - the maritime equivalent of ADS-B. Originally designed as a terrestrial system, there are now AIS receivers installed on satellites decoding AIS transmissions from ships. The Canadian company ExactEarth is already offering a commercial space-based AIS service using two microsatellites. It also has plans to launch two more microsatellites this year that will enable post-processing of the received AIS data on the ground to improve probability of detection performance. However, the requirements for the use of the AIS data may be different from the potential use of ADS-B data. The dynamics of a ship are very different to aircraft and AIS data is not used for providing separation services or collision avoidance. Satellite AIS data is often fused with other remote imaging data and the primary applications under investigation are homeland security, search and rescue and environmental monitoring. Current performance targets are of the order 80% probability detection and update rates in the order of minutes or even hours rather than seconds. Experience from current test or operational AIS satellites also indicate that probability of detection performance can be variable [11].

V. CONCLUSIONS

The assessment of a potential implementation of satellite ADS-B demonstrates the feasibility of decoding ADS-B messages with a high update probability via an ADS-B receiver installed on a satellite. The assessment also provides evidence that satellite ADS-B can successfully provide aircraft position updates to controllers at update rates similar to radar, and much higher than ADS-C, even considering oceanic traffic growth well beyond 2015. However, it is noted that this conclusion only holds true when the aircraft are out of the range of SSR radars. When aircraft are within radar coverage (e.g. close to shore) the interference environment experienced by the satellite will increase dramatically and detection performance will drop.

It is unlikely satellite ADS-B will ever enable surveillance separations in oceanic airspace that are currently achievable in Radar (RAD) airspace because for safety reasons a second layer of surveillance cover would be required that is sufficiently different from ADS-B. However, satellite ADS-B, particular when combined with ADS-B ATSA or ASEP applications may:

- Provide a cost-effective means of monitoring from the ground ATSA and ASEP enabled maneuvers in oceanic airspace (such as passing) providing increased safety.

- Enable more efficient flight procedures such as those enabled by ADS-B ground stations installed in Non-Radar Airspace (NRA).

The ADS-B-NRA application is designed to enhance the following ICAO air traffic services:

1) ATC service and flight information service principally for:

- ATC separation services, including the possible reduction of separation minima;
- transfer of responsibility for control;
- ATC clearances;
- flight information services;
- flight crew guidance for flight operations in ADS-B only surveillance airspace.

2) Alerting services, principally for:

- notification of rescue coordination centers;
- plotting of aircraft in a state of emergency or when deviating from intended track (e.g. because of bad weather).

However, the following critical differences between the application of satellite ADS-B in the oceanic region and ADS-B-NRA should be noted:

- the increased latency of ADS-B reports received by a satellite compared to a ground station;
- the lack of real-time voice (or data) communications in oceanic airspace compared to NRA.

In terms of implementation timescales it is likely that initial ADS-B satellite services may be available around the time of the European ADS-B mandate in 2015. The maritime domain is leading the way in that it already has commercially available satellite tracking services and satellite service providers have identified that a similar business opportunity may exist in aviation.

However, a word of caution: initial maritime applications appear to be focused on homeland security and environmental monitoring applications. If satellite ADS-B is to be used to improve the efficiency of oceanic operations through new procedures and reduced separations its actual performance in terms of probability detection, update rates, latency etc. must be demonstrated through live trials. Decisions on optimum spot sizes and the total number of satellites required to give sufficient satellite coverage also need to be made. Furthermore, if the satellite ADS-B concept is to be developed within the aviation community a rigorous cost-benefit analysis is required to ensure that additional benefits enabled by satellite ADS-B are cost-effective compared to other technical solutions.

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