FLIGHT SAFETY FOUNDATION

BENEFITS ANALYSIS OF Space-Based ADS-B

JUNE 2016

Benefits Analysis of Space-Based ADS-B

June 2016

Executive Summary

Introduction

The purpose of this report is to provide an overview of the benefits of automatic dependent surveillance–broadcast (ADS-B) satellite-based navigation with space-based ADS-B networks in the context of the safety challenges of managing predicted air traffic growth in commercial air transport over the next 20 years.

Growth in the number of airline destinations, routes flown and volume of aircraft operating at any one time — combined with important safety, efficiency and environment targets — will continue to drive innovation in air traffic management. As the aviation industry responds to these demands, an essential safety enabler will be technologies that take a global and regional approach to harmonization and standardization.

Context

The size of the forecast growth in this sector of aviation has significant implications for the entire world aviation system. This growth represents a particular challenge for air traffic management to ensure more aircraft are handled safely and efficiently in what will increasingly become constrained airspace.

Safety Benefits of space-based ADS-B

Space-based ADS-B will extend today's ADS-B Out technology from flight operations in continental airspace to oceanic and remote airspace, enabling any aircraft's position and other data, determined via satellite-based navigation, to be broadcast periodically to ground stations, and to become an integral part of responding to the entire global airspace system's capacity and efficiency challenges. The International Civil Aviation Organization believes that ADS-B will eventually become the preferred surveillance technology worldwide[1].

ADS-B networks use ground-based technology that is in operational use in many leading air traffic organizations, and it is reasonable to expect the benefits that have been demonstrated from these ADS-B networks will also be delivered from a space-based ADS-B network. Additionally, there are now a number of mandates in effect for the fitment of ADS-B to aircraft in some countries, including those in Europe and the United States, by 2020. There are a number of regulatory processes that will need to be completed for space-based ADS-B networks; however, the safety and efficiency drivers combined with the

[1] ICAO Guidance Material on Comparison of Surveillance Technologies (GMST), 2007.

ADS-B mandates (requirements in aviation regulations) are stimulating a compelling environment to drive these regulatory processes in a timely manner.

The analysis in this report, which has focused on the cumulative impact on the global aviation safety net, has concluded that there is an extensive range of immediate, mid-term and longer-term safety and efficiency benefits that can be expected with the introduction of space-based ADS-B. The following table summarises the main safety benefits explored in this report:

Anticipated Timeframes	Potential Benefits
Immediate	• A single global surveillance system. • Reduced oceanic separation standards. • Enhanced Situational Awareness. • Enhanced global flight tracking. • Enhanced Search and Rescue. • Reduction in Pilot and ATC workload. • Improved cross–flight information boundary error detection. • Improved and earlier detection of off-track errors. • Enhanced safety alerting. • Improved weather avoidance. • Enhanced Height Monitoring in RVSM airspace. • Increased surveillance system augmentation and elimination of surveillance gaps. • Enhanced safety for offshore helicopter operations. • Enhanced incident and accident investigations.
Mid Term	• Jumping a generation of surveillance technology and improving service in remote and difficult-terrain regions. • Facilitating improved cooperation in contingency management.

Anticipated Timeframes	Potential Benefits
	• Greater interoperability (an ICAO harmonization enabler). • Support for conflict zone and volcanic ash cloud management. • Enabler for more regional and local data sharing. • Reduced risk of controlled flight into terrain.
Longer term	• Enabler for global safety performance monitoring and analysis. • Supporting unmanned aircraft systems / remotely piloted aircraft systems. • Driving safety through innovation.

These benefits range from access to tactical air traffic control (ATC) tools through to strategic air traffic management (ATM) enhancements and global harmonization opportunities and over time may challenge some of the existing safety paradigms. For example the introduction of space-based ADS-B is likely to challenge risk levels currently accepted by the industry in oceanic and remote (non-surveilled) continental regions, applying the existing *as low as reasonably practicable (ALARP)* risk principle. Experts interviewed for this report believe it may introduce a step change in improving the safety of oceanic operations.

It has been the experience in other high tech environments that the full downstream potential of any new technology will not be fully exploited until it becomes available; however, it is reasonable to conclude that the cumulative effect, based on the current benefits identified if fully realized, should be an overall substantial improvement to the global aviation safety net.

Table of Contents

Introduction

Globally, regionally and locally, societal pressure and demands on airlines and the supporting service and regulatory infrastructure continue to intensify. With this comes the necessity for continuous improvement in safety, airspace capacity, operational performance and harmonization.

Technology in its many forms has been a key enabler to delivering and improving safe and efficient commercial air transport services. While the drive to squeeze even greater efficiency from already congested continental airspace continues, one of the real frontiers or opportunities is enhancing services over our oceans — and, in many cases, over remote and less developed continental regions where traditional surveillance services are either not available or limited by extremes of weather, terrain, access, cost and reliability.

This report assesses how space-based ADS-B is challenging the paradigms of traditional radar and types of surveillance, and this report will look at the anticipated benefits of this new surveillance capability, particularly over oceans and non-surveilled continental regions.

The report will also look at key regulatory and industry topics that will need to be considered to ensure that this technology's anticipated benefits can be fully realized. The report's primary focus is on the potential safety benefits, specifically where opportunities can be leveraged to reduce aviation risk. However, associated strategies to improve efficiency cannot be ignored, given that typically the efficiency objectives — such as predictability, on-time performance and access to the most suitable flight trajectory — are interrelated with safety goals and, in some cases, are interdependent with them. This relationship will be explored further as the report takes a holistic approach to the topic of space-based ADS-B.

In completing research for this paper, a cross-section of industry representatives has been interviewed. Interviews have been conducted with representatives of commercial passenger transport airlines, commercial cargo transport operators, regulators, aircraft manufacturers, air navigation service providers, offshore helicopter operators, aviation business analysts and the space-based ADS-B service provider. Their comments and feedback are reflected throughout the report, and Flight Safety Foundation (FSF) is grateful for their expert input.

For the purposes of this report, the safety and efficiency benefits of space-based ADS-B are focused on Oceanic ADS-B Out because this is the service that is expected to become available in 2018.

The Aviation Economic Environment

Growth in commercial air transport continues, as well as demand for greater efficiency — cost saving allied with improved safety performance. Consumers are currently spending 1% of global gross domestic product (GDP) on air transport;[2] this represents a spend of approximately $750 billion. Air travel continues to grow as well as expand with growth anticipated to be 6.9% in 2016 with about a 2.2% increase in new destinations. The past 20-year growth trend showed an average annual rate of 5.5% and, as airfare prices continue to reduce currently, new consumers are being attracted. Airfares are 61% lower than 20 years ago, adjusted for inflation.

The airline industry is responding to this accelerating market with new aircraft. In 2016, there are expected to be more than 1,700 new aircraft delivered, representing an investment of over $180 billion and, even counting the older aircraft being retired, the anticipated world passenger transport fleet is expected to grow by over 900 aircraft to 28,000 aircraft.[3]

The PwC report *Industry Perspectives 2015 Aviation Trends* says "airlines will need to continue to make large and on-going improvements and investments to operate more efficiently. Part of this will be the introduction of new technologies to streamline operations."

Conclusion

The aviation industry is growing consistently, with increases in the total number of aircraft in operation, global GDP plus new destinations. This growth means there are continued demands for greater efficiency — cost savings allied with improved safety performance. Part of this will be the introduction of new technologies to streamline operations.

---

[2] PWC 2015 Aviation Trends

[3] www.iata.org/economics2015End-year report

History of Air Traffic Control and Global Safety Regulation

ATC services date back to the 1920s, and even then there was a focus on the ability to direct and track the movements of aircraft. The essence of ATC has not substantially changed since then with the primary objectives being to:

- Prevent in-flight collisions between aircraft.
- Prevent collisions between aircraft on the airport maneuvering area and obstructions on that area.
- Expedite and maintain an orderly flow of air traffic.
- Provide advice and information useful for the safe and efficient conduct of flights.
- Notify appropriate organizations regarding aircraft in need of search and rescue (SAR) aid, and assist such organizations as required.

While the fundamentals of ATC services have been consistent, the operating environment has continued to change and expand. With the challenge to provide ever-increasing levels of service, ATC has had to innovate through communication, navigation and surveillance (CNS) technologies. The use of technology and infrastructure has been central to how efficient and safe services have been, and are, provided by ATC. It has been equally necessary for airlines, regulators, airport owners and other aviation support organisations to adapt, adopt and anticipate this evolution in technology.

With this backdrop of an ever-growing and complex industry, an essential element to enable technologies to deliver the expected safety and efficiency gains has been to adopt a global approach to harmonization and regulatory standardization. To this end, the International Civil Aviation Organization (ICAO) — with the support of many global, regional and local organizations and authorities — has driven a number of key initiatives to support new technology and its adoption by industry. Some of the requirements and concepts that have framed and influenced oceanic ATM include:

- ICAO future air navigation system (FANS) concept.
- ICAO standards and recommended practices (SARPs).
- 4D (four dimension–based [latitude, longitude, altitude and time]) operations, also called trajectory-based operations (TBO).

Maintaining and improving safety is and will always be a consistent requirement.

Future Air Navigation System (**FANS**)– This has been one of the significant building blocks for safe and efficient services since the concept was initiated in the 1980s. In essence, the work entailed the development of ATM concepts allied to CNS technology requirements to create a global CNS/ATM roadmap for harmonised operations. It also has been the central pillar by which safer and more efficient services are delivered in oceanic airspace.

Standards and Recommended Procedures (SARPs) – These are important, as they are the rule set of the technical requirements for delivering safe and efficient flight. This is particularly relevant in the definition of ATC separation standards and in the CNS requirements for reduced spacing between aircraft. Having the most effective separation standard is a key enabler to achieving the most efficient flight trajectory for each flight.

PBN or PBO – Performance-based navigation, also called performance-based operation, is one of the ATM umbrella terms to describe the three key technical performance areas: required communications performance (RCP), RNP and required surveillance performance (RSP).

Required Navigation Performance (RNP)– This is a statement of the navigation performance necessary for operation within a defined airspace. Specifically, RNP can be described as the requirement to keep the actual airplane position within a specified radius for a given percentage of the time. RNP is formally defined by four main terms:

- Accuracy.
- Integrity.
- Availability.
- Continuity.

Required Communication Performance (RCP) – This is a set of air traffic services (ATS) provisions — including communication services, operator requirements and flight crew requirements (e.g., RCP 240) — needed for communications supporting a performance-based operation within a defined airspace. Each RCP type denotes values for communication transaction time, continuity, availability and integrity applicable to the most stringent operational communication transaction supporting an ATM function.4

Required Surveillance Performance (RSP) – This is a statement of the performance requirements for operational surveillance in support of specific ATM functions. It is a set of ATS provisions — including communication services, aircraft requirements and operator requirements (e.g., RSP 180) — needed for surveillance supporting a performance-based operation within a defined airspace.5

4D/TBO – The 4D/TBO trajectory of an aircraft, as noted, consists of the three spatial dimensions plus time as a fourth dimension. In other words, the 4D trajectory concept is based on the integration of time into the traditional 3D aircraft trajectory. It aims to ensure flight on a practically unrestricted, optimum trajectory for as long as possible in exchange for the aircraft being obliged to meet very accurately an arrival time over a designated point.[6]

---

[4] ICAO RCP Manual Doc 9869 and GOLD Manual

[5] ICAO GOLD Manual

[6] www.skybrary.aero/index.php/4D_Trajectory_Concept

Conclusion

The fundamentals of ATC have not changed dramatically since services commenced in the 1920s; however, the operating environment has changed dramatically. The aviation industry is complex, and so, to be able to deliver expected safety and efficiency gains, the enabling technologies — taking a global approach to harmonisation and standardisation based on ICAO CNS requirements — must continue to be embraced by industry.

Other Comparable Surveillance Technologies

Several surveillance technologies are utilised across a variety of aircraft operating environments. Factors such as regulatory requirements, safety performance expectations, levels and mix of traffic, and the physical characteristics of the operating environment influence the utilisation of these technologies.

The suitability and safety effectiveness of any surveillance system are likely to be considered across a range of performance parameters, including:

- Coverage – the volume of airspace in which the system operates to specification.
- Accuracy – a measure of the difference between the estimated and true position of an aircraft.
- 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.
- Update rate – the rate at which the aircraft's position is updated to users.
- Reliability – the probability that the system will continue operating to specification within a defined period. Sometimes this is called *continuity.*
- Availability – the percentage of the total operating time during which the system is performing to specification.

The main surveillance technologies utilised today are[7]:

Primary surveillance radar (PSR) – This technology 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 based on the elapsed time between signal transmission and reception of the signal's reflection.

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

Secondary surveillance radar (SSR) – This system consists of two main elements, a ground-based interrogator/receiver and an aircraft transponder. The transponder responds to interrogations from the ground station, enabling the aircraft's identity, range and bearing from the ground station to be determined.

Mode S secondary surveillance radar – This system typically uses monopulse techniques to measure the azimuth position of an aircraft and has large vertical-aperture antennas and hence is less subject to multipath-signal effects that reduce accuracy. In addition, these

[7] http://www.icao.int/APAC/Documents/edocs/cns/gmst_technology.pdf

systems are able to discretely interrogate single aircraft transponders and hence to discriminate between two aircraft at the same geographical position.

SSR only – This system is used by ATC for en route radar control in many states[8] of the world where intruder detection is not required. An SSR-only installation is less expensive than a combined PSR plus SSR, 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.

Combined Primary and Secondary Radar – This combination 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 data processing performs filtering, combines the SSR data and PSR data, and tracks the radar reports.

ADS-B – As noted, this system uses GPS technology to determine an aircraft's location, airspeed and other data, and broadcasts that information to a network of transceivers, which relays the data to air traffic control displays.

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

ADS-Contract – ADS-C, using an automatic position-reporting system to provide a commercial service to operators and others, has been in wide use for over 30 years, particularly over oceanic airspace. ADS-C, as the acronym suggests, requires that a contract be established between the aircraft operator and the ground-based service provider.

ICAO makes the point that where accurate and reliable surveillance systems are used, and aircraft positions are updated relatively frequently, the airspace can be used more efficiently to safely accommodate a higher density of aircraft. Such systems also allow optimal aircraft vectoring for efficiency, capacity and safety reasons.[9]

In all cases, these surveillance technologies are reliant on ground-based infrastructure, so the benefits that they produce are limited to continental airspace and, in some cases, a limited area of transoceanic airspace by line of sight coverage out over the ocean. In some cases, the surveillance technologies available today are only used in and around airports.

ICAO recognized in 2007 at Air Navigation Commission 11 (ANC 11) that ADS-B is a technology of the future. ICAO said that states will work towards its deployment but will consider alternative technology, when cost effective, but that ADS-B is the only technology

[8] States are the equivalent of signatory countries to ICAO.

[9] ICAO Guidance Material on Comparison of Surveillance Technologies (GMST), 2007.

that supports future applications of air-to-air surveillance.[10] Many countries have seen this as a decisive strategic factor as they implemented or moved towards ADS-B.

Conclusion

There are many surveillance technologies utilized across a variety of operating environments. Factors such as regulatory requirements, safety performance expectations, levels and mix of traffic, and the physical characteristics of the operating environment influence the utilization of these technologies. ICAO recognized at ANC 11 that ADS-B is a technology of the future.[11]

---

[10] ICAO Guidance Material on Comparison of Surveillance Technologies (GMST), 2007.

[11] ICAO Guidance Material on Comparison of Surveillance Technologies (GMST), 2007.

ADS-B: Its Use and Future

ADS-B is an established surveillance technology globally and already used widely in continental airspace. ICAO has stated that it is widely recognized that ADS-B will eventually become the preferred surveillance technology worldwide, although this will take time. ICAO made another important point at ANC 11, where the meeting resolved that:

"ICAO and States recognize ADS-B as an enabler of the global ATM operational concept bringing substantial safety and capacity benefits."[12]

The introduction of space-based ADS-B is an innovation pathway in what is already a proven ground-based technology.

ADS-B can be described as follows:

- Automatic – The system transmits information without pilot and ATC input.
- Dependent – The position and velocity information transmitted is reliant on the global positioning system (GPS).
- Surveillance – It provides a method for determining various aspects of the aircraft's position and intent.
- Broadcast – The transmitted information is available to anyone with suitable receiving equipment.

ADS-B Out, for surveillance and separation service purposes, requires a third party as the service provider, and typically this is ATC.

ADS-B relies on a range of equipment including 1090-MHz ADS-B transponders on aircraft, and ATC requires compatible technology to host, gather and disseminate ADS-B information. In the case of space-based ADS-B, a suitable satellite or multiple satellites are required to gather and transmit the necessary data and information.

ADS-B has been adopted as the global standard for the next generation of surveillance technology. It is already widely used for ATC and airline services in many countries, including Australia and Canada.

Large-scale mandates are now in place for Europe and the USA for early 2020. The importance of these mandates and the influence this will have on equipage rates are discussed later in this report.

An additional but very important feature of ADS-B is the benefits that may be derived as the initial capabilities of ADS-B Out are enhanced through the implementation of ADS-B

[12] ICAO Guidance Material on Comparison of Surveillance Technologies (GMST), 2007.

In. ADS-B In is not envisaged as part of space-based ADS-B but is an important consideration in the longer-term utilisation of this surveillance capability.

It is possible, in the future that ADS-B In will facilitate flight crews' access to airborne situational awareness (SA) without the existing reliance on a ground-based third party such as ATC. Additional benefits may be derived from self-separation and enhanced trajectory decision-making in the future.

The global introduction of space-based ADS-B, for the first time, should enable the benefits of continental airspace ADS-B to be realized in oceanic and remote (i.e., non-surveilled) airspace. The implementation of space-based ADS-B is not without its challenges as is the case with all new technologies. There is a range of regulatory and performance standards that will need to be met. These issues will also be explored later in this report; however, the widespread use of ADS-B today, as noted, provides a valuable insight into the benefits anticipated with the introduction of space-based ADS-B. The domain expertise and knowledge already in place also should provide an accelerated approval and certification process, as the anticipated challenges that space-based surveillance represents are already well documented.

Conclusion

ADS-B is an established surveillance technology globally and is already widely used in continental airspace. ICAO has stated that it is widely recognized that ADS-B will eventually become the preferred surveillance technology worldwide. The introduction of space-based ADS-B is an innovation taking the industry beyond what is already a proven ground-based technology. The global introduction of space-based ADS-B, for the first time, should enable the benefits of continental airspace ADS-B to be realized in oceanic and remote (non-surveilled) airspace. The domain expertise and knowledge already available from experience with ground-based ADS-B should provide an accelerated approval and certification process.

Benefits of Space-Based ADS-B

Background

It is not possible in a benefits analysis to separate the safety and efficiency benefits, as they are often interdependent. This section will explore a range of benefits that could be considered in order to maximize benefits of the anticipated introduction of space-based ADS-B. Space-based ADS-B has not been fully deployed yet, so this benefits analysis assumes that the performance and benefits of ground-based ADS-B will be comparable after space-based ADS-B has been fully deployed in oceanic and remote (non-surveilled) continental regions.

At a holistic level, the report focuses on the global safety net and whether this new technology has the potential to enhance the overall safety performance of stakeholders in commercial air transport operations. The safety net in this report refers to worldwide system safety performance and considers the cumulative impacts of risks and benefits that have been identified.

The risk standard called *as low as reasonably practicable (ALARP)* and its equivalent safety risk methodologies assess aviation safety based on the principle of using proportionate resources to achieve an acceptable level of risk. The introduction of space-based ADS-B is likely to challenge the risk levels currently accepted by the industry in oceanic and remote (non-surveilled) continental regions. Experts interviewed for this report believe it may introduce a step change in improving the safety of oceanic operations. This step change may also challenge the current thinking behind the target level of safety for these types of airspace. Applying the principle of ALARP to such a paradigm shift may also pose a challenge to legacy systems in both safety benefits and the cost of their continued use in comparison to space-based ADS-B.

Immediate benefits

A single global surveillance system

The implementation of space-based ADS-B will be a world first in providing global surveillance from a single system. Later in this report, the safety and efficiency benefits of a single global system will be discussed, but one of the important safety benefits will be the immediate capability for surveillance to be utilized in airspace where traditional systems are impracticable and/or cost prohibitive to deploy.

Reduced oceanic separation standards

Performance-based navigation (PBN) refers to area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace. ICAO specifies performance requirements expressed in navigation specifications (e.g., RNAV specification, RNP specification) that define the accuracy, integrity, continuity, availability and functionality needed for the proposed operation.

ICAO's Separation and Airspace Safety Panel (SASP), established in 2000, undertakes specific studies and develops and reviews technical and operational ICAO provisions for improving safety. Part of its terms of reference is to improve efficiency while maintaining or improving safety using reduced aircraft separation minima. SASP conducts mathematical and collision-risk modelling to assess and report on the RNP requirements to meet ICAO separation standards. The current minimum separation standard for locations where traditional surveillance and direct VHF (very high frequency) radio communications are not available over the ocean is 30/30 nm (56/56 km), each number specifying lateral and longitudinal spacing, respectively). The RNP performance requirements described in a previous section of this report summarize the processes for meeting the necessary standards. SASP is about to change the 30 nm lateral standard of RNP 4 to 23 nm (43 km), and there are new RNP 2 longitudinal standards soon to be finalized. These standards will come at a cost to both operators and ANSPs. It will require operators to pay for an increased message reporting rate, additional flight crew training and, in some instances, aircraft certification fees. In addition, ANSPs will have to invest in upgraded conflict probing tools. ANSPs that have committed to space-based ADS-B will not need to invest in this capability.

The current RNP standards in ICAO's Doc 4444, Procedures for Air Navigation Services – Air Traffic Management, are:

<u>Longitudinal</u>

5.4.2.6.4.3 For aircraft cruising, climbing or descending on the same track, the following separation minima may be used:

Separation minima	RNP type	Maximum ADS-C periodic reporting interval
93 km (50 nm)	10	27 minutes
	4	32 minutes
55.5 km (30 nm)	4	14 minutes

<u>Lateral</u>

5.4.1.2.1.6 Lateral separation of aircraft on parallel or non-intersecting tracks or ATS routes. Within designated airspace or designated routes, lateral separation between aircraft operating on parallel or non-intersecting tracks or ATS routes shall be established in accordance with the following:

a) For a minimum spacing between tracks of 93 km (50 nm) a navigation performance of RNAV 10 (RNP 10), RNP 4 or RNP 2 shall be prescribed.

b) For a minimum spacing between tracks of 55.5 km (30 nm) a navigation performance of RNP 4 or RNP 2 shall be prescribed.

c) For a minimum spacing between tracks of 27.8 km (15 nm) a navigation performance of RNP 2 or GNSS [global navigation satellite system] equipage shall be prescribed. Direct controller-pilot VHF communication shall be maintained while such separation is applied.

d) For a minimum spacing between tracks of 13 km (7 nm), applied while one aircraft climbs/descends through the level of another aircraft, a navigation performance of RNP 2 or GNSS equipage shall be prescribed. Direct controller-pilot VHF communication shall be maintained while such separation is applied.

e) For a minimum spacing between tracks of 37 km (20 nm), applied while one aircraft climbs/descends through the level of another aircraft, whilst using other forms of communication than specified in d) above, a navigation performance of RNP 2 or GNSS equipage shall be prescribed.

Advice from ICAO SASP experts confirms that work is progressing on assessing space-based ADS-B with regard to determining reduced separation minima. There are two elements of work:

- A joint working group made up of Nav Canada, UK NATS and Airservices Australia representatives.
- SASP workgroup, which has a formal ICAO air navigation job card and is due to report to the Air Navigation Commission in the spring of 2017 with an anticipated recommendations-adoption date of November 2018.

The ICAO SASP view, at this stage of the research and analysis, is that a 15/15 nm (28/28 km) standard is anticipated, using space-based ADS-B combined with existing communications systems. It is expected that 12 months of data will need to be analyzed to validate this standard. The existing modeling for ground-based ADS-B will form a reference system from which the performance of space-based ADS-B can be evaluated. Controller-pilot data link communications (CPDLC) will provide the communications solution to meet the CNS requirements. The SASP advice suggests that the mathematical modeling and validation can confidently be completed by 2018. With this come enhancements to a range of safety and efficiency benefits for oceanic operations that are discussed in separate headings in this report, but include:

- More efficient and predictable flight trajectories.
- Improved situational awareness, conflict detection and reaction/resolution.
- Better management of risk and application of safety management system (SMS) tools.

- Improved management profiles of opposite-direction and crossing-traffic profiles.
- Greater availability to operate at preferred altitudes.
- Ability to vary speed to access tail winds and avoid headwinds.
- Reduction in ATC and pilot workload.

It is reasonable to anticipate that once the capability of space-based ADS-B is established, it is most likely to prompt a review of performance-based operations and the underpinning CNS requirements, and potentially lead to further reductions in separation minima.

Enhanced Situational Awareness

Space-based ADS-B should enhance ATC SA significantly because the data-update rate combined with the known accuracy, reliability and integrity of ADS-B will enable ATC to provide enhanced monitoring and separation services over the ocean and over remote (unsurveilled) regions. ATC experiences, where ADS-B has been introduced into a non-surveilled region, such as remote regions of Australia, has demonstrably enhanced the controllers' ability to safely manage complex traffic scenarios caused by challenging weather conditions such as thunderstorms. Prior to the introduction of ADS-B, complex traffic scenarios combined with bad weather would require highly restrictive management by controllers. This led to aircraft operating at non-preferred and often inefficient altitudes, and flight crews being forced to conduct extensive diversions, adding additional track miles to assure separation. The restrictive nature of the non-radar or procedural airspace, in these circumstances, often meant that passenger discomfort due to turbulence was increased because the ability for the controller to facilitate smoother rides at other altitudes was limited by the large separation standards required. The ATC SA benefits already experienced with ground-based ADS-B should translate to oceanic operations.

Enhanced global flight tracking

On 10 November 2015, the ICAO Council adopted Amendment 39 to Annex 6 — Operation of Aircraft, Part I — International Commercial Air Transport–Aeroplanes, which included normal aircraft tracking SARPs. These SARPs became effective on 20 March 2016 and will be applicable on 8 November 2018.

The normal aircraft tracking SARPs establish the air operator's responsibility to track its aircraft throughout its area of operations. They establish an aircraft-tracking time interval of 15 minutes whenever ATS obtain an aircraft's position information at greater than 15-minute intervals for aircraft with a seating capacity greater than 19. This aircraft-tracking time interval further applies as a recommendation to all operations of aircraft with a takeoff mass of 27,000 kg (59,525 lb.) and as a requirement to all operations of aircraft with a takeoff mass of 45,500 kg (100,310 lb.) when flying over oceanic areas.

The SARPs also establish the requirements for data retention to assist SAR responders in determining the last known position of the aircraft. Finally, the SARPs establish when an air operator needs to report missing aircraft–position information.

On 2 March 2016, the ICAO Council adopted Amendment 40 to Annex 6, Part I, which included, among other elements, SARPs relating to the location of an aircraft in distress. These SARPs address the Global Aeronautical Distress Safety System (GADSS) autonomous distress tracking (ADT) concept. The SARPs will become effective on 11 July 2016 and will be applicable on 1 January 2021. Amendment 40 will be issued in July 2016.

The SARPs relating to the location of an aircraft in distress establish the requirement for an aircraft to autonomously transmit information from which a position can be determined at least once every minute when in a distress condition. An aircraft is in a distress condition when it is in a state that, if the aircraft behavior event is left uncorrected, could result in an accident. The SARPs are applicable to new aircraft with takeoff mass greater than 27,000 kg from 1 January 2021. The SARPs recommendation applies to new aeroplanes with takeoff mass greater than 5,700 kg from the same date.

The provisions relating to one-minute distress tracking are performance-based, meaning that airlines and aircraft manufacturers may consider all available and emerging technologies that can meet the one-minute location-tracking standard. [13]

Considerable discussion and analysis continues as airlines, air navigation service providers (ANSPs) and regulators consider how best to meet these ICAO SARPs. While it is expected that the most suitable solution will vary from airline to airline, a surveillance technology will be a fundamental element of any solution. Space-based ADS-B, based on the expected global coverage and the known performance of ground-based ADS-B, would be expected to form a key part of many airline solutions leading up to 2018. With an anticipated update rate of one data transmission every 8 seconds, space-based ADS-B should meet both the 2018 and 2021 ICAO requirements. Combining the many safety and efficiency benefits that space-based ADS-B is anticipated to provide means that it is likely to become the preferred surveillance solution to meet ICAO's aircraft tracking requirements.

Enhanced Search and Rescue

Recent world events have refocused the aviation industry on its capability to identify the location of an aircraft lost, in distress or involved in an accident. The previous section of this report, where ICAO references a requirement for data retention to assist SAR responders in determining the last known position of the aircraft is a direct response to recent events. The time to locate an aircraft has a direct relationship to the survivability of occupants. The speed with which rescue and medical personnel can arrive at an accident site increases their ability to render assistance.

Space-based ADS-B will create a global surveillance "blanket" and, with this, an ability to support SAR services globally in retaining position data. The accuracy and update rates should mean that a close to real-time position will be available for all suitably equipped

[13] http://www.icao.int/safety/globaltracking/Pages/GADSS-Update.aspx

aircraft regardless of where they are in the world. This access to accurate position information for aircraft will be a significant enhancement to the global safety net and response capability of SAR operations.

Reduction in ATC and pilot workload

One benefit of enhanced ATC SA due to space-based ADS-B should be to reduce controller and pilot workload. This is predicted due to ADS-B's ability to display an accurate and near real-time traffic picture to ATC. This capability also should facilitate far more efficient planning and ATC's ability to use a wider range of traffic control and management tools.

Reduced pilot and ATC workload is an important safety benefit as there is less likelihood of induced errors and, conversely, time to plan and implement more efficient traffic management strategies.

Improved cross–flight information boundary error detection

Aircraft position errors that occur on or near the boundaries of two different flight information regions (FIRs) are still relatively common, creating significantly increased ATC and pilot workload and a negative influence on the overall safety net, particularly in oceanic airspace, where high-accuracy surveillance is currently limited or not available.

Where ground-based ADS-B has been implemented to survey oceanic FIR boundaries, the detection and correction of cross-boundary coordination information has improved. This has been the experience with the ADS-B infrastructure introduced in Australia.

The integrity and accuracy of space-based ADS-B should introduce significant safety benefits because cross-FIR boundary errors will be detected more regularly, and the handover between ATC at FIR boundaries should be more precise based on more accurate information, and the near-real-time SA. Boundary-error detection using alerts generated when ATC actions do not correspond with ATC system parameters — such as timing of transfer between sectors — should be a further safety enhancement.

Improved and earlier detection of off-track errors

Current monitoring of flight trajectory conformance is generally limited to every 30 minutes in oceanic and remote (non-surveilled) continental airspace. This varies depending on the RNP separation requirements, but 30 minutes is a useful rule of thumb globally when considering the benefits of introducing space-based ADS-B. The monitoring and tracking of a flight is discussed in more detail under the aircraft tracking section above.

Space-based ADS-B — with an anticipated data-update rate of once every 8 seconds, as noted — will introduce an almost real-time detection of an aircraft that is not conforming with its intended and planned flight path. Within the constraints of the alerting systems of a particular ANSP, space-based ADS-B will enable the detection of any such deviation much earlier than what is possible today, and with this, introduces an enhancement to the global safety net.

Enhanced safety alerting

The availability of a surveillance capability that has integrated flight data processing introduces access to a range of automated safety alerts to ATC. Some of the alerts that can be added to the global safety net include:

- Danger area infringement warning (DAIW).
- Short-term conflict alert (STCA).
- Minimum safe altitude warning (MSAW).
- Route adherence monitoring (RAM).
- Cleared level adherence monitoring (CLAM).
- Predicted level mismatch (PLM).

Each of these alerts is an important safety net enhancement because they are tools that support ATC decision making and safety monitoring processes. Space-based ADS-B would introduce a surveillance capability in non-surveilled airspace that would then give ATC access to these types of alerts, which are not available today. This would be a valuable improvement to the safety net.

Improved weather avoidance

The capability of airspace users, predominantly airlines and ANSPs, to assist flight crews to navigate safely and efficiently around weather — such as thunderstorms and associated convective cloud formations — is essential. There are already documented examples in which ADS-B has enhanced the ability of ATC to provide the most efficient off-track routing to minimize additional track miles, to manage multiple track deviation requests simultaneously and safely, and to provide the most effective options because of the reduced separation requirements, which enables greater utilization of the airspace. Referring again to the introduction of ADS-B across Australia, study of before and after operations illustrated a substantial advancement ADS-B has made in increasing weather-deviation flexibility, assuring ATC SA and enhancing the level of safety due to having an accurate, reliable and continuous traffic picture.

This is another example of how the introduction of space-based ADS-B should allow the safety benefits of weather-related diversions — currently provided by ground-based ADS-B for continental operations — also to become available across all oceanic and remote (non-surveilled) airspace. This would be a significant enhancement to the global safety net.

Enhanced Height Monitoring in RVSM airspace

ICAO requires states to have an acceptable method for monitoring aircraft height-keeping conformance in reduced vertical separation minima (RVSM) airspace. Annex 6 –

Operation of Aircraft, Paragraph 7.2.7 says, "The State of the Operator that has issued an RVSM approval to an operator shall establish a requirement which ensures that two aircraft of each aircraft type grouping of the operator have their height keeping performance monitored, at least once every two years or within intervals of 1,000 flight hours per aircraft, whichever period is longer." Traditionally, this has required devices to be fitted temporarily to the aircraft for the purposes of collecting data. This is a time-consuming and at times very costly activity. In many parts of the world, the current solution to delivering evidence of aircraft height-keeping performance requires specially designed infrastructure to capture flight profiles from the ground with the equipment fitted on the aircraft. ADS-B, because of the reliability and accuracy, has become an alternative to these legacy systems. With its high-integrity signal, it allows any monitoring authority (MA) with access to ADS-B data to now conduct height-keeping conformance monitoring on an almost real-time basis with no additional equipment and downtime costs to the airlines. The Australian RVSM Monitoring Authority (RMA), in cooperation with other RMA partners such as the U.S. Federal Aviation Administration (FAA), has introduced this monitoring method using ground-based ADS-B. The implementation of space-based ADS-B will mean that, over time, all RMAs will have access to this highly effective and efficient monitoring alternative.

A related safety benefit of using ADS-B is its contribution to real-time and ongoing aircraft airworthiness–monitoring capability. This should allow earlier detection and rectification of any hull that is operating outside the required tolerances. This leads to a reduction in overall airspace risk and enhances the quality of vertical separation services provide by ATC.

Increased surveillance system augmentation and elimination of surveillance gaps

For some existing ground-based surveillance infrastructure, space-based ADS-B should be a suitable augmentation to provide greater coverage and to fill gaps caused by terrain or shielding from other infrastructure for the lifetime of existing ground-based service installations. This should be a cost-effective means of service enhancement, availability and reliability.

Enhanced safety for offshore helicopter operations

Offshore helicopter operations are a niche, but an essential type of aircraft operation, and with them come some unique safety challenges; often the operations are conducted at low level and below traditional ATC surveillance service coverage. Some of these operations are using ground-based ADS-B today, in the oil and gas industry, because they now occur at extensive distances offshore and outside the coverage of land-based surveillance. The advent of space-based ADS-B may bring significant safety benefits because flights can be fully monitored and operations around adverse weather and SAR response can be better coordinated if ever required. This should be particularly valuable for helicopter operations that cannot access ground-based ADS-B today.

Reduced reliance on legacy infrastructure

The flexibility and availability of space-based ADS-B will reduce the need for ground-based legacy infrastructure. This is not just because of the potential to reduce costs (as noted in the report's previous discussion on comparative costs) but ground-based systems are sometimes not fully integrated, do not provide continuous and seamless service and — in the case of international operations where aircraft are crossing between FIRs of varying ANSPs — they experience different levels of surveillance and communications technology and ATC service capabilities. The global surveillance network offered by space-based ADS-B should facilitate more consistency and reliability.

More efficient flight trajectory

All ANSPs and airlines strive to deliver the optimum flight trajectory. This involves typically a combination of factors such as operating at the most fuel-efficient altitude and route, seeking the most favorable winds, consideration of passenger comfort with regard to the best ride, and the most efficient flight time.

Availability of preferred altitudes

All aircraft dispatchers and flight crews seek the most fuel-efficient altitude. This evolves during a flight as the fuel burn reduces the aircraft weight, making it possible for the aircraft to climb to operate at more efficient flight levels. The most efficient flight trajectory is made up of not just the route of flight but also the most efficient altitude at any given phase of the flight. This is a complex, four-dimensional scenario of time, speed, height and position, none of which is fixed. The ability of an aircraft to achieve the most efficient altitude can be compromised by other aircraft in the same airspace due to the limits of available separation distances. This, at times, can "block" access to the most efficient altitude. With the anticipated reduced separation minima that should be available with space-based ADS-B, ATC should be able to provide the optimum flight altitude at most times during flight unlike existing systems that limit ATC's capacity to facilitate access to the best altitude.

Route efficiency

The availability of space-based ADS-B should facilitate ATC's ability to ensure that aircraft access the routes least affected by headwinds or access to flight paths with the optimum tailwind component. As outlined in the previous paragraph, reduced separation standards combined with enhanced ATC SA will facilitate ATC's ability to provide individual aircraft with access to their preferred routing.

Speed management

Speed management can reduce fuel costs, enhance passenger comfort and provide accurate departure and arrival times, which are important objectives for airlines. Space-based ADS-B, because of the enhanced flight crew and ATC SA and the operator's ability to predict each aircraft's exact position and trajectory, should make it possible for fine-tuning of aircraft speeds over oceans, consistent with the types of speed management made possible by continental radar today. This, in turn, means that the most efficient profile can be achieved because of the certainty of the aircraft's current position and speed, and its relationship with all other aircraft occupying the same airspace.

Increased system integrity

One of the key requirements for a controller is assurance of the surveillance system's performance in providing separation services. The system must have means of checking integrity. Traditional radars have built-in mechanisms to perform system-integrity checks and provide periodic integrity reports to the operator. Standards similarly have been developed for ADS-B to transmit system-integrity messages along with the position and velocity reports.

This system integrity factor is a key benefit that should assure that space-based ADS-B can offer the reliability and availability necessary to provide reduced separation services and enable the subsequent benefits to be achieved.

Enhanced incident and accident investigations

Incident and accident investigations are often reliant on locating and accessing the recorded data from the "black boxes" on the aircraft. The data from the digital flight data recorder has many parameters that assist the investigation teams to reconstruct the events leading up to and during an incident or accident. For a variety of reasons, locating this device and the cockpit voice recorder is sometimes a challenge to rescue teams and air accident investigators. Reasons include delays in locating the aircraft and searching extensive areas of accident debris, often in very demanding circumstances. The reliance on black boxes has been a topic of discussion within ICAO and the International Telecommunications Union, which are exploring data cloud-based solutions as an alternative to the current reliance on infrastructure on the aircraft.

Space-based ADS-B may be an important additional source of time-critical flight data to assist in the reconstruction of some initial parameters of an accident. This should assist in an earlier indication of some of the factors and circumstances leading into and during an accident. As discussed in the report's section on SAR and global flight tracking, space-based ADS-B may offer an important benefit in locating the aircraft that, in turn, should improve the timeliness of locating the black boxes.

Reduced emissions and fuel burn

ICAO, in May 2016, announced a new environmental measure, which was unanimously recommended by the 170 international experts on ICAO's Committee on Aviation Environmental Protection (CAEP), paving the way for its ultimate adoption by the U.N. agency's 36-state Governing Council. Under the CAEP recommendation, the new CO_2 (carbon dioxide) emissions standard would not only be applicable to new aircraft type designs as of 2020, but also to new deliveries of current in-production aircraft types from 2023. A cut-off date of 2028 for production of aircraft that do not comply with the standard was also recommended. In its current form, the standard equitably acknowledges CO_2 reductions arising from a range of possible technology innovations, whether structural, aerodynamic or propulsion-based.[14] The establishment of a binding CO_2 emissions reduction goal will drive greater innovation, and space-based ADS-B would be expected to be a key enabler to meet these new targets.

Another airline operating in the United States currently utilizes ground-based ADS-B, and the nature of their operations — back of the clock — find them typically operating contra-flow to many other trans-Atlantic operations. They are often required to operate below optimum altitudes as a consequence of this, due to being "blocked" by constrained airspace at higher altitudes with the number of opposite-direction operations. On the assumption that space-based ADS-B will offer reduced separation minima and thereby facilitate improved access to preferred altitudes, this airline has calculated that the fuel burn saving per flight is on the order of 3,000 kg (6,614 lb). This represents a significant reduction in costs and emissions when extrapolated over multiple flights a week.

This same airline operates in the Asia Pacific region, where ground-based ADS-B services are available today, and the operation is saving on the order of $20,000 per day in fuel because of the ability to meet existing mandates and therefore participate at more efficient altitudes and on more efficient routes.

The following feedback from airlines encapsulates the broad environmental benefits of ADS-B surveillance that did not exist in the past:

- Flying shorter or more efficient routes that equates to less CO_2 is good.
- More on-time flights.
- Reduced reliance on legacy ANSP and navigation infrastructure, and saving money.

A case study of flights operating between the West Coast and East Coast of the USA, where convective weather induces deviations from planned track, the availability of ADS-B — ground-based ADS-B, in this case — provides efficiency gains by reducing diversion distances and track miles. Because of the integrity of the ADS-B surveillance, the operation during these diversions is regarded as being safer. In the cited example, the average dollars saved is on the order of $500 per flight. The multiplier effect of this when considering long-haul trans-oceanic flights is significant.

While the purpose of this paper has been to focus on safety, the efficiency gains and environmental benefits tie closely to the enhanced safety outcomes from surveillance

[14] http://www.icao.int/Newsroom/Pages/New-ICAO-Aircraft-CO2-Standard-One-Step-Closer-To-Final-Adoption.aspx

creating a close and interdependent relationship. Where having better SA and monitoring tools enhances safety, it is reasonable to expect that the consequential environmental benefits should follow.

Mid-Term Benefits

Jumping a generation of surveillance technology and improving service in remote and difficult-terrain regions

The inability of some individual countries to introduce legacy aircraft surveillance in regions where barriers such as terrain, cost or local and regional geopolitical or economic circumstances make it impracticable has meant that many of the safety and efficiency opportunities discussed in this paper are not being realized. The availability of space-based ADS-B, for these countries, has the potential to introduce "game-changing" services and should enable individual countries and regions to leap over a generation of legacy surveillance technologies and introduce ADS-B–based services where it has not been possible in the past. The safety and efficiency benefits discussed throughout this report should immediately become available to the operators in these regions.

Facilitating improved cooperation in contingency management

There are a number of well-documented examples of partial or complete failures of ATM automation systems. The safety implications — combined with the reduced efficiency of the system — means that ANSPs strive to have highly effective contingency and business continuity plans. In many cases, these plans are reliant on internal capability and backup systems. While these are reasonably effective, the introduction of space-based ADS-B will make it possible for adjacent ANSPs to "share" or transfer services and surveillance data more effectively in circumstances of system degradation or contingency. Having a common surveillance platform with associated common procedures should enhance the ability to provide seamless business continuity because operations can be shared or transferred from one ANSP to another when systems are degraded. This potential, almost real-time, contingency capability means that safety issues are less likely to occur.

Space-based ADS-B should also provide a solution in degraded-mode or redundancy circumstances where legacy surveillance infrastructure is approaching its reliability, availability and accuracy limits. This may be due to circumstances such as performance deterioration, age and availability of spare parts. When systems reach their end of life, space-based ADS-B should offer an effective safety net as well as a solution that guarantees that surveillance services can be sustained.

Greater interoperability (an ICAO harmonization enabler)

In most world regions, there is a common drive to improve safety, efficiency and capacity. The surveillance solution, which underpins these important objectives, is ADS-B. One example is the airspace that links the USA mainland with the adjacent Caribbean countries. In 2014, the RTCA Tactical Operations Committee (TOC) Eastern Region Task

Group (ERTG) was tasked with identifying infrastructure and airspace issues that need to be addressed to improve the safety, capacity and efficiency of operations in the Caribbean. ADS-B was a key recommendation that supported the need for better and expanded surveillance coverage in the region by installing additional ADS-B ground stations to increase surveillance coverage in the region to increase routes with radar separation standards in and out of the Caribbean.[15]

While this example relates to ground-based ADS-B as a key safety and capacity enhancement solution, it illustrates how the value of ADS-B is recognized with regard to regional harmonization activities being driven by ICAO and individual states. The deployment of space-based ADS-B, as noted, will provide a global surveillance "blanket" that will allow any region or country to immediately work collaboratively with adjacent countries to introduce regional interoperability programs and implement ICAO concepts such as airspace block upgrades (ASBU's).

Enabler for more regional and local data sharing

Having a common data platform, in the form of space-based ADS-B, should provide opportunities for greater data sharing both for real-time tactical operations but also for strategic safety and operational analysis and planning. The strategic planning benefits of space–based ADS-B are discussed in more detail in the "Air Traffic Flow Management (ATFM)" section later in the report.

At a strategic level, making ADS-B data available to all service providers and airline operations in a common format should lead to significant safety and efficiency enhancements and collaboration because traffic management and trajectory planning between adjacent sectors and ANSPs should, for the first time, be able to be planned regionally and collaboratively on a common operating platform with common flight data. The potential enhancement to safety management and to efficient trajectory management should be significant.

Support for conflict zone and volcanic ash cloud management

In airspace where there are designated conflict zones or volcanic ash clouds, and reliable surveillance is not available, space-based ADS-B should enhance the strategic planning, contingency management and operational situational awareness. The expected reliability and coverage of space-based ADS-B should enable service providers and regulators to enhance existing procedures, contingency route structures and plans due to greater SA and the accurate display of aircraft position and tracking. The enhanced SA should be an improvement to the global safety net. Space-based ADS-B should also facilitate and support the pre-planning of more accurate and efficient diversion routes and thereby

---

[15] A Report of the Tactical Committee in Response to Tasking from the Federal Aviation Administration, July 2015

reduce additional track miles for airlines. Space-based ADS-B, due to the accurate display of aircraft positions, should deliver — similar to weather diversions — enhanced ATC safety monitoring and separation assurance as aircraft deviate from planned routes.

Reduced risk of controlled flight into terrain

The full extent of space-based ADS-B has yet to be understood but given the risks and number of accidents associated with controlled flight into terrain (CFIT), combined with ATC's ability to monitor and intervene, it is important to at least consider the potential global safety net enhancement that space-based ADS-B may offer, particularly in circumstances where other surveillance services are not available. While it is understood that the initial focus of space-based ADS-B is to serve en-route operations, particularly oceanic and remote (non-surveilled) continental operations, it is important to at least identify some of the potential safety benefits that may evolve as the system's integrity and reliability is fully understood. Reducing the likelihood of CFIT may be a safety benefit due to the availability of automated ATC safety alerts such as MSAW, as noted.

Improved services to VFR aircraft

Aircraft pilots under visual flight rules (VFR) commonly operate either outside controlled airspace or at lower altitudes, below legacy surveillance radar coverage, so they generally receive limited safety services from ATC. It is not unreasonable to anticipate that VFR aircraft may, in time, access the space-based ADS-B network. There are a number of safety benefits that should then be available to VFR aircraft that are limited or not available today, including:

- Improved navigation and tracking services from ATC.
- SAR services if in distress or experiencing navigation issues.
- Improved SA supported by ATC traffic advisories.
- Improved weather-avoidance services.

Longer-term benefits

Enabler for global safety performance monitoring and analysis

Many states, organizations and authorities gather and analyze data with the objective to improve safety and efficiency. The systems and analytical approaches vary globally, as would be expected, but the analysis of safety incidents, casual factors and trends continually lead to many safety enhancements. The introduction of space-based ADS-B and the expected global surveillance coverage mean that for the first time, there would be a common surveillance database available to all states around the world. A previous section discussed regional data sharing to enhance safety, operational efficiency and contingency planning — and this could also be utilized at a global level. The potential for ICAO and other international safety organizations to be able to share and analyze a global traffic data set and from that identify and initiate new or enhanced global safety improvement programs should lead to an improvement of overall safety performance because better harmonized and standardized safety initiatives should reduce risk.

Enhanced global air traffic flow management

Exploring further the safety benefits of data sharing, there is potential for pre-tactical and strategic traffic management planning to occur at a global level. Strategic flow management and traffic management at a national level are becoming more and more common. There are a number of ANSPs that have established specialist facilities, typically in the form of an "operations facility" or a "command facility," to strategically coordinate the flow of air traffic. These operations are typically linked to airline operations facilities and strive to build the most efficient and safe day-of-operation through refined planning of flights to reduce delays and disruptions in any given airspace. Up to now, this type of cooperation has generally been limited to the boundary of any given ANSP's area of operation or FIR, with only some limited regional traffic management cooperation. The introduction of space-based ADS-B introduces a common surveillance capability globally and the opportunity to expand beyond traditional airspace boundaries and ownership to work towards global cooperation of air traffic flow management (ATFM). The benefits of such an initiative are significant because efficiency and safety should be enhanced by having common goals and objectives for operations, and would support ICAO's overall global harmonization objectives.

Supporting unmanned aircraft systems /remotely piloted aircraft systems

As UAV and RPAS operations grow, their integration into the existing piloted environment introduces many challenges. It is unrealistic to think that the ever-expanding applications for UAS/RPAS are likely to slow down for some time yet. One of the obvious but key safety issues is identifying precisely the position of the UAS/RPAS aircraft, whether it is used for ATC separation purposes or for traffic advisory services or for simply pilots' SA and planning purposes. This is equally relevant in controlled and uncontrolled airspace.

The ability to survey UAS/RPAS operations is an important enabler to allow the operation to occur but, more importantly, to allow it to operate safely both to protect other airspace occupants as well as people and infrastructure on the ground. Space-based ADS-B, where existing surveillance services cannot support UAS/RPAS activities, becomes a potential enabler for safer operations and avoiding disruptions to conventional aircraft operations. The full extent of the potential safety and efficiency benefits of space-based ADS-B in enabling UAS/RPAS operations is not fully explored in this paper. It is, however, reasonable to expect that as these types of activities both grow in number and expand in application, the need for reliable and accurate surveillance services will become an essential safety enabler and requirement.

Future capacity enabler

With the exception of a small number of regions, most oceanic and remote (non-surveilled) regions are not experiencing capacity issues yet, but the forecast regional growth and the opening of new destinations means this will not be the case in the future. Airspace will reach capacity limits if it is constrained by the capabilities of existing, legacy surveillance over the next two to three decades. This represents both safety and efficiency issues as ATC will need to manage greater complexity and workload to facilitate access, so aircraft are likely to be forced to operate more and more at non-preferred altitudes and non-preferred routes to be able to operate through constrained airspace. With this comes potential safety concerns with airspace operating at or near capacity and aircraft no longer able to operate on their preferred or planned flight trajectory.

The introduction of reduced separation standards, more efficient route structures and enhanced SA for controllers and pilots, enabled by space-based ADS-B, should ensure that such constrained airspace can be avoided. This means that the inherent risks of aircraft operating in airspace at or near capacity should be avoided.

Enhancing airport terminal airspace operations

The use of multilateration and ground-based ADS-B has transformed the safety and efficiency of operations at some airports, particularly those airports where the cost and practicality of introducing traditional primary and secondary radar surveillance could not be justified. An airline in the United States has established a regional ADS-B surface network to support ramp management, as it was a lower-cost option compared to other traditional surveillance options. It is used to improve the SA of the staff and operations.

Space-based ADS-B should offer the opportunity for regional and remote airports to introduce surveillance services that previously could not be envisaged. ATC is limited by strict procedural separation requirements where surveillance does not exist, particularly with regard to meteorological minima and terrain avoidance. Space-based ADS-B has the potential to allow safe and efficient services to operate on days and in circumstances that procedural ATC would not permit.

Enhancing airport ground handling

Space-based ADS-B also may have the potential to augment or support ground operations at airports. This would particularly be the case in low-visibility operations that reduce airport ground capacity, as the number of aircraft that can be safely maneuvered must be limited by ATC. As space-based ADS-B is introduced, and its capabilities are better understood, where ground surveillance does not exist today, it has the potential to be a significant safety and efficiency enabler to allow airports to continue to operate at near or full capacity on low-visibility days.

Pathway to air-to-air ADS-B In

The aviation industry is still considering the next step in ADS-B, which is the potential for self-separation and increased cockpit SA through the introduction of ADS-B In. This report does not seek to analyze the safety and efficiency benefits of ADS-B In nor is it being currently considered with the introduction of space-based ADS-B; however, given that ADS-B has been identified by ICAO as a surveillance standard for the future, it is important to recognize that space-based ADS-B — through its global introduction — becomes a potential stimulus for exploring the next generation of safety benefits that ADS-B In may offer.

Challenging existing CNS and FANS requirements

The introduction of space-based ADS-B should stimulate a review of the traditional CNS requirements to achieve FANS compliance, which for decades has stipulated ADS-C and CPDLC as the components for communications and surveillance. It would not be unreasonable to anticipate that ICAO may consider how space-based ADS-B may support the CNS requirements framework, as ADS-B is already a globally recognized surveillance technology. This presents a new paradigm and safety performance enhancement opportunity for oceanic and remote (non-surveilled) operations.

Driving safety through innovation

It has been the experience in other high-tech environments that the full potential of a new technology cannot be understood or exploited until it is fully implemented. In the long run, high (disruptive) technologies often are bypassing, upgrading or replacing legacy systems and networks.

In an industry where continuous improvement in airspace capacity, operational performance, harmonization and safety are part of the everyday operating landscape, innovation, in its various forms, is a key enabler to meeting these challenges. It is unacceptable, while there are still accidents and incidents occurring, to not pursue safety improvements through innovation. Space-based ADS-B has the potential to be one of these important global safety innovations. It is fair to say, based on the experiences of other technology innovations that we are not yet in a position to anticipate the types of downstream, disruptive innovations that such a global surveillance may stimulate. It is reasonable to expect that other benefits not yet identified will manifest as the technology is deployed and its full potential is explored.

Downstream economic and social benefits

Looking beyond the immediate aviation safety benefits that space-based ADS-B may introduce to countries where surveillance has not yet been deployed, there may be downstream economic, political and social benefits for some countries that could be considered, as noted. It is beyond the scope of this report to explore or quantify these likely benefits, but it is reasonable to highlight that this surveillance technology should enable many non-aviation benefits to flow beyond the immediate aviation industry, particularly in countries where surveillance is not available today.

Conclusion

Space-based ADS-B has the potential to improve safety and efficiency through an extensive range of short, medium and long-term benefits. It has been the experience in other high-tech environments that the full downstream potential of a new technology cannot be understood or exploited until it becomes fully available; however, it is reasonable to conclude that the cumulative effect on safety, based on the current benefits identified — if fully realized — should deliver a substantial improvement to the global safety net.

Space-based ADS-B: Success factor challenges

Throughout the research for this report and in discussions with various stakeholders, there have been some important topics that must be addressed to ensure the realization of the many safety and efficiency benefits of space-based ADS-B.

Space-based ADS-B integrity

Space-based ADS-B will require state regulatory approval. The system will be required to develop a safety argument, based on valid evidence, that the system can meet the latency and reliability requirements and, in doing so, demonstrate it can meet the necessary safety standards.

Individual state regulators will also need to conduct the necessary assessment of ANSP Part 171 and Part 172 certification for ground-based elements of the system.

New and retrofit aircraft will also be subject to ADS-B avionics certification.

These regulatory activities, also relevant to the work to achieve reduced separation minima, are not considered as a barrier but they are important regulatory safety processes that must be completed.

ADS-B equipage rates

To derive the benefits of any new technology requires a level of momentum and a tipping point at which the level of participation enables the full benefits to be realized. This is true of space-based ADS-B, where avionics equipage and the will of states to encourage or mandate the use of ADS-B will be a highly influential consideration in securing the safety and efficiency gains.

A number of states have already mandated or are instituting mandates for the adoption of ADS-B over the next three to four years — countries such as Australia, Singapore, Hong Kong, Canada, New Zealand and Vietnam are examples. Global ADS-B equipage rates will be strongly influenced by the U.S. mandate of January 1, 2020, in most controlled airspace[16] and in Europe where the mandate is June 8, 2016, for new aircraft and June 7, 2020, for retrofit.[17]

These mandates will have a significant influence on total equipage rates globally and would be expected to achieve sufficient uptake to allow the many benefits from space-based ADS-B to flow.

---

[16] https://www.law.cornell.edu/cfr/text/14/91.225

[17] http://www.eurocontrol.int/spi-ir

Quality of signal and impact of antennae location on the aircraft

The modelling for space-based ADS-B is based on top-mounted antennae, which is consistent with the positioning of TCAS (traffic-alert and collision avoidance system) equipment for an aircraft. The evaluation of system and signal reliability, availability and latency will need to be part of the certification and approval processes to meet regulatory requirements.

Adoption by ANSPs

The implementation of space-based ADS-B will require some ANSPs to procure or upgrade existing ATC automation systems. This is an important interdependency to ensure the service can be delivered. The previous section, which explored ADS-B mandates, should be a key stimulus for ANSPs to be suitably equipped.

It is reasonable to anticipate that airlines and regulators will expect ANSPs to be ADS-B–capable in time to meet the various mandates.

Security

Network cyber security is an important concern that has become very topical given the move towards concepts such as "black box in the cloud" and other information processing–supported technologies. The International Telecommunications Union (ITU) has established expert working groups that are considering cloud-based solutions for aircraft tracking and to enhance SAR capabilities. The cyber security of the various communications support networks has been identified as a topic that still needs to be fully understood.

Space-based ADS-B is likely to be subject to security-related scrutiny, given its likely central role in aircraft tracking and SAR support.

Conclusion

There are a number of regulatory safety performance and certification processes that must be completed; however, the range of ADS-B mandates that must be complied with over the next 5-6 years should stimulate both equipage uptake and regulatory processes to manage the various risks identified.