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A safety assessment framework for the Automatic Dependent Surveillance Broadcast (ADS-B) system

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ABSTRACT

The ATM system is currently undergoing various fundamental changes to improve air travel performance. A key change is the transition from a mainly reactive and tactical system to a significantly more predictive and strategic system. This is encapsulated in the concept of 4D trajectory based operations, currently being developed in Europe and the USA through the Single European Sky (SES)/Single European Sky ATM Research (SESAR) and the Next Generation Air Transportation System (NextGEN) respectively. At the core of this transition, is the need for improved situational awareness, shared between relevant stakeholders. The Automatic Dependent Surveillance Broadcast (ADS-B) system is a key enabler of this concept, targeted at distributing real-time positioning and navigation information to stakeholders. Therefore, the safety and credibility of the ADS-B system to support various ground and airborne applications are key, and need to be assessed and validated. This paper reviews existing safety assessment methods, identifies key limitations and proposes a novel, comprehensive and rigorous safety assessment framework for the ADS-B system.

1. Introduction

Current surveillance systems within the Air Traffic Management (ATM), and in particular Air Traffic Control (ATC) systems are at their operational limits and no longer able to accommodate the anticipated future increase in air traffic. Amongst others, current surveillance systems suffer from a lack of availability in low altitude, remote and oceanic areas, and during extreme weather conditions. Furthermore, these systems often rely on outdated equipment without spare parts (ICAO, 2000). The lack of appropriate surveillance, results in incidents and accidents. For example, during 1990–2009, there were 568 commuter aircraft and air taxi crashes in Alaska. A common cause identified for the incidents is due to limited surveillance services resulting in controlled flight into terrain (CFIT) (NIOSH, 2013). This is a result of difficulties in siting appropriate radar in the Alaskan airspace.

The surveillance system provides Air Traffic Control Operators (ATCOs) with aircraft situational awareness, to perform separation management and effectively manage a given airspace. Systems currently in use for surveillance are Primary Surveillance Radar (PSR) (Aeronautical Surveillance Panel (ASP), 2007; ICAO, 2007; Wassan, 1994), Secondary Surveillance Radar (SSR) (ICAO, 2004c, 2007; Wassan, 1994), Monopulse Secondary Surveillance Radar (MSSR) (ICAO, 2007), Surface Movement Radar (SMR) (ICAO, 2004a) and MultiLATeration (MLAT) (Owusu, 2003). The performance of these systems is however insufficient to satisfy the functional requirements of 4D trajectory based operations, including high-performance situational awareness.

Therefore, to address these limitations, the International Civil Aviation Organization (ICAO) proposed a new surveillance system: the Automatic Dependent Surveillance Broadcast (ADS-B) system. ADS-B is a surveillance system which relies on onboard aircraft navigation systems to obtain the aircraft position. It transmits this position and other aircraft state information to ATC on the ground and other ADS-B equipped aircraft within a specified range, via a communication link. The ADS-B system consists of many elements, including onboard navigation and communication systems, as well as other system elements on the ground or onboard other aircraft, making it a very complex system and significantly more prone to failures than the radar system. To ensure system safety, a rigorous, clear and comprehensive safety assessment approach is thus required.

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A number of methods exist to assess the safety level of a system. These include 'Evaluation of system risk against a threshold value (Absolute Method)' (ICAO, 1998); 'Comparison with a reference system (Relative Method)' (Butcher, 2002; ICAO, 1998) and 'Absolute-Relative Risk Assessment Methodology' (Vismari and Camargo, 2008). However, none of these methods are capable to fully assess the ADS-B system safety performance. The former method requires historical hazard frequency data which is not available for ADS-B at present. The next method is not applicable when the reference system is significantly different than the ADS-B system. The latter method inherits the drawbacks of the two former methods.

In addition to the methods stated above, Hammer et al. (2007) and Zeitlin (2001) proposed safety assessment methods for ADS-B based ground and airborne applications, with the current focus being on implementation. They do not assess the performance of the ADS-B system itself as the surveillance data source for the airborne and ground applications. In this paper, the aim is to develop a comprehensive safety assessment framework for ADS-B to ensure that the system is acceptably safe to support any airborne or ground based applications for air traffic control and aircraft navigation operations by Air Navigation Service Providers (ANSP) worldwide. This requires a detailed understanding of the system, including functionality and physical architecture. The framework also aims to adopt the guidelines provided by ICAO (2005) to asses safety of an equipment. These guidelines are stipulated in Section 4.

2. Principle of ADS-B operation

ADS-B is a function on an aircraft or a surface vehicle, which periodically broadcasts its position and other information without knowing the recipients and without expecting acknowledgement. The system is automatic in the sense that it does not require external intervention to transmit the information. It is a dependent and cooperative surveillance system. It is dependent on aircraft avionics to obtain position and navigation information. It is a cooperative system, because of the need for common equipage by relevant stakeholders to participate in the system. ADS-B provides aircraft state information such as horizontal position, altitude and vector, velocity, as well as intent information. The latter is critical amongst others for trajectory prediction, key enablers of the Single European Sky (SES)/Single European Sky ATM Research (SESAR) and Next Generation Air Transportation System (NextGEN) Concept of Operations.

The ADS-B system architecture can be divided into two subsystems, "ADS-B Out" and "ADS-B In". ICAO (2003a) defines "ADS-B Out" as the broadcast of ADS-B information from the aircraft, without the installation of complementary receiving equipment to process and display this information in cockpits. ADS-B Out transmissions can additionally be received by the air traffic controllers on the ground, thereby enabling ground-based surveillance of aircraft. The complementary subsystem is the "ADS-B In", which enables reception of the ADS-B Out broadcast information and thereby air–air situational awareness. The ADS-B In system element is significantly more complex and requires the implementation and evaluation of ADS-B Out system beforehand. In other words, ADS-B In implementation requires fully operational ADS-B Out system in a particular airspace.

This paper will exclusively focus on ADS-B Out. An ADS-B equipped aircraft uses an on-board navigation system, for example based on GNSS, to obtain the aircraft position. The system then broadcasts the position, velocity and intent data to other ADS-B equipped aircraft and ADS-B ground stations within its range via a data link service periodically with an update rate of one to two seconds. The ground stations transmit the received ADS-B reports to a surveillance processing unit to process the data for ATC use. Fig. 1 illustrates the ADS-B system.

3. ADS-B performance requirements

Performance requirements for surveillance are determined by the application, including the airspace in which the aircraft operates. For example, reduced separation minima application in terminal area requires better performance than in the en-route sector. A general requirements for the ADS-B performance suitable for this application stipulated in the SPI-IR (EUROCONTROL, 2011) and ED-142 (EUROCAE, 2010) are summarized in Table 1.

Total latency is the amount of time taken to broadcast aircraft position relative to the time of applicability of the position measurement. Uncompensated Latency is the amount of total latency that is not or cannot be compensated by the ADS-B system. It is the difference between the time of applicability perceived by the ADS-B receiving subsystem and the true time of applicability of the transmitted data (RTCA, 2009).

4. Safety assessment

EUROCONTROL (EUROCONTROL, 2010b) envisages that the distinctions between safety assessment and safety case must be understood before they are established. EUROCONTROL states that safety assessment looks at hazards, and their effects and mitigations, and makes reasonable assumptions about the behavior of the system elements (such as their reliability and accuracy levels or failure rates) so as to be able to assess quantitatively the likelihood of hazards resulting in incidents or accidents. A safety case collects data to verify that the assumptions are valid in a real life situation. Performance assessment captures system behavior. Its objective is to ensure that the system will perform its intended function, while a safety assessment indicates that the system will not induce dangerous situations. Therefore, performance covers the nominal (*non-adjusted*) modes of operation whereas safety focuses on non-nominal modes (ICAO, 2006). Performance requirements such as accuracy, integrity and availability are integral to safety assurance of the ATC surveillance system (ICAO, 2006). In order to ensure that the ADS-B implementation is safe, both safety and performance assessments must be undertaken, whereby hazards are identified and barriers are introduced to reduce the risk that may be caused by these hazards. Safety assessment is a structured and systematic process for the identification of hazards and the risks associated with each hazard. A safety assessment essentially addresses the following three fundamental questions (ICAO, 2005):

- What could go wrong?
- What would be the consequences? and
- How often is it likely to occur?

According to the ICAO, safety assessments shall consider all relevant factors determined to be safety-significant, including:

- types of aircraft and their performance characteristics, such as aircraft navigation capabilities and navigation performance;
- air traffic density and distribution;
- airspace complexity, ATS route structure and classification of the airspace;
- aerodrome layout, including runway configurations and lengths as well as taxiway configurations;
- type of air to ground communications and time parameters for communication dialogues, including controller intervention capability;