4-2018

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ISSN (O): 2393-8609
International Journal of Aerospace and Mechanical Engineering
Volume 5 – No.2, April 2018

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ABSTRACT

ADS-B is one of the significant implementation systems of NextGen, to help pilots and air traffic controllers to create a safer, and more efficient National Airspace System (NAS). First, this research paper will briefly describe the ADS-B system, its design structure, ADS-B In and ADS-B Out systems, its efficiency both in pilot applications and in air traffic control applications, and then discuss about the system safety analysis. The preliminary hazard analysis and fault tree analysis will be done for the identified and selected hazards, and will be briefly discussed. The paper will conclude by providing recommendations to prevent/mitigate the hazards identified.

General Terms
Research Paper

Keywords
ADS-B, NextGen, human factors, safety, surveillance, PHA, FTA.

1. INTRODUCTION

The fastest mode of transportation is the air transportation and generally, it is considered to be safe. The United States National Airspace System (NAS) reported that it has achieved low accident rates since 1960 with a dramatic decrease in major accidents (Boeing, 2016). There were approximately 3.8 billion air travelers in 2016 and the International Air Transport Association (IATA) predicts that there will be a 3.7% annual growth rate and expects about 7.2 billion passengers to travel by air in 2035 (International Air Transport Association [IATA], 2016). Meanwhile, the worldwide traffic of air cargo is expected to grow by an average of 4.2 percent per year over the next 20 years (Boeing, 2016-2017). Though, the forecasted growth in both passenger and cargo flights is expected to be nearly 5% in the coming decades the existing air traffic management system cannot handle this growth.

Apart from the increasing demands related to the capacity, the United States national airspace is also under pressure to reduce the operating costs, traffic congestion, delays, accident rates and greenhouse gas emissions, and at the same time, it has to ensure safety. The Federal Aviation Administration (FAA) has to address the current and future air traffic congestion, and it is also poised to handle the future demand. To handle these issues efficiently, FAA has been developing the Next Generation Air Transportation System (NextGen) with the purpose of changing the way the NAS operates.

NextGen will meet future demand and support the economic viability of the air transportation system. It will improve the safety and support environmental initiatives such as reducing the traffic congestion, green gas house emissions, noise, and fuel consumption through increased energy efficiency. As a part of NextGen to achieve the above-mentioned goals, FAA has determined that it is essential to shift from ground-based surveillance and navigation system to more dynamic and accurate airborne-based systems and procedures which will help to enhance the capacity, reduce delays, and improve the environmental performance. Hence, as a part of NextGen operation, the Automatic Dependent Surveillance–Broadcast (ADS–B) system has been developed and installed worldwide. This paper will discuss the Automatic Dependent Surveillance–Broadcast (ADS–B), the ADS-B IN and ADS-B OUT systems, identify the hazards related to ADS-B in general and then analyze the human factor issues related to ADS-B system, discuss the current safety regulations related to ADS-B system and conclude by providing few recommendations to mitigate the identified hazards.

2. RESEARCH METHODOLOGY

An online literature search was carried out using Google Scholar, Science Direct, Hunt Library of Embry-Riddle Aeronautical University, Web of Science and Federal Aviation Administration website. The database was filtered to collect the appropriate data related to the Automatic Dependent Surveillance–Broadcast (ADS–B) system, related hazards, and its role in the success of the aviation industry.

System safety is important to the development of any system mainly to reduce the risks, protect lives and resources by preventing mishaps. The foremost aim of system safety is on hazards analysis and it is important to collect and record the information, such as "the prime hazard causal factors (e.g., hardware failure, software error, human error, etc.), the major mishap category for the hazard (e.g., fire, inadvertent launch, physical injury, etc.), and any safety critical (SC) factors that will be useful for subsequent analysis (e.g., SC function, SC hardware item, etc.)" (Ericson, 2015). Based on this system safety aim, the hazards related to ADS-B were identified and a Preliminary Hazard Analysis was conducted using the methodology obtained from MILSTD-882E for System Safety (Department of Defense [DOD], 2012). The identified ADS-B system hazards were organized on the basis of the checklist provided in the book Risk Assessment: Theory, Methods, and Applications by Rausand (Rausand, 2011, p. 67) and the format of the table is adapted from the textbook Hazard Analysis Techniques for System Safety by Erickson (2015). Hazard Risk Assessment Matrix was adapted from MILSTD-882E for System Safety (DOD, 2012). As the ADS-B system is very complex, out of the different hazard categories identified, this paper discusses only the hazards that occur due to human error especially three hazards namely pilot error, ATC error, and error that occurs due to miscommunication of

ISSN (O): 2393-8609
International Journal of Aerospace and Mechanical Engineering
Volume 5 – No.2, April 2018

both was further analyzed using the fault tree analysis methodology (Ericson, 2015).

3. RESULTS AND DISCUSSION

Automatic Dependent Surveillance–Broadcast (ADS–B)

The most advanced surveillance technology in the aviation industry is the Automatic Dependent Surveillance–Broadcast (ADS–B) system. The term ADS-B refers to Automatic – A system which transmits information without the input from pilot and ATC; Dependent – the information transmitted with regard to the position, altitude, and velocity of the aircraft is dependent on the global positioning system (GPS) and on the navigation avionics of the aircraft; Surveillance – It provides a method for determining various aspects of the aircraft's position and intent; and Broadcast – The information transmitted is available to anyone with suitable receiving equipment (Civil Aviation Safety Authority [CASA], 2012).

ADS-B is the major component of NextGen as it is intended to move air traffic control (ATC) to a satellite-derived aircraft location system from a radar-based system. The ADS-B technology creates a more precise surveillance interface between an aircraft and the ATC based on the combination of the positioning source of the aircraft, avionics equipment and the infrastructure on ground (Federal Aviation Administration [FAA], 2017, a). ADS-B equipment is an advanced surveillance system with air to air, and air to ground applications. It involves two main components namely the Airport Surface Detection System–Model X (ASDE-X) and Airport Surface Surveillance Capability (ASSC) ground surveillance systems. These two systems link ADS-B with other surveillance technologies and this facilitates the ATC to track the aircraft movement on ground and airport ground vehicles. It provides more precise information to both pilots and air traffic controllers to keep the aircraft safely separated on runways and in the sky (FAA, 2017, a).

3.1 ADS-B System Design

The ADS-B system consists of both airborne and ground components. The ground components are GPS (Global Positioning System) Clock, ADS-B receiver, and antenna, ADS-B situational display and communication link. The function of ADS-B receiver and the antenna is to receive the messages broadcast from aircraft, while the communication link transmits the messages to the surveillance data processing unit of the air traffic control from the ground station. The function of ADS-B situation display is to exhibit the position of the aircraft and to indicate the vector just like the radar-based surveillance system (CASA, 2012). The ADS-B airborne infrastructure consists of the navigational source the GPS, ADS-B Avionics (standalone box for UAT), Control Panel, Barometric Altimeter, Altitude Encoding Altimeter, Antenna for ADS-B, Transponder, and GPS, Antenna Duplexer, and Flight Management System (FMS) (FAA, 2017,b). The function of GPS is to collect and broadcast the position of the aircraft position and indicate the vector information to the ADS-B emitter. While the ADS-B avionics system encode and transmit ADS-B messages and the function of Antenna for ADS-B, Transponder, and GPS is to support both ADS-B IN and OUT i.e., to support ADS-B OUT, a single antenna is required at the bottom of the aircraft and to support ADS-B IN, two antennas are required (one at the top and one at the bottom of the aircraft). Antenna Duplexer enables to share the antenna between the transponder and ADS-B unit. Barometric altimeter develops the aircraft altitude, and the Altitude Encoding Altimeter organizes the information about the altitude that is transmitted by the ADS-B message and altitude transmitted by the transponder. Control Panel permits the pilot to key in the inputs and select aircraft identification, emergency pulse etc. and FMS helps to manage the flight plan (FAA, 2017,b). Based on these components ADS-B is classified into two main subsystems namely ADS-B IN and ADS-B OUT (Fig.1).

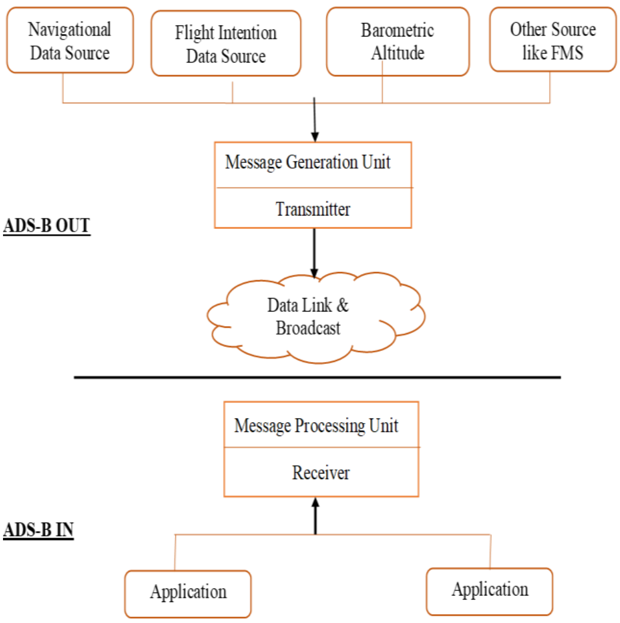

Fig.1. Design of ADS-B System (FAA, 2017, a)

3.2 ADS-B IN and ADS-B OUT Systems

The basic design of ADS-B consists of two subsystems such as "ADS-B IN" and "ADS-B OUT". ADS-B OUT is the part of the system that transmits the data about the aircraft such as its altitude, airspeed, velocity, and location, to the ADS-B ground stations and the avionics, is shown in Fig.2.

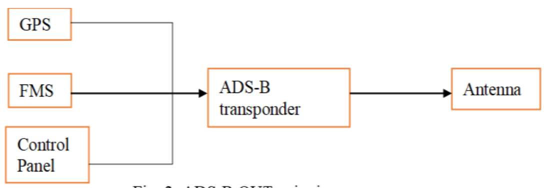

Fig. 2. ADS-B OUT avionics

While ADS-B IN is the receiving part which when equipped in an aircraft interpret the data received from other aircraft on an electronic flight bag in the cockpit. This system requires

ADS-B OUT system with an "in" capability receiver (Houston, 2017). To enhance the efficiency along with the receiver part some aircraft are also equipped with CDTI (Cockpit Display Traffic Information) (CASA, 2012) and their related avionics is illustrated clearly in Fig.3.

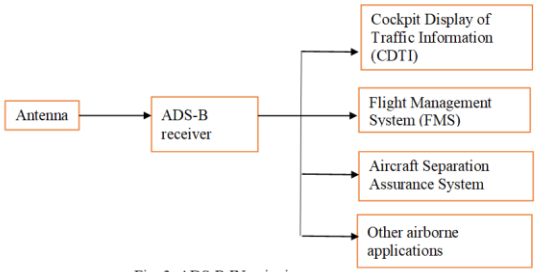

Fig. 3. ADS-B IN avionics

3.3 Efficiency of ADS-B system

Capezzuto (2005), Director of Surveillance and Broadcast Services, FAA, classified the efficiency / capability of ADS-B system into four types namely (i) Air to Air application - which transmits data from one aircraft to another in the air and hence improves the separation standards, improves low visibility approaches, enhances see and avoid, and enhances operations for en route air to air, (ii) Air to Ground applications i.e., applications that require the transmission of the data from an aircraft to fixed ground users which enhances both radar and non-radar airspace surveillance coverage area, (iii) Ground to Ground application which transmits data from aircraft/vehicle to others on the ground which in turn improves the taxiway navigation and ultimately improves surface traffic management, and (iv) Ground to Air self – contained application which transmits the weather information to the cockpit which in turn reduces of controlled flight into terrain (Capezzuto, 2005).

These applications were categorized into three groups by Results Through Collaboration in Aviation (RTCO, 2002). They are

1) Ground-based surveillance applications such as ATC surveillance in airspace with radar and non-radar coverage, surface surveillance at the airport, and aircraft derived data for ground-based ATM tools.

2) Aircraft-based surveillance applications – (i) increases the situational awareness by enhancing the visual acquisition of traffic, enhancing traffic awareness on the airport surface, during flight operations and by enhancing the successive visual approaches. (ii) improves the airborne separation by enhancing the in trail procedure and merging the operations.

3) Other applications such as ramp control/gate management, monitoring the noise, enhances the situational awareness of obstacles and Search and Rescue (SAR) operation.

On the other hand, FAA (FAA, 2017 c) classified these applications in different perspective i.e., (1) ADS-B in Pilot applications which includes the Traffic Information Services – Broadcast (TIS-B), Flight Information Services – Broadcast (FIS-B), ADS-B in Interval Management Applications, In Trail Procedures, Traffic Awareness System and (2) ADS-B in Air Traffic Control applications, which is briefly described below.

3.3.1 ADS-B in Pilot Applications

In the cockpit, ADS-B offers more safety and efficiency by providing up to the second information about traffic, and weather, through the ADS-B In receivers that can receive UAT broadcasts (FAA, 2017 c). It offers two broadcast services namely Traffic Information Services – Broadcast (TIS-B) and Flight Information Services – Broadcast (FIS-B). TIS-B increases the situational awareness of the pilots by broadcasting the accurate real-time traffic position reports that are relevant to the aircraft which is properly equipped. As the data is displayed to both the pilots and ATC they have shared situational awareness. FIS-B is available only to those aircraft which can receive data over 978 MHz (UAT) (FAA, 2017, c). It spontaneously transmits weather information such as turbulence, lightning, icing, and cloud tops based on both national and regional focus to all equipped aircraft. This real-time aeronautical and weather information helps the pilots to efficiently plan a safe flight path and during the flight, it helps them to make strategic decisions to avoid the hazardous weather conditions.

In Interval Management Applications, ADS-B increases the situational awareness of the crew by providing guidance regarding the speed which helps the crew to maintain an interval from target aircraft and fly safely. This is more effective in air traffic control at the oceanic regions, en route, and at terminals. As it provides efficient direct flight path, and low-variance spacing between aircraft it reduces the fuel burn, noise, and emissions (CASA, 2012). In Trail Procedures (ITP) is an advanced ADS-B In application which allows the aircraft to fly at ideal flight levels. It also increases the fuel economy, reduces the emission by avoiding the turbulent altitudes. ADS-B Traffic Awareness System (ATAS) helps to detect the potential traffic encounters, alert the pilots and thus reduces the air collisions to a greater extent (Richards, Brien, & Miller, 2010).

3.3.2 ADS-B in Air Traffic Control applications

The real-time accuracy of the data provided by ADS-B enhances safety by helping the air traffic controllers to efficiently and effectively manage the air traffic for improved safety and capacity (FAA], 2017 d). These services are provided through Wide Area Multilateration (WAM), Airport Surface Surveillance Capability (ASSC), and Advanced Surveillance Enhanced Procedural Separation (ASEPS). WAM can be installed in areas where radar service is unavailable or limited. It is a ground-based surveillance system that offers surveillance outside the range of radar coverage. It enhances the efficiency, safety, and capacity by reducing the flight delays, diversions, cancellations, and fuel emissions (FAA, 2017 d). ASSC increases situational

ISSN (O): 2393-8609

International Journal of Aerospace and Mechanical Engineering

Volume 5 – No.2, April 2018

awareness in all kinds of weather by improving the surveillance at the airport surface. It plays a significant role in preventing the runway collisions, helps to correlate the information regarding the flight-plan with real-time position displays and provides accurate surveillance data (FAA, 2017 e).

The subsequent level of NextGen is the Advanced Surveillance Enhanced Procedural Separation (ASEPS) project. Its aim is to improve the oceanic surveillance. FAA is evaluating two methodologies to improve the surveillance coverage in oceanic regions through Space-Based ADS-B reports and more frequent Automatic Dependent Surveillance – Contract (ADS-C) reports (FAA, 2017 f). Space-Based ADS-B is an approach to move from the present system of ADS-B ground stations to radios hosted on satellites, which will enable enhanced surveillance across the entire globe (FAA, 2017 f). It will help to track the aircraft that might fly anywhere in near real-time and will increase the safety and efficiency for all users. It will also reduce the separation standards in oceanic airspace and improve precise approach in non-radar airspace and provide accurate and real time information for search and rescue operations (FAA, 2017 f).

3.4 System Safety Analysis of ADS-B

As discussed ADS-B offers a lot of advantages like enhancing the efficiency of airspace capacity and usage by the efficient use of runways, increases the safety by providing real-time information regarding the aircraft position, velocity etc. to both pilots and ATC. It automatically provides traffic call-outs and provides warnings of an upcoming potential runway incursion. In addition, the implementation, and maintenance of the system is cost efficient compared with the radar-based system. It is efficient in areas where radar is unavailable or ineffective, and increases the situational awareness, and reduces the workload (CASA, 2012 and Richards, Brien, & Miller, 2010, p. 7-10). Due to the complete surveillance technology for commercial operators, it provides both fuel and time savings (FAA, 2017, a), enables the airlines to fly direct routes and reduce the ticket cost per passenger by flying at more efficient altitudes and speeds with uninterrupted climbs and descents. It also reduces the environmental impact by decreasing the emissions from engines, reduces the noise through continuous descent and curved approaches (Richards et al., 2010).

Today's systems are highly complex with human-machine interface, machine-machine interface and prone to hazards that results in mishaps. ADS-B is one such highly complex system. The ADS-B specific components such as ADS-B IN and ADS-B OUT are integrated to develop a complete system which is dependent on external systems such as navigation systems, communication, and different operators/consumers. As different systems are interlinked with each other there is a probability for errors and failures to occur at any stage/ system such as navigation system, avionic components that are both air borne and those that are at the ground stations, data linking and processing unit, transmission, reception etc. Hence system safety is is important for any type of project. Ericson (2015) defined system safety as the "process of managing the system, personnel, environmental, and health mishap risks encountered in the design development, test, production, use, and disposal of systems, subsystems, equipment, materials, and facilities". The main aim is to eliminate the hazards that might result in the loss of the system, injury, death, and environmental damage. The main intention of system safety is the mishap risk management by identifying the hazards and mitigating them.

Preliminary Hazard Analysis (PHA) is defined as a safety analysis tool that is used for identifying hazards, related causal factors and hazardous effects, risk level, and which provides mitigating design measures (Ericson, 2015). PHA evaluates the system design at the preliminary level without comprehensive information and it comes under the Preliminary Design Hazard Analysis Type (PD-HAT). The main aim of the PHA is to analyze the hazards that are identified in the Preliminary Hazard List (PHL) and to identify previously unrecognized hazards early in the system development. It identifies the hazard causal factors, consequences, and relative risk associated with the initial design concept. The PHA is applicable to the "analysis of all types of systems, facilities, operations, and functions and can be performed on a unit, subsystem, system, or an integrated set of systems" (Ericson, 2005, p. 74).

Based on FAA's Capstone Safety Engineering Report #1 - ADS-B Radar-Like Services (FAA, 2000), FAA's Capstone Phase II RNAV Preliminary Hazard Analysis Status Report (FAA, 2003), and the Capability Safety Assessment report (Joint Planning and Development Office [JPDO], 2012) the hazards relate to ADS-B were identified, and preliminary hazard list (PHL) was prepared. Based on the PHL the Preliminary Hazard Analysis (PHA) was conducted for the hazards related to ADS-B IN Avionics hazards, ADS-B OUT Ground hazards, ADS-B OUT Avionics hazards, Environmental Hazards and hazards that occur due to human error and the results of PHA alone were provided in Table 1.

As the ADS-B system is very complex, out of the different hazard categories identified, this paper discusses only the hazards that occur due to human error especially three hazards namely pilot error, ATC error, and error that occurs due to miscommunication of both and was further analyzed using the fault tree analysis methodology (Ericson, 2015).

Fig.4 represents the Fault Tree Analysis of Loss of separation that might occur due to the error in aircraft, ground station (ATC) and miscommunication between air and ground operations. With regard to the loss of separation, the causes were related to the error that occurs in aircraft due to pilot, error that might occur due to miscommunication between pilot and ATC and error that occur in ground station due to ATC. All the links are connected with an OR node as any of those factors can cause the loss of separation.

ISSN (O): 2393-8609

International Journal of Aerospace and Mechanical Engineering

Volume 5 – No.2, April 2018

Table.1. Preliminary Hazard Analysis of Automatic Dependent Surveillance-Broadcast System

Generic Hazard Evaluation (PHA)						
System : Automatic Dependent Surveillance-Broadcast System						
No	**Hazard description**	**Cause**	**Effect**	**IM RI**	**Preventive actions / Mitigation**	**FMRI**
ADS-B IN Avionics Hazards						
IN AVH 1	Loss of data which might affect the ADS-B IN application.	Failure of aircraft's ADS-B receiver.	Situational awareness will be reduced.	1D	Back up Ground radar station/ On board establishment of ADS-B receiver.	3C
IN AVH 2	Aircraft position might not be correct.	Receiver antenna collapses.	ADS-B might provide wrong navigational aids and result in false situational awareness.	1C	Regular maintenance Ground Radar station/Development of GPS Based back tools	3D
IN AVH 3	Loss of data to ADS-B IN application.	Receiver antenna malfunction.	Situational awareness will be reduced.	1D	Regular calibration and maintenance/backbone ATC Radar Stations	3D
IN AVH 4	Track of aircraft might not be displayed to the pilot.	Failure of the systems that connects ADS-B receiver and other application systems	Situational awareness will be reduced & affect pilot.	1B	Use ATC Radar Stations	3C
IN AVH 5	System hangs suddenly.	Failure of CDTI display	Situational awareness will be reduced & affect pilot.	1C	Reboot the system. A second Back up system like IPAD with Flash Memory is recommended	3D
IN AVH 6	Aircraft position might not be correct. May remain for a long time.	Malfunction of the ADS-B report assembly systems.	ADS-B might provide wrong navigational aids and result in false situational awareness.	1B	Use Manual Nav Aids like GPS. For route mapping/Regular testing of the software, identify the bug that cause the error and resolve the issue by debugging.	4B
IN AVH 7	Related to human factor/error.	Pilots lack of experience about the system functionalities	Results in undesirable events.	2C	Provide efficient and comprehensive training to the crew/engage Auto pilot	4D
ADS-B OUT Ground Hazards						
O GH 1	Loss of data which have an impact on the controller inputs.	Power supply failure	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	2D	Back up UPS facility should be provided.	4B
O GH 2	Due to corruption it display wrong data to controller.	Error in the data link	Without the awareness of the controller it lead to break down in separation and affect all the aircraft.	2C	Regular Firmware updates/Anti Virus Protection maintenance and calibration.	3B
O GH 3	Position of aircraft might be affected.	Error in data decoding process	Without the awareness of the controller it lead to break down in separation and affect all the aircraft.	2D	Identifying & debugging should be done to resolve the bug that causes the decoding error.	3D
O GH 4	Abrupt loss of data that might affect the controllers work.	Failure of data link between controller working position and ground station	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	2C	Provision of back up and availability of different links.	4B
O GH 5	Due to corruption displays incorrect data to the controller.	Error in the ADS-B Receiver	Without the awareness of the controller it lead to break down in separation and affect all the aircraft.	2C	Regular maintenance and testing.	3B
ADS-B OUT Avionic Hazards						
O AVH 1	Failure of GPS time input will cause	Failure of GPS Clock	Affect all the aircraft as it lead to incorrect intent	2B	Data verification system should be installed.	3C

	unexpected loss of time synchronisation.		data.			
O AVH 2	Sends corrupted position data to ADSB emitter.	Error in GPS receiver unit	There might be error in the display of the position of the aircraft and it might lead to break down in separation.	2C	Availability of back up receiver.	3B
O AVH 3	Position data will not be sent to ADS-B emitter.	Malfunction of GPS receiver	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	2C	Back up facility for the navigational system on board.	4C
O AVH 4	Loss of ADS-B position data affects the controller input.	Failure of GPS antenna	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	3B	Back up facility for the navigational system on board.	4B
O AVH 5	Positional accuracy will be lost.	Error of accuracy performance equipment in the aircraft	Error with regard to the position of the aircraft displayed.	3C	Regular CALIBRATION maintenance and testing.	4C
O AVH 6	Altitude data transmitted to ADS-B emitter might be wrong.	Malfunction of Altitude encoder	Without the awareness of ATC it might lead to break down in separation.	2C	Altitude quality indicator alerts. Regular maintenance and testing.	3D
O AVH 7	Altitude data transmitted to ADS-B emitter might be corrupted.	Altitude sensing fails	Without the awareness of ATC it might lead to break down in separation.	2C	Altitude quality indicator alerts. Regular maintenance and testing.	3D
O AVH 8	Position of the aircraft displayed might be incorrect.	Error in Transponder/ ADS-B emitter	Without the awareness of ATC it might lead to break down in separation.	2B	Installation of data validity mechanism on board.	3C
O AVH 9	Loss of data which might affect the controller.	Failure of aircraft's transponder/emitter	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	3C	Back up transponder/ emitter.	4C
O AVH 10	Altitude data not transmitted to ADS-B emitter.	Malfunction of Altimeter	Data related to altitude is not transmitted. ATC should revert back to procedural control.	2C	Data from GPS can be used as back up.	3C
O AVH 11	Loss of data which might affect the controller.	Malfunction of ADS-B Out Antenna	ATC has to reassess the traffic by transitioning back to procedural control. Increases the workload. Situational awareness is lost.	3B	Back up.	4C
O AVH 12	Broadcasted data might be incorrect.	Deterioration of ADS-B Out Antenna	Without the awareness of ATC it might lead to break down in separation.	2D	Installation of data validity mechanism on board and at ground station.	3D
O AVH 13	Error in the display of aircraft position.	Data corruption during transportation might result in broadcasting incorrect data	Without the awareness of ATC it might lead to break down in separation.	2C	Installation of data validity mechanism on board and at ground station.	3B
O AVH 14	Broadcasting of incorrect data.	Data encoding process error	Without the awareness of ATC it might lead to break down in separation.	2C	Identifying & debugging should be done to resolve the bug that causes the decoding error.	3B
O AVH 15	Total ADS-B service loss.	Failure of Satellite	ADS-B tracks not displayed on ATC	2B	Back up of navigation aids on board.	3C

			console.			
O AVH 16	Distortion of data and interruption of signals.	Interference by Radio Frequency	Without the awareness of ATC and pilot the error in the aircraft position might lead to break down in separation.	2C	Installation of data validity mechanism on board and at ground station.	3B
Environmental Hazards						
EH 1	Data might be corrupted.	Aircraft external equipment, and outdoor equipment at the ground station might be affected by the extreme weather conditions	Lead to loss of separation or navigation.	1B	Use GPS/Regular maintenance and calibration.	3A
EH 2	Inaccurate data.	Limited forecast of the weather	Lead to loss of separation or navigation.	1D	Use GPS/Increasing the facility.	3B
EH 3	Lack of data or inaccurate data.	Limited number of weather reporting stations	Lead to loss of separation or navigation.	2B	Establishing more reporting stations.	3C
EH 2	Data unavailability.	Lack of coverage	Lead to loss of separation or navigation.	2C	Increasing the area coverage or setting up of new reporting stations.	3B
Hazards due to Human error						
HH 1	Data - not broadcasted.	Inappropriate use – Pilot might set the transponder at a wrong mode	Increases the workload due to the transition back to procedural control. Loss of situational awareness.	3B	Reminder by co-pilot or through the navigation document.	4B
HH 2	Before take-off pilot might enter the wrong pressure in altimeter	Lack of proficiency – wrong pressure adjust value given by ATC	Collision on ground or air.	3C	If pilot repeats the value or if the controller is experienced it can be mitigated.	4B
HH 3	Pilot enters wrong pressure in altimeter.	Lack of proficiency – error in altimeter setting by pilot	Collision on ground or air.	3C	Double checking the altimeter setting.	4D
HH 4	Affects all operations.	Lack of proficiency – Inadequate knowledge of ADS-B system	Loss of separation.	3B	Adequate training on new systems.	4B
HH 5	Pilot enters wrong pressure in altimeter.	Missed communication – Pilot mishears the pressure adjust value given by ATC	Collision on ground or air.	3C	If pilot repeats the value it can be mitigated.	4D
HH 6	Attaching the label to wrong flight.	Lack of situational awareness by ATC – incorrect Callsign in flight plan	Increases the workload of the controller due to incorrect coupling.	3D	Controller should cross check the flight plan.	4D
HH 7	Incorrect coupling with flight plan.	Lack of situational awareness by Pilot – in correct Callsign in FMS	Broadcasting of incorrect data.	3D	Reminder by co-pilot or through the navigation document.	4B
HH 8	ATC might be confused by the values displayed based on geometric and barometric levels.	Confusion – different altitude sources displayed might confuse ATC	Different display lead to confusion.	3D	Compulsory training regarding the function of the ADS-B systems.	4C
HH 9	ATC might apply either radar or ADS-B separation standard to the flight plan.	Confusion – Due to radar and ADS-B tracks ATC might be confused	Incorrect separation.	3D	Compulsory training regarding the function of the ADS-B systems.	4B

ISSN (O): 2393-8609
International Journal of Aerospace and Mechanical Engineering
Volume 5 – No.2, April 2018

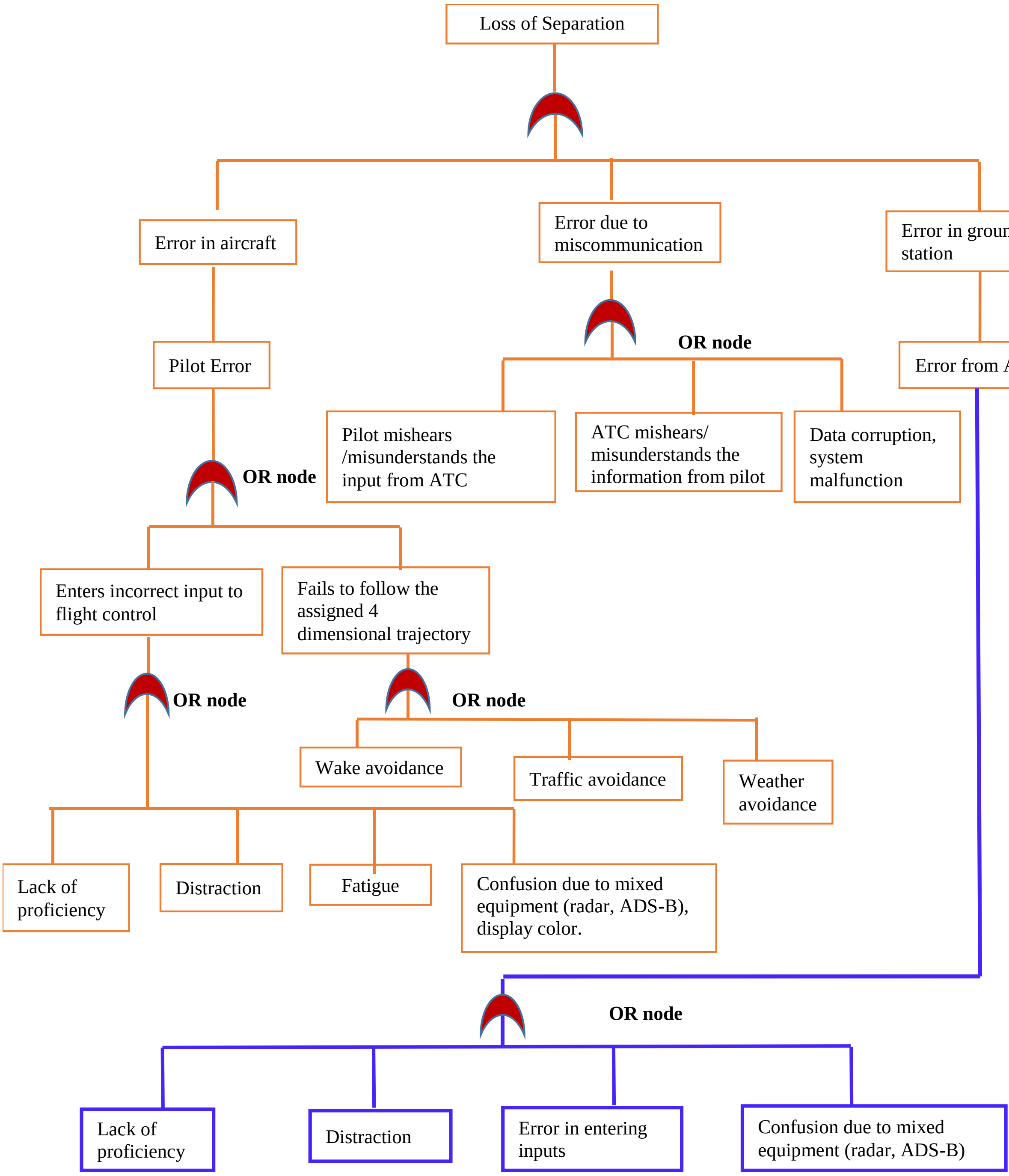

Fig.4. FTA of the human factors of ADS-B System

The contributing factors for the pilot error were the incorrect input entered by the pilot to the flight control and failure to follow the assigned four-dimensional trajectory. This is linked by OR node as any of this two can lead to loss of separation and with regard to incorrect input to flight control the factors that contribute together are the lack of proficiency, distraction, fatigue and confusion of the pilot due to mixed equipment, display color in the cockpit etc. As they contribute individually to the mishap they are linked by OR node. While the factors such as wake avoidance, traffic avoidance, and weather avoidance contribute individually to the failure to follow the assigned 4D trajectory hazard they are connected by OR node.

The error that occurs due to miscommunication between air and ground stations are – when pilot mishears or misunderstands the input from ATC and vice-versa, and the other factors are data corruption, system malfunction etc.

The error in the ground station that occurs due to ATC is the lack of proficiency, distraction, error in entering the inputs, and confusion due to mixed equipment such as radar and

ISSN (O): 2393-8609
International Journal of Aerospace and Mechanical Engineering
Volume 5 – No.2, April 2018

ADS-B. As any of these issues might lead to loss of separation it is linked by OR node.

4. RECOMMENDATIONS

Based on the PHA, the hazards that are ranked as 1B, 1C, and 1D, are unacceptable risks; those that are ranked as 2B, 2C, and 2D are having high risk which needs more attention, and continuous monitoring; hazards that are ranked as 3A, 3B, 3C, and 3D have medium risks but should not be ignored while 4B, 4C, and 4 D have low risks which need occasional inspection and maintenance. If the preventive measures specified in this report are done properly the risks can be reduced to a greater extent.

With regard to the hazards related to human errors analyzed using FTA, the best recommendation would be to provide a relevant mandatory training to both pilots and ATC officers with regard to technology, situational awareness, awareness about the loss of separation, safety aspects regarding the air-ground communications systems, decision making, and crew resource management. Other solutions would be to encourage and mandate both the pilot and ATC to use high quality communication systems, Transponders (Mode C and Mode S) and ACAS. Training can be provided with regard to ground safety nets such as Short Term Conflict Alert (STCA), Area Proximity Warning (APW), Minimum Safe Altitude Warning (MSAW), and Approach Path Monitor (APM). With regard to air-borne safety nets, training can be provided with regard to Airborne Collision Avoidance System (ACAS), Ground Proximity Warning System (GPWS), High Energy Approach Monitoring Systems, and Runway Overrun Protection Systems (ROPS). Above all, depending on their designation a recurrent training should be mandated to prove their currency and a type rating should be mandated for ADS-B technology usage. If these training and ratings were implemented it would play a major role in reducing the ADS-B related mishaps.

5. CONCLUSION

In this digital age, the aviation industry is becoming more and more sophisticated with the emerging new technologies such as ADS-B, Head-Up Displays (HUDs), Global Navigation Satellite Systems (GNSS), Digital voice and Controller-Pilot Data Link Communications (CPDLC), Cockpit Display of Traffic Information, Textual and graphical Flight Information Service (FIS) data link and Onboard terrain, obstacle and noise-impacted area databases. These technologies serve as an efficient tool in collaborative decision making when it is integrated into Air Traffic Management (ATM) systems and used by the pilots, and controllers. ADS-B is the new surveillance technology which is proposed to be flight-deck based system to support a wide range of aircraft-based separation applications during flight operations and provide collision avoidance protection when operating on the airport surface.

The important issue with this technology is how the information can be utilized effectively by different users such as pilots, controllers, dispatchers, and vehicle operators within their relevant responsibilities. The human factor issues are the acceptance and utilization by pilots and controllers, building a collaborative work ethic between pilots, controllers, and certification authorities, and how to delegate their roles and responsibilities for safe operation of the aircraft. Especially, with regard to the separation process which is evaluated using the FTA methodology in this paper, there are three approaches that can be adapted. The first approach is that the separation responsibility must be always with the controller. The second approach emphasizes that with accurate real-time information the responsibility can be shared partially between the pilot and ATC especially during en route phase. The third approach is that flight crew can modify and coordinate their preferred or desired routines to the ATC for approval.

One of the common perspectives of both the pilot and controllers about the ADS-B implementation is regarding the responsibility. The certification authorities and the rule making team must assign the responsibility in a way that it will enhance the overall safety. Safety must be their main concern in developing new policies to define the responsibility and liability of the users. Attempts should be made to include and insist the basic principles of situational awareness as part of the advanced decision making training for pilots and controllers. If the mitigation measures and proper training suggested in this study is implemented, the accidents that might occur due to human error can be reduced significantly. ADS-B technology provides the chance to reduce the separation standards, increase the efficiency and capacity of the air space and flight operations, provides flexibility, and enhances the situational awareness. Simultaneously, it plays a significant role in enhancing the environmental quality by reducing the emissions, noise and helps to save economically by reducing the fuel cost. The real challenge which is ahead of the aviation industry is developing an air traffic management system by integrating the human component and assigning the responsibilities among pilots and controllers and making the entire system to function efficiently.

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ISSN (O): 2393-8609
International Journal of Aerospace and Mechanical Engineering
Volume 5 – No.2, April 2018

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