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ICAO – Annex X volume IV: analysis of requirements and their implementation

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Contents

Introduction 5
ICAO – Annex X volume IV 5
ICAO activities 5
Transponder 7
GA Transponder 8
Mode A, C, S 9
Possible Outcomes and Impact on Operations 13
Typical Scenarios 13
Existing surveillance technologies 15
Mode S definition 17
Mode S ELS (Elementary Surveillance) 18
Functionality 18
Benefits 18
Mode S EHS (Enhanced Surveillance) 19
Functionality 19
Benefits 20
Surveillance coverage redundancy of Mode S radar 21
ATC and SSR Transponder 22
Primary Surveillance Radar (PSR) 23
Secondary Surveillance Radar (SSR) 25
Conclusions 31
Wide Area Multilateration (WAM) 34
Description 34
Benefits 36
How it works 36
Availability 39
TCAS 40
ACAS Principles 40
ACAS Standards 41
Difference between ACAS and TCAS 42
ACAS I 42
TCAS II Versions 43

Versions 6.02 AND 6.04a ... 43
Version 7.0 ... 44
Version 7.1 ... 44
Difference between TCAS I and TCAS II ... 45
New Level Off RA ... 45
Improved reversal logic ... 47
Hybrid Surveillance ... 50
Future of collision avoidance: ACAS X ... 51
ACAS X principles ... 51
ACAS X Variants ... 51
ACAS X BENEFITS ... 52
Requirements ... 54
ADS-B ... 57
ADS-B Technology ... 57
Benefits ... 61
ADS-B In Europe ... 62
ADS-B Implementation Plan ... 62
CIR (EU) 2020/587 Amending SPI IR ... 63
Integration in the European ATM systems ... 64
Ground Implementation ... 67
Operational use in ATC by Air Navigation Service Providers ... 68
ADS-B WORLDWIDE ... 69
Global Mandate Map ... 69
Upgrade from ADS-B Version 0 and Version 1 to Version 2 ... 70
Low-Power ADS-B for GA Operating in Low Altitude Airspace ... 71
Airborne ADS-B In Applications ... 72
ADS-B Integration into Existing Ground Infrastructure ... 73
Supporting Services ... 74
Barriers for wider deployment of ADS-B ... 74
Low-Power ADS-B Concept ... 76
ADS-B requirements ... 81
Regulating the spectrum used by European surveillance systems ... 83
Differences between amendments Annex 10 volume IV: evolution history ... 91
Commission Implementing Regulation (EU) No 2020/587 ... 99

Deadline to equip an aircraft with a Mode S Transponder 106
Aircraft which have obligations to be provided by TCAS 108
Notes 110
Glossary 111
Bibliography 114

Introduction

ICAO – Annex X volume IV

ICAO (International Civil Aviation Organization) is a specialized agency of United Nations whose primary expertise is to supervise and improve civil aviation. It was established in 1944 following the ratification of Chicago Convention by the 52 participant states.

ICAO fosters the processing and adoption of international regulations and conventions about aeronavigation, passengers and items transportation, onboard safety, as specified in Article 46 of the Convention. All new rules and recommendations issued by ICAO are exposed to the ratification from every member state.

Nowadays there are 193 member states; they meet up every three years in General Assembly (last one was in September 2019 in Montreal). The General Assembly is the top directorial entity, while the Council has executive authority. The Council is consisting of 36 members and it's renewed every three years for the General Assemblies.

Italy is a member of the Council and is also included in the closed group constituted by the 10 most advanced countries about civil aviation. This handful of states was instituted to solve faster specific problems; all these member states are representatives to ONU.

ICAO has located in Montreal, Canada, where the Secretary, the Council and Technical Committee (Air Navigation Commission, Air Transport Committee, Committee on Joint Support of Air Navigation Services, Finance Committee, the Committee on Unlawful Interference, Technical Co-operation Committee and the Human Resources Committee) work.

Volume IV of Annex 10 contains Standards and Recommended Practices and guidance material for secondary surveillance radar (SSR) and airborne collision avoidance systems (ACAS), including SARPs for SSR Mode A, Mode C and Mode S, and the technical characteristics of ACAS.

ICAO activities

The first ICAO aim is to make progress and update regulation in every civil aviation field providing recommendations, based upon the 18 annexes of the Chicago Convention, to all the member states, in particular based on flight and passengers safety, environment safeguard and respect of international regulations.

Main activities are also:

- Technical studies improvement and recommendations for Standards and Recommended Practices (SARPs), regularity and efficacy of international aeronavigation;
- Assistance for member states to realize technical cooperation projects in civil aviation sector.

The main surveillance technologies used today are:

- **Primary surveillance radar (PSR)** transmits a high-power signal, some of which is reflected by the aircraft back to the radar. The radar determines the aircraft’s position based on the elapsed time between signal transmission and reception of the signal’s reflection (range) and the antenna position (bearing). PSR does not provide the identity or the altitude of the aircraft but does not require any specific equipment on the aircraft, such as transponder.
- **Secondary surveillance radar (SSR)** 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 SSR** is an improvement of the SSR. It contains all the functions of SSR, and also allows selective addressing of targets by the use of unique 24-bit aircraft addresses, and a two-way data link between the ground station and aircraft for the exchange of information.
- **SSR only** is used by ATC for en route radar control in many states of the world where intruder detection is not required.
- **Combined PSR/SSR** makes use of the advantages of the two radar types in one installation.
- **Multilateration** relies on signals from an aircraft’s transponder being detected at a number of receiving stations to locate the aircraft. It uses a technique known as Time Difference of Arrival (TDOA) to determine the position of the aircraft.
- **ADS-Contract (ADS-C)** uses an automatic position-reporting system to provide a commercial service to operators and others. It has been in wide use for over 30 years, particularly over oceanic airspace. It requires that a contract be established between the aircraft operator and the ground-based service provider.
- **ADS-Broadcast (ADS-B)** 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.

Transponder

A transponder is a device whose function is to receive/transmit data and will produce a reply signal as a result of an interrogation. The two signals (interrogation from control tower and reply from the airplane) employ different frequencies:

- Interrogation codes on a 1030 MHz carrier wave
- Reply codes on a 1090 MHz carrier wave

This datalink can theoretically support 4 Mbits/s uplink and 1 Mbits/s downlink.

Transponders were first introduced for military aviation, so military authorities could distinguish friendly aircraft as a function of a received coded signal from the interrogated target (IFF, Identification Friend or Foe).

Progressively, transponders have been largely introduced in civil aviation with Mode A/C; progressively it has been significantly improved to include the Mode S service. Nowadays is advisable to require on board a specific four-digit transponder code to each aircraft flying in controlled airspace, so that ATCO (Air Traffic Controllers) can easily observe a precise aircraft on an uncluttered screen, thanks to the SSR. In this clear situation, it's possible for the controller to inspect more aircraft simultaneously into the controlled airspace.

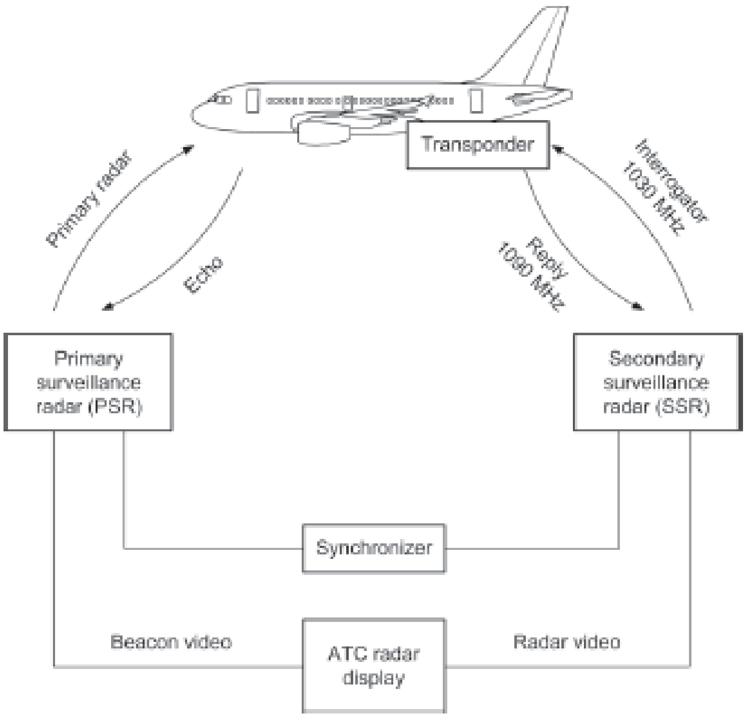


Figure 1 Combined PSR and SSR

In the last years ATC Transponder system has been upgraded adding the possibility to supply flight number and altitude of the aircraft, displayed on the controller's screen.

There are some important codes used in specific situations:

- 2000 → for aircraft which have not been assigned a transponder code
- 7000 → same reason mentioned above, in some European states
- 7500 → hijack
- 7600 → loss of communication
- 7700 → general emergency

The aircraft transponder provides the link between the aircraft and ground stations.
General aviation products have a combined panel and transponder to save space and weight. These can be Mode S capable for IFR operations. The ground station SSR antenna is mounted on the antenna of the primary radar surveillance system, thereby rotating synchronously with the primary returns. The airborne transponder receives interrogation codes on a 1030 MHz carrier wave from the ground station via one of two antennas located on the airframe. These signals are then amplified, demodulated and decoded in the transponder. The aircraft reply is coded, amplified and modulated as an RF transmission reply code on a 1090 MHz carrier wave. If the transponder is interrogated by a TCAS II equipped aircraft, it will select the appropriate antenna to transmit the reply. This technique is called **antenna diversity**; this enhances visibility with TCAS-equipped aircraft flying above the host aircraft.

GA Transponder

General Aviation (GA) transponders are typically self-contained within a single panel mounted unit. The Avidyne AXP340 transponder, Figure 2, is a Mode S transponder, with support for 1090MHz Extended Squitter (ES), that meets all the current requirements for Mode S elementary surveillance transponders for both IFR and VFR flight. This unit has additional functionality, e.g. pressure altitude and GPS readout, Flight ID entry, one-touch VFR code entry, stopwatch timer, flight timer, and altitude alert. The AXP340 also supports the latest Version 2 1090 MHz Automatic Dependent Surveillance Broadcast (ADS-B) Extended Squitter, i.e. “ADSB out”. When interfaced with a suitable GPS receiver, the transponder transmits position information to appropriately equipped ground stations and other aircraft. This provides improved airborne surveillance, provides vital information for airport ground surveillance, and is a key feature of future airspace plans.

Figure 2 AXP340 ADS-B Out Panel Mount Transponder

It delivers 240 Watts of transmitter power and responds to both legacy Mode A/C interrogations and to Mode S interrogations from both ground radar and airborne collision avoidance systems. In the Mode S environment (S stands for Select), a Mode S interrogator can selectively address a single transponder. This allows accurate position plotting with lower reply rates, which in turn reduces frequency congestion and interference.

Mode A, C, S

<u>Mode A</u>: transponder transmits an identification code only. In this transponder system, the pilot selects the four-digit code on the ATC control panel prior to each flight. The SSR system confirms this aircraft's azimuth on the controller's screen with an icon confirming that the aircraft is equipped with a transponder. If the controller needs to distinguish between two aircraft in proximity an identity code will be requested; the pilot pushes a switch on his ATC control panel, and this highlights the icon on the controller's screen. Since each aircraft is allocated with a unique code, only one icon per aircraft will be highlighted; this unique identification is referred to as a squawk code. Each of the four digits ranges from 0 to 7, these are then coded as octal numbers for use by the transponder. (This system is called Mode 3 for military users.)

<u>Mode C</u>: transponder provide the aircraft altitude or flight level. Azimuth is now augmented by pressure altitude; this is displayed on the controller's screen, adjacent to the aircraft icon thereby providing three-dimensional information. Altitude can be taken from the pilot's altimeter from an encoder that sends parallel data (in Gillham/Gray code) to the transponder. This coded data is in 100-foot increments. Aircraft with air data computers will send altitude to the transponder in serial data form, typically ARINC 429.

<u>Mode S (Select)</u>: all the Mode A/C functions are present in this Mode, and it's possible a selective addressing of targets using the unique 24-bit aircraft addresses. Another detail is a bi-directional data information exchange between the ground station and aircraft. With this Mode, the resolution for the altitude data is 25 ft, even though accuracy and resolution also depend on the amount of the altitude sensor systems located onboard.
In addition to the basic identification and altitude information, Mode S includes a data linking capability to provide a cooperative surveillance and communication system. Aircraft equipped with

Mode S transponders allow specific aircraft to be interrogated; this increases the efficiency of the ATC resources. To illustrate this point, when aircraft equipped with Mode A or C transponders are interrogated, all aircraft with this type of transponder will send replies to the ground station. This exchange occurs each time an interrogation signal is transmitted. Imagine a room full of people; the question is asked: 'please state your name and location in the room'. The person asking the question could become overwhelmed with the replies. If the question was posed in a different way, i.e. on a selective basis: 'Mike, where are you?' followed by: 'David, where are you?', the replies are only given by the person being addressed.

The Mode S system has several advantages:

1. Increased traffic densities
2. Higher data integrity
3. Efficient use of the RF spectrum
4. Reduced RF congestion
5. Alleviation of Mode A and C code shortages
6. Reduced workload for ground controllers
7. Additional aircraft parameters available to the ground controller.

Mode S transponders only send a reply to the first interrogation signal; the ground station logs this aircraft's address code for future reference. Mode S provides additional surveillance capability into controlled airspace; this is being introduced on a progressive basis. Aircraft equipped with Mode S transponders are also able to communicate directly with the Mode S transponders fitted to other aircraft; this is the basis of the traffic alert and collision avoidance system (TCAS).

SSR determines the aircraft's position in range from the elapsed time between the Interrogation and reception of the Reply. The direction of the aircraft is determined from the direction in which the narrow beam radar antenna is facing. The Reply contains the aircraft Identity and/or Altitude. The Identity information can be input by the pilot and the altitude information comes from a barometric encoder or air data computer on the aircraft. SSR will only detect an aircraft fitted with a functioning transponder. SSR with Mode S may also datalink many aircraft parameters such as heading, track, bank angle and selected altitude to the Radar.

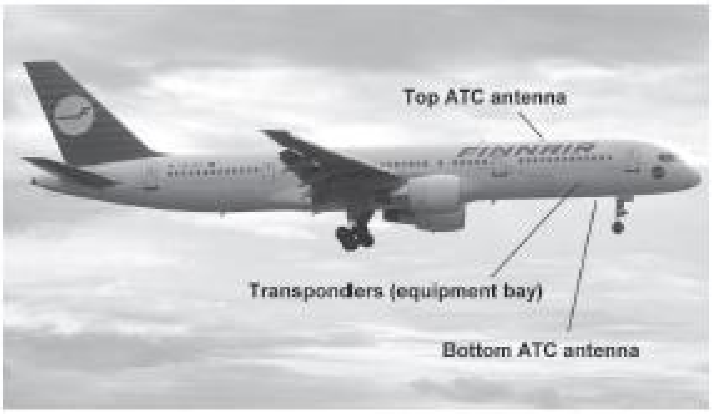


Figure 3 ATC airborne equipment location

Down here, a summary table that describes the main features of different transponder types:

Transponder types and properties		
Mode A/C	**Mode S**	**ADS-B**
4-digit octal code (12 bits)	Six digital hexadecimal code (24 bits)	Periodically transmit ID, position etc.
Assigned by ATC	Assigned uniquely by aircraft transponder	No interrogation required
Only respond to interrogation	Assigned non-uniquely for vehicles	
	Transmit mode S code periodically	
	Respond to interrogation for mode A, mode C, flight ID	

Airborne equipment

Commercial transport aircraft are installed with two ATC antennas, a control panel and two transponders as illustrated in Figure 3. Since the ATC system and distance measuring equipment (DME) operates in the same frequency range, a mutual suppression circuit is utilised to prevent simultaneous transmissions.

Control panel

This is often a combined air traffic control and traffic alert and collision avoidance system (TCAS) control panel.
The four-digit aircraft identification code is selected by either rotary switches or push buttons and displayed in a window. Altitude reporting for Mode C transponders can be selected on or off.
When requested by ATC, a momentary make switch is pressed; this transmits the selected code for a period of approximately 15 to 20 seconds.

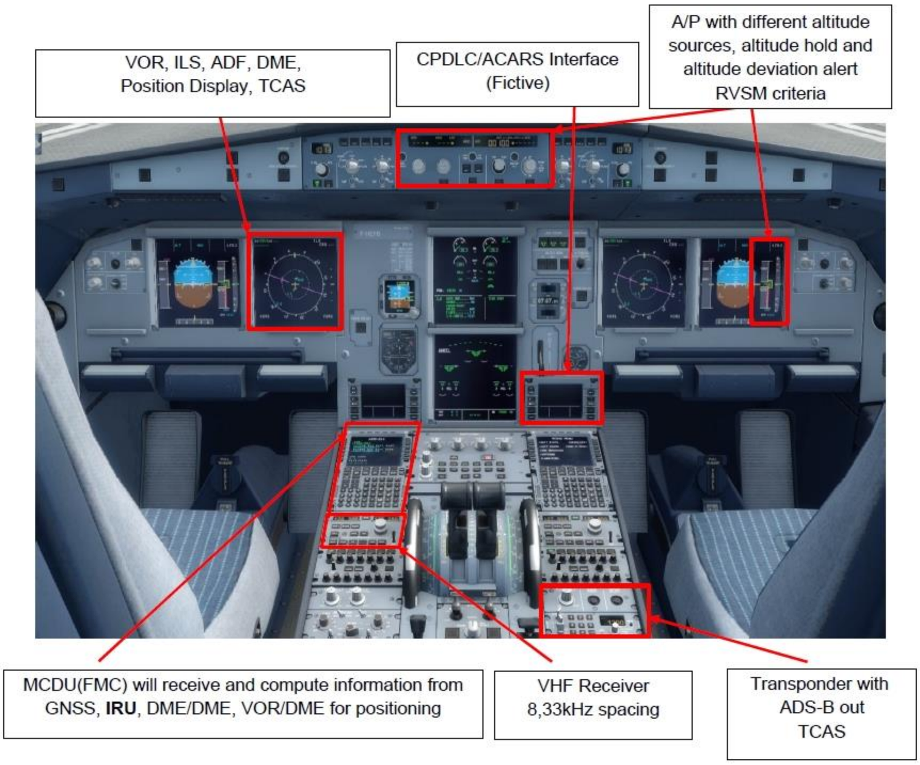


Figure 4 A320 equipment (mediawiki.ivao.aero)
Transponder is located near throttle, on the lower right

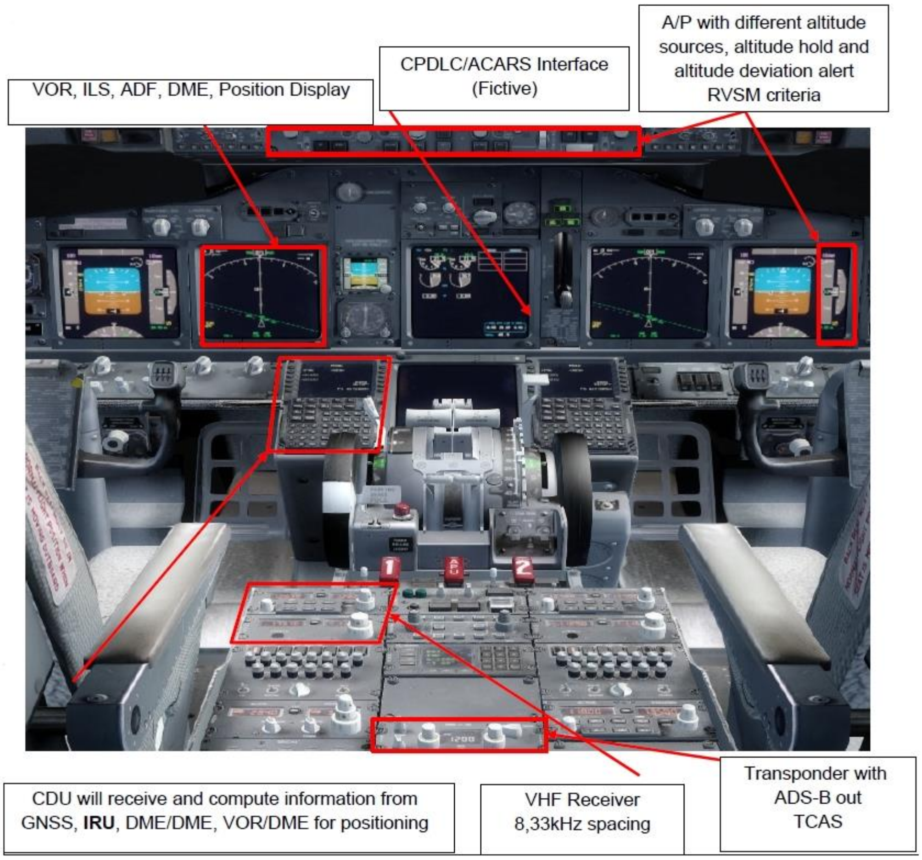


Figure 5 B737 equipment (mediawiki.ivao.aero)

Possible Outcomes and Impact on Operations

Depending on the circumstances, the following may occur following a transponder failure:

- Incorrect assumption about the aircraft level (which may result in a loss of separation event);
- ATC clearance issued to a wrong (not intended) aircraft;
- ATC system considering a surveillance track to be fake, therefore 'dropping' it;
- ATC system producing numerous false alerts;
- Loss of communication;
- Incomplete controllers’ situational;
- Airspace infringement;
- Loss of separation;
- Possibility of a CFIT;
- Inefficient planning and conflict detection by air traffic controllers;
- Inefficient/compromised TCAS operation.

Typical Scenarios

A total loss of transponder information may happen due to a number of factors, e.g.:

- Poor surveillance coverage (e.g. due to terrain, low altitude or surveillance sensor failure);
- Transponder technical failure;
- Other avionics failure (e.g. a restart of an aircraft system leading to the transponder being switched to standby mode);
- Flight crew not turning the transponder on;
- Flight crew accidentally switching the transponder to standby mode;
- Flight crew switching transponder to standby mode after miscommunication with the controller.

Intermittent or corrupted mode C signal may be caused by various technical faults of the on-board equipment or by radar detection failures. Duplicate Mode S addresses although unlikely, may happen due to:

- Technical fault in the avionics;
- Transponder being transferred from one aircraft to another.
- Incorrect Mode S address of newly delivered or registered aircraft (due to block allocation of addresses to aircraft within a state);

ATC system failures may sometimes result in outcomes similar to transponder failure, e.g.:

- Flight level data of surveillance tracks being swapped (e.g. if an aircraft is right above/below another);
- A surveillance track being dropped (e.g. if an aircraft is right above/below another).

Existing surveillance technologies

As indicated above, surveillance systems used in air traffic environment can be divided into airborne and ground based. Conventional ground-based surveillance systems are Primary Surveillance Radar (PSR) and Secondary Surveillance Radar (SSR), which are in some locations complemented with more recent surveillance technologies such as Automatic Dependent Surveillance - Broadcast (ADS-B) and/or Multilateration systems as Wide Area Multilateration (WAM).

Figure 6 Surveillance systems

A typical representative of non-cooperative sensor is the Primary Surveillance Radar that is based on the echolocation principle. Continually rotating antenna of radar sends out a narrow beam of radio energy which is reflected back by an aircraft surface. The distance and bearing of the aircraft are calculated from duration between transmission and reception and from measured direction of incoming echo, respectively.

Main advantages are high level of data integrity and no requirements on airborne device (and thus possibility of non-cooperating aircraft detection). Cons are evidently no identification of traffic, low data rate, high installation cost, high power requirements, and limited range. Although the PSR technology has been known since the World War II, it still finds applications in modern Air Traffic Management (ATM). It is used mainly for approach and sometimes for en route surveillance. PSR is often co-mounted with the SSR.

SSR technology requires an aircraft equipped by the responding counterpart onboard called Air Traffic Control Radio Beacon System (ATCRBS) transponder. Aircraft equipped by transponders are able to reply by transmission of encoded message with aircraft data to interrogator. Transponders receive interrogations on 1030 MHz and reply on 1090 MHz. SSR identifies the distance and azimuth of an aircraft from time and direction of arrival of its transponder's response, respectively.

Transmitted data depend on communication mode. Civil traffic uses modes A, C, and S. Altitude information is provided by the aircraft in its response (except for mode A) so even this type of surveillance is already partially depending on avionics of monitored aircraft.

When interrogator asks in Mode A, the aircraft is requested to provide its identification by squawk code (assigned by Air Traffic Control). Aircraft reply consists of set of impulses giving four digits squawk code. The first and last impulse is used for distance measuring. Military traffic uses mode 3 which is technically identical with civil mode A, so this is another contributor to radio frequency (RF) load.

Mode C contains aircraft barometric altitude in quantification of 100 ft in addition to identification.

Mode S brought innovation in ability to perform selective interrogations. Addressed interrogations (called roll call) to concrete aircraft come after general interrogations scanning all area (called all call). When radar acquires an aircraft, it transitions to selective interrogations. This interrogation contains request to aircraft transponder to be switched to lock-out regime (where no replies to all-call are sent) for given time.

There are two basic types of surveillance provided by Mode S:

- Elementary Surveillance (ELS)
- Enhanced Surveillance (EHS), differing in amount of transmitted information.

The ELS provides a kind of basic functionality, e.g., automatic reporting of aircraft identity, flight status, and transponder capability report. Benefits of Mode S Elementary Surveillance are mainly improved data integrity, unambiguous aircraft identification, improvement of traffic picture, and elimination of synchronous garbling, to produce a more stable speed vector and to acquire aircraft altitude reporting in 25ft increments (if supported by compatible barometric avionics).

Mode S Enhanced Surveillance contains other information in addition to the ELS. This information is Downlink Aircraft Parameters (DAP) and it includes attitude (e.g., roll angle, magnetic heading, and true track) and air data (e.g., indicated airspeed, vertical rate, and selected altitude).

When an aircraft enters SSR coverage area, it gets all call interrogations.

The ability to detect low altitude targets by ground based PSR and SSR installations is directly affected by radar line of sight limitations (hills, mountains, buildings...). This is a primary reason why ATC has often quite limited surveillance information about low altitude operations outside of the airport areas.

Wide Area Multilateration (WAM) also depends on aircraft's transponders by using several beacons located in different places which receive transponder signals and determine position by measuring the Time Difference of Arrival (TDOA) among different locations. Main benefits are no extra aircraft equipment, possible installation in higher number of locations (small beacon size) and option of very effective integration with ADS-B. Synergy of ADS-B and WAM is very natural due to the same antenna type and RF reception which enables to integrate them just as software update. Multilateration systems are typically used for surveillance in terminal areas (WMA) or on ground, especially in difficult environments.

An example is their use for A-SMGCS (Advanced Surface Movement Guidance & Control System, a system providing routing, guidance and surveillance for the control of aircraft and vehicles in order to maintain the declared surface movement rate under all weather conditions within the aerodrome visibility operational level (AVOL) while maintaining the required level of safety).

Airborne surveillance used by today's commercial aviation includes two main means: active surveillance which is conceptually very similar to SSR (interrogation of intruder's transponder while measuring distance and bearing from time of arrival and incoming direction of the response, and using altitude information provided in the response), and ADS-B. Airborne surveillance is used primarily for airborne collision avoidance systems (TCAS II and in future ACAS X; Traffic Alert and Collision Avoidance System (**TCAS**) is an implementation of the ICAO Airborne Collision Avoidance System (**ACAS**) standard. In fact, it's currently the only implementation of the **ACAS** so the two terms, **TCAS and ACAS**, are often used interchangeably**.**) and for traffic situation awareness tools such as TAS, TCAS I, or various ADS-B In applications. It should be highlighted that similarly as for ground there are considerable differences in complexity of technical systems providing active and ADS-B surveillance, higher complexity and power requirements of active surveillance are considerable limiting factors for some types of airspace users.

Non-cooperative airborne traffic surveillance is handled by air-to-air on-board sensors. Although there is an intensive research and standardization in this area covering multiple technologies including radars with various frequency bands, lidar, electro-optical/infrared cameras, etc., motivated to large extent by new airspace users, so far there are not really solutions on the market fully satisfying the operational and business needs of civil low altitude users.

Mode S definition

Mode S is a Secondary Surveillance Radar process that allows selective interrogation of aircraft according to the unique 24-bit address assigned to each aircraft. Recent developments have enhanced the value of Mode S by introducing Mode S EHS (Enhanced Surveillance).

Description

Mode S in its basic form has been standardised by ICAO for many years. It employs ground-based interrogators and airborne transponders and operates in the same radio frequencies (1030/1090 MHz) as conventional SSR systems with which it is backwards compatible.

Mode S has been deployed because the historical SSR systems have reached the limit of their operational capability. This takes the form of exceeded maximum number of targets, RF pollution, lost targets, identity errors and Mode A code shortage. Mode S is therefore an essential development for both SSR and the new ATM processes which will be essential in airspace subject to high levels of traffic density or absence of ATC radar coverage.

There are five sources of RF pollution:

1. Acquisition Squitter
2. Extended Squitter
3. Airborne Collision Avoidance System (ACAS) transactions
4. Self-generated Second Time Around Replies
5. Replies from other Radar Interrogations

Mode-S employs airborne transponders to provide altitude and identification data, with Automatic Dependent Surveillance Broadcast (ADS-B) adding global navigation data typically obtained from a Global Positioning System (GPS) receiver. The position and identification data supplied by Mode S/ADS-B broadcasts are available to pilots and air traffic controllers.

Mode S/ADS-B data updates rapidly, is very accurate and provides pilots and air traffic controllers with common air situational awareness for enhanced safety, capacity and efficiency. Further, it can provide a cost-effective solution for surveillance coverage in non-radar airspace.

In Europe, SSR Mode S Elementary Surveillance (ELS) is rapidly being succeeded by Mode S Enhanced Surveillance (EHS).

Mode S ELS (Elementary Surveillance)

Functionality

Aircraft compliant with Mode S ELS provide the following functionality (this is also referred to as "Basic Functionality"):

- Automatic reporting of aircraft identity. This is the aircraft callsign used in flight which is automatically presented to the controller
- Altitude reporting in 25ft intervals (subject to aircraft capability)
- Transponder capability report - a technical function to enable ground systems to identify the data link capability of the transponder
- Flight status (airborne / on the ground) - a technical function
- SI code capability - a technical function to identify transponders capable of operating within a Surveillance Identifier (SI) code ground environment (which permits a reduction in ground infrastructure complexity). Basic functionality with SI code capability is the minimum level permitted for operations in European airspace.

Benefits

Aircraft compliant with Mode S ELS provide the following operational benefits:

- **Unambiguous aircraft identification**. The availability of almost 17 million unique aircraft addresses, in conjunction with the automatic reporting of flight identity, permits the unambiguous identification of aircraft independently of any Mode 3/A code assignment. Mode S is the primary means of correlating radar tracks with system flight plans in automated ATC systems.
- **Improved integrity of surveillance data**. Selective interrogation and the superior resolution ability of Mode S over existing SSR and MSSR installations eliminates synchronous garble, resolves the effects of over interrogation and simplifies aircraft identification in the case of radar reflections.
- **Improved air situation picture and tracking**. Radar controllers are presented with a better current air situation picture through system acquisition of flight identity and enhanced tracking techniques. The greater accuracy of Mode S radars (less random or systematic errors together with the production of more stable speed vectors) results in an improved horizontal and vertical tracking capability over current SSR installations.
- **Alleviation of Mode 3/A code shortage**. The situation concerning SSR code shortage in the EUR Region is reaching a critical stage. The unique aircraft address ability of Mode S will, in conjunction with other measures, help ease this problem.
- **Improvements to Safety Nets** (e.g. Short Term Conflict Alert (STCA)). The ability of Mode S to eliminate synchronous garbling, to produce a more stable speed vector and to acquire aircraft altitude reporting in 25ft increments (if supported by compatible barometric avionics), provides valuable improvements to the quality of safety nets. These improvements should reduce the number of nuisance alerts and enhance the integrity of separation assurance.
- **Increased target capacity**. In order to handle current and forecast increases in traffic, Mode S radars are able to process many more aircraft tracks (approximately double the number) than conventional MSSR installations.

Mode S EHS (Enhanced Surveillance)

Functionality

Aircraft compliant with Mode S EHS provide ELS functionality features (see above) plus some or all of the following downlinked aircraft parameters (DAPs):

- Selected Altitude - the flight level which is manually entered in the FMS by the pilot. Selected Altitude provides an indication of the intended flight path and should reflect the ATC clearance with a few exceptions. It is used to improve controller situation awareness and conflict detection tools. The use of Selected Altitude values in Safety Net systems is expected to considerably reduce false alarms (an STCA study showed that by using Selected Altitude more than 90% of all false alarms could have been avoided) for aircraft engaged in vertical manoeuvres (level-off scenarios)and, thereby, to considerably increase the performance capability of the Safety Net systems. At the same time, the display of the Selected Altitude in the track label (either fully automated for cross checking with controller input or just presented as additional information) has proven to be an efficient tool to identify and mitigate the risk for potential level busts.
- Roll Angle, True Track Angle and Track Angle Rate - these are technical parameters which may be used to enhance the radar tracking capability and/or tactical trajectory prediction by the ground ATC systems. The Roll Angle can be used in conjunction with the True Airspeed by the surveillance data processing systems to improve the recognition of horizontal manoeuvres and increase tracking accuracy. The True Track Angle, in combination with the Ground Speed, can be used to improve track initialisation (initialisation after just one plot and not after two or three plots as is currently the case), to increase tracking performance (particularly at the edges of the radar systems' range) and to improve recognition of horizontal manoeuvre by monitoring changes in track angle. The Track Angle Rate (called also Rate of Turn) gives the turning speed of the aircraft. This parameter provides direct information to improve the recognition of horizontal manoeuvre and to increase tracking performance in surveillance data processing systems, better than a combination of roll angle and true airspeed. This leads to more accurate target positioning and a considerable error reduction for the predicted position.
- Ground Speed - calculated aircraft speed relative to the ground. Information provided by ANSPs show that the value of this parameter is not providing a significantly better accuracy than the ground speed calculated by the surveillance data processing systems.
- Magnetic Heading - the aircraft heading relative to magnetic north. Making this information available to controllers reduces R/T occupancy time as controllers no longer have to request the information from the pilot. The Magnetic Heading has the potential to improve horizontal manoeuvre recognition, either by the controller or by the surveillance data processing systems, via monitoring of heading changes.
- Indicated airspeed (IAS) and Mach-number. Making this information available to controllers supports separation provision tasks, reduces the R/T and hence the controller workload.
- Vertical rate (barometric rate of climb / descent) - this parameter is not used operationally by ATC due to the significant variations caused by a number of factors, such as turbulence, small but rapid aircraft vertical movements, etc.
- TCAS downlinked resolution advisories.

Benefits

In addition to the benefits for Mode S ELS, identified above, aircraft with Mode S EHS also provide the following operational benefits:

- **Improved situation awareness**. A clearer air situation picture, enhanced tracking and access to pertinent information direct from the aircraft enables the controller to benefit from quicker and more accurate recognition of airborne events.
- **Progressive reduction of R/T workload per flight**. There is scope for R/T usage between controller and individual flight under service to be reduced following the progressive introduction of Mode S Enhanced Surveillance. It applies in particular to the current requirement for SSR code verification procedures and also where system enhancements and/or the display of downlink aircraft parameters obviate the need for certain voice communication exchanges, e.g. “ABC123, report heading”.
- **Safety enhancement**. Access by controllers to aircraft intent DAPs, such as selected altitude enables cross-checking of climb/descent instructions and helps the early identification of potential level bust incidents.

Surveillance coverage redundancy of Mode S radar

A reference indication of the redundancy of surveillance coverage (i.e. number of overlapping surveillance coverage) considering operational Mode S radars (civil and military) at 30,000ft in the ICAO EUR region and the ICAO MID region is provided in the Figure 7 below. This reference indication is derived from the Mode S interrogator code allocation plan published at the end of the MICA Cycle 28 (effective date: 16 August 2018).

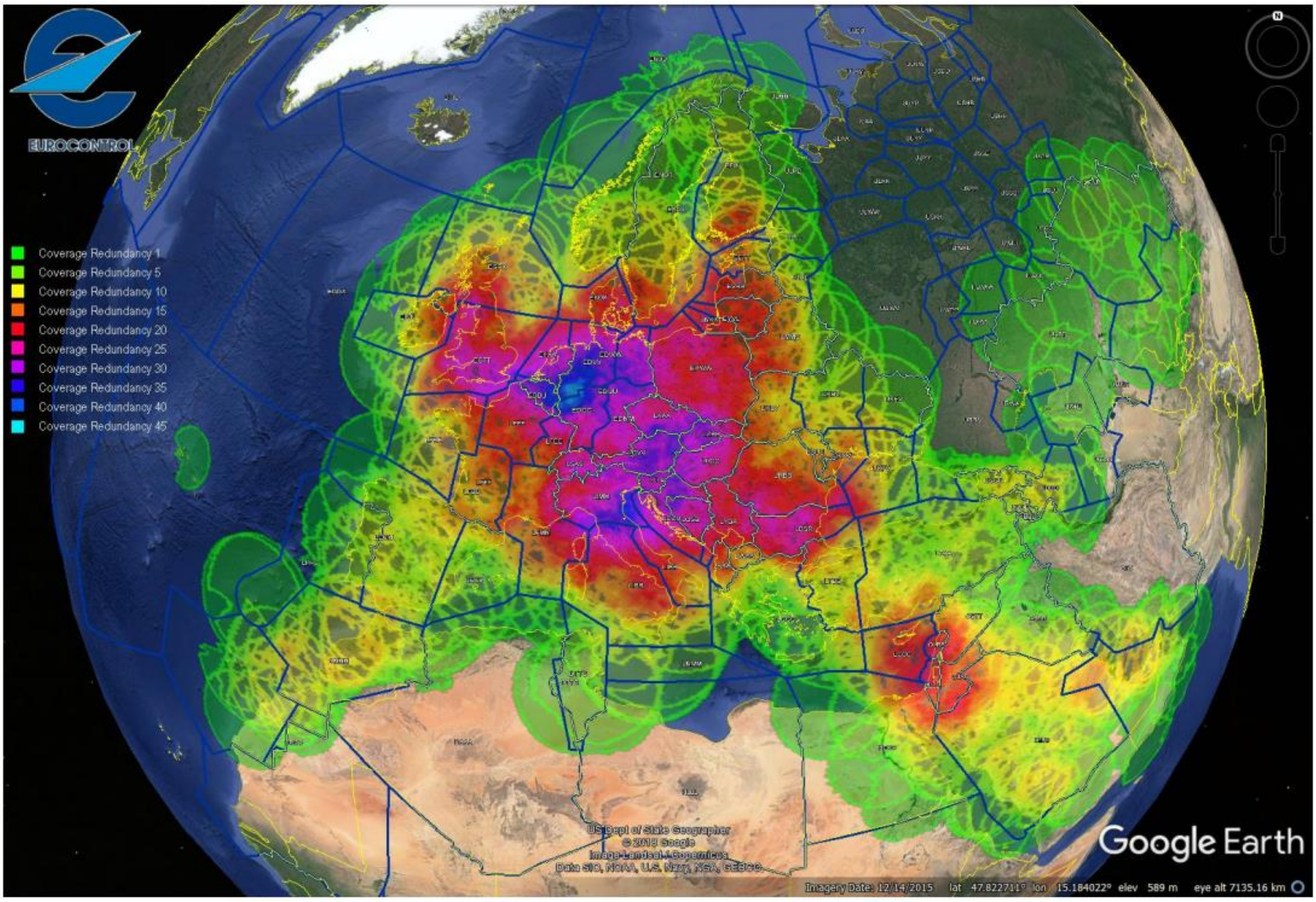


Figure 7 Surveillance coverage redundancy of Mode S radar

ATC and SSR Transponder

ATC (Air Traffic Control) is a set of regulations and organisms that contributes to keep a safety and orderly airplanes flux, on the ground or in the air. This activity has been created to best manage air traffic for the airports, especially the busiest.

Because of safety reasons, air traffic controllers can't supervise an excessive number of flying aircraft simultaneously.

With the increases of aircraft, the traditional ATC with mode A/C only cannot fit in with the needs, then ATC with mode S is developed. So, how to assess the capacity of ATC SSR is an important work for its operation orderly.

Air traffic control system modernization activities are accelerating worldwide. It is vital that aircraft owners begin to make informed decisions about how to comply with emerging and existing regulatory mandates immediately by selecting the right equipment for their aircraft's typical mission.

Taking an aircraft out of service represents a major financial risk for operators. However, the inconvenience of having your aircraft grounded might be an even greater financial risk. This is why it is important for operators to understand the emerging and existing Communications, Navigation and Surveillance (CNS) mandates and how to address them. These mandates might be required to retain access to region-specific airspace but can also bring additional operational capabilities that operators should not ignore.

Additional facts to consider include the aircraft's residual value which will be negatively impacted if it is not properly equipped to meet regulatory mandates. Also, a non-compliant aircraft could mean lost revenue for operators due to airspace access restrictions. Unfortunately, there is much misunderstanding, myths and outright wishful thinking within the owner/operator community.

Computers used to manage air traffic, calculate exactly where an aircraft will be at a certain moment and make sure that controllers can face safely the flight in a determined airspace.

The goal is to collect and supply information useful for safety, security, efficiency and regularity of air navigation: in ATC what matters most is to guarantee that flights are safe, efficient, profitable and reduce environmental impact. These objectives could be achieved by means of advanced technologies.

In ATC we can find different types of radars:

- PSR: Primary Surveillance Radar
- SSR: Secondary Surveillance Radar
- Multilateration (MLAT)
- Automatic Dependent Surveillance Broadcast (ADS-B)

Primary Surveillance Radar (PSR)

Primary surveillance radar is characterized by a high energy signal oriented by an antenna to detect a target, that may be an aircraft, the terrain or cloud. Then, the energy is reflected from aircraft's surface, and when the signal comes back, computer calculates azimuth and distance from the elapsed time between transmission and reception of the reflection. After that, the PSR arranged the aircraft on a PPI (Plane Position Radar). There is one main problem for this radar: energy used to transmit the signal is much more than the reflected one, so if the target is tiny, it may additionally reduce the quantity of reflected energy. PSR doesn't provide the identity or the altitude of the aircraft, nevertheless no specific equipment is requested to make it work.

The primary radar system provides a single icon per aircraft on the ATC controller's display; this means that each icon will look similar, depending upon the amount of reflected energy. As a consequence, an aircraft would have to change direction in order for it to be uniquely identified.
Let's see pros and cons of this device (from ICAO "Guidance Material on Comparison of Surveillance Technologies GMST").

Pros:

- PSR doesn't need a transponder to be installed or operating on aircraft
- Possibility to supply a weather channel output if weather display is required
- Well suited for aerodrome surface surveillance
- PSR is the only surveillance sensor used in civil aviation that does not require any on-board equipment to locate aircraft. Unlike SSR, ADS-B and MLAT it can discover an aircraft experiencing Transponder Failure or an intruder

Cons:

- PSR doesn't provide identity
- No level data available. Civil PSRs do not have the ability to obtain target level. This may be mitigated either by receiving pilot reports or by combining the PSR with other types of sensors. Note that some military radars have this feature (either by using a second antenna or an antenna array). Nevertheless, this information is not to be used for air traffic control purposes as it is geometric and not pressure-derived
- Position is based on slant range measurement instead of true one
- Can frequently report false targets (birds, ground vehicles etc). The radar relies on reflected signals but is not aware if they are received from aircraft or from other objects (e.g. terrain, buildings, clouds). Such reflections are called clutter. This can somewhat be mitigated by processing the data using an MTD (moving target detector). This feature uses the doppler shift of the received signal to determine whether it came from a stationary or a moving target
- Expensive device, compared to SSR
- An update rate between 4 and 12 seconds (longer than typical Multilateration or ADS-B)
- High transmitter power required for long range performance: it causes interference and environmental issues
- Systems are very expensive to install and maintain

- Systems require optimum site with unobstructed view to aircraft and with the minimum of ground clutter visible to the radar
- Can't define two aircraft at a similar location at the same range, due to poor azimuth resolution performance
- Cone of silence. Due to the radiation pattern, there is a part of the airspace above the antenna that cannot be surveyed. This effect is mitigated by placing an array of radars in such a way that each radar's cone of silence is covered by another radar
- Difficult correlation. Due to the data received (position only) it is not possible to use automatic correlation. Manual correlation (after proper aircraft identification) is possible, however. The downside is that this requires a lot of controller effort and is therefore not suitable for busy airspaces
- Unambiguous range limit. When receiving the signal, it is not possible to determine the corresponding emitted pulse. Therefore, a false target can be detected (usually close to the radar) if the reflected signal reaches the antenna after a second pulse is transmitted. This effect is mitigated by adjusting the transmitted energy and the antenna rotation speed
- Minimum range limit. The PSR operates on one frequency which means that it cannot emit and receive signal at the same time. If the target is too close to the radar antenna, the reflected signal may be received before the end of the transmission. If that happens, the target will not be detected. Note that shortening the pulse will also reduce the amount of emitted energy thus limiting the maximum range of the radar. This is mitigated by adjusting the pulse length and the antenna rotation speed

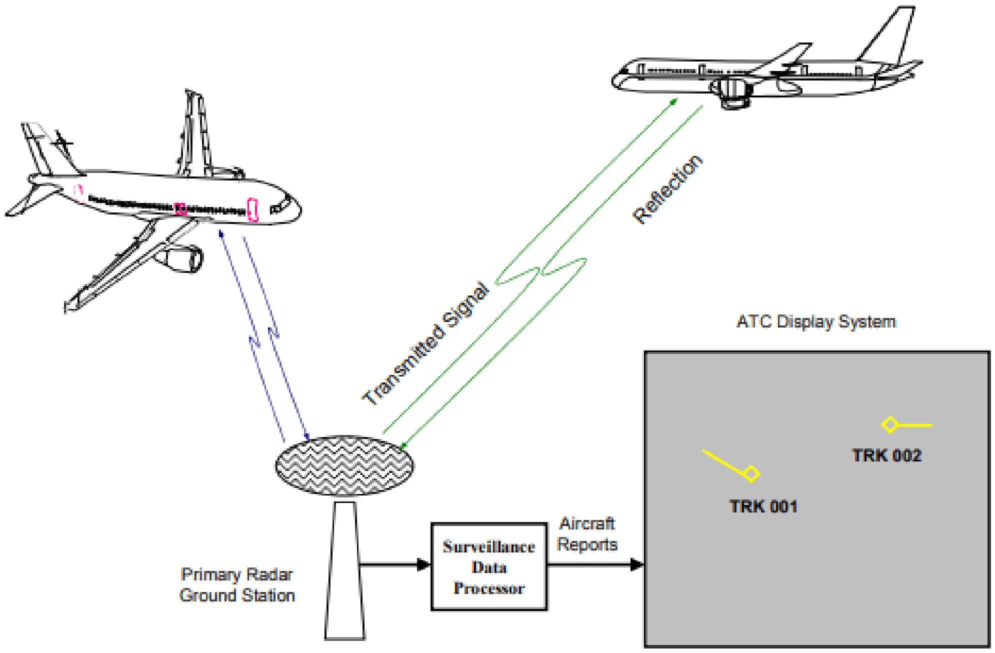


Figure 8 Primary Surveillance Radar

Secondary Surveillance Radar (SSR)

Secondary surveillance radar is composed of two main components, a ground-based interrogator/receiver and a transponder fitted in the aircraft; the ground station emits a specific low energy signal (interrogation signal) to a known target. The signal is then analysed by a transponder which sends back a new signal (please note: it's not a reflected signal but a reply) to the ATC ground facility. Fig.8 depicts the flowchart of the signal, interrogator transmits interrogations to the transponder, the interrogator can be elicited replies for identity, pressure-altitude and surveillance in accordance with interrogation modes. SSR determines the aircraft's position in range from the elapsed time between the Interrogation and reception of the Reply. The direction of the vehicle is obtained from the direction in which the narrow beam radar antenna is facing. The ID information is given as input by the pilot, while the altitude information is achieved from a barometric encoder or air data computer onboard.

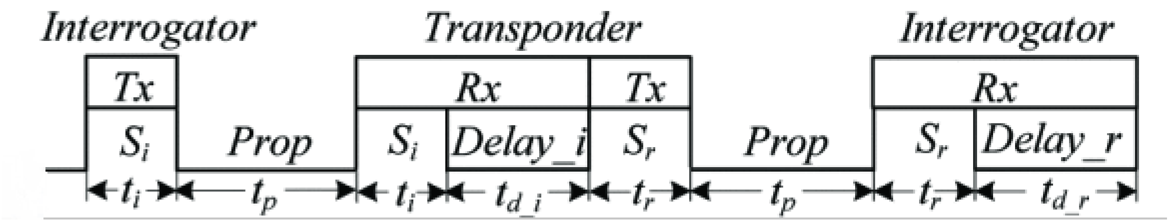


Figure 9 Transformation flowchart of ATC SSR signal

The waveform of baseband signal for interrogation is shown in Fig.10, there are six kinds of signal durations in accordance with interrogation modes.

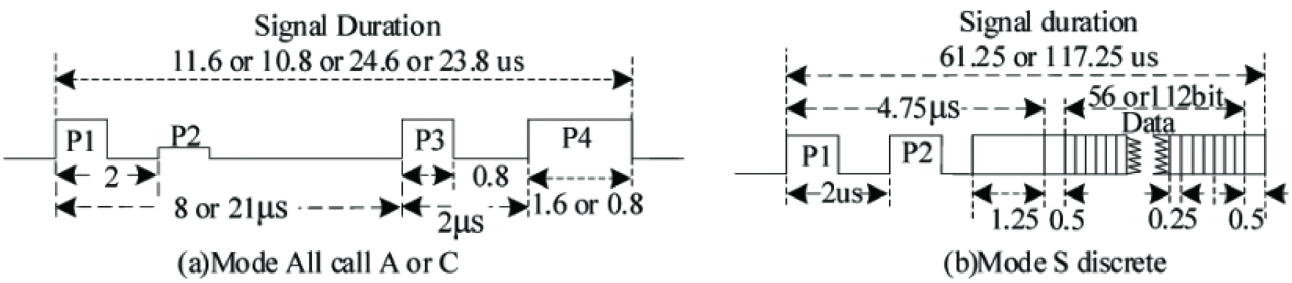


Figure 10 The waveform of baseband signal for interrogation

The waveform of baseband signal for a reply is shown in Fig.11, we can see that mode A and C reply have the same signal duration 21.1 microseconds (every pulse in mode A/C reply has the same duration 0.8 microseconds), SPI pulse can be selected to exist or not. Mode S reply has two signal durations, they are 64 microseconds (56+8) and 120 microseconds (112+8) respectively.

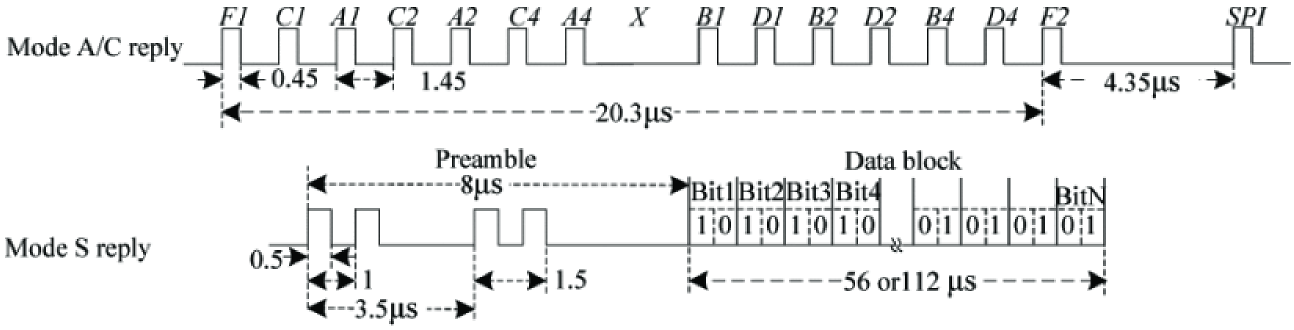


Figure 11 The waveform of the baseband signal for reply

Interrogations are transmitted by a rotating antenna at a certain speed. There are many transponders in the radiation pattern of the antenna in the space, they receive the same interrogations and then transmit replies to interrogator at the same carrier frequency. Naturally, due to the different positions of aircraft, replies may be overlapped with each other during the transmission to the interrogator. Generally speaking, under the same conditions, the more aircraft is, the higher reply collision probability is. Thus, a certain capacity of ATC SSR system should be limited to assure its operation rightly.

Assessing the capacity of ATC SSR system is to construct the relationship between characteristics of ATC SSR system and number of aircraft, i.e. calculating the maximum allowed the quantity of aircraft, subject to certain characteristics.

A. Assumptions

The aim of this paper is to analyse the capacity of ATC SSR system, for simplicity, some characteristics can be assumed.

• No inter-system interference, there exists intrasystem interference only, so we need not consider the impact of intra-interference.

• One ground interrogator, which means that the number of replies from transponder equals that of interrogations received by the same transponder. There is no interference on interrogations and they can be received wholly.

• Link margin is larger than zero, we need to analyse the capacity of ATC SSR system in the time domain only.

• Pulse collision means interference, anyone of those pulses in a frame signal overlaps with other pulses, the whole frame signal is regarded as being interfered, then the signal frame in Fig.3 and 4 can be thought to be a pulse with a signal duration when they are used to analyse pulse collision.

• Poisson process, the process of reply signals from different aircraft to interrogator is said to be a Poisson process with rate λ. λ denotes pulse density (pulse per second).

• The capacity of signal processing, both interrogator and transponder work well, and the time of signal processing equals signal duration.

B. The calculation for the probability of signal receiving rightly

The right receiving of the signal consists of two requirements, one is that the signal does not overlap with its next neighbouring signal, the other is that the receiver should be idle when the signal arrives. Let P_r denotes probability of signal receiving rightly, P_o denotes the probability of signal no overlapping with its neighbouring signal and P_i denotes the idle probability of receiver, then P_r equals P_o times P_i.

• Calculation for P_0. The sequence of interarrival times for a Poisson process with rate λ forms a set of mutually independent, identically distributed exponential random variables with parameter λ. Hence, P_0 can be calculated as follows:

$$P_0 = e^{-\lambda t} \tag{1}$$

• Calculation for λ (in pulse per second). Transponder antenna is omnidirectional, however, interrogator antenna is a directional antenna with a beam width α (in degree), it rotates with speed ω_{ant} (in degree per second); then transponder is not always in the radiation pattern of interrogator antenna. It can be assumed that aircraft distribute in the radiation zone uniformly along the rotation arc. Let f_{int} (in Hz) denotes pulse recurrence frequency (PRF) of interrogation, then the pulse density of interrogations received by n aircraft can be given as follows:

$$\lambda = n \cdot \frac{\alpha}{360} \cdot \frac{\alpha}{2\omega_{ant}} \cdot f_{int} \tag{2}$$

• Calculation for P_i . The pulse stream of ATC SSR has a Poisson distribution, and the time of signal processing is deterministic according to a certain mode. The pulse is received only when the receiver is idle at its arrival time, otherwise, the pulse is discarded. So, let μ denotes service rate, the probability of signal receiving designated P_i can be calculated as follows:

$$P_i = \frac{\mu}{\lambda+\mu} \tag{3}$$

C. Modelling the reply efficiency of ATC SSR

From Fig.9, an operational cycle of ATC SSR is composed of the receiving of interrogation and reply signals. Reply signals received by interrogator may be overlapped with each other, therefore, reply efficiency (RE) can be defined as the probability of reply signal passing through interrogator rightly. Upon combining (1)-(3), we find

$$RE = P_o \frac{\mu}{P_o\,\lambda+\mu} = \frac{\mu}{n\frac{\alpha}{360}\frac{\alpha}{2\omega_{ant}}f_{int}+e^{n\frac{\alpha}{360}\frac{\alpha}{2\omega_{ant}}f_{int}\tau}\mu} \tag{4}$$

where τ denotes pulse duration of reply signal.

D. RESULTS AND DISCUSSIONS

Using (4), we can solve the system capacity of ATC SSR designated n, n can be regarded as a function of other parameters, e.g., $\tau, \mu, \alpha, \omega_{ant}$ and f_{int}. In this section, we validate the validity of (4) and analyse the relationship between n and other parameters.

A. System capacity versus RE

To validate (4), we compared the differences of system capacity VS reply efficiency between calculation of (4) and Monte Carlo simulation (*). We assumed that

$\omega_{ant} = 6\, {}^{r}/_{m}\ \alpha = 2.45°,\ \ \tau = 21.1\,\mu s\ \ \ \mu = {}^{1}/_{\tau}\ \ and\ f_{int} = 450Hz.$

The curve is shown in Fig.11. It can be seen that the maximum difference is about 0.2%. We can see that reply efficiency almost decreases linearly with system capacity. With the increase of system capacity from 5 to 3800, RE decreases about 0.2%, the minimum of reply efficiency is above 98% which is the threshold recommended.

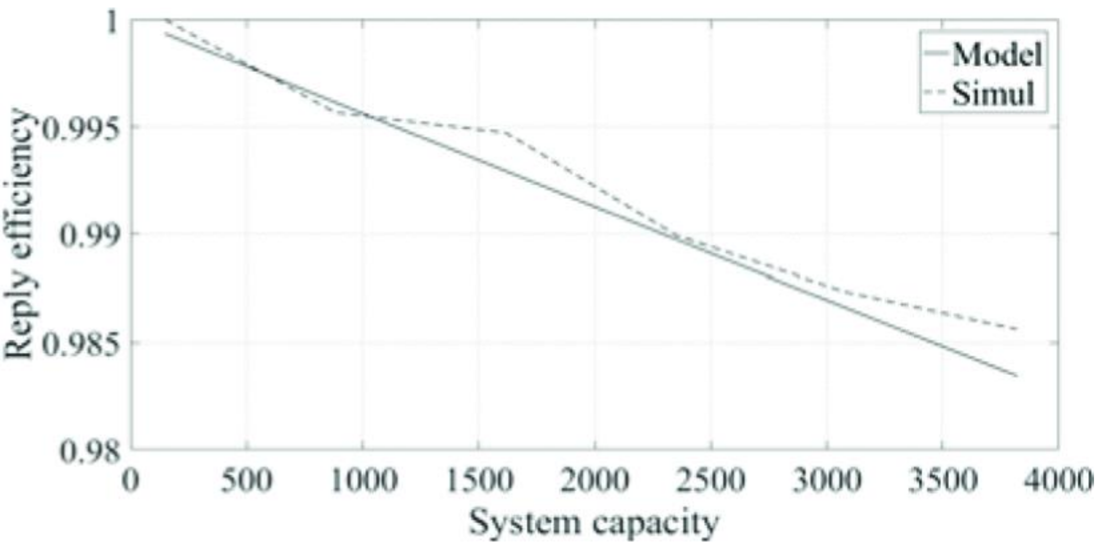


Figure 12 Reply efficiency VS system capacity using different methods

(*) A Monte Carlo simulation is a model used to predict the probability of different outcomes when the intervention of random variables is present. It helps to explain the impact of risk and uncertainty in prediction and forecasting models.

B. The capacity n versus PRF of interrogation

Let RE equals 98%, the other parameters in (4) are the same as Fig.5 except f_{int} . When the PRF of interrogation designated f_{int} increases from 150 to 450Hz spacing 50Hz.

The curve of system capacity and the number of interrogations in a beam width VS PRF of interrogations are depicted in Fig.13: the number of interrogations increases linearly with PRF, so the probability of pulse collision increases, consequently, system capacity decreases.

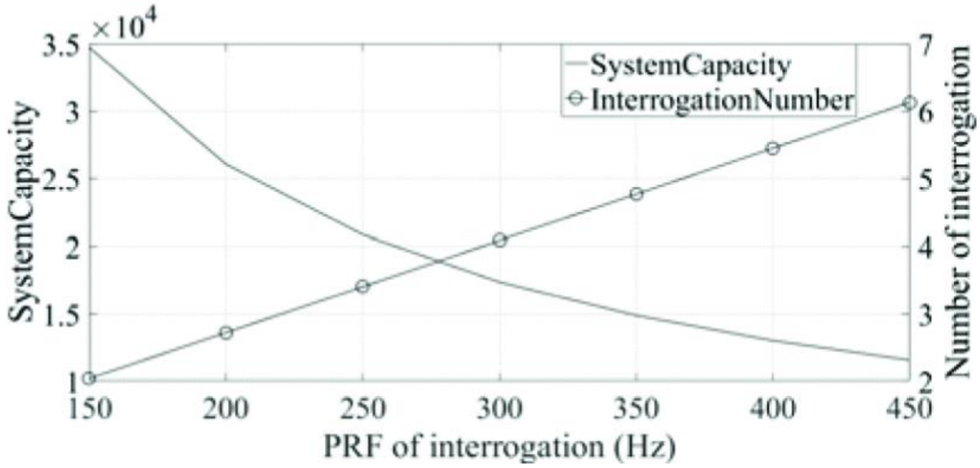


Figure 13 System capacity and the number of interrogations in a beam width VS PRF of interrogation

C. The capacity n versus time of SSR mode

There are four pulse durations $21.1\ \mu s, 26.25\ \mu s, 64\ \mu s\ and\ 120\ \mu s$ in Fig.14. They correspond to AC reply, AC reply with SPI, short S and long S modes, respectively. Let $f_{int} = 150\ Hz$, the other parameters are the same as those in Fig.6 except τ . The curve of system capacity VS operation mode is shown in Fig.7. It can be seen that system capacity decreases rapidly with pulse duration. We can conclude that improving the time of signal processing of interrogator is an effective method for increasing system capacity.

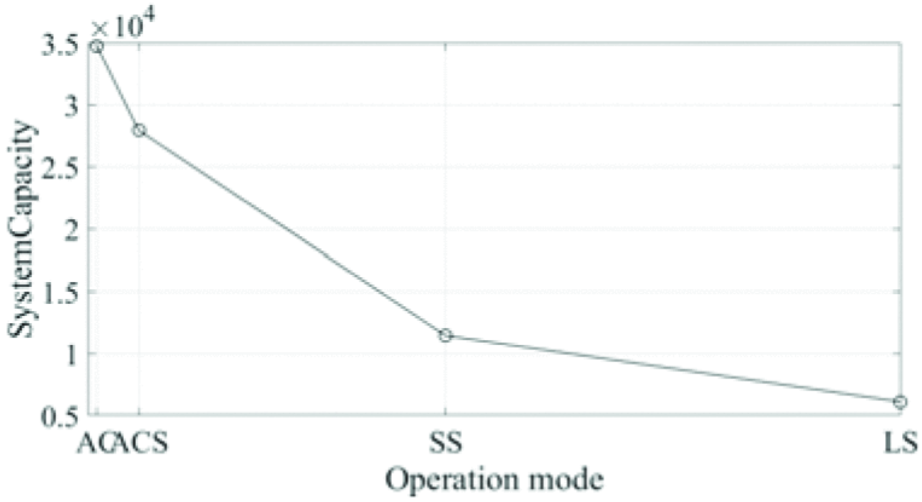


Figure 14 System capacity VS operation mode

D. The capacity n versus rotation speed of antenna

Let $f_{int} = 450\ Hz$, the other parameters are the same as Fig.6 except ω_{ant}, as the rotation speed of antenna ranges from 6 to 15 with interval 1, system capacity and number of interrogations in a beam width are depicted in Fig.8. Fig.8 shows that the number of interrogations decreases as rotation speed increases, however, system capacity increases with rotation speed, which is in accordance with the fact that the probability of pulse collision decreases with the number of interrogations, then system capacity increases.

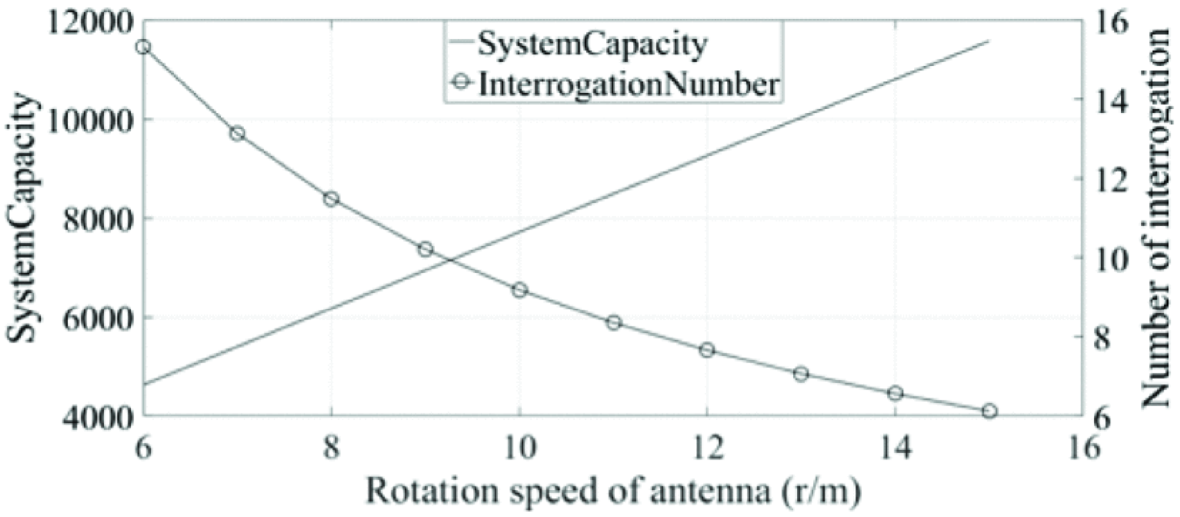


Figure 15 System capacity and number of interrogations in a beam width VS rotation speed of antenna

Conclusions

The analytical model based on queuing theory for assessing the relationship between system capacity with other parameters is valid. System capacity can be adjusted through changing SSR mode, PRF of interrogation, and rotation speed of interrogation antenna. The model can be used not only for assessing the parameters of ATC SSR system in the first principle but also for the other second radar system. It should be pointed out that the results are calculated based on many assumptions, and it is larger than the actual value.

The following shows, as with PSR, pros and cons of this device (from ICAO "Guidance Material on Comparison of Surveillance Technologies GMST").

Pros:

- SSR allows communication of identity (4-digit octal codes) when matched with flight plan data held by the ground system
- Requires much less power to achieve the desired range, in comparison to PSR. This is because the transmitted signal only needs to reach the aircraft, while the PSR needs to emit a signal strong enough to reach the aircraft and travel back to the antenna
- The information provided is not limited to range and bearing from the antenna but also includes additional data based on the transponder mode of operation (A, C or S)
- Targets are easier to distinguish due to the different SSR codes
- Allows communication of altitude and emergency states to ground system
- SSR is immune to clutter as it uses different frequencies for interrogation (1030 MHz) and replies (1090 MHz). Consequently, even if an echo on 1030 MHz is received, it is not processed by the system. Therefore, terrain, buildings and weather phenomena (clouds and precipitation) do not produce clutter, as is the case with PSR. These can interfere with the signal, though, thus sometimes making detection of real targets more difficult.
- Provides moderately high update rate
- Provision of altitude allows correction for slant range error

Cons:

- Poor azimuth accuracy and resolution (particularly for classical SSR)
- Can sometimes report false targets or position (reflections, multipath)
- Can sometimes confuse Mode A replies as Mode C and vice versa
- Can sometimes report false altitude or 4-digit code
- No error detection provided in downlinked 4-digit code and altitude from Mode C transponders
- Systems are expensive to install and maintain
- Systems require optimum site with unobstructed view to aircraft
- Cannot resolve two aircraft at the same location (garbling/ resolution performance)

- Dependent on aircraft avionics
- Not accurate enough for aerodrome surface applications due to transponder delay uncertainty
- The SSR relies on the onboard equipment to discover aircraft. In case of transponder failure the SSR will receive no reply and will therefore not discover the target. This is mitigated by combining the SSR with a PSR. If proper signal processing is used, it is possible to continue to track an aircraft (and preserve Correlation) even if the transponder has failed completely provided that reliable primary data is received. Note that in this case level information will be less reliable and more frequent pilot reports will be necessary

- Sometimes two replies are received at the same time (if the slant range and the bearings of the aircraft the same). This phenomenon is called "garbling" and may result either in the "detection" of a false (non-existing) aircraft or in a target not being detected (the radar considers that there is a false target)
- Another phenomenon that may produce false indication is FRUIT (*False Replies Unsynchronised In Time* or *False Replies Unsynchronised to Interrogator Transmissions*). This happens when the radar receives a reply from a transponder that has been interrogated by another radar. Since all SSRs operate on the same frequencies, it is not possible to detect that the reply is related to another radar's transmission. Moreover, as the time of the interrogation is not known, the range calculation will most likely be wrong. As a result, a false target may appear on the situational display. Additionally, if another (valid) transponder reply is received at the same time, garbling could occur. Garbling and FRUIT are aggravated by the need of "classic" SSRs to use several interrogations for proper azimuth determination and can be mitigated by:
    - Using an MSSR (monopulse SSR). This is an advanced radar that uses a different beam pattern that provides more accurate azimuth determination. As a result, fewer interrogations are required to determine the azimuth.
    - Mode S selective interrogation. This is a feature of the Mode S SSRs that allows them to interrogate a specific aircraft (other aircraft may receive the interrogation but would ignore it).
- SSRs are vulnerable to antenna shadowing (i.e. the onboard antenna is shadowed by the aircraft fuselage, e.g. due to the bank angle). This is mitigated by placing more than one antenna (usually two - one on top of the aircraft and one at the bottom

The advantages of the PSR and SSR are often combined by co-locating them.

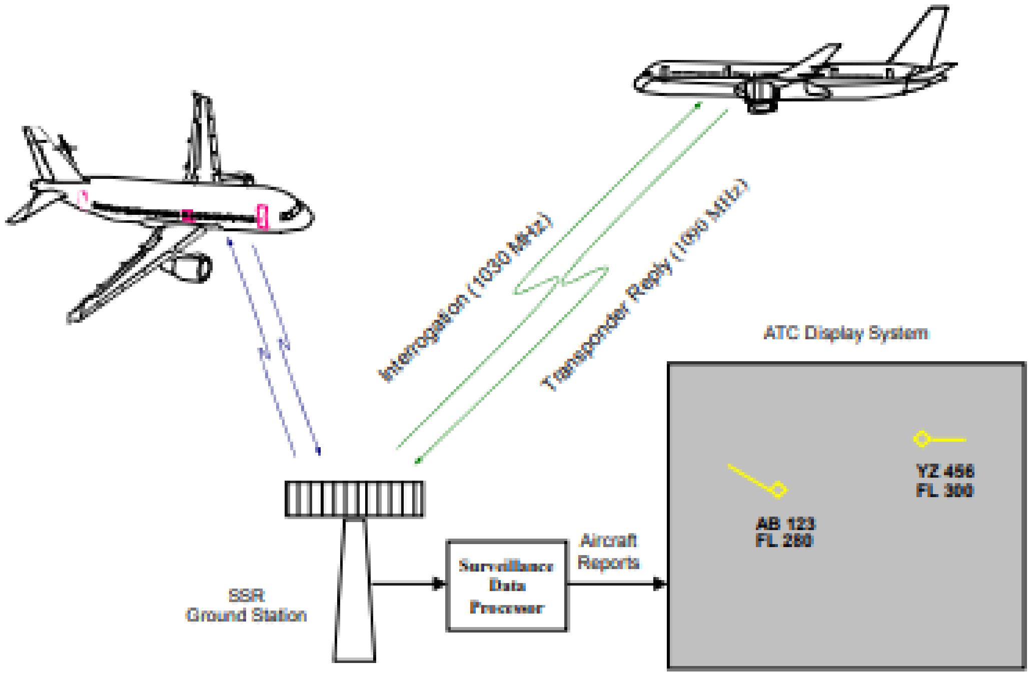


Figure 16 Secondary Surveillance Radar

By implementing the SSR transponder system, each icon can be identified via a unique **four-digit code** (allocated by ATC for each flight). Using SSR also means that the effects of clutter (from trees, buildings and hills, etc.) are not displayed on the controller's screen. With an uncluttered screen, and each aircraft readily identified, more aircraft can be allowed into the controlled airspace.
Here is a representation of the two sensors, from skylibrary.aero website:

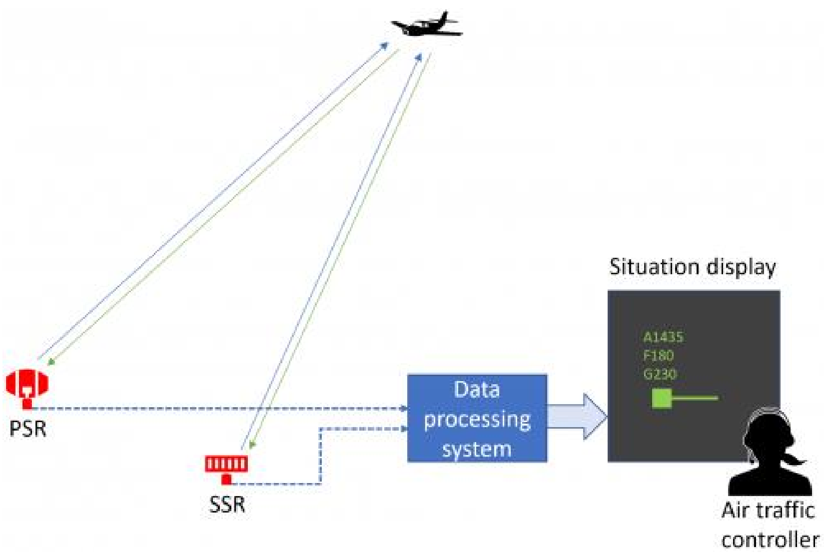


Figure 17 PSR and SSR data processing

Usually, SSR is co-located with a PSR, with the SSR located on top of the PSR antenna.

Wide Area Multilateration (WAM)

Description

Wide Area Multilateration is a Surveillance technique that exploits the 1090 MHz transmissions broadcast from aircraft. From these signals it can create a track containing parameters such as aircraft identification, position, height, etc. Active interrogation is also possible in order to trigger transmission.

Although the manner in which WAM constructs Surveillance data differs significantly from Automatic Dependent Surveillance Broadcast (ADS-B), the synergies between these two Surveillance techniques in addition to their high performance and lower cost are expected to bring significant operational benefits. Consequently, composite WAM/ADS-B systems are widely offered by industry and deployed by ANSPs in Europe and worldwide, thus exploiting these synergies.

The optimal mix of the various Surveillance techniques (Transponder Mode S, ADS-B, WAM) will however depend upon the local environment, operational needs and business case, from an overall ATM Network viewpoint.

ADS-B and WAM are key enablers of the future European ATM Network, contributing to the achievement of the Single European Sky (SES) performance objectives, including safety, capacity, efficiency and environmental sustainability.

Multilateration is a proven technology that has been in use for many decades. It was developed for military purposes to accurately locate aircraft — many of which did not wish to be "seen" — by using a method known as Time Difference of Arrival (TDOA).

Multilateration employs a number of ground stations, which are placed in strategic locations around an airport, its local terminal area or a wider area that covers the larger surrounding airspace.

These units listen for "replies," typically to interrogation signals transmitted from a local SSR or a Multilateration station. Since individual aircraft will be at different distances from each of the ground stations, their replies will be received by each station at fractionally different times. Using advanced computer processing techniques, these individual time differences allow an aircraft's position to be precisely calculated.

Multilateration requires no additional avionics equipment, as it uses replies from Mode A, C and S transponders, as well as military IFF and ADS-B transponders. Furthermore, while the radar and Multilateration "targets" on a controller's screen are identical in appearance, the very high update rate of the Multilateration-derived targets makes them instantly recognizable by their smooth movement across the screen. A screen displaying Multilateration information can be set to update as fast as every second, compared with the 4 - 12 second position "jumps" of the radar-derived targets.

MLAT in Action:

1. Mode A/C/S Interrogation
2. Mode A/C/S Reply, ADS-B, IFF
3. Time Difference of Arrival (TDOA) Processing
4. Hyperbolic Positioning
5. Aircraft Position Display

In the future ADS-B environment, today's secondary surveillance radars will essentially be decommissioned or become backup systems. ANSPs that have announced ADS-B programs, such as Airservices Australia and the FAA, have also stated their intention to correspondingly reduce their SSR installations by as much as 50 percent.

Many ANSPs are also considering Multilateration as a more economical solution to future backup requirements, after analysing the continuing costs of SSR maintenance, power, fuel and other expenditures.

Another key consideration is that Multilateration systems have built-in ADS-B capabilities, with today's ground-based Multilateration sensors capable of tracking aircraft ADS-B transmissions as equally effective as those from Modes A, C, S and military IFF transponders.

Four other important considerations also arise. First, an installation of a Multilateration network, to either serve a new area of airspace or to replace a legacy SSR, will be the initial step towards the eventual transition to ADS-B. This is so because the newly installed network can immediately track early-equipped ADS-B aircraft.

Second, as the transition to ADS-B draws closer, Multilateration sensors can serve as full-featured ADS-B ground stations at significant cost savings.

Third, the already installed Multilateration network can perform both essential ADS-B backup and validation functions.

Finally, the Multilateration system will continue to track non-ADS-B traffic throughout and beyond the authorities' lengthy expected transition period, making the service available at minimal or no additional cost to the ANSP.

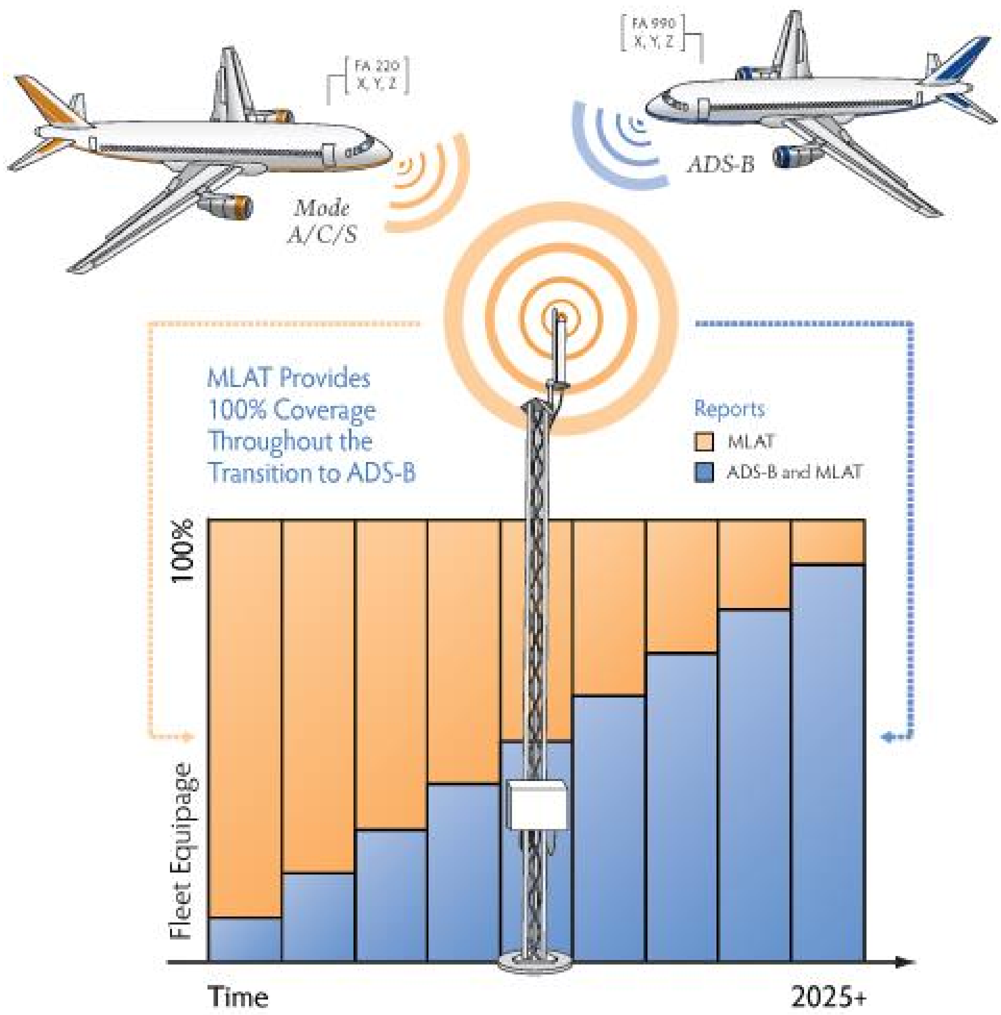


Figure 18 Because MLAT is backward compatible with existing SSR transponders and forward compatible with ADS-B, it provides full fleet coverage today and in the future, independent of the pace of aircraft equipage

Benefits

- Provides flexibility in surveillance coverage for any desired airspace
- Provides an additional layer of cooperative surveillance, where needed
- Improves safety, efficiency, and capacity
- Reduces flight delays, cancellations, and diversions to other airports

How it works

WAM is comprised of a network of sensors that are deployed throughout a desired coverage area or potentially deployed on satellites in space. WAM capabilities are typically combined within ADS-B receivers to provide a complementary surveillance overlay to ADS-B.

WAM sensors receive signals from aircraft avionics based on ADS-B squitters or transponder replies. WAM ground sensors can also interrogate transponders to elicit replies that are then received and processed by the WAM system. WAM system applications multilaterate on those signals to determine the precise location of aircraft while utilizing the data in the squitters and replies for aircraft identification and barometric altitude information. This surveillance data is delivered to air traffic management systems and presented to air traffic control to safely provide aircraft separation services.

The basic principle of MLAT is the use of a hyperbolic curve and determination of hyperbolic position. These measurements use the time difference of arrival (TDOA) [**19**] of the received signal from four receivers. One of the receivers is used as a reference, and the remaining three calculate the position of the aircraft. The specific methods for TDOA are as follows [**20**,**21**]. The distance between each receiver and the target aircraft is calculated as follows:

$$D_i = \sqrt{(x_i - x)^2 + (y_i - y)^2 + (z_i - z)^2} \quad (1)$$

where (x_i, y_i, z_i) denotes the location of each receiver; i is the number of receivers, and (x, y, z) is the position of the aircraft. In other words, the distance between the aircraft and the receiver can be calculated. If a particular receiver is set as the origin, the distance between that receiver and the aircraft is:

$$D_0 = \sqrt{x^2 + y^2 + z^2} \quad (2)$$

If the propagation speed is v and propagation travel time is t, the difference between Equations (1) and (2) is the product of speed and distance, that is:

$$D_i - D_0 = vt$$

Thus, with four receivers, the three-dimensional coordinates (x, y, z) can be determined. If you receive altitude information from secondary surveillance radar, you can determine the aircraft position using only three receivers. Figure 19 shows how to measure aircraft position by MLAT. The aircraft position error in MLAT is known to be 3–6 m near an airport and 10–13 m at 16 km distance away from an airport.

Multilateration (MLAT) is employed when the installation and operation of radar is difficult or there is an aircraft surveillance dead zone. MLAT is very useful when such dead zones exist, or when the cost of installing additional radar facilities is prohibitively high because of the structural propagation characteristics of current radar through the airport and major airways. It also can be useful in aircraft detection below a certain altitude and screen jamming due to mountains and obstacles. The basic concept of wide-area Multilateration (WAM) is the same as that of MLAT, but it can monitor areas far from the airport. In other words, MLAT monitors aircraft and moving objects in close range such as the airport grounds, and WAM is a system that monitors aircraft on major airways.

MLAT techniques were developed by the military decades ago and have been successfully employed for airport surveillance more recently. Today, these same techniques are being used for larger areas to cover the en-route and approach phases of flight. Such systems are called WAM systems.

In WAM, the stations are spread much further apart, at distances of up to 100 km between each other.

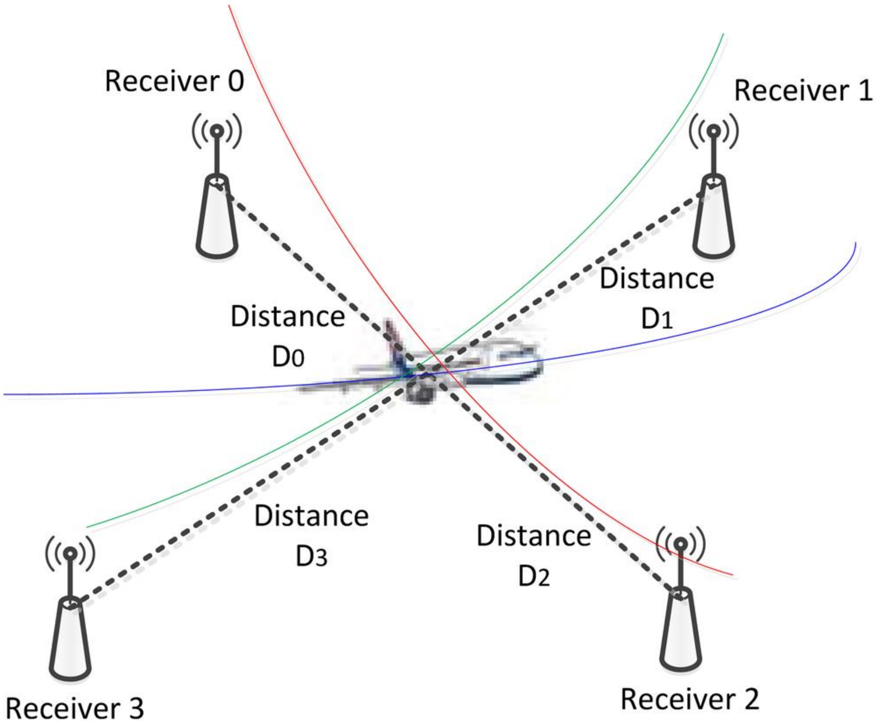


Figure 19 MLAT

Availability

Under a partnership with the Colorado Department of Transportation, the FAA installed WAM at a number of airports in the Rocky Mountains. WAM has been providing surveillance at these locations for a number of years, helping to keep flights operating safely and spaced efficiently. This system is especially useful during the busy winter ski season in reducing capacity constraints that occur when weather might otherwise cause diversions or flight cancellations.

WAM is also operational at Juneau, Alaska. Juneau is another mountainous area without radar, which has a notoriously difficult approach. Flights into Juneau are now safer and more efficient with WAM surveillance providing a traffic situational awareness picture to ATC.

In Charlotte, N.C., WAM was added to correct coverage deficiencies and tracking anomalies from the airport's limited radar input. With WAM in place, Charlotte fuses it with radar and ADS-B data to provide a comprehensive surveillance picture to ATC which readily supported fully transitioning to ADS-B as the preferred surveillance service.

The FAA most recently installed WAM services at the Southern California Terminal Radar Approach Control Facility (SCT) to mitigate interference to existing radars that resulted from the construction of the National Football League's new SoFi Stadium.

Additional WAM services in the Atlanta and the New York metropolitan areas are planned for activation after 2021 to mitigate spectrum congestion on surveillance frequencies and potentially replace existing radar assets.

TCAS

ACAS AND TCAS Currently, TCAS II is the only implementation that meets the ACAS ICAO Standards and Recommended Practices (SARPs). Therefore, the term ACAS II is typically used when referring to the standard or concept and TCAS II when referring to the implementation. However, often both terms are used interchangeably. In this Guide, the terms ACAS (the standard) and TCAS (the implementation) are used synonymously, unless specifically noted.

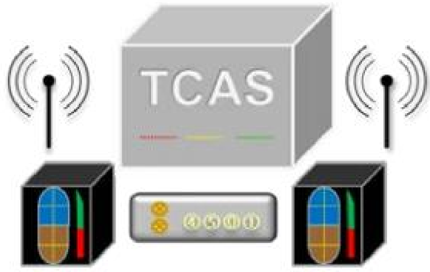
ACAS	TCAS
Airborne **C**ollision **A**voidance **S**ystem	**T**raffic alert and **C**ollision **A**voidance **S**ystem
Standard: ICAO Annex 10 vol. IV	The only implementation of the ICAO ACAS standard (equipment)
	

Table 1 ACAS and TCAS: standard and implementation

ACAS Principles

ACAS is designed to work both autonomously and independently of the aircraft navigation equipment and any ground systems used for the provision of air traffic services.

Through antennas, ACAS interrogates the ICAO standard compliant transponders of aircraft in the vicinity. Based upon the replies received, the system tracks the slant range, altitude (when it is included in the reply message) and bearing of surrounding traffic.

ACAS can issue two types of alerts:

- Traffic Advisories (TAs), which aim to help the pilots in the visual acquisition of the intruder aircraft, and to alert them to be ready for a potential resolution advisory.
- Resolution Advisories (RAs), which are avoidance manoeuvres recommended to the pilot. An RA will tell the pilot the range of vertical rates within which the aircraft should be flown to avoid the threat aircraft. An RA can be generated against all aircraft equipped with an altitude reporting transponder (Mode S or Mode A/C); the intruder does not need to be fitted with ACAS II. When the intruder aircraft is also fitted with an ACAS II system, both systems coordinate their RAs through the Mode S data link, in order to select

complementary resolution senses. ACAS II does not detect non-transponder equipped aircraft or aircraft with a non-operational transponder.

ACAS was recognised by ICAO on 11 November 1993. Its descriptive definition appears in Annex 2; its use is regulated in Annex 6, PANS-OPS (Doc. 8168) and PANS-ATM (Doc. 4444). In November 1995, the SARPs for ACAS II were approved, and they have been published in ICAO Annex 10 volume IV. In 2006 ICAO published Doc. 9863 – Airborne Collision Avoidance System (ACAS) Manual. The purpose of the Manual is to provide guidance on technical and operational issues applicable to ACAS.

ACAS Standards

Three types of ACAS have been specified in ICAO Annex 10:

- ACAS I provides information as an aid to “see and avoid” action but does not include the capability for generating RAs;
- ACAS II provides vertical RAs in addition to TAs;
- ACAS III provides vertical and horizontal RAs in addition to TAs

Although ACAS III is mentioned as a future system in ICAO Annex 10, ACAS III is unlikely to materialise due to difficulties which the conventional surveillance systems have with horizontal tracking and, consequently, issuing horizontal avoidance manoeuvres. A future collision avoidance system for Remotely Piloted Aircraft Systems (RPAS) – ACAS Xu – is being developed and will incorporate horizontal manoeuvres by utilizing modern surveillance methods, such as ADS-B.

The latest TCAS II Minimum Operational Performance Standards (MOPS) have been developed jointly by RTCA and EUROCAE (European Organisation for Civil Aviation Equipment). For the current TCAS II version (7.1) the Standards have been published in RTCA document DO-185B and EUROCAE document ED-143. In order to be certified, any ACAS II equipment must meet the standards specified in the MOPS.

ACAS equipment is available from three principle vendors, all of them based in the USA. Systems by other manufacturers may become available. While each vendor’s implementation is slightly different, they provide the same core functions and the collision avoidance and coordination algorithms ("the logic") contained in each implementation is the same. Currently, there are at least 25,000 TCAS II equipped aircraft worldwide, including passenger airline and air freight operations, business aviation, and government and military aircraft.

Difference between ACAS and TCAS

TCAS II is the only implementation that meets the ACAS ICAO Standards and Recommended Practices (SARPs). The term ACAS II is typically used when referring to the standard or concept and TCAS II when referring to the implementation.

ACAS I

ACAS I is an airborne collision avoidance system that provides only advisories to aid visual acquisition.
Unlike ACAS II, ACAS I does not issue any specific collision avoidance advice (RAs are not issued).

ACAS I provides three levels of advisories:

- Other Traffic;
- Proximate Advisories (PA);
- Traffic Advisories (TA).

TAs are issued based on either τ (warning time) or proximity to an intruder aircraft, using two sensitivity levels.
The sensitivity level depends on the altitude of own aircraft and varies from 1 to 7 (see Table 2). The greater the SL, the more protection is provided.

Own Altitude	Sensitivity levels (*SL*)
Stand-by mode	1
0 – 1000 ft AGL	2
1000 – 2350 ft AGL	3
2350 ft AGL – FL50	4
FL50 – FL100	5
FL100 – FL200	6
Above FL200	7

Table 2 Sensitivity Levels

The SL is also coordinated with each intruder, with the higher of the two SLs applying to both aircraft.
Nominally, all transponder equipped intruder aircraft within five nautical miles are detected and shown on a traffic display.

The display of a TA is accompanied by an aural alert (“Traffic, traffic”) to inform the crew a TA has been displayed. The aural annunciations are inhibited if own aircraft is below 400 feet AGL (on an aircraft equipped with a radio altimeter) or when the landing gear is extended (if no radio altimeter is installed). When TCAS I is installed on a fixed-gear aircraft without a radio altimeter, the aural annunciations will never be inhibited.

ACAS I advisories provide the crew with the intruder's range, bearing, and for altitude reporting intruders, relative altitude and vertical speed. The criteria for generating these advisories were chosen to provide the crew enough time to visually acquire the intruder aircraft prior to the closest approach of the intruder aircraft.

ICAO SARPs for ACAS I are published in ICAO Annex 10, volume IV and are limited to interoperability and interference issues with ACAS II. Currently the only implementation of the ACAS I concept is TCAS I. TCAS I MOPS have been published by RTCA (DO-197A) in September 1994.

ACAS I is not, nor has it ever been, mandated in Europe and there are no operational rules regarding the use of ACAS I. The main purpose of ACAS I is to aid pilots in acquiring threats visually; the collision avoidance manoeuvre direction is left to pilots' discretion. ACAS I operations cannot be coordinated with ACAS II.

ACAS I is still mandated or allowed on some aircraft operating in US airspace. In Europe ACAS I may be found on some aircraft outside the current European mandate (i.e. either military or those falling outside the mandated weight or number of passenger seats thresholds).

TCAS II Versions

Versions 6.02 AND 6.04a

Throughout the 1980s, the performance evaluations of early versions of TCAS II contributed to the gradual enhancement of the equipment and software. In September 1989 the design of version 6.02 was completed and put into operations from April 1990.
In order to determine the TCAS II system performance, ICAO commissioned a worldwide operational evaluation in the late 1980s. The evaluation was conducted in the early 1990s.
As a result of the evaluation a number of improvements were suggested. That led to the development and release of version 6.04a in 1993. The new version aimed to reduce the number of nuisance alerts, which were occurring at low altitudes and during level-off encounters.

Neither version 6.02 nor 6.04a were compliant with the ICAO ACAS SARPS (Annex 10, volume IV).
Version 6.02 is longer used. Version 6.04a is still mandated or allowed on some aircraft operating in US airspace. In Europe version 6.04a may be found on aircraft outside the current European mandate (i.e. either military or those below the mandated weight or number of passenger seats thresholds).

Version 7.0

After the implementation of version 6.04a, further operational evaluations were carried out and proposed performance improvements led to the development of version 7.0. It was approved in December 1997 and became available at the beginning of 1999.
Version 7.0 further improved TCAS II compatibility with the air traffic control system. The most significant enhancements brought by version 7.0 were:

- the introduction of a horizontal miss distance filter;
- 25-foot vertical tracking;
- sophisticated multi-threat logic;
- compatibility with Reduced Vertical Separation Minima (RVSM) operations;
- the reduction of electromagnetic interference;
- allowing RA reversals in coordinated encounters;
- simplified aural annunciations.

Version 7.0 was the first TCAS II version to be compliant with the ICAO ACAS SARPS (Annex 10 volume IV).

Version 7.0 is still mandated or allowed on many aircraft operating in US airspace and other parts of the world. In Europe version 7.0 may be encountered on aircraft outside the current European mandate (i.e. either military or those below the mandated weight or number of passenger seats thresholds).

Version 7.1

TCAS II version 7.1 is the only ACAS version meeting the current requirements of ICAO and European mandates. It was developed based on an extensive analysis of version 7.0 performance, with two major changes implemented to improve TCAS performance.

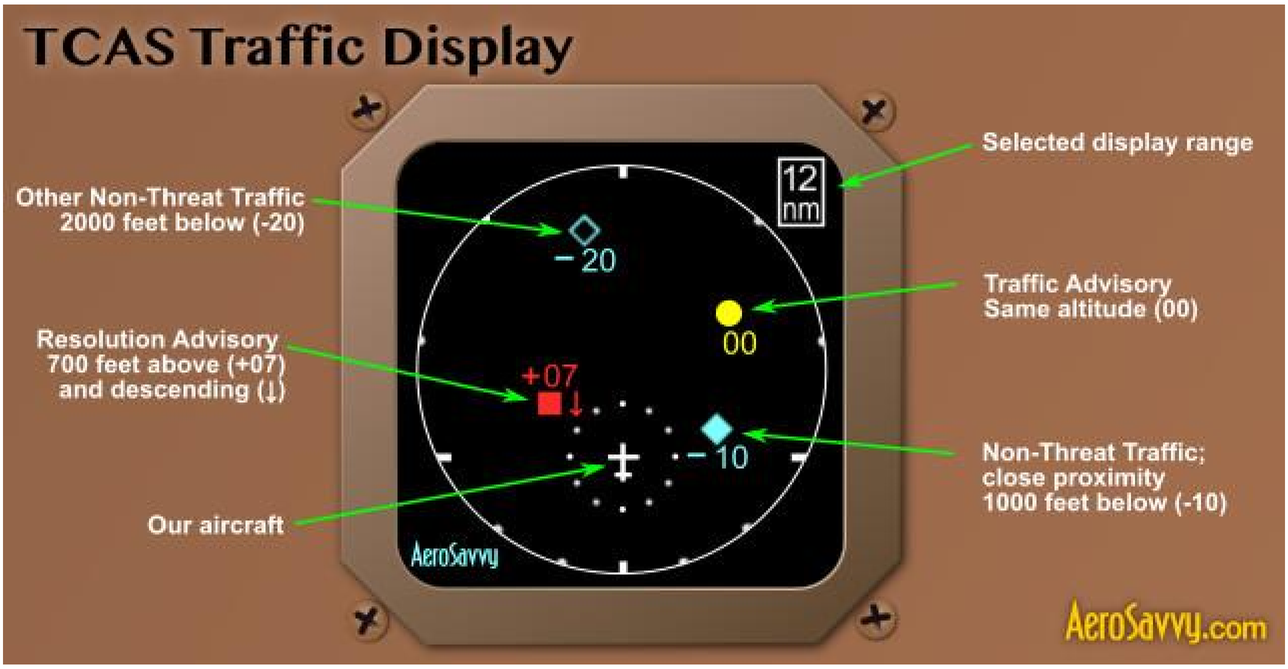


Figure 20 TCAS display

Difference between TCAS I and TCAS II

TCAS I provides traffic advisories (TAs) to assist the pilot in the visual acquisition of intruder aircraft. TCAS II provides TAs and resolution advisories (RAs), i.e., recommended escape manoeuvres, in the vertical dimension to either increase or maintain the existing vertical separation between aircraft.

TCAS works by sending interrogations to other aircraft's transponders. The transponder will reply to the interrogation in a similar way it responds to radar. From the time difference between the interrogation and the reply, the distance to the other aircraft is calculated.

New Level Off RA

Operational monitoring of version 7.0 revealed two issues with pilots' responses to Reduce Climb and Reduce Descent RAs (announced as "Adjust vertical speed, adjust"). Those were:

- incorrect response: the pilots increased their vertical rate instead of reducing it, consequently causing a deterioration of the situation;
- level busts when pilots following the Reduce Climb and Reduce Descent RAs flew through their cleared level, often causing a follow up RA for the other aircraft above or below, and disrupting ATC operations.

To address these issues, in version 7.1 the Reduce Climb/Descent RAs have been replaced with a new "Level off, level off" RA. The "Level off, level off" RA requires a reduction of vertical rate to 0 ft/min. The level off is to be achieved promptly, not at the next standard flight level (e.g. FL200, FL210, etc.). The “Level off, level off” RA may be issued as an initial RA (as illustrated in Figure 21) or as a weakening RA (following, for instance, a “Climb, climb” or “Descend, descend” RA) when the vertical distance between the aircraft increases after the initial RA has been issued (as illustrated in Figure 22). The aural message “Level off, level off” has the benefit of being intuitive and the associated manoeuvre corresponds to the standard levelling off manoeuvre.

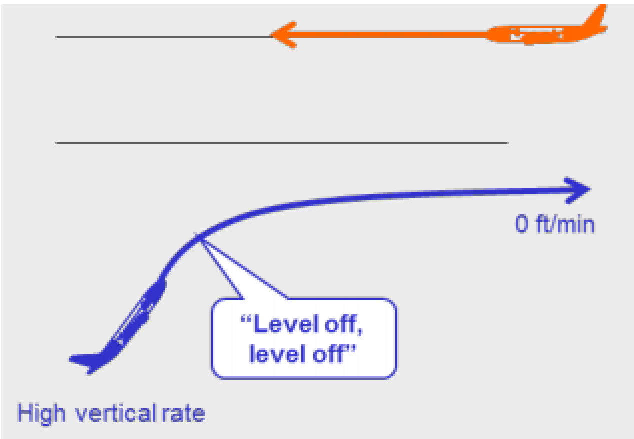


Figure 21 Level Off RA as an initial RA

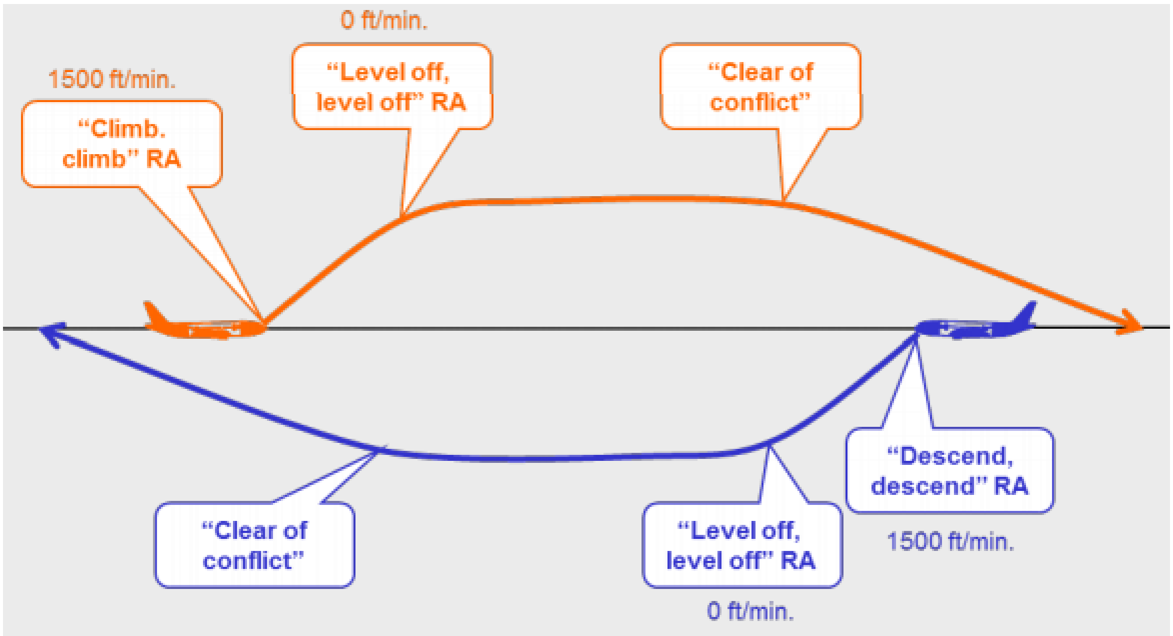


Figure 22 Level Off RA as a weakening RA

Improved reversal logic

The design of TCAS II version 7.0 allowed for reversal RAs (i.e. "Climb, climb NOW" and "Descend, descend NOW") to be issued in coordinated encounters (i.e. both aircraft TCAS II equipped) when the current RA is no longer predicted to provide sufficient vertical spacing.

After version 7.0 was introduced in the early 2000s, a weakness in the sense reversal logic was discovered in "vertical chase with low vertical miss distance" geometries: version 7.0 failed to reverse an RA if two aircraft converging in altitude remained within 100 feet (see Figure 22). This scenario could occur when one aircraft was not following the RA or was not TCAS II equipped and followed an ATC instruction or performed an avoidance manoeuvre based on visual acquisition. A number of these cases have occurred, the most notable events being the Yaizu (Japan) mid-air accident January 2001[2] and the Überlingen (Germany) mid-air collision in July 2002[3]. In 5 years following the Überlingen accident, eight other occurrences have been observed in European airspace[4].

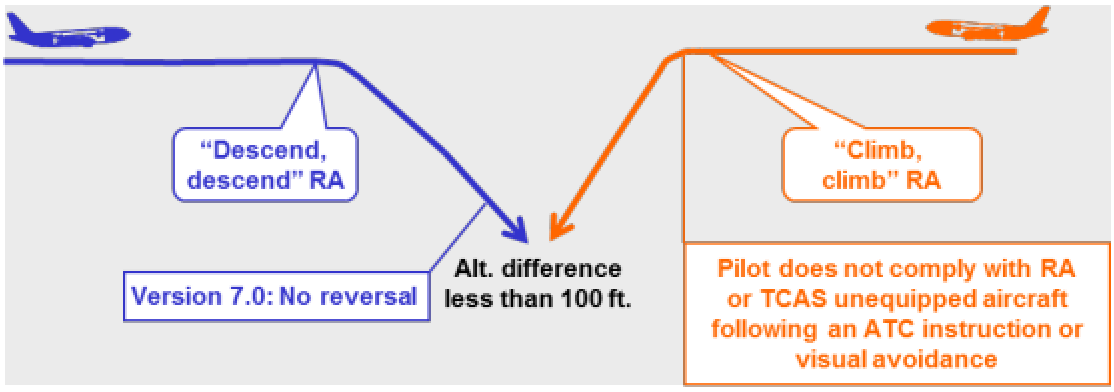


Figure 23 Geometry in which version 7.0 did not reverse an RA

Version 7.1 brought improvements to the reversal logic by detecting situations in which, despite the RA, the aircraft continue to converge vertically.

A feature has been added to the version 7.1 logic which monitors RA compliance in coordinated encounters. When the logic detects that an aircraft is not responding correctly to an RA, it will issue a reversal RA to the aircraft which manoeuvres in accordance with the RA15 (i.e. "Climb, climb NOW" or "Descend, descend NOW" RA) and will change the sense of RA issued to the aircraft that is not responding correctly to be compatible with the reversal, e.g. "Maintain vertical speed, maintain" RA (see Figure 24). The feature will be activated only if:

- at least 4 seconds remain before CPA, Closes Point of Approach (because a reversal RA triggered in the last 4 seconds gives little chance for correct pilot's response)

and

- only if at least 10 seconds have elapsed since the initial RA, because a reversal RA triggered too early does not give the pilot enough time to comply with the initial RA.

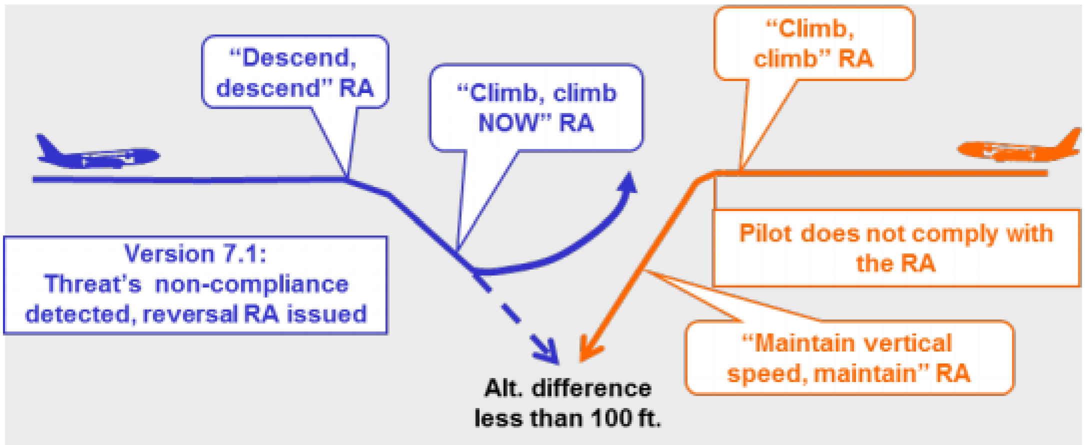


Figure 24 Improvement of reversal logic in version 7.1 (both aircraft equipped)

In single equipage encounters, version 7.1 recognises the situation and will issue a reversal if the unequipped threat aircraft moves in the same vertical direction as the TCAS II equipped aircraft (see Figure 25).

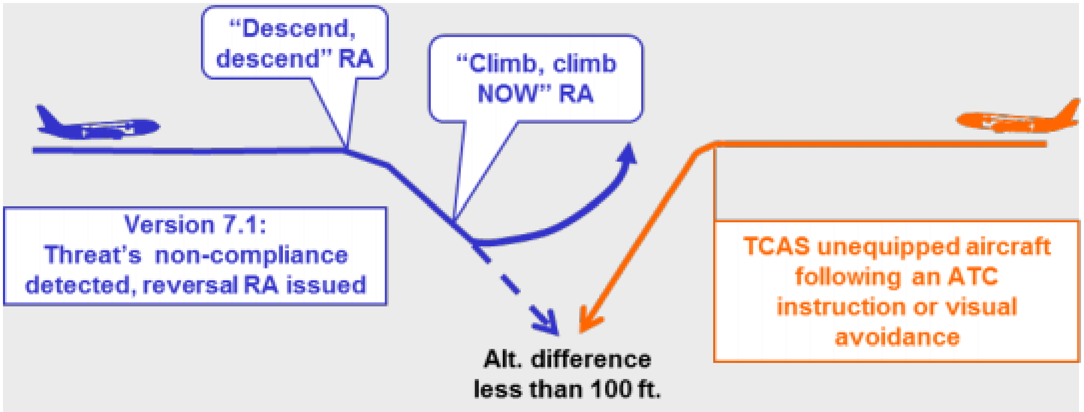


Figure 25 Improvement of reversal logic in version 7.1 (only one aircraft equipped)

Although the reversal logic change is transparent to flight crews, it, nevertheless, brings significant safety improvements.

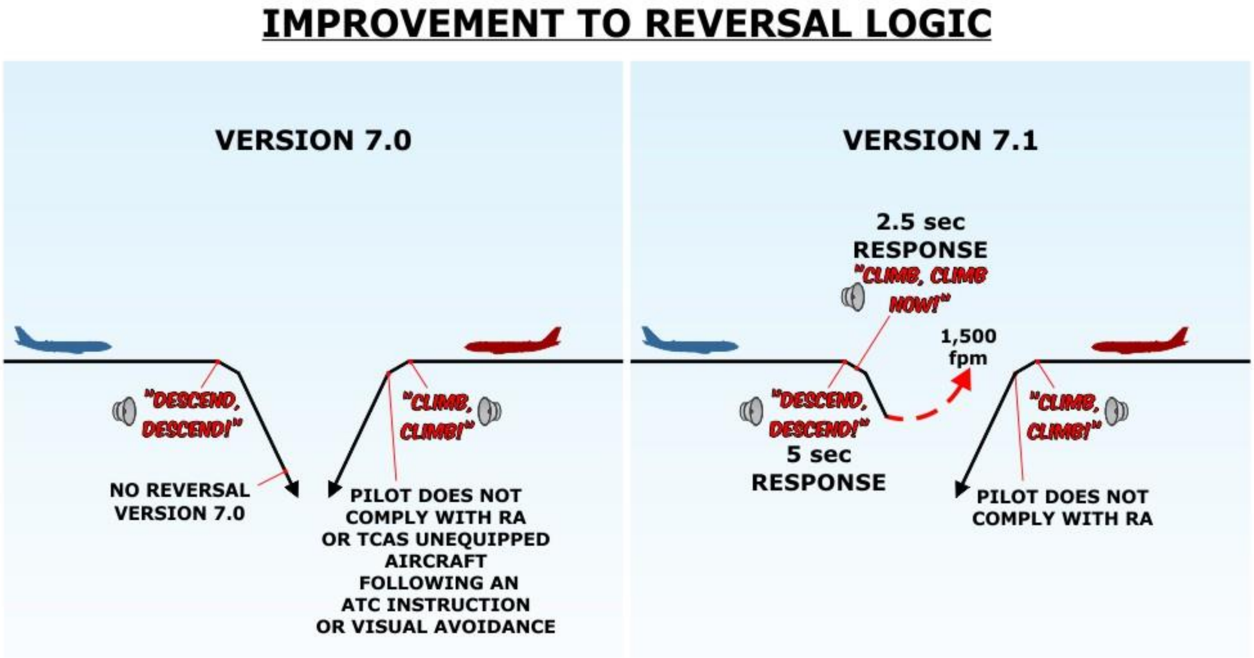


Figure 26 Improvement to Reversal Logic in V. 7.1

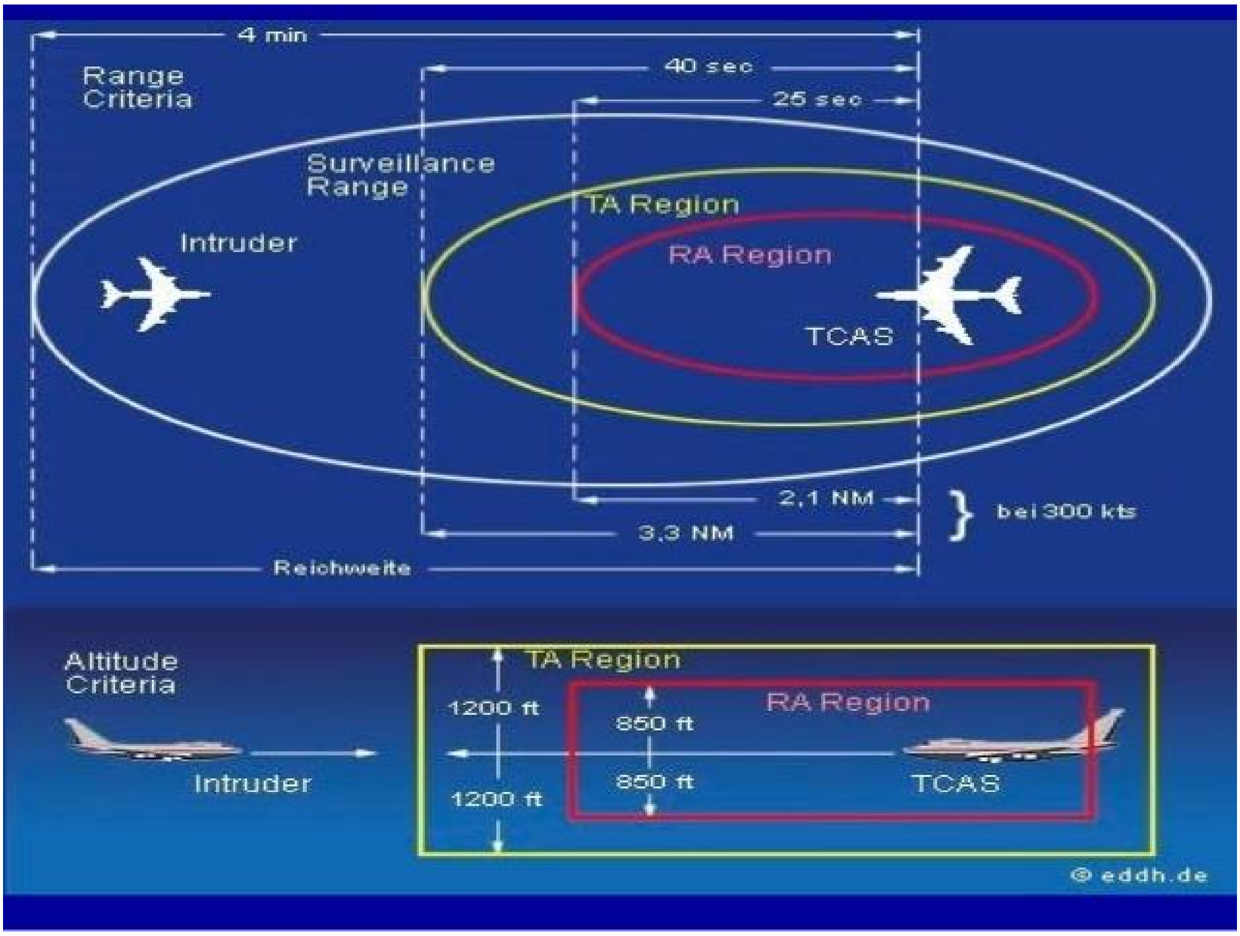


Figure 27 TCAS II Protected volume

Hybrid Surveillance

Hybrid surveillance is a method that decreases the number of Mode S surveillance interrogations made by an aircraft's TCAS II unit. This feature, new to TCAS II version 7.1, may be included as optional functionality in TCAS II units. TCAS II units equipped with hybrid surveillance use passive surveillance instead of active surveillance to track intruders that meet validation criteria and are not projected to be near-term collision threats. With active surveillance, TCAS II transmits interrogations to the intruder's transponder and the transponder replies provide range, bearing, and altitude for the intruder. With passive surveillance, position data provided by an on-board navigation source is broadcast from the intruder's Mode S transponder. The position data is typically based on GNSS and received on own aircraft by the use of Mode S extended squitter, i.e. 1090 MHz ADS-B, also known as 1090ES. Standards for Hybrid Surveillance have been published in RTCA DO-300. The intent of hybrid surveillance is to reduce the TCAS II interrogation rate through the judicious use of validated ADS-B data provided via the Mode S extended squitter without any degradation of the safety and effectiveness of TCAS II.

Active interrogations are used to track any intruder which is perceived to be a threat (Figure 28):

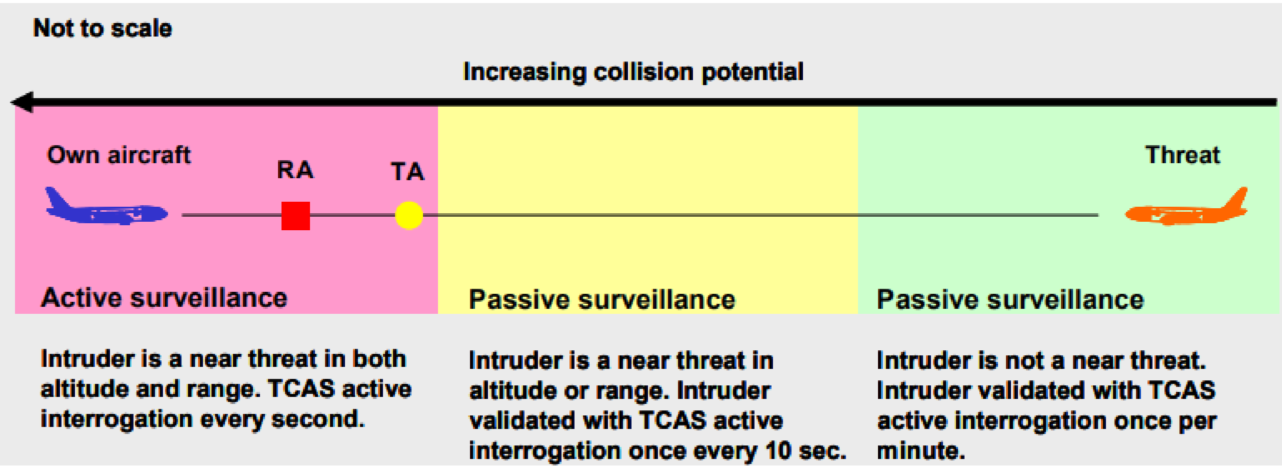


Figure 28 Hybrid surveillance: transition from passive to active surveillance

Conclusions

Airborne Collision Avoidance Systems are a last resort system designed to prevent mid-air collisions between aircraft. Currently, this role is fulfilled by TCAS II and a new generation of Airborne Collision Avoidance Systems (ACAS X) is being developed. The technical features of the system provide a significant improvement in flight safety and TCAS II has attained universal recognition in the world of aviation. TAs and RAs are relatively infrequent and are unplanned events, which call for prompt and appropriate reactions from the flight crew. Consequently, flight crew require specific and recurrent training in TCAS procedures. TCAS II operations have an effect on ATC. It is therefore essential that controllers have a good knowledge of the TCAS II system's characteristics and of the procedures used by pilots. Controllers are also required to provide the same ATC service, especially with regard to traffic information or the maintenance of the relevant ATC separation, whether the aircraft are fitted with TCAS or not. The implementation of TCAS II has increased the safety and reduced the possibility of mid-air collision. However, in order for TCAS II to continue to deliver its safety benefit, it is essential that pilots and controllers are adequately trained on TCAS II operations and followed the procedures.

Future of collision avoidance: ACAS X

The United States Federal Aviation Administration (FAA) has funded research and development of a new approach to airborne collision avoidance (known as ACAS X[22]) since 2008. This new approach takes advantage of recent advances in 'dynamic programming' and other computer science techniques (which were not available when TCAS II was first developed) to generate alerts using an off-line optimisation of resolution advisories.

ACAS X principles

Instead of using a set of hard-coded rules, ACAS X alerting logic is based upon a numeric lookup table optimised with respect to a probabilistic model of the airspace and a set of safety and operational considerations.
The ACAS X probabilistic model provides a statistical representation of the aircraft position in the future. It also takes into account the safety and operational objectives of the system enabling the logic to be tailored to particular procedures or airspace configurations.
This is fed into an optimisation process called dynamic programming to determine the best course of action to follow according to the context of the conflict. This employs a "*rewards* versus *costs"* system to determine which action would generate the greatest benefits (i.e. maintain a safe separation while implementing a cost-effective avoidance manoeuvre). Key metrics for operational suitability and pilot acceptability include minimising the frequency of alerts that result in reversals/intentional intruder altitude crossings or disruptive advisories in noncritical encounters.
The lookup table is used in real-time on-board the aircraft to resolve conflicts. ACAS X collects surveillance measurements from an array of sources (approximately every second). Various models are used (e.g. a probabilistic sensor model accounting for sensor error characteristics) to estimate a state distribution, which is a probability distribution over the current positions and velocities of the aircraft. The state distribution determines where to look in the numeric lookup table to determine the best action to take (which includes the option 'do nothing'). If deemed necessary, resolution advisories are then issued to the pilots.

ACAS X Variants

- **ACAS Xa –** The general purpose ACAS X that makes active interrogations to detect intruders. ACAS Xa is the baseline system, the successor to TCAS II. The Standards are expected to be ready by 2018[23] and ACAS X may become commercially available in 2020.
- **ACAS Xo –** ACAS Xo is an extension to ACAS Xa designed for particular operations, like closely spaced parallel approaches, for which ACAS Xa is less suitable because it might generate a large number of nuisance alerts. The Standards are prepared jointly with ACAS Xa standards

and also are expected to be ready by 2018; however currently it is not known when ACAS Xo will become commercially available.

- **ACAS Xu –** Designed for Remotely Piloted Aircraft Systems (RPAS), incorporating horizontal resolution manoeuvres. Work on Standards has started in 2016 and is expected to be finished in 2020.
- **ACAS Xp –** A future version of ACAS X that relies solely on passive ADS-B to track intruders and does not make active interrogations. It is intended for general aviation aircraft (that are not currently required to fit TCAS II).

ACAS X BENEFITS

The following benefits are foreseen through the introduction of ACAS X:

- Reduction of 'unnecessary' advisories: TCAS II is an effective system operating as designed, but it can issue alerts in situations where aircraft will remain safely separated.
- Safety improvement: It is envisaged that ACAS Xa will provide an improvement in safety while reducing the unnecessary alert rate.
- Adaptability to future operational concepts: Both SESAR[25] and NextGen[26] plan to implement new operational concepts which will reduce the spacing between aircraft. TCAS II in its current form is not compatible with such concepts and would alert too frequently to be useful.
- Extending collision avoidance to other classes of aircraft: To ensure advisories can be followed, TCAS II is restricted to categories of aircraft capable of achieving specified performance criteria (e.g. aircraft must be able to achieve a rate of climb of 2500 ft/min.), which excludes many General Aviation (GA) and Unmanned Aircraft Systems (UAS) or Remotely Piloted Aircraft Systems (RPAS).
- Use of future surveillance environment: Both SESAR and NextGen make extensive use of new surveillance sources, especially satellite-based navigation and advanced ADS-B functionality. TCAS II however relies solely on transponders on-board aircraft which will limit its flexibility to incorporate these advances.

ACTIONS TO BE TAKEN AFTER INSPECTIONS		Class of actions		
		Class 1 Information to Captain (POI)	Class 2 Information to the operator and the responsible NAA	Class 3 Immediate action
Category of findings	**General Remark** Any observation from the inspector not classified as safety relevant	**Yes**	**Not applicable**	**Not applicable**
	Cat 1 - Minor: any detected non-compliance with the applicable requirements or the terms a certificate that has a minor influence on safety	**Yes**	**Possible** Debriefing and notification through the ramp inspection tool without further communication	**Not applicable**
	Cat 2 - Significant: any detected non-compliance with the applicable requirements or the terms of a certificate that has a significant influence on safety	**Yes**	**Yes** Normal communication through the ramp inspection tool for follow-up actions Note: Written communication to the operator and to the NAA (findings of several inspections may be summarised in one communication). This should only be used if the inspecting NAA have a national requirement for this	**Not applicable**
	Cat 3 - Major: any detected significant non-compliance with the applicable requirements or the terms of a certificate that has a major influence on safety	**Yes**	**Yes** All communication are normally to be uploaded in the inspection tool for follow-up transparency. In case of aircraft damage affecting airworthiness and not possible to be rectified before flight, the operator should establish a direct communication with the responsible NAA regarding return to flight status (e.g. "permit to fly").	**Yes** Note: the specific actions consisting of operational restrictions, corrective actions before flight or at maintenance-base, grounding and/or entry permit repercussions have to be reported.
	General Remark Any observation from the inspector not classified as safety relevant	**Yes**	**Not applicable**	**Not applicable**

Table 3 The relations between the category of findings and the resulting class of actions to take

Requirements

Eurocontrol has announced that all aircraft equipped with TCAS II version 7.0 must upgrade to version 7.1 by December 1, 2015, to conduct flights in European airspace.

TCAS I is mandated for use in the U.S. for turbine powered, passenger-carrying aircraft having more than 10 and less than 31 seats. TCAS II is mandated by the U.S. for commercial aircraft, including regional airline aircraft with more than 30 seats or a MTOM greater than 33000 lbs.

From: "EASA Ramp Inspection Manual (RIM)", 2019:

A03 - Equipment

From 1 January 2005, all turbine-engine aeroplanes of MCTOM>5,7t or MOPSC (Maximum Operational Passenger Seating Configuration) >19 Pax shall be equipped with an airborne collision avoidance system (ACAS II).

TCAS version 7.1

Part-AUR.ACAS establishes airspace requirements, applicable to all airspace users irrespective whether the aircraft is registered in an EASA state or not.

- Before 01.12.2015 only aircraft with CoA first issued on or after 01.03.2012 are required to be equipped with TCAS version 7.1;

- As of 01.12.2015 all European airspace users need version 7.1

RVSM Equipment

Reduced Vertical Separation Minimum (RVSM) is defined as the reduction of vertical space between aircraft from 2,000 to 1,000 feet at flight levels from 29,000 feet up to 41,000 feet. RVSM was implemented as a means to increase airspace capacity and provide access to more fuel-efficient flight levels.

Aircraft used for operations in RVSM airspace shall be equipped with:

(a) 2 independent altitude measurement systems;

(b) an altitude alerting system;

(c) an automatic altitude control system;

(d) a secondary surveillance radar (SSR) transponder with altitude

reporting system to use for altitude control.

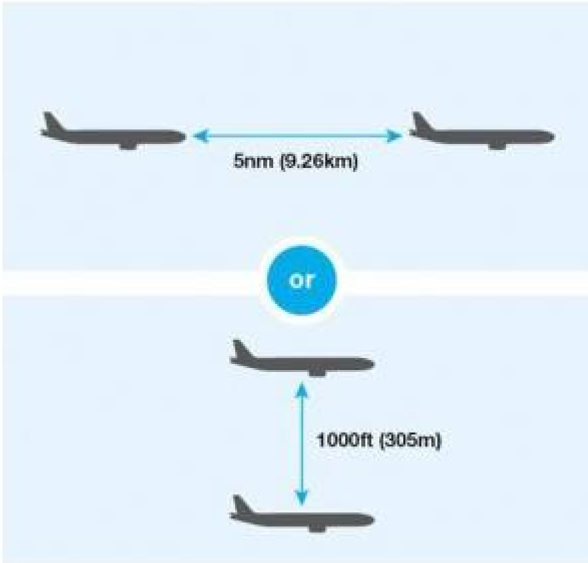


Figure 29 Horizontal and Vertical separation

Aircraft flying under instrument flight rules (IFR) in controlled airspace up to 29 000 ft (8800 m) must be separated by 1000 ft (305 m) vertically unless they are separated horizontally.

Above 29 000 ft, the vertical separation increases to 2000 ft (610 m), except in airspace where Reduced Vertical Separation Minima (RVSM) is applied.

When aircraft are separated vertically, horizontal separation can be reduced without compromising safety.

In controlled en route airspace, the horizontal separation standard between aircraft flying at the same altitude is 5 nm (9260 m). In terminal area airspace, the minimum separation is 3 nm (5500 m). Within the confines of an airport control zone, the separation can be as close as practicable as long as the aircraft remain separated.

In airspace not monitored by radar or other satellite-based navigation services, aircraft separation is achieved by the use of various procedural rules including time and estimated position.

Inspection Item	Inspections Item Title	Inspecting Instructions
A03	Equipment	*Note: Inspectors, while checking this inspection item, should also assess whether the required equipment is obviously not being used, e.g. if an equipment is found to be covered and therefore rendered unusable, this should result in a CAT 3 finding. If equipment is found to be obstructed (e.g. by a manual) during flight preparation phase, this should not lead to a finding.* **All Flights**: a) TAWS (E-GPWS) Check if installed and serviceable. If unserviceable check if properly deferred (reported in the ATLB) and check if still within MEL dispatch limits. Verify that the installed GPWS has a forward looking terrain avoidance function. If the terrain database is found to be expired, verify against the MEL the dispatch conditions. When an operational test can be performed by the pilot, it should be requested *Note: On certain aircraft such a test cannot be performed by the pilots but only by maintenance personnel: this does not constitute a finding.* *Note: Some CIS-built aircraft are equipped with GPWS systems like the SSOS or SPPZ (SPBZ) that do not fulfil the ICAO requirements regarding the E-GPWS. Only the 7-channel (SRPBZ) with forward looking terrain avoidance function meets the ICAO requirements.* In the case where an aircraft is found not to have TAWS (E-GPWS) installed then the competent authority should consider imposing an immediate operating ban on that aircraft. The aircraft should be allowed to depart only on a non-revenue flight. *Note:* Aeroplanes of a maximum certificated take-off mass of 5 700 kg or less and authorized to carry 9 passengers or less *are not required to be equipped with a TAWS installation.* b) ACAS II (TCAS) Check if installed and serviceable. If unserviceable check if properly deferred (reported in the ATLB) and check if still within MEL dispatch limits. When an operational test can be performed by the pilot, it should be requested. *Note: On certain aircraft such a test cannot be performed by the pilots but only by maintenance personnel: this does not constitute a finding.* All aeroplanes (MCTOM over 5.700 kg or MOPSC in excess of 19 passengers) shall be equipped with ACAS II collision avoidance logic version 7.1. Verification of compliance can be done by verifying the ACAS call-outs in the crew procedures in the operations manual (Part B, systems description); for version 7.1 these procedures should show the new resolution advisory "Level off, level off". Other documents like the radio station licence might contain evidence on (non-)compliance as well. A finding should only be raised if evidence is found that version 7.0 or lower is installed. A CAT 3 finding should be raised whenever evidence is found that a version 7.0 or lower is installed and that no mitigating measures are in place. A CAT 2 finding should be raised in all other cases.

		Note: Mitigating measures would consist out of one or both of the following as required by Part AUR.ACAS.1010. • *Appropriate operational procedures (Inspectors could check, whenever possible, the operations manual).* • *Appropriate training in the avoidance of collisions and use of ACAS II (Inspectors could raise questions to the flight crew).* *The most critical element is the requirement in Regulation 923/2012, SERA 11014(b)(2) to "follow the RA even if there is a conflict between the RA and an ATC instruction to manoeuvre". It is this requirement that the inspector should be looking for when checking the OM or interviewing the flight crew; if this element is found in the OM or known by the flight crew, mitigating measures are considered to be in place.* *Note: In case of a CAT 3 finding, where a version lower than 7.1 is installed and no mitigating measures are in place, the aircraft could be released after the operator has issued an operational memo or a temporary amendment to the operations manual introducing appropriate mitigating measures (as a Class 3a action). The temporary amendment should hold, as a minimum, instructions on how to react to conflicting ACAS advisories and ATC instructions, and preferably:* • *the elements in Regulation 923/2012, SERA 11014 and/or ICAO DOC 9863 Chapters 5.2.1.14 to 5.2.1.19 regarding the actions to be taken during and after an RA indication; and* • *the information provided in EASA SIB 2009-16 and/or ICAO DOC 9863 Chapter 5.5.8 regarding the ambiguous "Adjust vertical speed adjust" RA* *Note: In case of a CAT 3 finding, the operator cannot declare the (non-compliant) ACAS installation inoperative and subsequently release the aircraft in accordance with the MEL as this will not render the aircraft compliant.*

ADS-B

More and more people prefer to travel by airplane nowadays because of the economic growth and development. Federal Aviation Administration (FAA) predicts, as of 2033, the number of passengers in commercial aviation will increase to an unprecedented 1.15 billion. As a result, the number of aircraft in the airspace will continue to increase for the foreseeable future, and the airspace will be more crowded. In order to enlarge current airspace capacity, improve flight safety and meet future navigation needs, Federal Aviation Administration (FAA) was formulated NextGen (Next Generation Air Transportation System) project in 2004, the project aims to gradually transform a land-based ATC system which relies on radar networks into the satellite-based navigation system, ultimately realizing the modernization of the National Airspace System. As a pivotal part of the NextGen project, ADS-B can greatly improve the operational efficiency of air traffic control and reduce the maintenance cost of air traffic control infrastructure. Compared to traditional radar-based surveillance systems, ADS-B can provide not only real-time and accurate aircraft positioning information, but also has a lower maintenance cost and longer service life. Specifically, the construction and maintenance costs of which are only one-tenth of the former. Federal Aviation Administration (FAA) claims, as of January 2020, all commercial aircraft must be retrofitted ADS-B Out device.

ADS-B Technology

Automatic dependent surveillance broadcast (ADS–B) is a surveillance technology in which an aircraft broadcasts periodically its position and other information. No external stimulus is required (that's why it is automatic), but it relies on on-board navigation sources (GNSS) and on-board broadcast transmitting subsystems (that's why it is dependent) in order to provide surveillance information to other users. There are several frequencies which were originally planned to be used to transmit ADS-B messages: 1090 MHz for Mode S extended squitter, 978 MHz for Universal Access Transceiver (UAT), and very high frequencies around 136 MHz for VHF Digital Link mode 2 or 4.
In European airspace only 1090 MHz is used contrary to the US where 1090 MHz is used for commercial aviation while UAT frequency is used for GA.
The ADS-B system includes two main components:

- message generation and transmission by the source aircraft
- message reception/report assembly by the user.

The transmit functionality is called ADS-B Out and the receiver functionality ADS-B In.
Major benefits of ADS-B are:

- low data latency
- high refresh rate
- accuracy of position and velocity (assuming reliable on-board navigation/positioning function)
- mainly transmission of additional flight parameters

ADS-B is a suitable surveillance method for all applications – en route, terminal and also surface movements.
ADS-B mandate that recently started to be in force both in the USA and Europe is related only to ADS-B Out. Retrofit requirement in Europe took effect in June 2020 and it will be related to all aircraft with maximum take-off weight above 5700 kg or with maximal true airspeed above 250 kts. Starting on January 2020, ADS-B Out becomes mandatory in Classes A, B, C and E of US airspace.

The big advantage of ADS-B surveillance is a very simple technical installation of the receiver (ADS-B In) both onboard the aircraft and on the ground. It is in reality a passive system with omni-directional antenna, with minimum power requirements and very good range coverage (the actual detection range being dependent on the class of ADS-B Out system onboard the monitored aircraft, but for standardized systems this range is well beyond usual coverage of active surveillance). The key drawback is the fact that the surveillance systems is relying on information provided by monitored aircraft without actually measuring the surveillance data. Although ADS-B messages include so-called quality parameters describing accuracy, integrity, etc. of the provided position and velocity information, these parameters are again reported by other aircraft without straightforward possibility to verify them. In this context the use of ADS-B surveillance for safety critical applications requires implementation of some techniques mitigating risks associated with this dependency - usually through cross-check of ADS-B data against surveillance information received from some independent source.

In recent years ADS-B emerged as a cost-effective surveillance technology with great potential towards innovative applications.

One successfully implemented NexGen component, ADS-B, has resulted in increased availability and usage of satellite based navigation, in addition to giving pilots the ability to have the same information as air traffic controllers regarding traffic along with access to in-flight weather information, all at a relative low cost. In particular, this technology would largely achieve the goals of modernizing the National Airspace System and bringing critical information to pilots.

ADS-B stands for Automatic Dependent Surveillance-Broadcast. ADS-B units are similar in purpose to transponders and radar in that they will allow air traffic controllers to see an aircraft's position, identification, and altitude. What differs is the way this position is obtained and that, in of itself, is quite remarkable.

The old tech was a transponder and a ground-based radar station. The radar signal would reach the aircraft, bounce back to the station, and an air traffic controller would see the aircraft appear as a target on their scope. The transponder would also send back a signal carrying the aircraft's identification and its altitude. As these signals go back and forth, the radar station would then determine the aircraft's movement. ADS-B transmits the aircraft's position and movement based on GPS signal, doing so automatically without any interrogation signal from a ground-based system. This is the reason why the words automatic and surveillance-broadcast appear in the acronym. The word *dependent* refers to the fact that ADS-B depends on an aircraft's navigation system for position information (GPS).

At first it sounds like ADS-B is just a fancier version of a transponder, but it really isn't. The really interesting thing is that while ADS-B units broadcast aircraft position and identification information, other ADS-B units can receive this information as well and display it to pilots.

ADS-B involves the aircraft using a certified position source to determine own position and broadcasting it in short intervals by means of a data link in radio frequency spectrum. This functionality is usually referred to as ADS-B Out.

Conversely, an aircraft can be fitted with an ADS-B receiver – processor to display the detected ADS-B transmissions from other aircraft to the pilot. This is then referred to as ADS-B In.

With ADS-B, real-time visibility is provided to air traffic control and to other equipped ADS-B aircraft with position and velocity data transmitted periodically. ADS-B also provides the data infrastructure for inexpensive flight tracking, planning, and dispatch.

In high complexity environments such as the EU airspace, ADS-B is envisaged to operate in conjunction with existing independent cooperative chains, greatly enhancing accuracy, data availability and reducing frequency load.

At the request of the European Commission in 2018, the SESAR Deployment Manager (SDM) developed an ADS-B Implementation Plan to map, guide and support the broader adoption of ADS-B as a surveillance technique alongside radar and Multilateration.

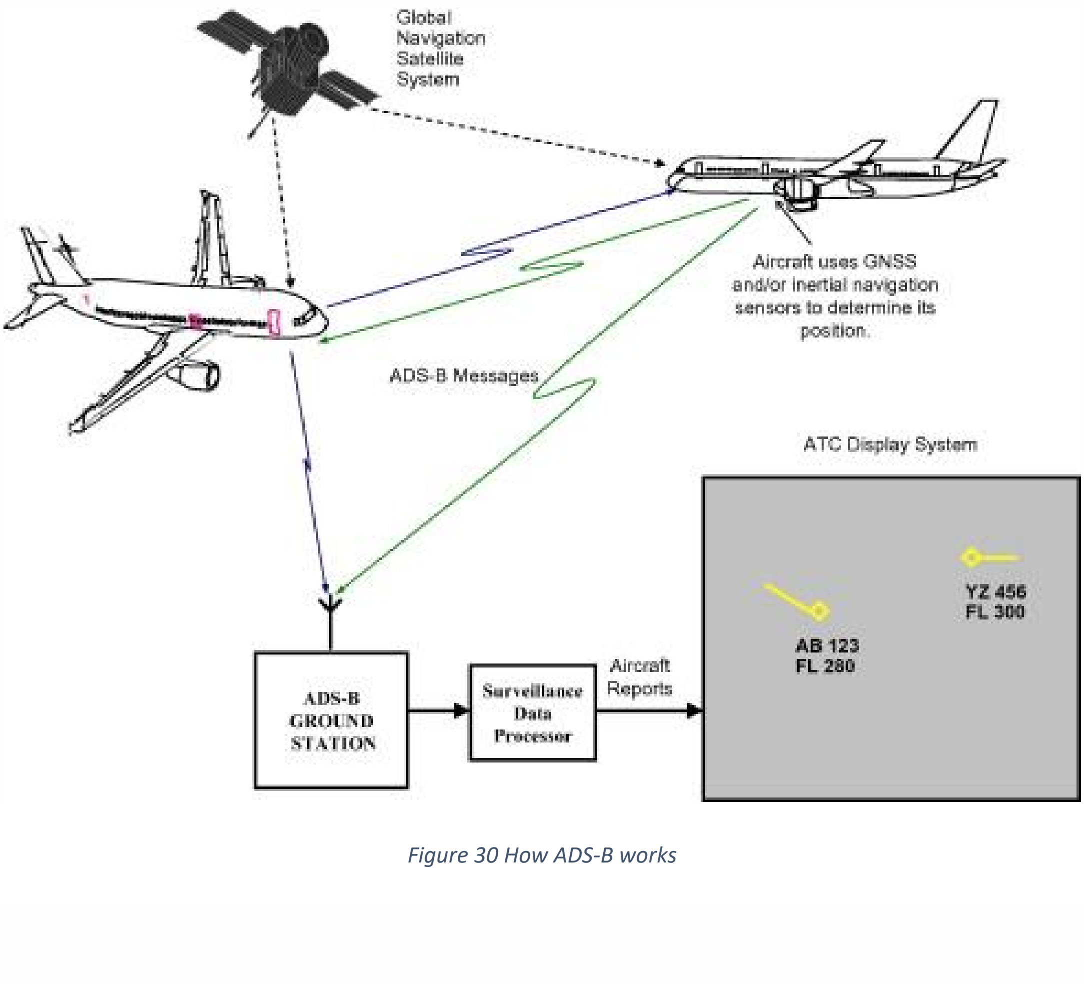


Figure 30 How ADS-B works

Overview of Mandates and Deployment Activities

All aviation regions that have significant operations will continue to leverage a combination of Secondary Surveillance (Mode S or A/C) and primary radars for purpose of surveillance of cooperative and non-cooperative aircraft. In addition to the existing radar infrastructure, several countries are also deploying ADS-B ground stations to provide for certain operational efficiencies, such as enhanced aircraft tracking and air-to-air surveillance including hybrid TCAS and ADS-B In.

- Australia: Operations in Australia require ADS-B equipage, with some exceptions, starting February 2, 2017, using a ground service network of 74 stations. The Australian deployment leverages ADS-B ground stations to provide surveillance for the less populated western parts of Australia as well as around the major metropolitan areas.
- Canada: Aircraft operating in certain airspace around Hudson Bay should be equipped with ADS-B to increase operational efficiency. Currently, five ground stations are deployed around Hudson Bay. Canada is also expanding ADS-B services toward Greenland using ground-based stations and, in the long-term, space-based ADS-B for remote and oceanic areas.
- Europe: Certain aircraft operating in Europe must be equipped with not only ADS-B capability, but also Elementary or Enhanced Mode S transponders as of June 7, 2020. The EU Surveillance Performance and Interoperability Regulation applies to fixed-wing aircraft with a MTOW greater than 5700 kg (12500 lb.) and with a max airspeed over 250 knots, but EASA is expected to introduce a proposal for an expanded airspace-based mandate in summer 2017.
- United States: All aircraft operating above 10000 feet and in Class B and C airspace must be equipped with ADS-B by January 1, 2020.

A number of countries in the Asia Pacific region are also establishing ADS-B mandates for certain airspace and select routes including Singapore, Hong Kong, Republic of China, Vietnam, India, Indonesia and the Seychelles as well as in South America including Columbia and Mexico.

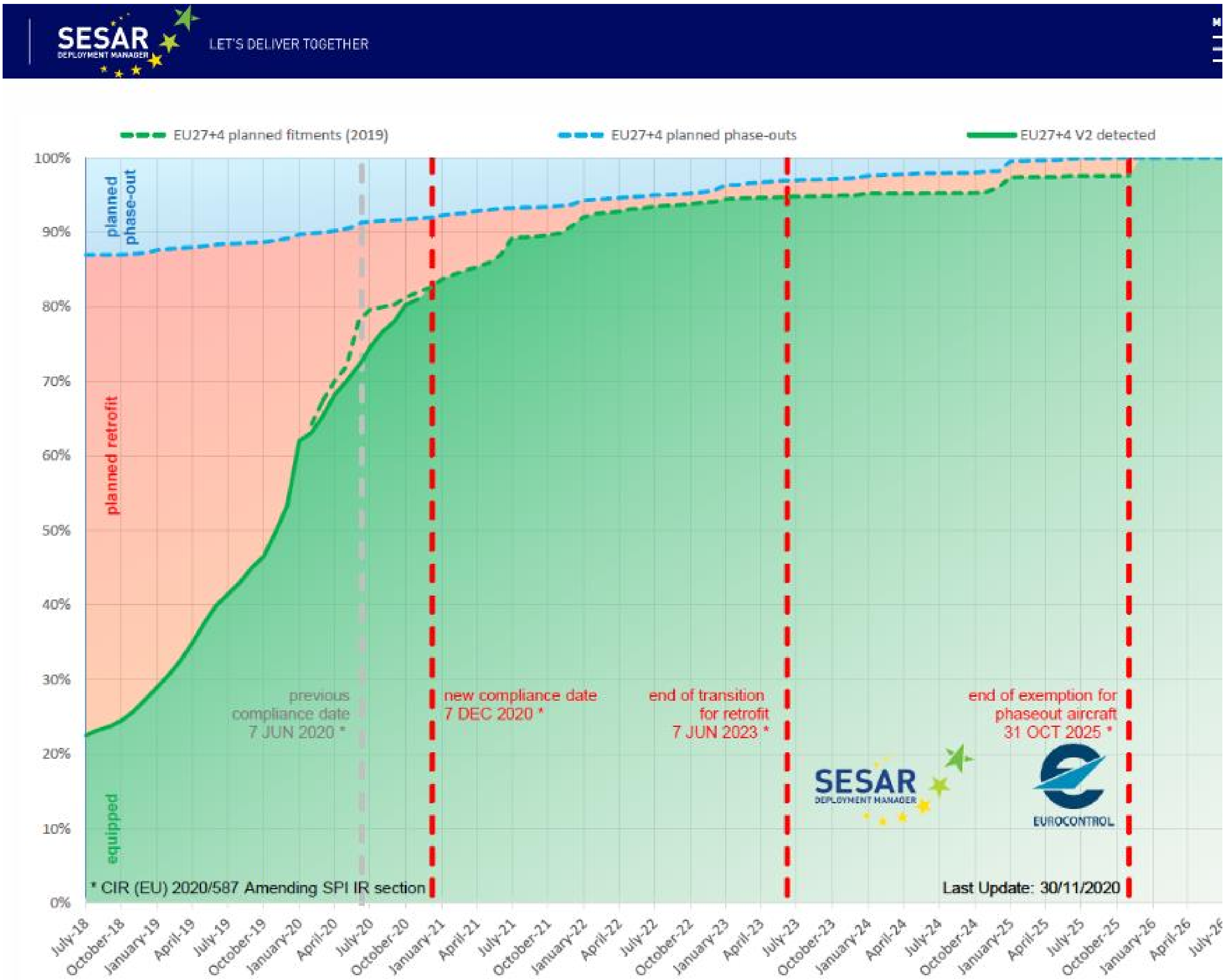
Current Equipage Trends

- Australia: According to Airservices, 94 percent of business jets; 98 percent of turboprops; 64 percent of helicopters; and 89 percent of IFR aircraft were compliant as of October 25, 2016.
- United States: The FAA, as of September 1, 2017, tracked 41590 ADS-B equipped aircraft, including 30351 fixed wing general aviation aircraft, 1249 rotorcraft, and 1287 Part 121 air carrier aircraft. The FAA shares make/model equipage data through the Equip 2020 program and this data can be obtained through GAMA. Equipage solutions are available for most aircraft models including airplanes and rotorcraft.

Benefits

- ADS-B provides direct benefits to the government and air navigation service provider by providing higher update rate of the aircraft's position (i.e., one position update per second as opposed to four or 12 seconds for radar) resulting in an improved tracker.
- ADS-B improves operations of Traffic Collision Avoidance System (TCAS) by allowing strategic use of ADS-B data versus active interrogation of closer aircraft which will, in the long-term, enable improved spectrum utilization that improves airspace capacity and throughput.
- ADS-B is a low-cost collision avoidance technology for general aviation aircraft that are not equipped with TCAS. GA aircraft equipped with ADS-B In obtained enhanced situation awareness about surrounding traffic and some ADS-B In traffic applications provide for annunciation of potential traffic conflicts.
- The U.S. deployment of ADS-B has expanded surveillance, especially at lower altitudes and in mountainous regions, specifically benefiting GA through better flight following and earlier "direct to" routing.
- The U.S. ADS-B program also includes the deployment of Flight Information Services (i.e., weather) on one of the two ADS-B links as free safety service to the general aviation community.
- Rotorcraft operators in the Gulf of Mexico are among the early adopters of ADS-B. Operations in the Gulf of Mexico benefit from surveillance where there was no surveillance before which allows for operations to be conducted during weather conditions that did not permit operations before (*i.e.*, IFR) and shorter routes that result in significant fuel savings for each operation and improving safety by the aircraft being under positive surveillance by ATC. FAA analysis of operational data shows fuel savings of 96 pounds per flight and distance savings of 14 nm per flight. A conservative estimate showed that operators saved 20000 pounds of fuel during the first 30 days of ADS-B operations in the Gulf of Mexico.

In the diagram below, we can see the continued evolution of the equipage, categorized in the three populations as effectively created by the most recent amendment of the mandate. The diagram is based on airline planning data covering 60% of the EU-based, mandated fleet, responsible for at least 85 % of monthly IFR movements. The evolution of the actual equipage (solid green curve) is monitored by EUROCONTROL.



ADS-B In Europe

ADS-B Implementation Plan

To pave the way for the transformation of the European surveillance infrastructure towards the less costly and more spectrum efficient ADS-B technology, Airspace Users operating in EU airspace with airplanes of more than 5.7 tons maximum certified take-off mass (MTOM) or maximum cruising true airspeed capability greater than 250 knots (KTAS) have been mandated by European Commission per Commission Implementing Regulation EU No 1207/2011 (SPI IR), amended by EU No 1028/2014 and EU 2017/386 to implement SPI IR compliant avionics, including ADS-B version 2 (according to EASA CS-ACNS and EUROCAE ED-102A) before June 7th 2020. The mandate applies to all GAT/IFR flights within the EU airspace, including operators whose state of registry is outside of the EU but operate into or across the EU airspace.

The European Commission tasked SESAR Deployment Manager (SDM) with the planning and execution of a coordinated and synchronized aircraft and ground implementation of ADS-B. In response to this request SDM produced the ADS-B Implementation Plan, the first edition of which was delivered and published in December 2018. SDM partnered with EUROCONTROL which supports the activity, by, amongst others, performing the operational and technical coordination, feedback from its NM performance monitoring on ADS-B as well as contributing to the preparation of the activity deliverables.

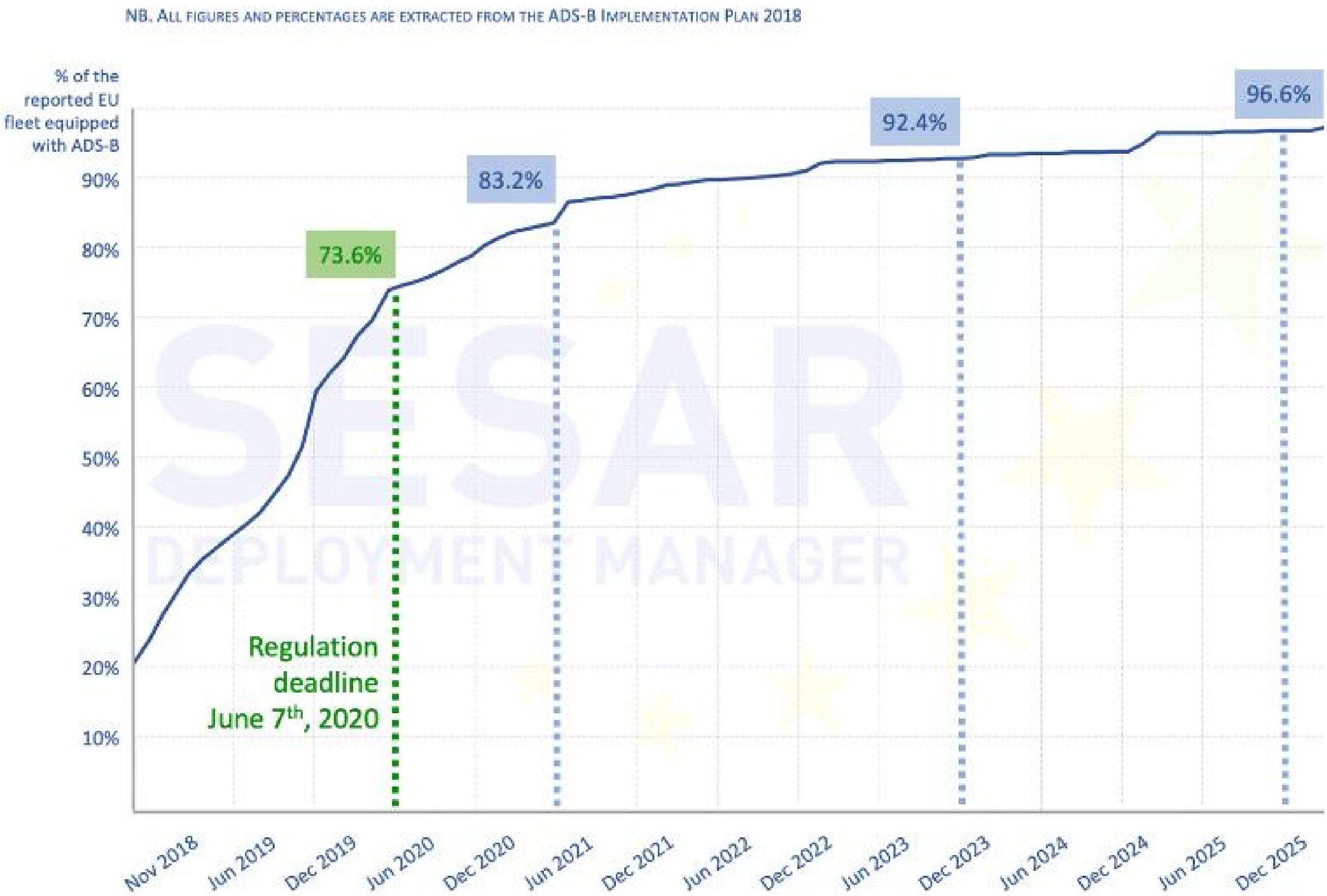


Figure 31

CIR (EU) 2020/587 Amending SPI IR

The 2018 edition of the ADS-B Implementation Plan established that the target date of the SPI IR, 7th June 2020, was not likely to be achieved by a non-negligible portion of the affected EU-based Airspace Users. Continuous monitoring of the implementation effort currently predicts the achievable compliance rate of the mandated fleet as approaching 80%. In order to provide an appropriate measure of legal accommodation of the residual fleet, the European Commission published Commission Implementing Regulation (EU) 2020/587.

The regulation amends the existing SPI IR 1207/2011 and 1206/2011. Concerning the airborne implementation, it provides, beside the general shift of the compliance date, conditional transitional arrangements and exemptions, as shown in Figure 32.

Amendment to EU Implementing Regulation 1207/2011

	Changes in scope and compiance date
ADS-B + EHS Forward Fit	Due date 07 DEC 2020 • Aircraft with first individual C of A on or after 07 DEC 2020
ADS-B + EHS Retrofit	Transitional phase ending 07 JUN 2023 • Aircraft with first individual C of A between 06 June 1995 and 07 DEC 2020 **and** • A retrofit program established prior to 07 DEC 2020 demonstrating compliance prior 07 JUN 2023 **and** • The aircraft has not benefitted from EU funding for the retrofit implementation
ADS-B + EHS Exemptions	• Aircraft with first individual C of A before 07 June 1995, **or** • Aircraft that cease operations within SES airspace prior to 31 OCT 2025, **or** • Operations for purposes of maintenance and export
Mode S ELS	Due date 07 DEC 2020, all aircraft
Status	Published on the eur-lex.eu portal on 30 April 2020 , see link in the text above. AMC/GM is under elaboration by EASA and expected to be published in June 2020

Figure 32

Integration in the European ATM systems

The EU Air Navigation Service Providers (ANSPs) have reported a substantial ADS-B sensor coverage in Europe available from ground-based systems; primarily from combined WAM/ADS-B systems but also ADS-B only Ground systems. ADS-B capable radars as well as space-based ADS-B coverage are expected to make a substantial contribution towards a global ADS-B coverage in the coming years.

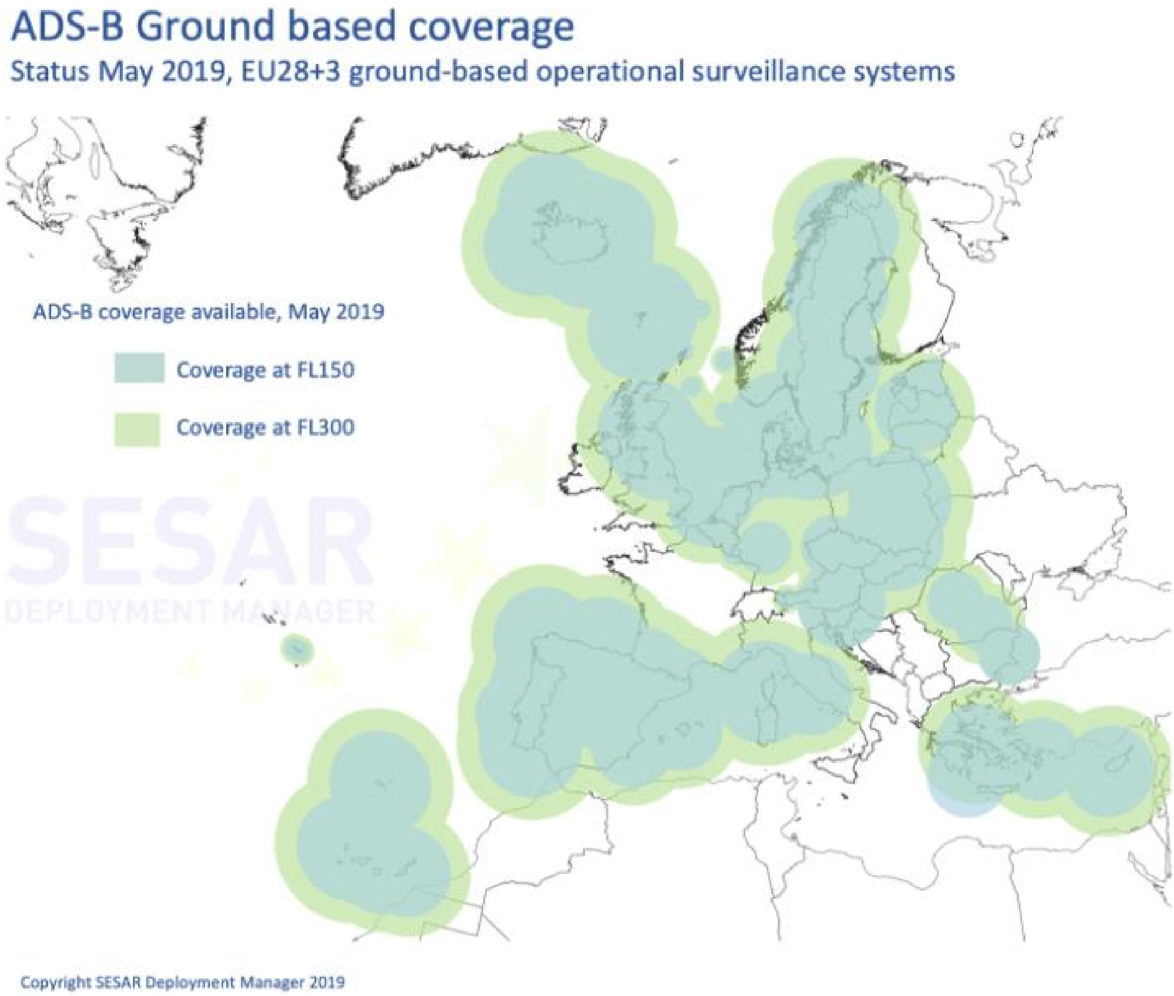


Figure 33

Having secured coverage, the ANSP will next proceed to integrate ADS-B data in its surveillance chain; this integration in the EU ATM systems is currently limited, with ANSPs citing aircraft ADS-B equipage, ADS-B performance and regulatory concerns as the necessary conditions to be resolved. However, a majority of EU based national ANSPs have at least some plans in place to proceed with integration in the near future, given the availability of a sufficient aircraft equipage ratio. SDM believes that those concerns will be addressed and resolved adequately as ADS-B implementation progresses.

If the integration is properly synchronized across domains and supported by a competent programme to catalyse ground investment plans, many ANSPs indicated their willingness to commit to technical and operational integration activities that could use the ADS-B sensor coverage across the vast majority of the continental airspace as early as 2023.

The primary use-case for ADS-B in the complex and traffic heavy European airspace is that of a complementary sensor to independent surveillance. In that role, ADS-B will open up substantial rationalization potential in the very dense European network of secondary radars. The use of ADS-B as sole means will occur in specific environments, characterized by low traffic density and/or lack of independent alternatives. This use case has already been successfully deployed operationally in a number of locations; the ICAO NAT region is a prime deployment location for sole-means ADS-B.

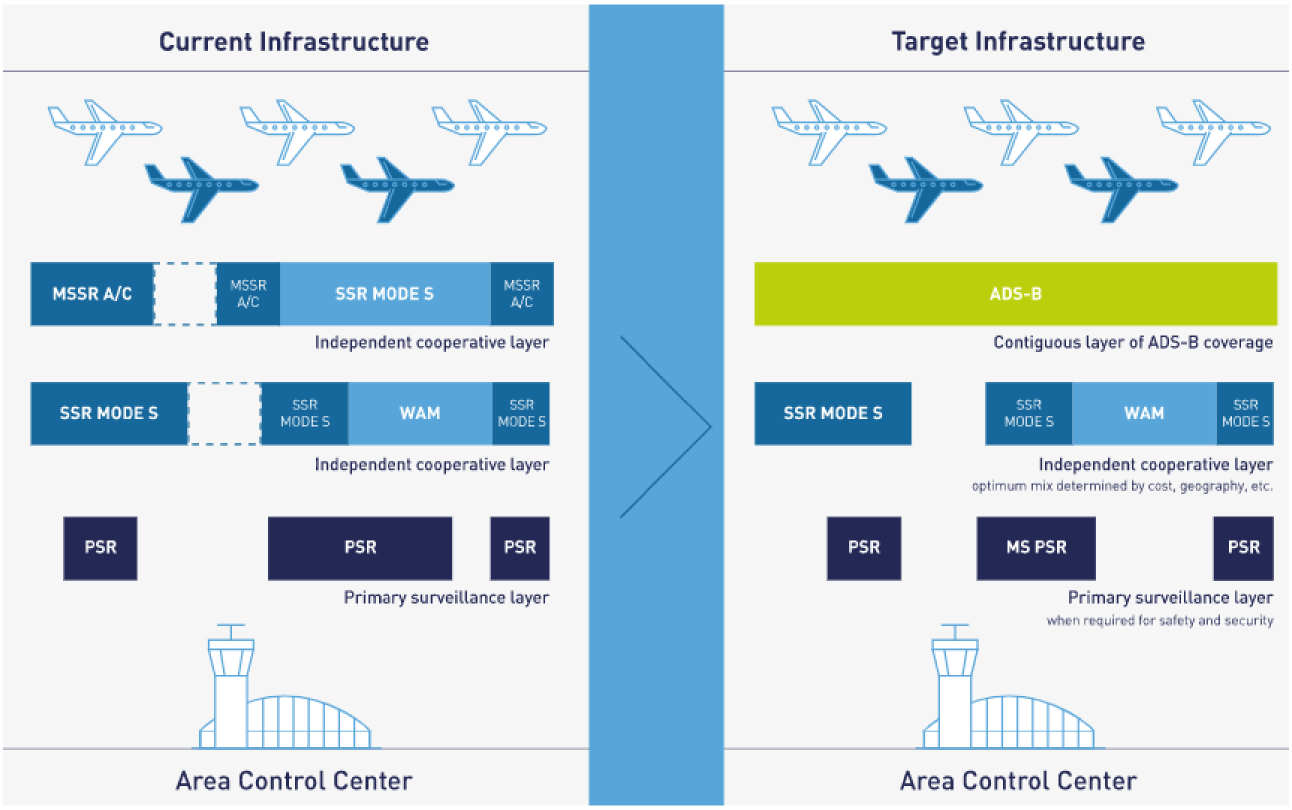


Figure 34

It is evident that a strong momentum to progress with ADS-B deployment exists in both the airborne and the ground domain. A harmonized ground and air deployment programme is important to synchronize and catalyse these efforts, to ensure that substantial ADS-B operational use is commonplace in Europe from mid 2020s.

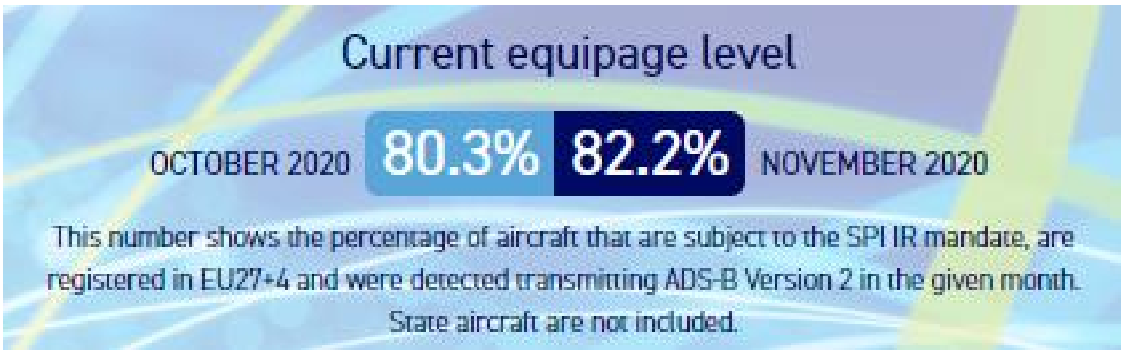


Figure 35

Ground Implementation

Available ground-based ADS-B coverage

The following maps show the current extent of ground-based ADS-B coverage generated by ANSPs installed systems, estimated at 3000ft and FL300. This comprises primarily combined WAM/ADS-B systems but also dedicated ADS-B Ground stations, and ADS-B capable airport Multilateration systems and Mode S radars. Different colours illustrate the status of the systems as of December 2019.

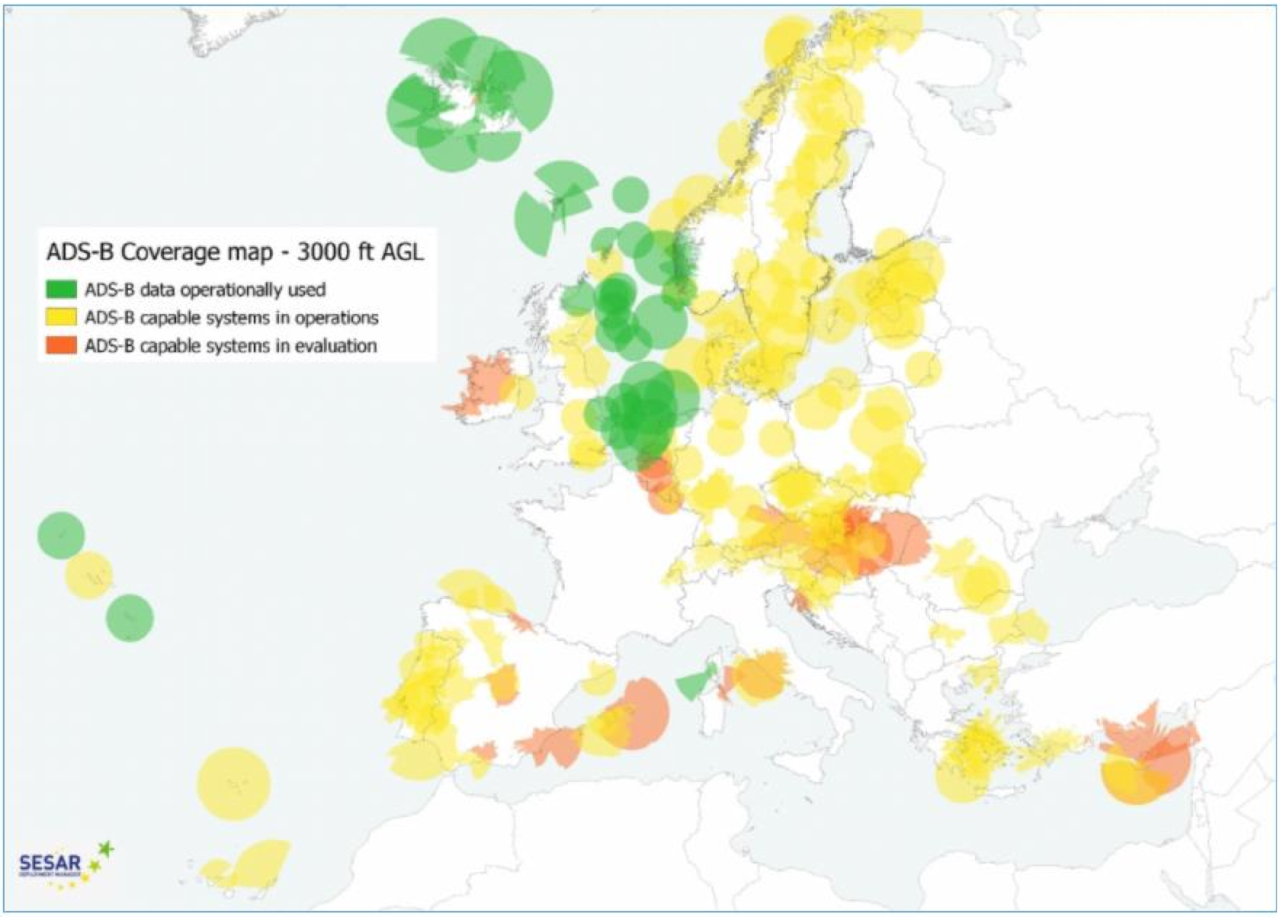


Figure 36

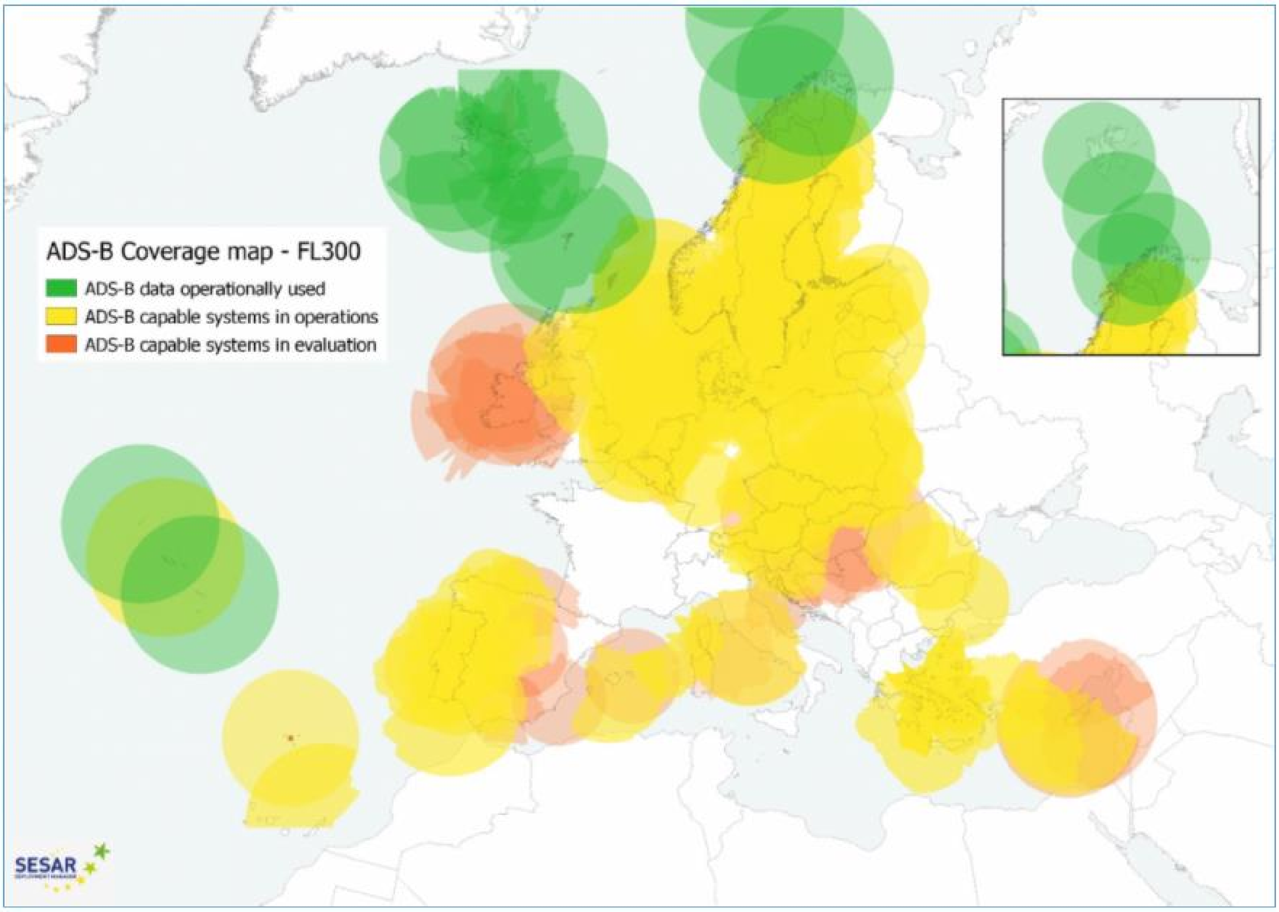


Figure 37

Operational use in ATC by Air Navigation Service Providers

In parallel to the deployment of ADS-B capable sensors to achieve the intended coverage, the other main step for ANSPs is to integrate ADS-B data in the surveillance chain.

If the integration is properly synchronized across domains and supported by a competent programme to catalyse ground investment plans, a large majority of European ANSPs indicated in 2019 that they could start providing separation using ADS-B in the continental airspace by end of 2023, assuming that 95% of EU commercial fleet will be ADS-B equipped and that outstanding technical and/or regulatory issues in the space, airborne and ground domains are satisfactorily addressed.

Airborne implementation

Some of the changes relevant to the airborne implementation are as follows:

a) Flight plans

Operators of non-equipped State aircraft communicated as per Article 8(3) and operators of aircraft not equipped in accordance with Article 5(5) operating within the Single European Sky airspace, shall include the indicators SUR/EUADSBX or SUR/EUEHSX or SUR/EUELSX or a combination thereof, in Item 18 of the flight plan.

b) Scheduled Maintenance

The paragraph on the check of the transponder system at least every two years was removed.
Note: Manufacturer Maintenance Planning Documents and/or local requirements apply.

c) Defective Transponder System

For aircraft where the capability of the transponders to comply with the requirements on ADS-B and EHS is temporarily inoperative, operators shall be entitled to operate that aircraft in the Single European Sky airspace for a maximum of 3 consecutive days.

d) Certification Requirements

The installation requirements per Annex 10 to the Chicago Convention, Volume IV, Fourth Edition have to include all amendments up to No. 77, (previously No. 85)
Note: This pertains to Mode-S legacy equipment predating ADS-B V2.

e) Mode S EHS exemption

The EHS exemption for aircraft where required parameters are not available on a digital bus on-board has been clarified.

Ground implementation

Some of the changes relevant to the ground implementation are as follows:

a) 24-Bit Address assignment standard

The standard for the assignment of 24-Bit ICAO aircraft addresses per Chapter 9 of Annex 10 to the Chicago Convention has to include all amendments up to No 90 instead of No 85

b) Data sharing

The definition of formal arrangements between air navigation service providers for the exchange or provision of surveillance data has been facilitated

c) Avionics monitoring

The requirement for Air Navigation Service Provider to inform operators of identified aircraft whose avionics exhibit a functional anomaly, has been deleted
Note: The scope of avionics monitoring remains covered by provisions in other regulations.

Figure 38

ADS-B WORLDWIDE

Global Mandate Map

There are numerous ADS-B mandates anticipated or already in place in many parts of the world. The map below shows in green the regions requiring at least ADS-B version 0, in blue the ones requiring ADS-B version 2, together with the anticipated date of entry-into-force, and in grey where regulatory activity is ongoing and mandates are expected in the near future.

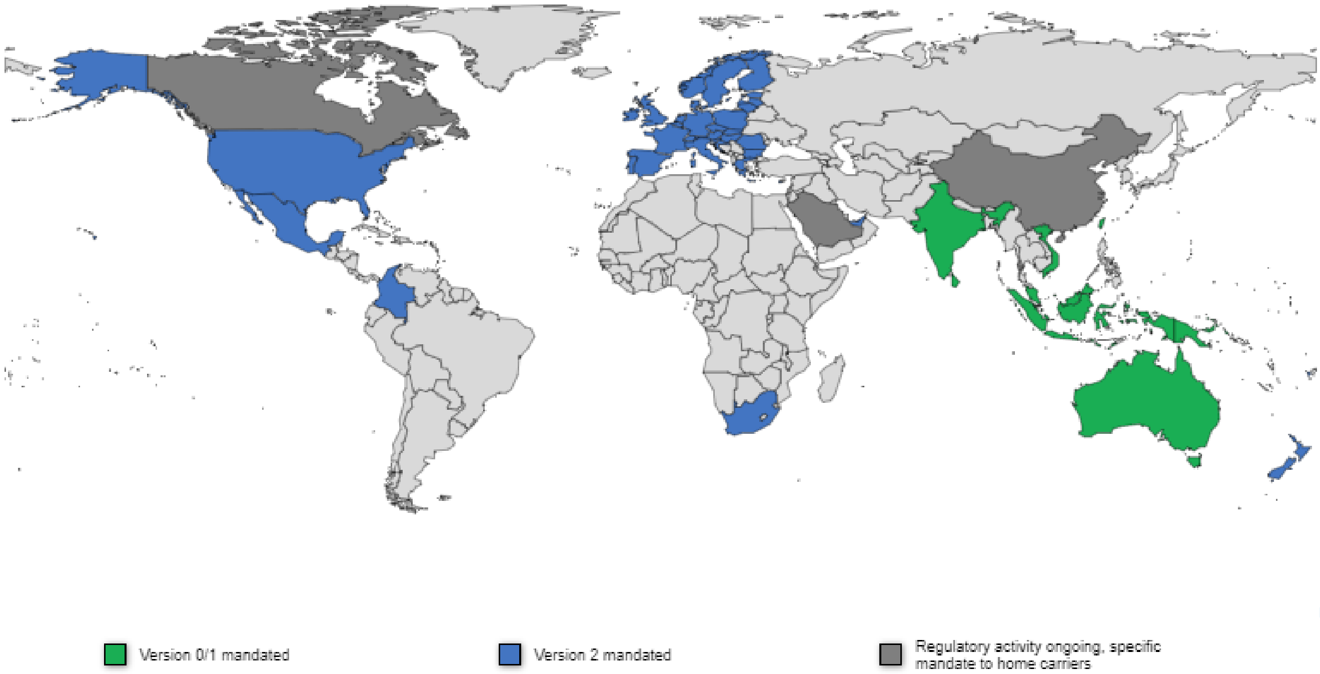


Figure 39 Global mandate map

Upgrade from ADS-B Version 0 and Version 1 to Version 2

ADS-B Version 2 provides the performance required to safely provide ATC service in the dense and complex European continental airspace.

Version 2 ADS-B conveys improved data accuracy, latency and integrity, borne among others from the requirement to directly wire the Global Navigation Sensor System to the ADS-B Transponder unit.

At system component level it is expected to happen in an increasing measure; this decision is for each ANSP to make, taking into account the specifics of own operational environment. As a technology, in continental Europe ADS-B is expected to complement, rather than replace, the independent cooperative layer, consisting of Mode S and Multilateration systems and to a diminishing part, the legacy Mode A/C radars. The respective EUROCAE Standard for this application is the ED-161 and the deployment is already in progress in Europe.

Work is ongoing in further standardization of integrating ADS-B with independent cooperative sensors.

Low-Power ADS-B for GA Operating in Low Altitude Airspace

Nowadays in Air Traffic Management world we can distinguish two main uses of traffic surveillance: ground surveillance typically employed by Air Traffic Control (ATC), and airborne surveillance used by Airborne Collision Avoidance System (ACAS). However, it's not obvious that all airspaces and onboard aircraft have access to these functions. In particular, in non-controlled low altitude airspace, ACAS isn't set up on majority of General Aviation (GA) and ground surveillance is nearly (or completely) absent. In such cases, there is still a great confidence in visual flight and operations management by pilots: this is possible because of air traffic and speed are pretty limited in these areas.

At some point, regrettably, things change and the increase number of new types of users, e.g. UAV and urban air mobility, intensifies exponentially traffic density in low altitude airspaces. Another important issue consists to consider these two factors:

- Small size
- Relative high speed

If combined together, it becomes even more difficult (or impossible), for pilot, detecting the presence of these targets. This will inevitably lead to increased operational needs for traffic surveillance both for these new users and GA aircraft or rotorcraft.
Traffic surveillance can be classified as cooperative or non-cooperative:

- Cooperative surveillance consists in assessing the position of a selected aircraft without reliance on its onboard instruments
- Non-Cooperative surveillance consists in assessing the position of a selected aircraft with reliance on its onboard instruments

Although there is intensive research and development of non-cooperative surveillance, unfortunately, the independence on equipment of surrounding traffic is typically compensated by higher size, weight, power, and cost (SWaPC) demands of the surveillance equipment and usually also lower accuracy of the resulting surveillance employments. On the other hand, traffic monitoring systems for cooperative surveillance are usually cheaper and less complex, however, their dependence on the equipment of monitored traffic needs to be somehow addressed to fully cover operational functions. In addition, cooperative surveillance systems give the opportunity to send further information regarding the status of the aircraft, the quality of data, intent information and so on.
This information then can be used by a ground or airborne surveillance application which further increases efficiency and safety of associated operations.
Based on the above, an ideal solution seems to be that all vehicles use the same type of cooperative surveillance systems. Unfortunately, there are several hitches associated with such an approach. Surveillance systems used by today's aviation (ATCRBS transponder, ADS-B Out) utilize the 1090 MHz frequency which is already quite saturated. Wide use of this frequency by a large number of new users would increase the risk of frequency congestion. This can be potentially addressed by utilizing separated frequencies by different classes of users such as use of Universal Access

Transceiver (UAT) frequency for ADS-B on-board GA in the US. But then the interoperability among the different types of users is lost and needs to be handled by complementary means, e.g., in the US through rebroadcast (ADS-R) meaning that locally both frequencies need to be used. Another potential problem is associated with affordability of such on-board systems for some types of users.

Airborne ADS-B In Applications

ADS-B In capability enables many operational benefits resulting from cockpit applications increasing pilot's situation awareness both in the air and on the airport surface. Cockpit Display of Traffic Information (CDTI) is in this context a key system element while the basic situation awareness applications are referred as ATSA-AIRB and ATSA-SURF (for air and surface, respectively). Considering more specific applications, there are for instance two applications addressing approach phase of the flight and helping to maintain separation or spacing interval with respect previous aircraft in the arrival sequence:

- CDTI Assisted Visual Separation (CAVS)
- Flight-deck Interval Management (FIM)

Another nice example is In-Trail Procedure (ATSA-ITP) aiming to enable more efficient use of flight levels during oceanic operations.

When looking on airport surface operations, Airport Surface with Indications and Alerts (SURF IA) is ADS-B In application lowering the runway incursion/collision risk by displaying runway traffic on the airport moving map and providing traffic alerts. The SURF IA represents another example of ADS-B In applications resulting in important increase of flight safety as the runway incursions is one of the top safety risks in today's ATM.

Focusing now more on GA, one possible application bringing benefits especially for GA pilots is Traffic Situation Awareness with Alerts (TSAA). The TSAA is a standardized ADS-B In application for non-TCAS II equipped airplanes and rotorcraft (similar to TAS but benefitting from ADS-B surveillance), which provides the flight crew with caution alerts on surrounding ADS-B traffic. The crew roles and responsibilities remain the same; the application only helps with out-of-window aircraft acquisition. It can be used in any airspace type, i.e. controlled, uncontrolled and special use airspace, under both instrument flight rules and visual flight rules. There is no coordination with other traffic or air traffic control. In addition to ADS-B input, ADS-R and TIS-B data can be used where available.

There are two classes of the TSAA equipment:

- Class 1 provides relative position of the target aircraft (defined as traffic of particular interest to the flight crew) via voice annunciations and attention-getting visual cues
- Class 2 relies on both the voice annunciations and Traffic Display which has to be compliant with the EVAcq or AIRB requirements.

Contrary to, e.g. TCAS II, the conflict detection algorithm for TSAA alerts is not standardized.

Enhanced TSAA, denoted as TSAA+, is a solution developed under the SESAR project PJ.11-A4. The aim of the enhancement is reducing the mid-air collision risk between a TCAS II equipped and a non-

equipped aircraft. When a TCAS II equipped aircraft follows a resolution advisory (RA), the non-equipped aircraft is not aware of its intent and could unintentionally manoeuvre in the non-desired direction. The TSAA+ application is able to provide information on Resolution Advisory generated by a TCAS II system in the vicinity, as the RA information is part of an ADS-B message.
Within the project, workshops with pilots and fast time simulations were performed with the aim to assess operational benefits and human performance. The initial results are very promising. Pilots were able to notice traffic and start manoeuvring earlier than without any situational awareness application and the probability of near mid-air collision (NMAC) with TSAA+ has decreased compared to TSAA.

ADS-B Integration into Existing Ground Infrastructure

In general, integrated installation of multiple surveillance technologies brings many advantages and easily address the problem of verification of ADS-B data. Adding ADS-B In receiver into current ground installations seems very useful in this context, similarly, as beaten track of co-mounting of PSR and SSR. There are two possible approaches coming into consideration:

- integration of ADS-B into an SSR
- integration of ADS-B into WAM station.

These solutions exist in different modifications and are already in sale. The ADS-B In integrated into SSR enables validation of the ADS-B reports and higher performance due to high positional update rate [7]. This way seems to be useful because of high number of installed SSR's and upcoming ADS-B mandate. The ADS-B data precision is not degrading with increasing distance unlike the SSR (higher loss of messages is observed, no decrease of data precision), whereas surveillance by SSR interrogations provides required redundancy and can serve for verification of ADS-B data.
Integration of WAM with ADS-B In is very natural as well due to identical antenna and hardware. Enhancement from WAM to ADS-B (and also the opposite direction) brings options especially for the airport and the terminal area.
Multilateration sensors can perform both necessary ADS-B backup and validation functions. Finally, the Multilateration system can continue to track traffic without ADS-B equipment throughout the authorities' expected lengthy transition period, making the service available at minimal additional cost to the ANSP.
Even if changes in ground infrastructure are usually costly and complex, the rationalisation of ground infrastructure (e.g., through radar clustering, i.e., grouping of cooperating SSR Mode S interrogators) and maximum usage of existing technologies synergistically integrated with the maturing ones can be seen as optimal way forward.

Supporting Services

Additional possible benefit of ADS-B system is its use as an enabler of supporting services. Typical examples are ADS-B In pilot application provided to US pilots equipped with the Universal Access Transceiver (UAT) - the TIS-B (Traffic Information Service-Broadcast) and the FIS-B (Flight Information Service-Broadcast). The TIS-B (broadcasted on both 1090 MHz and UAT) and the FIS-B (broadcasted on UAT) provide gathered information about traffic, weather and aeronautical data including information such as special use of airspace, NOTAMs (Notice to Airmen) or pilot reports free of charge. Receiving this information can be a strong motivation also for non-mandated airspace users.

Barriers for wider deployment of ADS-B

While there is obvious community interest for wide deployment of interoperable cooperative surveillance, when talking about ADS-B over 1090 MHz frequency, there are two main problems. Possible spectrum congestion and resulting interference issues are the main problems at the regulator level. As previously described, the 1090 MHz frequency is already heavily used by responses of aircraft transceivers to active interrogations from both ground (SSR, WAM) and airborne (TAS/TCAS I, TCAS II, ACAS X) systems.
When considering possible mitigations of this problem there are two complementary questions:

- Whether the existing systems use frequency efficiently and/or whether there is an opportunity for improvements?
- Whether there is a possibility to reduce ADS-B Out impact on the frequency load?

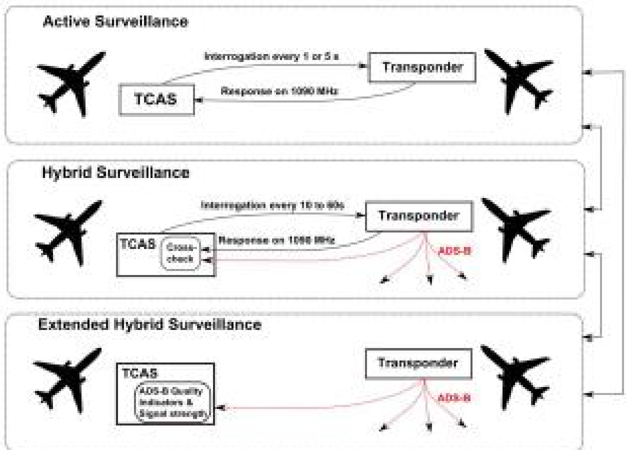


Figure 40 Surveillance methods

The possible answer on the <u>first question</u> can be demonstrated through example of (extended) hybrid surveillance for TCAS II, standardized in the DO-300A since 2014 (and requested for new TCAS II certifications in the US). TCAS EHS represents a next step in spectrum saving beyond the hybrid surveillance concept introduced a few years earlier. Both are based on receiving and using ADS-B messages for tracking non-threat traffic, but the difference is how the quality of reported data is verified, handling thus also the dependency on intruder's systems: while the hybrid surveillance uses active Mode S interrogations with lower frequency and performing crosscheck of obtained results with ADS-B reports, the extended hybrid surveillance relies on the quality parameters which the ADS-B reports contain (only version 2 or higher of ADSB Out capability is allowed) while monitoring the squitter messages signal strength. In both cases the TCAS switches to the active surveillance using only Mode S interrogations before the intruder could become a threat (before any alert is needed).

Results obtained through flight evaluations and simulations within SESAR 9.47 project (to develop TCAS solutions to enable aircraft to operate in the future ATM environment while leveraging additional surveillance information) demonstrated that in this way more than 80% of TCAS II interrogations (and therefore of its 1090 MHz use) can be eliminated.

A similar conceptual approach could likely be applied to other surveillance systems (both airborne and on ground) using interrogation of aircraft transponder. Considering that ADS-B reports are usually more accurate than position obtained through active interrogation of transponders, if ADS-B report information is regularly available for some aircraft, the interrogation rate of Mode S transponder on this aircraft could be considerably reduced and active interrogation used only for verification of quality and validity of ADS-B data. In this way the surveillance will not rely only on information provided by aircraft avionics and the use of 1090 MHz frequency would be much more effective.

Concerning the <u>second question</u>, the current standards well address operational needs of commercial aviation and a part of GA. The performance requirements are defined taking into account both airborne and ground surveillance. Nevertheless, when considering which users need to be targeted to maximize operational benefits (i.e., who are not equipped today), these are mostly users operating a majority of time at low altitude in uncontrolled airspace, and relatively slow. This raises the question how much the requirements driven by ground surveillance are important for their operations (when weighting against spectrum congestion risk) and whether for these users a new class of ADS-B equipment targeting primarily air-to-air surveillance would be more appropriate.

Furthermore, considering their typical operating speeds the needed detectability range could be probably considerably reduced. Being even more aggressive and looking for minimal requirements it is possible to think what are the next best alternatives for air-to-air detection by these users (today often even without transponders): visual contact or potentially some kind of non-cooperative sensor (considering for instance requirements in RTCA DO-366 as an example). Going in this direction and revisiting operational requirements for these users could drive the definition of a new class of ADS-B equipment with considerably lower transmission power and therefore impacting frequency load only in close proximity of aircraft.

The above discussion of the targeted airspace users should be further extended considering the barriers on users' side. When talking about low altitude users, it is definitely cost, which is to the large extent affected by certification costs of the equipment.

Low-Power ADS-B Concept

Within the project EMPHASIS, a concept of low power ADS-B system (complemented with use of cellular networks to access supporting services) was proposed and validated through evaluations in real environment (flight tests measuring detectability and additional metrics) and simulations of 1090 MHz spectrum load considering multiple possible scenarios and environments.

Low power
Per DO-260B, the lowest category of ADS-B transmitter intended for General Aviation conforms to 70 W of transmission power. According to our analysis, there is a space for low power ADS-B transceiver, considering transmission power from 10 to 20 W. Corresponding detection distance is then about 12 km for GA category ADS-B In sensitivity (Minimum Triggering Level -72 dBm) or about 25 km for large aircraft ADS-B In sensitivity (Minimum Triggering Level -79dBm).
This distance seems to be enough for low and very low airspace where we assume airspeed at most 240 km/h [1]. So, all potential intruders flying the airspeed up to roughly 240 km/h can detect the own-ship equipped with the low-cost ADS-B transceiver sufficiently (approximately 3 minutes) in advance to be able to perform avoidance manoeuvre.

Interrogation rate management
Update of interrogation rate management would be a very effective way to protect the capacity of the frequency band. Since majority of Part 23 and Part 25 aircraft will be equipped with high transmission power and high sensitivity ADS-B, UAV and small GA can use something like reduced broadcast frequency when no aircraft equipped with transponder/ADS-B Out is in the vicinity. This approach enables saving the frequency and not disturbing faster aircraft by information about slow traffic far away. Furthermore, safety will not be threatened because nominal broadcast rate is applied when another aircraft getting closer.
A useful suggestion is to reduce the broadcast frequency ten times for Aircraft Position and Aircraft Velocity messages and two times for Aircraft Operational Status Message. Broadcast of Aircraft Identification message would keep the same rate, because its required rate is already in interval [4.8-5.2] seconds. So, no message has longer interval than six seconds in our concept. Fig.40 summarizes suggested low-power ADS-B solution for low altitudes.

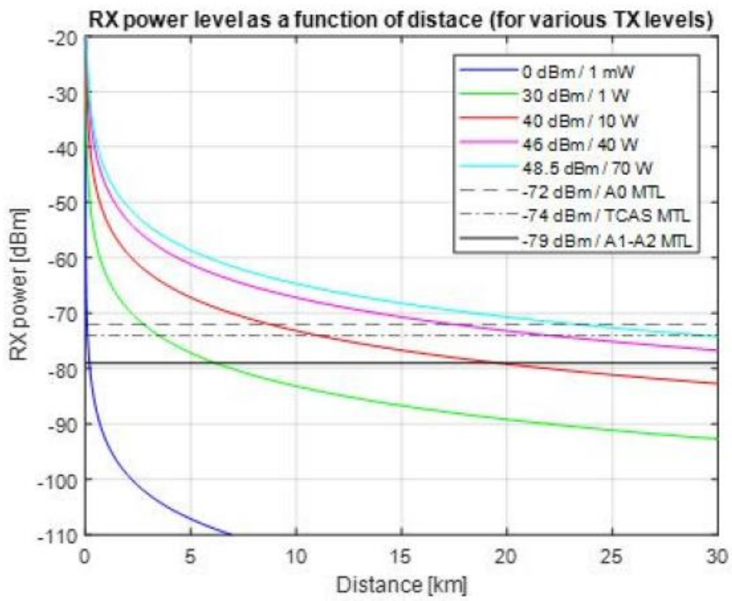


Figure 41 Receiver power as function of distance

1090 MHz Spectrum Load Simulations

A. Simulation Scenarios

Proposal of low-power ADS-B was evaluated by the MATLAB simulations prepared for the SESAR 2020 EMPHASIS project.

The aim was to use simulations to evaluate an increase of 1090 MHz messages in urban area with assumed future dense traffic. Metrics for frequency load is a number of transmitted messages per second. The model includes following interactions:

- interaction of transponders with secondary surveillance radars (both modes A/C and S),
- airborne TCAS to transponders interactions,
- ADS-B broadcast, and
- automatic broadcast of acquisition and extended squitter.

Airspace was divided into four altitude levels. The lowest airspace called very low level was bounded by altitude of 1000 ft and assumed to be occupied primarily with drones with their typical speed. Two areas with different traffic density were established - the first called urban area with assumed very dense traffic and rural area with thousand times lower traffic density. Low-power ADS-B was considered as a surveillance equipment for all drones in very low-level airspace. The second lowest airspace is called low level airspace and it is defined by altitudes from 1000 ft up to 7000 ft. Traffic density was set approximately to ten times denser traffic than in the rural area in very low altitudes. Heterogeneous traffic is presumed in this airspace, so multiple aircraft equipment types are simulated - part of aircraft equipped with low-power ADS-B and the remaining part with Mode S Transponder with ADS-B Out A0 category. The highest airspace segment was filled by aircraft with following equipment: Mode S Transponder, ADS-B A3 category and TCAS (corresponding to commercial transport), Mode S Transponder with TCAS (without ADS-B), Mode A/C Transponder, Mode S Transponder and Mode S Transponder with GA ADS-B Out.

Frequency load is measured by deployment of four virtual receivers (VRs) in simulated area. To enable comparison with current state, data gained from real aircraft are used. Evaluation is based on criterion that sum of all messages measured at a long-range VR shall not be more than 150 % of message's sum measured at real aircraft.

The primary objective was assessment of increase in the number of messages transmitted through 1090MHz caused by intended equipment of vehicles in very low and low airspace by low-cost ADS-B. The second task was the demonstration of significant effect of TCAS extended hybrid surveillance capability.

For research purposes, five scenarios were generated (Table II).

Scenario 1 was run as case when low-cost ADS-B has the same parameters in terms of broadcast rate and transmission power as current standard ADS-B for general aviation. It conforms to DO 260B A0 transmitter category. No TCAS included in this scenario has extended hybrid surveillance capability. This scenario serves as simulation baseline, representing worst case. There are four other scenarios that include modification of ADS-B equipment in terms of transmission power and broadcast rate. Scenarios are summarized in the Table II.

TABLE I
LOW-POWER ADS-B SOLUTION CHARACTERISTICS

Parameter	Low-Power ADS-B Concept	DO-260B A0 Category Value
Transmitting power	10 W	70 W
Broadcasted messages	Pos, vel, status, ident	Pos, vel, status, ident
ADS-B DO-260B compliance	Compliant except of Tx power and msg frequency	Yes
ADS-B transceiver broadcast frequency (no close traffic)	Aircraft position 4.0 -6.0 sec	Aircraft position 0.4 -0.6 sec
	Aircraft velocity 4.0 -6.0 sec	Aircraft velocity 0.4 -0.6 sec
	Aircraft identification 4.8 - 5.2 sec	Aircraft identification 4.8 - 5.2 sec
	Aircraft operational status 4.8 - 5.2 sec	Aircraft operational status 2.4 - 2.6 sec

TABLE II
SIMULATION SCENARIOS

Scenario	TCAS Capability	Low-Cost ADS-B Parameters
1	100 % hybrid surveillance	DO 260B A0 category (GA)
2	80 % extended hybrid surveillance, 20 % hybrid surveillance	DO 260B A0 category (GA)
3	80 % extended hybrid surveillance, 20 % hybrid surveillance	10 W transmission power, broadcast rate per DO 250B
4	80 % extended hybrid surveillance, 20 % hybrid surveillance	10 W transmission power, reduced broadcast rate[a] 1
5	80 % extended hybrid surveillance, 20 % hybrid surveillance	10 W transmission power, reduced broadcast rate[b] 2

[a] Reduced broadcast period 1: airborne position message $\langle 2.0, 3.0 \rangle$ sec, airborne velocity $\langle 2.0, 3.0 \rangle$ sec, aircraft ident. $\langle 4.8, 5.2 \rangle$ sec, aircraft oper. status message $\langle 4.8, 5.2 \rangle$ sec

[b] Reduced broadcast period 2: airborne position message $\langle 4.0, 6.0 \rangle$ sec, airborne velocity $\langle 4.0, 4.0 \rangle$ sec, aircraft ident. $\langle 4.8, 5.2 \rangle$ sec, aircraft oper. status message $\langle 4.8, 5.2 \rangle$ sec

Simulation Results Discussion

Differences in results for Scenario 1 and Scenario 2 show the effect of TCAS extended hybrid surveillance. The significant decrease in amount of messages is not surprising. With assumption of conditions enabling passive surveillance instead of active, above 90 % reduction of number of TCAS messages was achieved. These results confirm that extended hybrid surveillance is a very powerful tool in preventing of 1090 MHz congestion.

For ADS-B, reduction of transmission power from 70W to 10W resulted in decrease of RF load from 50 to 80 % (depending on location of virtual receiver). The only exception was short-range virtual receiver which was intentionally placed into urban area with very dense very low altitude traffic, which implies that reduction of power did not affect the number of messages so significantly. When reduced broadcast rate was inserted to simulation, another decrease of RF load was observed. This decrease varied between 8 and 90 %, depending on randomly assigned flight parameters affecting the mutual movement.

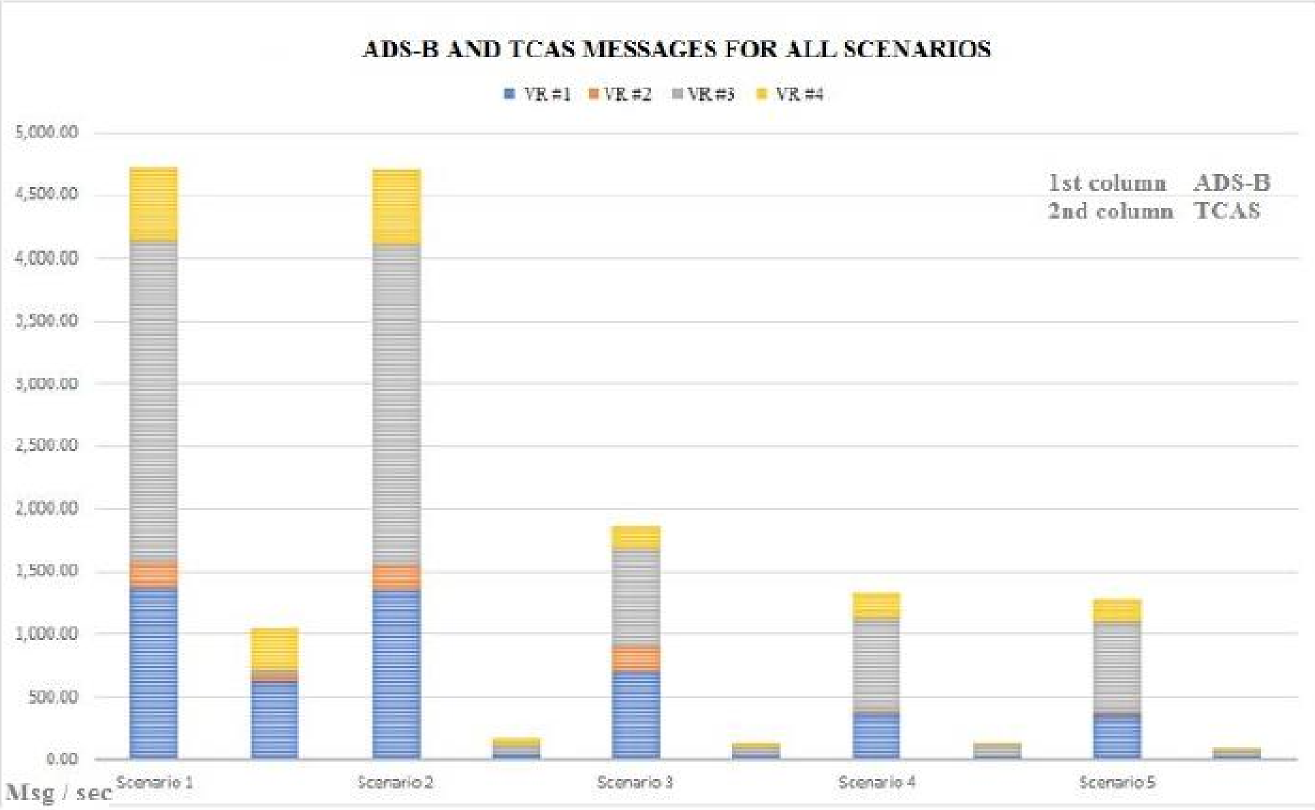


Figure 42 TCAS and ADS-B Messages - Simulation results

Simulation results can be summarized into following statements:

- Low-power low-cost ADS-B In/Out concept can help to solve surveillance demands associated with increasing heterogeneous traffic in low altitudes
- Lowering of ADS-B transmitting power up to 10 W is a major factor for efficient radio-frequency use while maintaining safe range for vehicles with airspeed up to 240 km/h
- Dynamic reduction of the broadcast rate at lowest class ADS-B seems to be reasonable not to disturb faster aircraft in high altitudes (when nobody in low heights is close)
- ADS-B Integration into existing ground surveillance infrastructure as SSR or WAM could bring synergic effect in terms of cost, accuracy and reliability
- TCAS extended hybrid surveillance seems to be a very efficient way for 1090 MHz congestion prevention

- Low-power concept was successfully evaluated by flight testing regarding the operational range which conforms to theoretical assumptions
- Simulations show interoperability with anti-collision systems being developed for UAVs (ACAS Xu, ACAS sXu)

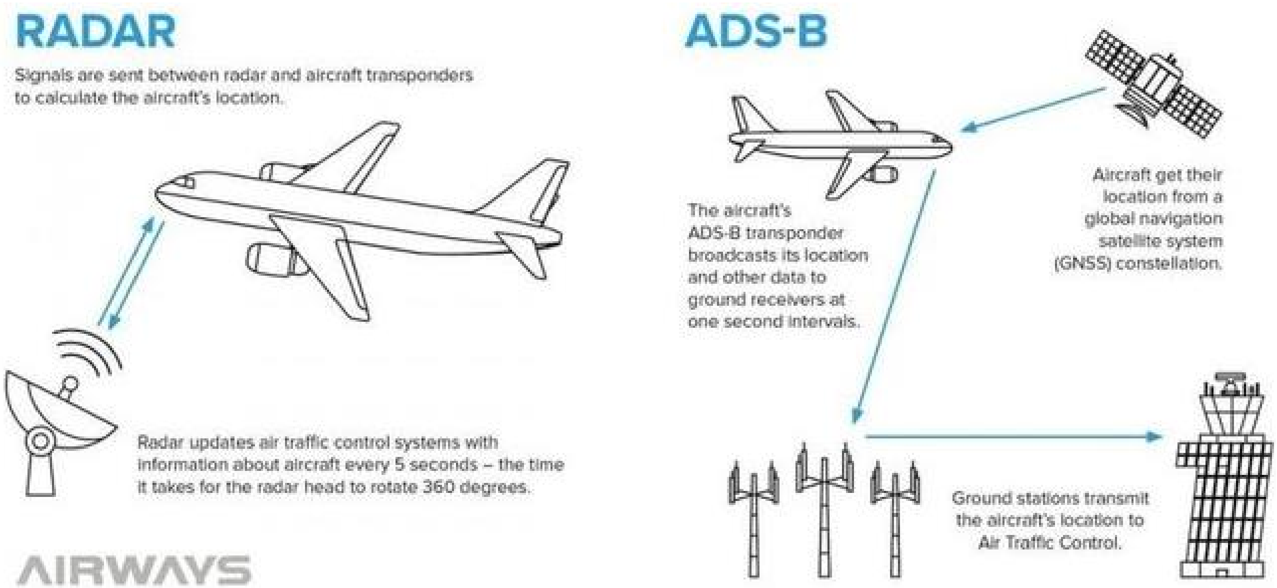


Figure 43 Radar and ADS-B differences

ADS-B requirements

L 138/6 EN Official Journal of the European Union 30.4.2020

ANNEX II

Annex II to Implementing Regulation (EU) No 1207/2011 is amended as follows:

(1) Part A is amended as follows:

(a) point 1 is replaced by the following:

'1. The minimum capability for the secondary surveillance transponder shall be Mode S Level 2 meeting the performance and functionality criteria of Annex 10 to the Chicago Convention, Volume IV, Third Edition including all amendments up to No 77.';

(b) point 5 is replaced by the following:

'5. The data items referred to in point 4 shall only be transmitted by the transponder via the Mode S protocol. The aircraft and equipment certification process shall cover the transmission of those data items.';

(c) point 6 is deleted;

(2) Part B is amended as follows:

(a) point 1 is replaced by the following:

'1. The minimum capability for the secondary surveillance transponder shall be Mode S Level 2 meeting the performance and functionality criteria of Annex 10 to the Chicago Convention, Volume IV, Third Edition including all amendments up to No 77.';

(b) point 15 is replaced by the following:

'15. Except for military reserved formats, the data items referred to in point 14 shall only be transmitted by the transponder via the extended squitter ADS-B protocol. The aircraft and equipment certification process shall cover the transmission of these data items.';

(c) point 16 is deleted;

(3) Part C is amended as follows:

(a) in point 2, the introductory phrase is replaced by the following:

'2. The following data items, where available on a digital bus, shall be transmitted by the transponder as requested by the ground-based surveillance chain, via the Mode S protocol and in accordance with the formats specified in ICAO document 9871 (2nd edition):';

(b) point 4 is replaced by the following:

'4. The data items referred to in point 3 shall only be transmitted by the transponder via the Mode S protocol. The aircraft and equipment certification process shall cover the transmission of these data items.'.

We can see point 15 of Implementing Regulation (EU) No 1207/2011 below:

15. Except for military reserved formats, the data items referred to in point 14 shall only be transmitted by the transponder via the extended squitter ADS-B protocol if the aircraft and equipment certification process covers the transmission of these data items via the extended squitter ADS-B protocol.

Figure 44 Point 15 Annex II IR (EU) No 1207/2011

The difference between these two versions of point 15 is based on the possibility to use ADS-B protocol. In the 2020 version, ADS-B protocol shall be used and so the equipment needs to be in compliance with this technology.

Class of Airspace	Airspace Description (per Designations in the United States)	FAA ADS-B OUT Requirements Effective on January 1, 2020
Class A	Airspace from 18,000 ft MSL up to and including FL600, including the airspace overlying the waters within 12 NM of the cost of the 48 contiguous states and Alaska.	Required for all aircraft (except aircraft without electrical system).
Class B	Airspace from the surface to 10,000 ft surrounding the nation's busiest airports. The configuration of class B airspace is tailored around each airport and consists of several layers.	Required for all aircraft. In addition to class B airspace, the rule requires equipage for all aircraft operating within 30 NM of FAA-specified airports, which are among the busiest in the nation.
Class C	Airspace from the surface to 4000 ft above the airport elevation surrounding specified airports.	Required for all aircraft.
Class D	Airspace from the surface to 2500 ft above the airport elevation surrounding those airports that have an operational control tower.	Not required.
Class E	Controlled airspace that is not in Class A, B, C, or D is classified as Class E. Class E airspace extends upward from the surface or a designated altitude to the overlying or adjacent controlled airspace. Unless otherwise designated at a lower altitude, Class E airspace begins at 14,500 ft MSL over the United States, including that airspace overlying the waters within 12 NM of the coast of the 48 contiguous states and Alaska. Class E airspace does not include the airspace at 18,000 ft MSL up to FL600 (as this is class A airspace) but does include airspace above FL600.	In portions of the Class E airspace, ADS-B OUT is required for all aircraft (expect aircraft without electrical systems) as specified: • Required for aircraft operating above 10,000 ft MSL in the lower 48 states and the District of Columbia, excluding the airspace at and below 2500 ft above the ground. • Required in the Gulf of Mexico for aircraft at and above 3000 ft within 12 NM of the U.S. coastline.
Class G	Uncontrolled airspace. Class G airspace is airspace that is not designated as Class A, B, C, D, or E.	Not required.

Figure 45 FAA Requirements

Regulating the spectrum used by European surveillance systems

1030/1090 MHz Radio Frequency bands

Cooperative surveillance systems use two frequencies to build a picture of the air situation: 1030 MHz for interrogating aircraft transponders and 1090 MHz for the aircraft transponder replies or spontaneous message transmissions (squitters). The 1030/1090 MHz radio frequency (RF) band is a critical resource for ATC. Aircraft surveillance is based on numerous cooperative surveillance systems all relying on the good operation of this RF link. It is used by Mode A/C radars, ELS and EHS Mode S radars, ADS-B, Multilateration systems for airport surface surveillance (MLAT) or over a wide area (WAM), and military systems. In addition, air-air anti-collision systems (ACAS) and future ADS-B IN applications also share the same link.

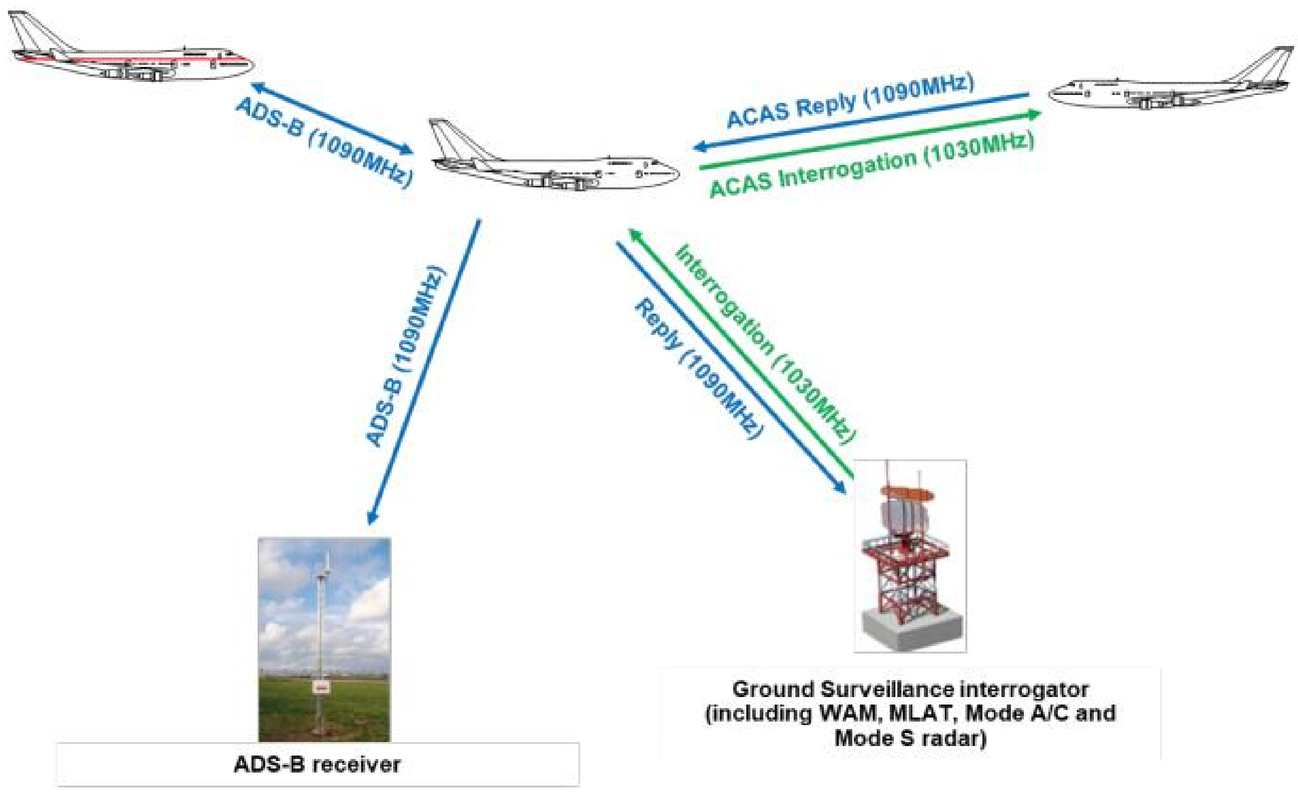


Figure 46 The use of Surveillance Radio Frequency Bands

The 1030/1090 MHz RF link can experience a degraded performance when:

- transponders are interrogated beyond their capability;
- there are too many transmissions on the frequencies;
- there are unexpected transmissions on the frequencies (e.g. non-ATC, noise); or
- transponder interoperability issues occur.

Excessive activity on the 1030/1090 MHz RF link can result in a loss of aircraft surveillance leading to possible traffic restrictions, delays and/or network capacity restrictions. A bad RF environment could also result in the need to deploy more surveillance sensors to be able to maintain the right level of performance (e.g. more ADS-B stations) or the need to deploy other technical systems operating on a different RF link. The 1030/1090 MHz RF link is a common resource shared between multiple airborne and ground users with a performance that depends on systems operating within several countries, calling for collaborative and harmonised practices between States. One of the goals of the Surveillance Performance Interoperability Implementation Rule (SPI IR) is to sustain the performance of the 1030 MHz and 1090 MHz frequencies in the Single European Sky airspace thereby avoiding the need to deploy a new surveillance RF link. Article 6 of the SPI IR supports this goal by mitigating the number of interrogations received by transponders ensuring they operate within their capacity limits.

Article 6 of the SPI IR (as amended), details the provisions relating to spectrum protection:

Article 6

Spectrum protection

1. *By 2 January 2020 at the latest Member States shall ensure that a secondary surveillance radar transponder on board any aircraft flying over a Member State is not subject to excessive interrogations that are transmitted by ground-based surveillance interrogators and which either elicit replies or whilst not eliciting a reply are of sufficient power to exceed the minimum threshold level of the receiver of the secondary surveillance radar transponder.*
2. ~~*For the purpose of paragraph 1, the sum of such interrogations shall not cause the secondary surveillance radar transponder to exceed the rates of reply per second, excluding any squitter transmissions, specified in paragraph 3.1.1.7.9.1 for Mode A/C replies and in paragraph 3.1.2.10.3.7.3 for Mode S replies of Annex 10 to the Chicago Convention, Volume IV, Fourth Edition.*~~
3. *By 2 January 2020 at the latest Member States shall ensure that the use of a ground based transmitter operated in a Member State does not produce harmful interference on other surveillance systems.*
4. *In the event of disagreement between Member States regarding the measures detailed in paragraphs 1 and 3 the Member States concerned shall bring the matter to the Commission for action.*

As illustrated in Fig.46, aircraft are subject to multiple sources of interrogations (both ground and air-based). However, it’s important to note that the obligations on States relate to the civil and military ground-based surveillance interrogations upon which States can take action.

For the purpose of these guidelines it is essential to develop an understanding of the term “excessive” defined in point 1 of Article 6 of the SPI IR. Indeed, as the performance of the 1030/1090 MHz RF link depends on systems installed throughout Europe, there is a need for States to share the same understanding of that term. Secondly, the term “harmful interference” used in point 3 of Article 6 will be clarified to ensure that all States share the same understanding of that term. Finally, these guidelines recommend that the above points are verified by States on a regular basis (e.g. new installation, new configurations) as described by the following sections.

Defining “excessive interrogations” for Art. 6 point 1

All interrogations from surveillance interrogators with a power level that exceeds the minimum threshold level of an aircraft transponder, eliciting or not a reply, are processed by the transponder and have an impact on the occupancy of the transponder. An aircraft transponder which is too occupied may not be able to process all received interrogations. In addition, an aircraft transponder which is subject to too many interrogations may not be able to reply to all interrogations when the number of triggered replies exceeds its capability. Therefore, it is necessary to ensure that an aircraft transponder does not generate an excessive number of replies and that its occupancy remains below a maximum threshold. The minimum reply rates capability of aircraft transponder is defined in ICAO Annex 10, Volume IV. Some aircraft transponders have been designed and tested to strictly meet this minimum capability; they may not be able to generate a number of replies higher than this minimum capability or may have an unexpected behaviour if the number of triggered replies exceeds the minimum capability. Therefore, these guidelines recommend that States verify that the occupancy generated by interrogations eliciting or not eliciting a reply remains below a maximum threshold for any aircraft transponder flying in its airspace. They also recommend that States verify that the maximum rate of replies per second (peak rates) of any aircraft transponder flying in its airspace does not exceed the minimum reply rates capability defined in ICAO Annex 10, Volume IV. For the purpose of these guidelines, values from ICAO Annex 10, Volume IV, Fifth Edition, Amendment 89 are used.

With regard to the editions and amendments of ICAO Annex 10, Volume IV the following is to be duly considered:

• At the date of publication of the Regulation, the rates of ICAO Annex 10, Volume IV, Fourth Edition, Amendment 85 (July 2010) were applicable. At the date of publication of these guidelines, Amendment 90 (July 2018) of ICAO Annex 10, Volume IV, Fifth Edition changed section 3.1.2.10.3.7.3 with regard to Mode S minimum reply rate capability for transponder used in conjunction with ACAS.

• A number of aircraft in operation are equipped with transponders that are certified against values that were specified in ICAO Annex 10, Volume IV, Third Edition (Amendment 77) and therefore differ with other aircraft certified against values in recent Amendments.

• Surveillance service providers are required to comply with Annex VIII (Part-CNS) to Commission Implementing Regulation (EU) 2017/373 by demonstrating that their working methods and operating procedures are compliant with the international Standards and Recommended Practices (SARPs) of Annex 10 ‘Aeronautical Telecommunications’ to the Chicago Convention on International Civil Aviation. In particular, the rates of reply per second of the transponder on board any aircraft flying over a Member State shall be computed and compared to the minimum reply rates supported by transponder accepted in the airspace, specified in the ICAO Annex 10, Volume IV, Fourth Edition including all amendments up to and including No 89.

ICAO Annex 10 Volume IV Requirement	Annex 10 Vol IV, Ed 3 Amendment 77	Annex 10 Vol IV, Ed 4 Amendment 85	Annex 10 Vol IV, Ed 5 Amendment 89	Annex 10 Vol IV, Ed 5 Amendment 90	ICAO values used by these Guidelines
Minimum reply rate for Mode A/C per second (3.1.1.7.9.1)	1200	500	500	500	**500**
Minimum reply rate for Mode S replies per second (3.1.2.10.3.7.3)	50	50	50	50	**50**
Minimum reply rate for long Mode S replies per second (3.1.2.10.3.7.3)	16 of 50 replies for levels 2, 3, 4 24 of 50 replies for level 5	16 of 50 replies for levels 2, 3, 4 24 of 50 replies for level 5	16 of 50 replies for levels 2, 3, 4 24 of 50 replies for level 5	16 of 50 replies for levels 2, 3, 4 24 of 50 replies for level 5	**16 of 50 replies**
ACAS equipped – ACAS coordination replies per second (3.1.2.10.3.7.3)	at least 3 of 50 Mode S replies	at least 3 of 50 Mode S replies	at least 3 of 50 Mode S replies	60 Modes S replies	**Recommended to use real measurements or at least 3 of 50 Mode S replies for coordination (does not include ACAS tracking messages detailed in these guidelines)**
Maximum number of Modes S all-call replies (3.1.2.11.1.1.2)	N/A	N/A	On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds	On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds	**On average no more than 6 Modes S all-call replies per 200ms and no more than 26 per 18 seconds**
These guidelines consider the minimum capabilities of aircraft transponders as defined by ICAO Annex 10 (blue cells) and the maximum number of Modes S all-call replies triggered on average by ground-based surveillance interrogators for the optional verifications 4 and 5 (brown cells).					

Table 4 Comparison of requirements in different Amendments of ICAO Annex 10

ICAO Annex 10, Volume IV defined minimum reply rates. The minimum reply rate capability for Mode A/C replies is provided in section 3.1.1.7.9.1 of ICAO Annex 10, Volume IV:

"3.1.1.7.9.1 All transponders shall be capable of continuously generating at least 500 replies per second for a 15-pulse coded reply. Transponder installations used solely below 4 500 m (15 000 ft), or below a lesser altitude established by the appropriate authority or by regional air navigation agreement, and in aircraft with a maximum cruising true airspeed not exceeding 175 kts (324 km/h) shall be capable of generating at least 1 000 15-pulse coded replies per second for a duration of 100 milliseconds. Transponder installations operated above 4 500 m (15 000 ft) or in aircraft with a maximum cruising true airspeed in excess of 175 kts, shall be capable of generating at least 1 200 15-pulse coded replies per second for a duration of 100 milliseconds." While old aircraft transponders (ICAO Annex 10, Volume IV, Third Edition Amendment 77 or before) have the capability to reply to 1200 Mode A/C interrogations per second, aircraft transponders compliant with more recent versions of the ICAO Annex 10 , Volume IV (Amendment 85 or above) are only capable to reply to 500 Mode A/C interrogations per second. Therefore, these guidelines recommend that States verify that transponders are not required to reply to more than 500 Mode A/C replies per second.

The minimum reply rates capability for Mode S replies are provided in section 3.1.2.10.3.7.3 of ICAO Annex 10, Volume IV:

“3.1.2.10.3.7.3 Minimum reply rate capability, Mode S. A transponder capable of transmitting only short Mode S replies shall be able to generate replies at the following rates:

50 Mode S replies in any 1-second interval

18 Mode S replies in a 100-millisecond interval

8 Mode S replies in a 25-millisecond interval

4 Mode S replies in a 1.6-millisecond interval

In addition to any downlink ELM transmissions, a level 2, 3 or 4 transponder shall be able to generate as long replies at least:

16 of 50 Mode S replies in any 1-second interval

6 of 18 Mode S replies in a 100-millisecond interval

4 of 8 Mode S replies in a 25-millisecond interval

2 of 4 Mode S replies in a 1.6-millisecond interval

In addition to downlink ELM transmissions, a level 5 transponder shall be able to generate as long replies at least:

24 of 50 Mode S replies in any 1-second interval

9 of 18 Mode S replies in a 100-millisecond interval

6 of 8 Mode S replies in a 25-millisecond interval

2 of 4 Mode S replies in a 1.6-millisecond interval

In addition, a transponder within an ACAS installation shall be able to generate as ACAS coordination replies at least 3 of 50 Mode S replies in any 1-second interval.”

Based on aircraft fleet monitoring performed in 2019 in the European core area, less than 1% of flights are operated with a level 5 transponder. Therefore, for the purpose of these guidelines the verification of Mode S long replies will use the minimum reply rate capability required for a level 2, 3 or 4 transponder.

As SPI IR Article 6(1) only refers to rates of reply per second, these guidelines only verify the following rates:

• the number of Mode A/C replies per second interval (500 Mode A/C replies per second),

• the number of Mode S replies per second interval (50 Mode S replies in any 1-second interval), and

• the number of Mode S long replies per second interval (16 of 50 Mode S replies in any 1- second interval)

These rates may correspond to the maximum capability of some aircraft transponders. Therefore, they will be assessed by verifying the maximum number of Mode A/C replies and the maximum number of Mode S replies per second (peak reply rates per second) transmitted by any aircraft transponder flying in State airspace. ICAO Annex 10, Volume IV [RD 5] specifies the minimum reply rates capability for Mode A/C and Mode S replies, whatever they are triggered by airborne or ground-based surveillance interrogators. Those rates do take into account ACAS replies but do not take into account ADS-B extended squitters and acquisition squitter. Section 2.3.3 explains how to take into account replies triggered by airborne surveillance interrogators (ACAS).

Background of SPI IR

SSR Mode A/C and Mode S radar interrogate aircraft transponders on the 1030 MHz RF band. Transponders reply on the 1090 MHz RF band. In addition, the 1030 and 1090 MHz RF bands are also used by other systems like ACAS, IFF military radars, ADS-B and WAM/MLAT.

SSR Mode A/C and Mode S radar, IFF military radars and WAM/MLAT are ground-based surveillance interrogators while ACAS and AWACS military radars are airborne interrogators. They all use the 1030 MHz RF band to interrogate aircraft transponders, which reply on the 1090 MHz RF band. ADS-B is using airborne long squitters spontaneously transmitted on the 1090 MHz RF band.

These transmitters access randomly the same 1030 and 1090 MHz frequency bands to transmit messages without any synchronisation between each other, comparable to a multiple access based on Aloha protocol principle. The multi-use of the RF bands may cause collision in the reception of interrogations and replies.

Three issues have been identified:

• Transponder capability of reply:

  o Transponder occupancy: when receiving an interrogation, the transponder processes the message to verify if the interrogation elicits a reply or not. If so, the transponder prepares the reply and sends it. During this time of processing, the transponder is unable to reply to other interrogations. As a result, if the transponder receives too many interrogations, it may not be able reply to all of them, which may affect the performances of surveillance interrogators. When a surveillance interrogator does not receive a reply to a selective interrogation, it generally re-interrogates the transponder, which increases the number of interrogations on 1030 MHz and the transponder occupancy.

  o Transponder capacity limit: when the number of interrogations eliciting a reply exceeds the transponder maximum capacity of reply, the transponder may not be able to reply, partly or completely, to new interrogations it receives.

• Garbling: if a large number of aircraft transponders are in a receiver coverage, the high number of replies leads to interference and garbling. The receiver faces difficulties to decode the replies. Omni-directional antennas are more impacted by garbling than rotating antennas, which have a narrow beam.

• Interrogations collision: if the number of interrogations issued from different surveillance interrogators is excessive, interrogations arrive at the same time and the transponder will reply to only one of them.

Some examples highlight these issues:

• Transponder capacity limit: loss of detection of some aircraft in June 2014 in central Europe. The analysis showed that aircraft were over interrogated; some transponders overheated and stopped replying. More information is provided in the EASA report.

• Transponder capacity limit: Some transponders have implemented a limitation of their transmission when reaching the minimum reply rates specified in the ICAO Annex 10, Volume IV.

• Interrogations collision: A BDS swap happens when two surveillance interrogators send an interrogation to the same transponder, asking for two different BDS. If the interrogations reach the transponder at the same time, the transponder will only reply to one of them. One of the two interrogators will then receive a wrong reply. The more interrogators, the larger the number of BDS swaps. Several cases have been identified through measurements made on board a test aircraft. Per radar, there can be around 5 to 6 swaps per day, which decreases radars performance. The monitored number of BDS swap shows an increasing number of occurrences of such phenomenon in the core area of Europe.

• SESAR Simulation: This simulation conducted in SESAR Working Package 15.1.6 in 2011 was aimed to determine the congestion on the 1030/1090 MHz frequency bands in high RF interference environments. Results show the 1030/1090 MHz frequencies are highly congested. According to the SESAR 15.1.6 study, the congestion seems to be at the limit of acceptability in core area of Europe and the performance of surveillance systems could degrade rapidly if it keeps increasing. As a result, the general objective is to monitor the transmissions made on 1030/1090 MHz RF frequency bands in order to maintain the surveillance performance of the different systems at an acceptable level. In particular, the following recommendations with high priority are provided in the EASA report to the European Commission about detection losses in Central Europe on the 5th and 10th of June 2014:

1. States are reminded that Article 6 of SPI regulation (1207/2011 and amendments) clearly identifies their responsibility for spectrum protection at the latest by 5 February 2015. States should put in place required mechanisms to comply with it.

2. States should decrease the amount of interrogations in their airspace originating from ground systems (e.g. from SSRs, MSSRs, MLAT, WAM, test transmitters, military SSR/MSSR), so that each transponder is interrogated well below the rates required in the MOPS; Particular attention should be paid to tests or maintenance activities that use interrogators in the 1030/1090 MHz frequency;

3. States ensure that the use of the 1030/1090 MHz frequency band is monitored and recorded. This monitoring and recording shall not be limited to direct ground sensor observation but shall also

include observation of all the transmissions by a subset of aircraft in the air. The recordings shall be kept for at least 6 months to allow post event investigation;

4. States should ensure that each MLAT/WAM interrogator use a unique interrogator code and interrogations are kept to a minimum. The level of interrogations should be coordinated within the States and across boundaries;

5. Neighbouring States should collaborate particularly within the FABs, but ensuring also wider collaboration at the EU level, to make sure that recommendations numbers 1, 2, 3 and 4 are carried out in a consistent and harmonised way;

6. States should notify the Agency and the European commission of safety occurrences in a timely manner. The Agency should be provided with the relevant available data to facilitate the timely identification of the causes as well as the identification of potential measures to be taken

Note: The SPI IR is an airspace requirement that is applicable to all GAT (General Air Traffic) operations undertaken by EU and Non-EU operators, within the Single European Sky (SES) airspace**,** regardless of the State of operator.

Differences between amendments Annex 10 volume IV: evolution history

ICAO requirements related to surveillance are mainly contained in Annex 10 volume III "Communication Systems" and Volume IV "Surveillance and Collision Avoidance System".

ICAO Annex 10 are discussed 3 categories of features for the Mode S transponders:

a. The Levels
Five Mode S transponders levels are defined (Annex 3).
The minimum capability required by the European regulation is Level 2. It includes Mode A/C and Mode S capabilities:

- Addressed altitude and identity reporting
- Data exchanges based on the Comm-A and Comm-B protocols
- Air-air services for cooperation with surrounding aircraft equipped with ACAS

b. SI code capability;

c. The Extended Squitter capability to support ADS-B.

If Mode S transponders have those 3 capabilities, they are designated "2es".

Over the time, rules changes, in particular if we're talking about aerospace. In the last century, the technological progress has been the main feature, especially in this sector, thanks to the effort that has been made by thousands and thousands of engineers and researches. All these improvements lead to a lot of advantages as growth of flights or more security and safety. Millions of people take the airplane every single day, and so the world is never been so little.
An important consequence of these developments is the introduction or adjust of regulations.

Here, starting from Amendment 73/1998 until Amendment 89/2014, we're going to analyse main changes and enhancements of the ICAO Annex X Volume IV

Date	Amdt	Annex 10 Vol III	Annex 10 Vol IV	Doc 9871
1998	73	Introduction of Mode S Specific Services (Ch. 5 of Part I)		
2002	77	Introduction of 1090 MHz Extended Squitter (ADS-B Version 0) (addition of Appendix 1 to Ch. 5 of Part I)	Addition of requirements for - 25 ft Altitude resolution - SI code with associated dates for mandates	
2007	82	Relocation of Mode S and extended squitter ADS-B data formats to separate manuals.	Slight modifications of 1090 MHz ES definition	Ed 1 Addition of ADS-B Version 1
2010	85		Updates of Modes A/C, Mode S and 1 090 MHz extended squitter resulting from operational experience;	
2012				Ed 2 Addition of ADS-B Version 2.
2014	89		Updates of Modes A/C, Mode S and 1 090 MHz extended squitter resulting from operational experience;	

Table 5 ICAO Mode S relevant document update

Here is another document extracted from ICAO, more detailed and more up to date, starting from Amendment 70/1995 to Amendment 90/2018, with improvements associated.

Amendment	*Source(s)*	*Subject(s)*	*Adopted/approved* *Effective* *Applicable*
70	Air Navigation Commission; Fifth meeting of the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel	Creation of Volume IV and introduction of Standards and Recommended Practices and related guidance material for the airborne collision avoidance system (ACAS).	20 March 1995 24 July 1995 9 November 1995
71	Air Navigation Commission; Fourth and fifth meetings of the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICASP)	Changes to material related to SSR Mode S air-ground data link system and the carriage of SSR transponders.	12 March 1996 15 July 1996 7 November 1996
72	—	No change.	—
73 (2nd edition)	Air Navigation Commission; Sixth meeting of the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICASP)	Addition of specifications for the SSR Mode S system; introduction of material related to the performance of the collision avoidance logic; changes to guidance material related to the airborne collision avoidance system; introduction of Human Factors related material.	19 March 1998 20 July 1998 5 November 1998
74	Air Navigation Commission	Note related to the waiving of patent rights on Mode S extended squitter technique.	18 March 1999 18 March 1999 —
75	—	No change.	—
76	Seventh meeting of the Aeronautical Mobile Communications Panel (AMCP)	Note related to update of references to the ITU Radio Regulations.	12 March 2001 12 March 2001 —
77 (3rd edition)	Seventh meeting of the Secondary Surveillance Radar Improvements and Collision Avoidance Systems Panel (SICASP)	SSR Mode S (Chapters 2 and 3); and ACAS (Chapters 1 and 4).	27 February 2002 15 July 2002 28 November 2002
78	—	No change.	—
79	—	No change.	—
80	—	No change.	—
81	—	No change.	—
82 (4th edition)	Surveillance and Conflict Resolution Systems Panel (SCRSP)	Updates to SARPs on ADS-B	26 February 2007 16 July 2007 22 November 2007
83	—	No change.	—
84	—	No change.	—

Amendment	*Source(s)*	*Subject(s)*	*Adopted/approved Effective Applicable*
85	Aeronautical Surveillance Panel (ASP)	a) Update of provisions relating to secondary surveillance radar (SSR) (Modes A/C and S) and automatic dependent surveillance — broadcast (ADS-B) using 1 090 MHz extended squitter resulting from operational experience; b) introduction of a system-level and functional requirement for multilateration systems used for air traffic surveillance; c) introduction of an initial set of technical requirements for airborne surveillance applications that are enabled by the use of ADS-B IN messages on the flight deck; d) new requirements for display of proximate traffic, traffic advisory (TA) and resolution advisory (RA); e) update of provisions on hybrid surveillance in light of relevant recent developments; and f) introduction of a new functional requirement for monitoring own aircraft's vertical rate during an RA which would be affected by implementing a new version of the collision avoidance system (CAS) logic (commonly referred to as traffic alert and collision avoidance system (TCAS) Version 7.1). The new version of the CAS logic would also include a change in the annunciation of the RA "Adjust Vertical Speed, Adjust" to "Level Off".	26 February 2010 12 July 2010 18 November 2010
86	—	No change.	—
87	—	No change.	—
88-A	—	No change.	—
88-B	—	No change.	—
89 (5th edition)	Aeronautical Surveillance Panel (ASP)	Surveillance systems	3 March 2014 14 July 2014 13 November 2014
90	First and second meetings of the Surveillance Panel (SP/1 and SP/2)	a) airborne collision avoidance system (ACAS); and b) secondary surveillance radar (SSR) and wide area multilateration (WAM).	7 March 2018 16 July 2018 8 November 2018

Figure 47 ICAO Amendments, Annex X Vol. IV

Situation in 2002 with Annex 10 Amendment 77

The definition of Mode S transponders was relatively mature and stable at Amendment 77.
All the capabilities were present.

The standard was mainly provided by ICAO Annex 10 Vol IV (chapters 2 and 3). The definition of the format of registers with the parameters to transmit was introduced at Amendment 77 in the Volume III, Appendix to chapter 5 as well as a first definition of ADS-B parameters.
This definition will be named later "Version 0".

As a consequence, this standard was able to support Elementary Surveillance, Enhanced Surveillance and ADS-B.

Amendment 77 requires that by 1 January 2005 all Mode S transponders:

- All aircraft with 25 ft or better pressure altitude sources report pressure altitude encoded in 25 ft increments in Mode S replies.
- have the SI code capability.

Amendment 82 published in 2007:

This Amendment 82 goes particularly into Mode S.
In complement to the Volume IV modifications it also introduces a change of the Appendix to Chapter 5 in Annex 10 Volume III. The scope remains identical: definition of format and protocols for Mode S Services and definition of Extended Squitters.
On this occasion a new "version" of Extended Squitter was created. It was called Version 1 whereas the version resulting from Amendment 77 was named "Version 0".
Starting from Amendment 82, Extended Squitter ADS-B aspects are not any more covered by Annex 10 Volume III.

Amendment 85 published in 2010:

With amendments 82 and 85, different kinds of modifications have been introduced:

a) Modifications aiming at decreasing the number of unsolicited replies or spurious transmissions (N° 82-4, 82-6, 85-2 and 85-42), and at improving the robustness against radio-frequency interferences.

   One of the new requirements relative to spurious Mode A/C replies (85-4) was mandatory for new equipment certified as of 1 January 2011.

b) Non-Extended Squitter parameters:
   No significant changes concerning the content or meaning.
   (For aircraft without squat switch3, successive modifications of the way the ground forces "ground status bit" have been included (82-9, 85-7 and 85-8). In fact, they have been removed in the following amendment 89 as described in sections 4.3 and 6.2.4 last bullet).

c) Extended Squitter parameters Version 0.

   Slight modifications (Relaxation of some update rates)

d) Extended Squitter Version 1

   There are significant changes:

   - The position quality is no more reported through the NUC parameter, but accuracy and integrity are reported separately:
     a) navigation accuracy category (NAC);
     b) navigation integrity category (NIC);

c) surveillance integrity level (SIL).

- Reporting of additional status parameters

Version 1 formats are fully compatible with those of Version 0, in that a receiver of either version can correctly receive and process messages of either version.
Globally from amendment 77 to amendment 85 there was no change concerning the parameters transmitted by the Transponders contributing to ELS or EHS. The new ADS-B Version 1 was created but it is backwards compatible with version 0.

The evolutions regarding ELS and EHS concerned the protocols and the management of replies.

Changes made in Amendment 89

Amendment 89 was published in 2014.
Based on operational experience it introduces some changes in the management of replies to avoid radio frequency pollution, interferences on airport surfaces and to improve safety:

Reduction of transponder replies to Mode A/C and Mode S only all-call interrogations and broadcast of the full set of 1090 ES messages intended for surface aircraft (89-4, 89-5 and 89-8).

To this end after 2020 new Mode S transponder equipment in aircraft forward fit shall no longer reply to Mode A/C/S all-call interrogations (89-8).

Note: The squat switch is essentially a sensor that senses if the weight of the aircraft is resting on the gear. It is the most appropriate sensor to indicate that aircraft is on the ground.

- As of 2020 aircraft transponders are required to broadcast Data Parity with Overlay Control (89-4). The goal is to solve the “BDS swap” issue where, in some circumstances, transponders could reply a register different from the one requested. This change is operationally transparent for ground radar not compliant or for avionics not compliant.

- For aircraft without squat switch, the airborne transponder can be forced by a ground request to broadcast Surface Position Message (89-4). Amendment 89 comes back to Amendment 77 solution because the drawback was that to modify the on-the-ground Status broadcast to surrounding ASAS. In addition, the transponder is forced to temporally not reply to Mode A/C and Mode S All-Call interrogations (89-5).

- At aircraft level a means shall be provided for the aircraft identification to be displayed to the pilot, and, when containing variable data to be modified without the entry or modification of other flight data (89-1 and 89-2).

The modifications could be managed through Mode S Transponder software update or in some cases aircraft modifications, but they are without impact on the transmitted parameters.
They do not impact the interoperability with ACAS of surrounding aircraft and with ground interrogators.
The two mandates for 2020 expressed in this Amendment are primarily focused on the need to reduce 1090 MHz RF pollution to ensure that the Mode S technology will still operates safely even with an increasing number of aircraft using this frequency and on the need to solve the « BDS swap » issue. The RF pollution reduction mandate is a safeguard measure that need to be implemented at least in forward fit as soon as possible (i.e. 2020 consistent with the current mandate in the USA and the expected short terms revision of (EU) N° 1207/2011 Regulation in Europe).
Regarding ADS-B, the main impact concerning the transmitted parameters is the possibility to use Version 2 ES formats. They are defined in the second edition of the Doc 9871 Technical Provisions for Mode S Services and Extended Squitter" which was published in 2012.

Several changes are relative to the quality parameters (NIC and NAC):

- separated reporting of source and system integrity;
- additional levels of NIC to better support airborne and surface applications;
- eliminated the vertical component of NIC and NAC;

Some transmitted parameters are modified as follows:

- incorporation of the broadcast of the Mode A code into the emergency/priority message,
- increased transmission rates after a Mode A code change,
- the broadcast of the Mode A code on the surface;
- revision to the target state and status message to include additional parameters;
- capabilities were added to support airport surface applications.

Some update intervals are changed. A more detailed analysis is provided in section 5.4.
The three 1090 ES versions are compatible: an extended squitter receiver can recognize and decode signals of its own version, as well as the message formats from the previous versions.

The receiver, fitted with a lower version, can only decode the portion of messages received from a higher version that corresponds to its own capability.

Comparison between Amendment77 and Amendment 89

If we compare the requirements extracted from Amendment 77 with those extracted from Amendment 89, it results in the following points:

i. The evolutions consist essentially in improvements and clarifications.
ii. The majority of modifications are relative to the reduction and prevention of RF pollution.
iii. The interoperability is maintained on the principle of backward capability.

iv. Some modifications are mandatory (respectively 2005 for Amendment 77, 2011 for Amendment 85 and 2020 for Amendment 89). These mandatory dates are mainly focusing on the limitation of pollution of the Mode S frequencies and on a higher robustness of Mode S receivers against 1090 MHz interferences.

The transmitted parameters have not been modified regarding ELS and EHS. Three possible formats where gradually introduced for 1090 ES (ADS-B OUT), but with an objective of backward compatibility.
Regarding the ELS and EHS parameters, these various amendments do not define performance requirements such as: accuracy, availability, integrity, continuity and latency).
Regarding ADS-B (1090 Extended Squitter), some performance characteristics of the parameters transmitted outside the aircraft are defined (accuracy, integrity).

In conclusion of this analysis it appears that:

a. The technical specifications for ELS and EHS are very stable from the Annex 10 Amendment 77. The major improvements introduced in the following Amendments were focused upon the urgent need to limit the pollution of the Mode S frequencies. Each amendment brings its own set of improvements. The most demanding is certainly contained in Amendment 89.

b. The ADS-B functionalities have been continuously upgraded during the full cycle of Amendment (77 up to 89) with three major steps corresponding to the three ADS-B version (Version 0, 1 and 2). These three versions address data format on one hand but also quality of the broadcasted information (introduction of NIC and NAC parameters)

Commission Implementing Regulation (EU) No 2020/587

The European commission reunited and approved the implemented regulation (EU) No 2020/587 of 29th April 2020 revising implementing regulations (EU) No 1206/2011 and No 1207/2011. The first one directive establishes all the requirements about aircraft identification, in order to guarantee a surveillance for the single European sky; the second one sets requirements for the performance and the interoperability of the single European sky surveillance.

Improving the rules is fundamental, especially in this contest, because when human lives are in running, the most important thing is safety. The first aim of airline companies is to guarantee secure flights and efficiency not only onboard, but in all services around: airports, ATM, air navigation, and every single part of aviation must be controlled and continuously updated. Aircraft equipment needs efficient and prompt installation, in order to benefit all the planned advantages before the deadline. It’s necessary to distinguish clearly the airplanes which must be equipped or updated, and which could receive a waiver from the equipment requirements. The objective is to achieve a well-equipped aircraft to ensure safety, but without exceeding expenses.

Most of aircraft is in compliance with Annex X to the Chicago convention, volume IV, third edition, amendments up to No 77. This is the minimum requirement needed; it would be excessively lavish to impose the minimum up to amendment No 85.

State aircraft used for general aviation should be equipped with efficient SSR transponder; its characteristics should follow the requirements valid for civil aircraft as Article 5 of Implementing Regulation (EU) No 1207/2011 - points a) and c) - claims.

The two points are reported and highlighted in the next page, extracted from the “Official Journal of the European Union” (2011):

Article 5

Interoperability requirements

1. Air navigation service providers shall ensure that all surveillance data transferred from their systems identified in points (b) and (c) of Article 2(1) to other navigation service providers complies with the requirements set out in Annex III.

2. Air navigation service providers when transferring surveillance data from their systems identified in points (b) and (c) of Article 2(1) to other air navigation service providers, shall establish formal arrangements with them for the exchange of the data in accordance with the requirements set out in Annex IV.

3. Air navigation service providers shall ensure that, by 2 January 2020 at the latest, the cooperative surveillance chain has the necessary capability to allow them to establish individual aircraft identification using downlinked aircraft identification made available by aircraft equipped in accordance with Annex II.

4. Operators shall ensure that:

(a) aircraft operating flights referred to in Article 2(2) with an individual certificate of airworthiness first issued on or after 8 January 2015 are equipped with secondary surveillance radar transponders having the capabilities set out in Part A of Annex II;

(b) aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued on or after 8 January 2015 are equipped with secondary surveillance radar transponders having, in addition to the capabilities set out in Part A of Annex II, the capabilities set out in Part B of that Annex;

(c) fixed wing aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued on or after 8 January 2015 are equipped with secondary surveillance radar transponders having, in addition to the capabilities set out in Part A of Annex II, the capabilities set out in Part C of that Annex.

5. Operators shall ensure that by 7 December 2017 at the latest:

(a) aircraft operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued before 8 January 2015, are equipped with secondary surveillance radar transponders having the capabilities set out in Part A of Annex II;

(b) aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued before 8 January 2015 are equipped with secondary surveillance radar transponders having, in addition to the capabilities set out in Part A of Annex II, the capabilities set out in Part B of that Annex;

(c) fixed wing aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued before 8 January 2015 are equipped with secondary surveillance radar transponders having, in addition to the capabilities set out in Part A of Annex II, the capabilities set out in Part C of that Annex.

6. Operators shall ensure that aircraft equipped in accordance with paragraphs 4 and 5 and having a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots operate with antenna diversity as prescribed in paragraph 3.1.2.10.4 of Annex 10 to the Chicago Convention, Volume IV, Fourth Edition including all amendments up to No 85.

7. Member States may impose carriage requirements in accordance with point (b) of paragraph 4 and point (b) of paragraph 5 to all aircraft operating flights referred to in Article 2(2) in areas where surveillance services using the surveillance data identified in Part B of Annex II are provided by air navigation service providers.

8. Air navigation service providers shall ensure that, before putting into service the systems referred to in points (b), (c) and (d) of Article 2(1), they are implementing the most efficient deployment solutions taking into account the local operating environments, constraints and needs as well as airspace users capabilities.

Article 6

Spectrum protection

1. By 5 February 2015 at the latest Member States shall ensure that a secondary surveillance radar transponder on board any aircraft flying over a Member State is not subject to excessive interrogations that are transmitted by ground-based surveillance interrogators and which either elicit replies or whilst not eliciting a reply are of sufficient power to exceed the minimum threshold level of the receiver of the secondary surveillance radar transponder.

For those State aircraft that cannot be equipped with an efficient SSR Transponder, article 8 of Implementing Regulation (EU) No 1207/2011 explains the standard procedure:

23.11.2011 EN Official Journal of the European Union L 305/39

2. For the purpose of paragraph 1, the sum of such interrogations shall not cause the secondary surveillance radar transponder to exceed the rates of reply per second, excluding any squitter transmissions, specified in paragraph 3.1.1.7.9.1 for Mode A/C replies and in paragraph 3.1.2.10.3.7.3 for Mode S replies of Annex 10 to the Chicago Convention, Volume IV, Fourth Edition.

3. By 5 February 2015 at the latest Member States shall ensure that the use of a ground based transmitter operated in a Member State does not produce harmful interference on other surveillance systems.

4. In the event of disagreement between Member States regarding the measures detailed in paragraphs 1 and 3 the Member States concerned shall bring the matter to the Commission for action.

Article 7

Associated procedures

1. Air navigation service providers shall assess the level of performance of ground based surveillance chain before putting them into service as well as regularly during the service, in accordance with the requirements set out in Annex V.

2. Operators shall ensure that a check is performed at least every two years, and, whenever an anomaly is detected on a specific aircraft, so that the data items set out in point 3 of Part A of Annex II, in point 3 of Part B of Annex II and in point 2 of Part C of Annex II, if applicable, are correctly provided at the output of secondary surveillance radar transponders installed on board their aircraft. If any of the data items are not correctly provided then the operator shall investigate the matter before the next flight is initiated and any rectification necessary shall be introduced in line with normal maintenance and corrective procedures for the aircraft and its avionics.

3. Member States shall ensure that the assignment of 24-bit ICAO aircraft addresses to aircraft equipped with a Mode S transponder complies with Chapter 9 and its appendix of Annex 10 to the Chicago Convention, Volume III, Second Edition including all amendments up to No 85.

4. Operators shall ensure that on board the aircraft they are operating, any Mode S transponder operates with a 24-bit ICAO aircraft address that corresponds to the registration that has been assigned by the State in which the aircraft is registered.

Article 8

State aircraft

1. Member States shall ensure that, by 7 December 2017 at the latest, State aircraft operating in accordance with Article 2(2) are equipped with secondary surveillance radar transponders having the capability set out in Part A of Annex II.

2. Member States shall ensure that, by 1 January 2019 at the latest, transport-type State aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating in accordance with Article 2(2) are equipped with secondary surveillance radar transponders having in addition to the capability set out in Part A of Annex II, the capability set out in Part B and Part C of that Annex.

3. Member States shall communicate to the Commission by 1 July 2016 at the latest the list of State aircraft that cannot be equipped with secondary surveillance radar transponders that comply with the requirements set out in Part A of Annex II, together with the justification for non-equipage.

Member States shall communicate to the Commission by 1 July 2018 at the latest the list of transport-type State aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, that cannot be equipped with secondary surveillance radar transponders that comply with the requirements set out in Part B and Part C of Annex II, together with the justification for non-equipage.

The justification for non-equipage shall be one of the following:

(a) compelling technical reasons;

(b) State aircraft operating in accordance with Article 2(2) that will be out of operational service by 1 January 2020 at the latest;

(c) procurement constraints.

4. Where State aircraft cannot be equipped with secondary surveillance radar transponders as specified by paragraphs 1 or 2 for the reason set out in point (c) of paragraph 3 Member States shall include in the justification their procurement plans regarding these aircraft.

5. Air traffic service providers shall ensure that the State aircraft identified in paragraph 3 can be accommodated, provided that they can be safely handled within the capacity of the air traffic management system.

6. Member States shall publish the procedures for the handling of State aircraft which are not equipped in accordance with paragraphs 1 or 2 in national aeronautical information publications.

7. Air traffic service providers shall communicate on an annual basis to the Member State that has designated them their plans for the handling of State aircraft which are not equipped according with paragraphs 1 or 2. Those plans shall be defined by taking into account the capacity limits associated with the procedures referred to in paragraph 6.

Article 9

Safety requirements

1. Member States shall ensure that, by 5 February 2015 at the latest, a safety assessment is conducted by the parties concerned for all existing systems referred to in points (b), (c) and (d) of Article 2(1).

2. Member States shall ensure that any changes to the existing systems referred to in points (b), (c) and (d) of Article 2(1) or the introduction of new systems are preceded by a safety assessment, including hazard identification, risk assessment and mitigation, conducted by the parties concerned.

3. During the assessments identified in paragraphs 1 and 2, the requirements set out in Annex VI shall be taken into consideration as a minimum.

Article 10

Conformity or suitability for use of constituents

Before issuing an EC declaration of conformity or suitability for use provided in Article 5 of Regulation (EC) No 552/2004, manufacturers of constituents of the systems referred to in Article 2(1) of this Regulation or their authorised representatives established in the Union, shall assess the conformity or suitability for use of those constituents in compliance with the requirements set out in Annex VII.

However, certification processes complying with Regulation (EC) No 216/2008 of the European Parliament and of the Council [1], shall be considered as acceptable procedures for the conformity assessment of constituents if they include the demonstration of compliance with the applicable interoperability, performance and safety requirements of this Regulation.

Article 11

Verification of systems

1. Air navigation service providers which can demonstrate or have demonstrated that they fulfil the conditions set out in Annex VIII shall conduct a verification of the systems referred to in points (b), (c) and (d) of Article 2(1) in compliance with the requirements set out in Part A of Annex IX.

2. Air navigation service providers which cannot demonstrate that they fulfil the conditions set out in Annex VIII shall subcontract to a notified body a verification of the systems referred to in points (b), (c) and (d) of Article 2(1). This verification shall be conducted in compliance with the requirements set out in Part B of Annex IX.

3. Certification processes complying with Regulation (EC) No 216/2008 shall be considered as acceptable procedures for the verification of systems if they include the demonstration of compliance with the applicable interoperability, performance and safety requirements of this Regulation.

Article 12

Additional requirements

1. Air navigation service providers shall ensure that all personnel concerned are made duly aware of the requirements laid down in this Regulation and that they are adequately trained for their job functions.

2. Air navigation service providers shall:

(a) develop and maintain operations manuals containing the necessary instructions and information to enable all personnel concerned to apply this Regulation;

(b) ensure that the manuals referred to in point (a) are accessible and kept up to date and that their update and distribution are subject to appropriate quality and documentation configuration management;

(c) ensure that the working methods and operating procedures comply with this Regulation.

3. Operators shall take the necessary measures to ensure that the personnel operating and maintaining surveillance equipment are made duly aware of the relevant provisions of this Regulation, that they are adequately trained for their job functions, and that instructions about how to use this equipment are available in the cockpit where feasible.

4. Member States shall ensure compliance with this Regulation including the publication of the relevant information on surveillance equipment in the national aeronautical information publications.

[1] OJ L 79, 19.3.2008, p. 1.

The dissemination of Covid 19 pandemic all around the world announces the start of many problems in every economy sector.

In particular, aviation has been damaged because, in a lot of countries, flights were cancelled to contain the virus and avoid the diffusion.

For this reason, aviation operators, who works to inspect and update aircraft to make them in compliance with regulations, are going to benefit from an extension of the deadline in article 5 (paragraph 5) and in article 8 (paragraphs 1 and 2) of Implementing Regulation (EU) No 1207/2011: the new due date will be on 7th December 2020, so Implementing Regulation No 1206/2011 and 1207/2011 should be revised as a consequence.

Article 2 of the "Official Journal of the European Union" defines the conditions:

Article 2

Implementing Regulation (EU) No 1207/2011 is amended as follows:

(1) in Article 2, paragraph 2 is replaced by the following:

'2. This Regulation shall apply to all flights operating as general air traffic in accordance with instrument flight rules within the Single European Sky airspace with the exception of Article 7(3) and 7(4) which shall apply to all flights operating as general air traffic';

(2) in Article 4, paragraph 4 is deleted;

(3) in Article 5, paragraphs 5 and 6 are replaced by the following:

'5. By 7 December 2020 operators shall ensure that:

(a) aircraft operating flights referred to in Article 2(2) are equipped with serviceable secondary surveillance radar transponders that comply with the following conditions:

(i) they have the capabilities set out in Part A of Annex II;

(ii) they have the continuity sufficient to avoid presenting an operational risk;

30.4.2020 EN Official Journal of the European Union L 138/3

(b) aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued on or after 7 June 1995, are equipped with serviceable secondary surveillance radar transponders that comply with the following conditions:

(i) they have the capabilities set out in Parts A and B of Annex II;

(ii) they have the continuity sufficient to avoid presenting an operational risk;

(c) fixed wing aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, operating flights referred to in Article 2(2), with an individual certificate of airworthiness first issued on or after 7 June 1995, are equipped with serviceable secondary surveillance radar transponders that comply with the following conditions:

(i) they have the capabilities set out in Parts A, B and C of Annex II;

(ii) they have the continuity sufficient to avoid presenting an operational risk.

Points (b) and (c) of the first subparagraph shall not apply to aircraft that operate within the Single European Sky airspace and that belong to one of the following categories:

(i) they are being flown to undergo maintenance;

(ii) they are being flown for export;

(iii) their operations will be ceased by 31 October 2025.

Operators of aircraft with a first certificate of airworthiness issued before 7 December 2020 shall comply by 7 June 2023 with the requirements set out in points (b) and (c) of the first subparagraph, subject to the following conditions:

(i) they have established before 7 December 2020 a retrofit programme demonstrating compliance with points (b) and (c) of the first subparagraph;

(ii) those aircraft have not benefitted from any Union funding granted to bring such aircraft in compliance with the requirements set out in points (b) and (c) of the first subparagraph.

For aircraft where the capability of the transponders to comply with the requirements of points (b) and (c) of the first subparagraph is temporarily inoperative, operators shall be entitled to operate that aircraft in the Single European Sky airspace for a maximum of 3 consecutive days.

As we can read, this regulation must be applied to all flights operating as general air traffic respecting the instrumental flight rules inside the European sky airspace. The minimum feature requested to the SSR Transponder is Mode S Level 2, in accordance to performance and functionality

standards set in Annex X to the Chicago Convention, volume IV, third edition, included all amendments up to No 77 (Annex II part A, Official Journal).
Annex II part B of the Official Journal specifies that data items shall only be broadcasted by the Mode S protocol. This is referred to fixed wing aircraft with MTOM over 5700 kg or maximum TAS greater than 250 kts (about 460 km/h), operating flights described in Article 2 (paragraph 2), with a certificate of airworthiness released for the first time starting from 7th June 1995.

Mandate

Notwithstanding possible exemptions and time limited extensions as explained further below, operators shall ensure that **by 7 December 2020**:

a) All aircraft are equipped with serviceable secondary surveillance radar transponders having the capabilities set out in Part A of Annex II of Regulation (EU) No 1207/2011, requiring these aircraft to be compliant with **Mode S Elementary Surveillance**.

b) Fixed wing aircraft with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, for which the individual certificate of airworthiness was first issued on or after 7 June 1995, are equipped with serviceable secondary surveillance radar transponders having the capabilities set out in Parts A, B and C of Annex II of Regulation (EU) No 1207/2011, requiring these aircraft to be compliant with **Mode S Elementary, ADS-B Out and Mode S Enhanced Surveillance.**

c) Aircraft other than fixed wing with a maximum certified take-off mass exceeding 5 700 kg or having a maximum cruising true airspeed capability greater than 250 knots, for which the individual certificate of airworthiness was first issued on or after 7 June 1995, are equipped with serviceable secondary surveillance radar transponders having the capabilities set out in Parts A and B of Annex II of Regulation (EU) No 1207/2011, requiring these aircraft to be compliant with **Mode S Elementary and ADS-B Out Surveillance**.

Applicability

All the above provisions are applicable to all flights operating in accordance with instrument flight rules **within the Single European Sky airspace**.

Time Limited Extensions

Operators of aircraft with a first **certificate of airworthiness issued before 7 December 2020** shall comply **by 7 June 2023** with the ADS-B Out and Mode S Enhanced requirements, provided that:

- they have established **before 7 December 2020** a retrofit programme demonstrating compliance; AND
- those aircraft have not benefitted from any Union funding granted to bring such aircraft in compliance with the requirements.

For the time being, this **retrofit programme does not have to be submitted or approved by EASA**. However, EASA might decide at any point in time to verify compliance with the applicable requirements and verify whether all conditions have been met to benefit from these time limited extensions, which would include the establishment of a retrofit programme.

These rules are not applied to aircraft belonging to one of the following types:

- Aircraft in flight to be subject to maintenance
- Aircraft in flight for export
- The deadline for operations is within 31st October 2025

For those aircraft (general aviation or State aircraft) with transponder not pursuant to requirements as above, it's allowed their use up to three consecutive day inside the Single European sky airspace.

As written in the Article 3 of "Official Journal of the European Union", all requirements as above become law on the twentieth day after the Official Journal announcement (29th April 2020) for every member state, except for some categories that enjoy from special dispensations as explained previously.

Deadline to equip an aircraft with a Mode S Transponder

Operators operating as general air traffic under instrumental flight rules are required to equip their aircraft with Mode S transponders, in accordance with the SPI IR requirements by the following deadlines:

Aircraft with a first CofA issued prior to 7th June 1995:

- Aircraft with a first CofA issued prior to 7th June 1995, have to be:
    - ELS capable prior to 7th December 2020

Aircraft with a first CofA issued on or after 7th June 1995:

- Aircraft with a MTOM of 5700 kg or less with a maximum cruising TAS 250 kts or less, have to be:
    - ELS capable prior to 7th December 2020
- Rotorcraft (e.g. helicopters) with a MTOM exceeding 5700 kg or with a maximum cruising TAS greater than 250 kts have to be:
    - ELS capable prior to 7th December 2020
    - ADS-B out capable prior to 7th December 2020 or 7th June 2023 (where there is a retrofit programme in place prior to 7th December 2020)

- Fixed wing aircraft with a MTOM exceeding 5700 kg or with a maximum cruising TAS greater than 250 kts have to be:
    - ELS capable prior to 7th December 2020
    - ADS-B Out capable prior to 7th December 2020 or 7th June 2023 (where there is a retrofit programme in place prior to 7th December 2020)
    - EHS capable prior to 7th December 2020 or 7th June 2023 (where there is a retrofit programme in place prior to 7th December 2020)

According to the amendment, from 7th December 2020:

- Air operators shall have the ELS implementation completed;
- Airframes with first individual C of A issued on or after this date shall comply with ADS-B and EHS provisions as per SPI IR;
- Air operators shall indicate non-equipage in their flight plans
- Air operators should be able to show, on request by their competent authority:
    - a) ADS-B / EHS retrofit plans indicating compliance prior to 7th June 2023, or
    - b) fleet planning documents indicating a planned phase-out prior to 31st October 2025

Note:

- CofA: Certificate of Airworthiness
- ELS: Mode S Elementary Surveillance Capability
- EHS: Mode S Enhanced Surveillance Capability
- MTOM: Maximum Take Off Mass (certified)
- TAS: True Air Speed

Aircraft which have obligations to be provided by TCAS

From "Official Journal of the European Union", Commission Regulation (EU) 2016/583:

16.4.2016 EN Official Journal of the European Union L 101/9

ANNEX

'ANNEX

Airborne collision avoidance systems (ACAS) II

(Part-ACAS)

AUR.ACAS.1005 Performance requirement

(1) The following turbine-powered aeroplanes shall be equipped with collision avoidance logic version 7.1 of ACAS II:

(a) aeroplanes with a maximum certificated take-off mass exceeding 5 700 kg;

(b) aeroplanes authorised to carry more than 19 passengers.

(2) Aircraft not referred to in point 1 which are equipped on a voluntary basis with ACAS II shall have collision avoidance logic version 7.1.

(3) Point 1 shall not apply to unmanned aircraft systems.

AUR.ACAS.1010 ACAS II training

Operators shall establish ACAS II operational procedures and training programmes so that the flight crew is appropriately trained in the avoidance of collisions and becomes competent in the use of ACAS II equipment.'

Civil aircraft – Safety Assurance requirements				
Domain Programme Area	**Equipment Requirement**	**ECAC Airspace Requirement**	**Airworthiness or Operational Requirement**	**Remarks**
ACAS II	TCAS II Software Version 7.1 (adjacent column) ICAO Annex 10 vol.4, PANS OPS Doc 8168, PANS ATM Doc 4444, ICAO Doc 7030, ICAO Doc 9863 (ACAS Manual) ICAO Annex 6, Operation of Aircraft, Part 1 – International Commercial Air Transport – Aeroplane European Commission Regulation No 1332/2011, subsequently amended by Regulation No 2016/583	European Union Airspace: TCAS II version 7.1: - all (civil) aircraft with a maximum certified take-off mass exceeding 5,700 kg or authorised to carry more 19 passengers; - Aircraft not referred above but which are equipped on a voluntary basis with ACAS II, must be equipped with version 7.1. The above does not apply to unmanned aircraft systems. ECAC (outside EU airspace): All civil fixed-wing turbine-engine aircraft with a maximum take-off mass over 5,700 kg, or capable of carrying more than 19 passengers: aircraft with new ACAS installations after 1 January 2014 shall be compliant with version 7.1 and after 1 January 2017 all ACAS units shall be compliant with version 7.1 (per ICAO Annex 10 vol. IV, amendment 85, unless a State filed a difference).	European Commission Regulation No 1332/2011, subsequently amended by Regulation No 2016/583 For certification JAA TGL 8 Revision 2 For pilot training and operational procedures see ICAO PANS-OPS, Doc 8168, ICAO Doc 9863 and JAA TGL11. Guidance Document for MEL Policy JAA TGL 26	MEL for TCAS II throughout Europe is Class A - 10 days (excluding the day of discovery). MEL requirements concerning partial failures are listed in the TGL 26. Some States may have different requirements. E.g. in German airspace, the time period during which TCAS II may be inoperative is reduced to 3 days (refer to German AIP GEN 1.5 para 5). This applies to all aircraft.

In Figure 48 it's shown a summary of global mandates:

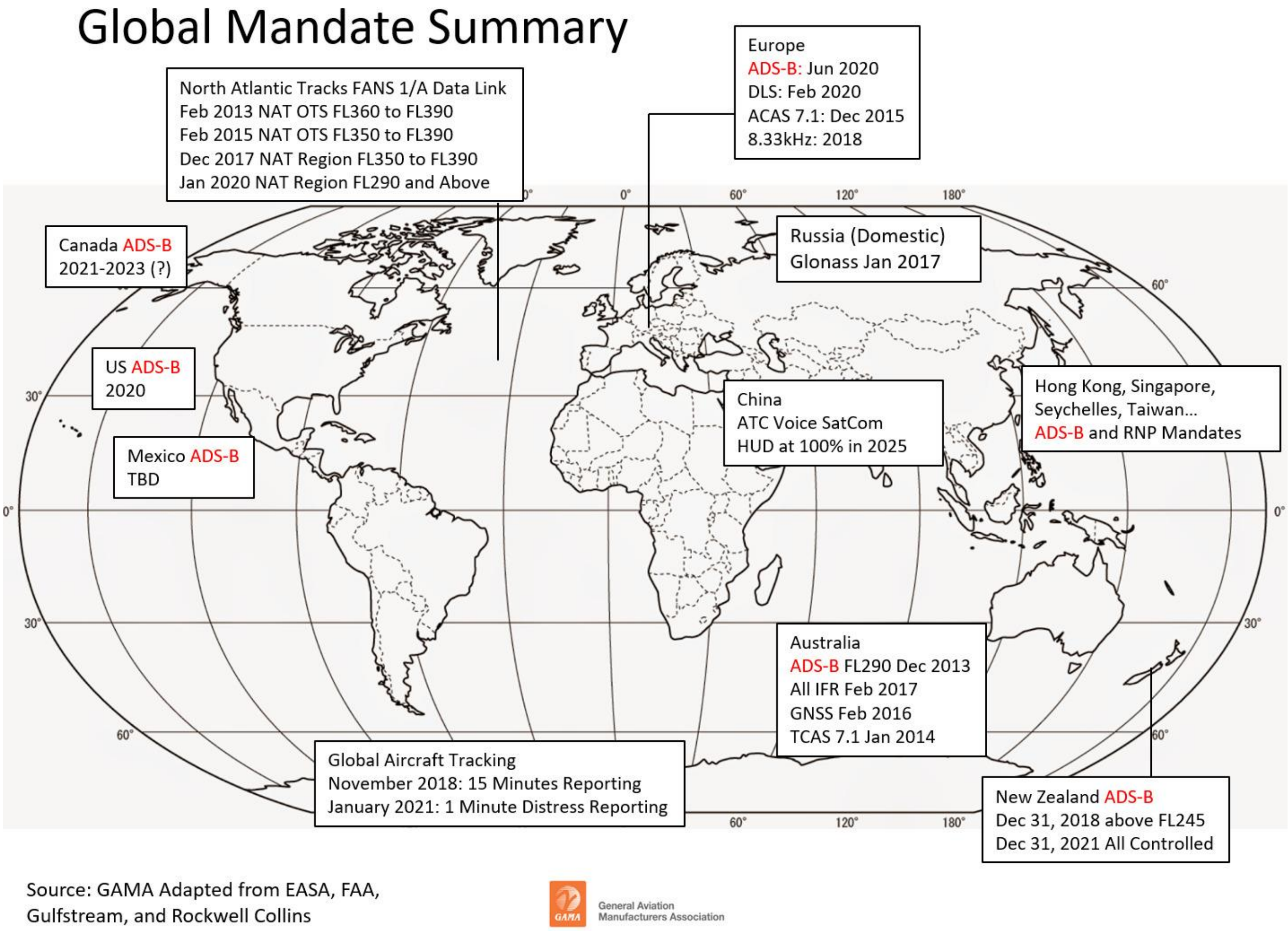


Figure 48

Notes

[1] Highest allowed speed is 463 km/h, but aircraft fly typically smaller speeds in these airspaces

[2] A DC-10 and a Boeing 747-400 were involved in this accident. The generation of RAs on both aircraft coincided with the controller instruction for the Boeing pilot to descend. The Boeing crew followed the ATC instruction, rather than the RA manoeuvre in the opposite direction. Late, aggressive visual avoiding manoeuvres by both pilots prevented the collision; however, 100 people on board of the Boeing were injured.

[3] A Tupolev 154 and a Boeing 757 were involved in this collision. The controller was unaware that RAs had been issued on both aircraft and instructed the Tupolev to descend while the RA called for a climb. The Tupolev pilot complied with the ATC instruction while the Boeing pilot followed his descend RA. The aircraft collided killing 71 people.

[4] Decision criteria for regulatory measures on TCAS II version 7.1, EUROCONTROL SIRE+ Project WP7/69/D, July 2008.

Glossary

ACAS I: Provides information as an aid to "see and avoid" action but does not include the capability for generating resolution advisories (RAs)

ACAS II: Provides vertical resolution advisories (RAs) in addition to traffic advisories (TAs)

ACAS III: Provides vertical and horizontal resolution advisories (RAs) in addition to traffic advisories (TAs)

ACAS X: A family of new collision avoidance systems currently under development. It takes advantage of recent advances in "dynamic programming" and other computer science techniques.

Accuracy: degree of conformity of the provided value of a data item with its actual value at the time when the data item is output from the surveillance chain.

ADS-B (Regulation (EC) No 1207/2011): automatic dependent surveillance — broadcast, a surveillance technique in which aircraft automatically provide, via a data link, data derived from onboard navigation and position-fixing systems.

Availability (Regulation (EC) No 1207/2011): degree to which a system or component is operational and accessible when required for use.

Aircraft identification (Regulation (EC) No 1207/2011): group of letters, figures or a combination thereof which is either identical to, or the coded equivalent of, the aircraft call sign to be used in air-to-ground communications, and which is used to identify the aircraft in ground-to-ground air traffic services communications.

Cluster: a set of Mode S interrogators connected with each other in the same network and using the same IC to share track information in order to allow aircraft acquisition already acquired by other stations in the same cluster.

Dwell time: duration that the target remains in the radar's beam during each scan.

Eligible Interrogator Code (Regulation (EC) No 262/2009): any code among the II codes and the SI codes, except:

1. II code 0;

2. the interrogator code(s) reserved for military entities, including intergovernmental organisations in particular North Atlantic Treaty Organisation (NATO) management and allocation.

Extended squitter: spontaneous periodic transmission of a 1090 MHz 112-bit Mode S signal format containing 56 bits of additional information (e.g. used for ADS-B, TIS-B and ADS-R).

Harmful interference (Regulation (EC) No 1207/2011): interference that prevents the achievement of the performance requirements.

Interrogation Rate Frequency (IRF): number of interrogations of a specified type transmitted over a one-second period.

Mode Interlace Pattern (MIP): sequence of interrogation periods that an interrogator is repeating.

MLAT: process of locating an object by accurately computing the time difference of arrival (TDOA) of a signal emitted from that object to three or more receivers.

Mode A/C Interrogation Recognition Probability or transponder availability (Mode A/C IRP): the probability of the aircraft recognising a Mode A/C interrogation in the presence of interference at 1030 MHz from other interrogators and from non-SSR equipment on the aircraft.

Mode S: cooperative surveillance technique for air traffic control, which enables the selective interrogation of aircraft and the extraction of air derived data through which new air traffic management functionalities, can be developed.

Mode S All Call interrogations: messages that are normally used by Mode S interrogators to acquire Mode S targets entering their area of coverage.

Mode S EHS: Use of downloaded flight parameters by ground systems in order to improve monitoring applications. It provides selected altitude, roll angle; true track angle and track angle rate, ground speed, magnetic heading, indicated airspeed, vertical rate and ACAS downlinked resolution advisories.

Mode S ELS: Use of downloaded aircraft identity, altitude, transponder capability report, SI code capability by ground systems for flight management.

Mode S interrogator (Regulation (EC) No 262/2009): a system composed of antenna and electronics, supporting addressing of individual aircraft through the Mode Select, known as Mode S.

Mode S Operator (adapted from Regulation (EC) No 262/2009): a person, organisation or enterprise operating or offering to operate a Mode S interrogator, including:

(a) Air navigation service providers;

(b) Mode S interrogators manufacturers;

(c) Airport operators;

(d) Military authorities;loc

(e) Research establishments;

(f) Any other entity entitled to operate a Mode S interrogator;

Power (visibility): power emitted by a radar to be visible by transponders.

State aircraft (Regulation (EC) No 1207/2011): any aircraft used for military, customs and police purposes.

Squitter: spontaneous periodic transmission by a Mode S transponder (nominally once per second) of a specified format, including the aircraft address, to permit passive acquisition.

Surveillance data (Regulation (EC) No 1207/2011): any data item, time stamped or not, within the surveillance system that pertains to:

• aircraft 2D position;

• aircraft vertical position;

• aircraft attitude;

• aircraft identity;

• 24-bit ICAO aircraft address;

• aircraft intent;

• aircraft velocity;

• aircraft acceleration

Transponder occupancy: a state of unavailability of the transponder from the time it detects an incoming signal that appears to cause some action or from the time of a self-initiated transmission, to the time that it is capable of replying to another interrogation.

Transponder processing time: time used by a transponder to receive an interrogation, process it, reply and recover or suppress.

Surveillance data processing system (Regulation (EC) No 1207/2011): system that processes all surveillance inputs received to form a best estimate of the current aircraft surveillance data.

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