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Analysis of differences between amendments - ICAO Annex 10, Volume IV

An agency of the European Union

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Table of content

List of Figures:

List of Tables:

1. Introduction

In Europe, Regulation (EU) N° 1207/2011, laying down requirements for the performance and the interoperability of surveillance for the single European sky (SPI-IR), requires all aircraft operating IFR/GAT in Europe to be compliant with Mode S Elementary Surveillance, whilst aircraft with maximum Take-Off Mass greater than 5700kg or maximum cruising True Air Speed greater than 250kts, must be compliant with both Mode S Enhanced Surveillance and ADS-B out requirements. Compliance was initially mandated by January 2015 for new build and by December 2017 for retrofit, with special provisions (including exemptions) for State aircraft.

A first revision of this Regulation has been approved in 2014 (EU) N°1028/2014. This revision mainly affected the dates of applicability for aircraft equipage retrofit (essentially for the ADS-B capabilities).

The last revision, Implementing Regulation (EU) 2017/386, amending IR (EU) No 1207/2011, was published in March 2017.

EASA has received the mandate from EU to revise these Regulations to ensure alignment of implementation dates with the FAA Regulation regarding ADS-B capabilities. The mandate also addresses the extension of the applicability to potentially all airsace users (including VFR only flights).

Mode S technology has been developed in the 70’s of the last century. When it has been designed it was coping with structural deficiencies of Secondary Surveillance Radar by the introduction of a selective call. This selective call acted as an addressing mechanism and opened the door for data exchanges between aircraft and ground radar stations using the basic secondary radar frequencies (i.e. 1030 & 1090 MHz).

Mode S was also initially designed to provide a full data-link capability compatible with the ATN OSI transport layer selected in ICAO as the transport layer standard in the 90’s of the last century. This functionality has been de facto ignored in the various avionic mandates and in the development of Mode S avionics by industry.

Two main surveillance functions are part of the Mode S design: the Elementary Surveillance (ELS) and the Enhanced Surveillance (EHS). In addition to these functionalities that are directly improving the basic cooperative surveillance function, additional squitter provision have been included leading to ADS-B capabilities. A summary of ELS and EHS capabilities and potential operational benefits is presented in Annex 1.

Finally, Mode S equipage provides also a significant improvement for Aircraft Collision Avoidance System (ACAS) by providing the data exchange capability between aircraft in case of conflict detection to coordinate the conflict resolution.

The following figure illustrates the Mode S EHS parameters exchanges mechanism.

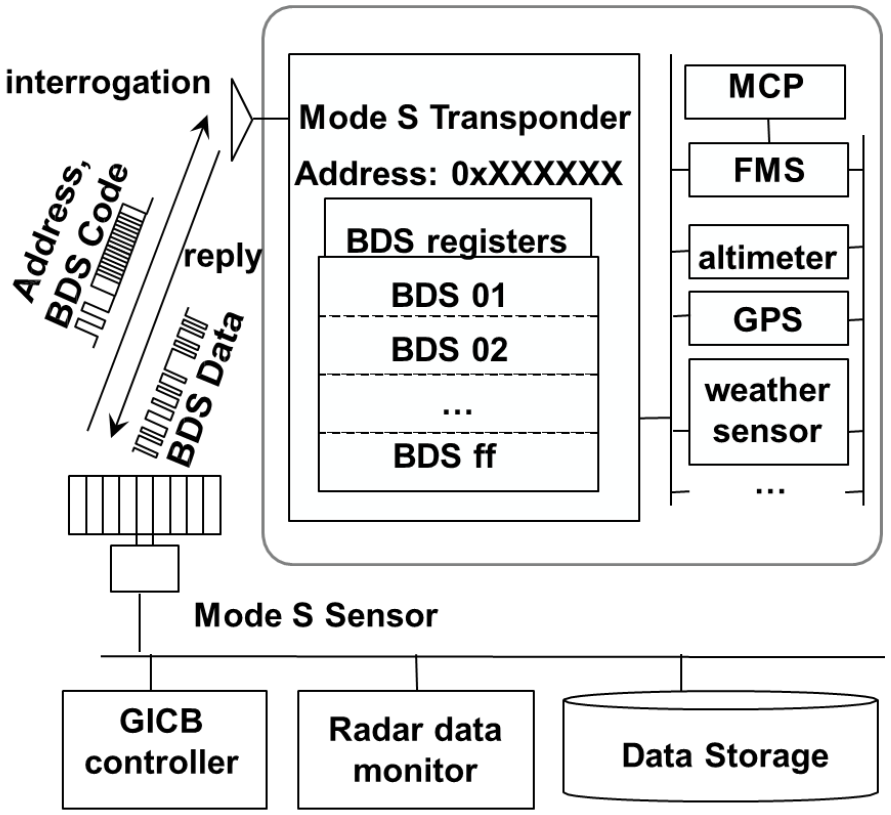

Figure 1 EHS parameter exchanges

2. Scope of the study

The intention and final objective of the study is to assist EASA in the task of revision of Regulation (EU) N° 1207/2011 on surveillance performance and interoperability (SPI regulation).

This regulation currently includes minimum capability requirements for the Mode S transponder, depending on the aircraft MTOM, speed and if it is a fixed wing aircraft or not.

The current regulation (EU) N° 1207/2011requires direct compliance with certain paragraphs of the ICAO Annex 10 Amendment 85 and does not mention Amendment 89. Additionally, EASA has issued the CS-ACNS which can be used as a means of compliance to this regulation. The Mode S equipment minimum standard level are covered by ETSO-C112d and ETSO-C112e, pointing to EUROCAE ED-73E and ETSO-C166b pointing to EUROCAE ED-102A.

Therefore, the scope of this study is to provide the link between the evolutions of ICAO Annex 10 (i.e. amendments 77, 85 and 89) regarding Mode S surveillance system focusing on the three following capabilities that are Elementary Surveillance (ELS), Enhanced Surveillance (EHS) and extended squitter function (ADS-B OUT), and their impact on the ATM surveillance function as far traffic separation is concerned. The operational impact of aircraft fitted with Mode S system only compliant with Amendment 77 on the surveillance chain and associated traffic separations will be particularly assessed.

The study will also provide the links between these system and functions evolutions and the standards that have been identified as relevant Means of Compliance through ETSO mechanism and their references within the CS-ACNS.

The study will identify the coverage of the EUROCAE standards with respect to system capability and functions as defined by ICAO Annex 10 evolutions.

This study should provide a clear identification of the nature of the technical and performance requirements that are added or changed by the various Amendments of Annex 10 Volume IV regarding Mode S system.

The result of this analysis should help EASA to assess the potential operational limitations induced by aircraft compliant only with the Amendment 77 on the overall performance of the surveillance chain in the European airspace context.

In order to achieve these objectives, the study will consist of the following steps:

1. The first step will consist in the identification of the changes covered by the various ICAO Annex 10 Amendments: The nature of the change wil be assessed based on the following criteria:
    - Function/service impacted (i.e. ELS, EHS or ADS-B squitter)
    - Addition or modification of existing requirements (e.g. higher performance and Mode S transponder robustness)
    - Frequency congestion mitigation
    - Impact on aircraft equipage (in particular the induced requirements to establish physical connection between avionic system on board or to upgrade the current equipment to integrated avionic solutions)
    - Backward compatibility

A binary comparison between the three ICAO Annex 10 Volume IV amendments will be conducted with respect to Mode S surveillance, ADS-B surveillance for both aircraft and ground systems, as follows.

- Amendment 85 versus Amendment 77
- Amendment 89 versus Amendment 85
- Amendment 89 versus Amendment 77

2. The second step will identify the operational impacts of these changes (limited to the scope of the regulation (EU) N° 1207/2011 that is ANSP surveillance chain performances and associated traffic separation):

   - On ELS and EHS requirements within the (EU) N° 1207/2011Regulation published in 2011 (based on Annex 10 Amendment 85);

   - The evolution (if any) included in the Annex 10 Amendment 89 (2014) that could be needed in the scope of the (EU) N° 1207/2011regulation and the technical complexity associated with airborne and ground system upgrades.

   - Potential operational limitations associated with Mode S transponder compliant with Amendment 77 only.

3. The third step will consist in the mapping between the above evolutions and the associated airborne and ground standards that could facilitate the compliance demonstration in order to demonstrate the good coverage of the standards:

   - List of current standards and standards revisions relevant to Mode S or ADS-B OUT capabilities
   - List of standards identified in the associated ETSO

4. The last step will consist in a set of recommendations addressing the minimum standards that could satisfy the safety, interoperability and performance objective of the surveillance chain as indicated in the SPI rule.

3. Scope of the Deliverable 2.

The second deliverable (D2) is providing the complete results of this study. It includes the changes resulting from the review of D1 and the sections covering the conclusions and recommendations.

4. ICAO Annex 10 Volume IV evolution history

4.1. General remarks

The ICAO requirements relative to surveillance are mainly provided by Annex 10 volume III *"Communication Systems "* and Volume IV *"Surveillance and Collision Avoidance System"*. The ICAO doc 9871 has also to be considered because from 2008 a part of Volume III (Appendix to Chapter 5) has been removed from this volume and moved into the ICAO Doc 9871 "Technical Provisions for Mode S Services and Extended Squitter".

In addition, Annex 6 *"Operation of Aircraft"* mandates aircraft operators to have on-board some specific capabilities starting from a given date.

It is important to keep in mind that the standards provided by ICAO in the Annexes with a SARPs statute are generally made mandatory through member State's enforcement. They only provide a number of capabilities the States can mandate to Airspace users or ANSPs. Amongst those capabilities States elect to mandate such or such subset. There are within the SARPS some rare mandates with an associated date when necessary to ensure safety.

In this context the present section will mainly focus on the capabilities used by the European regulation. For example, Volume IV defines 5 levels for the Mode S Transponders whereas the European regulation considered only Level 2. Only Level 2 will be addressed and ADS-R, ADS-B Non-transponders, ADS-B IN or TIS-B will not be considered in this study.

ICAO Annex 10 manages 3 categories of capabilities for the Mode S transponders:

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

Mode S transponders having those 3 capabilities are designated "2es".

This section addresses mainly the requirements relative to Elementary Surveillance (ELS), Enhanced Surveillance (EHS) and ADS-B. It must be noted that ELS and EHS requirements for harmonised

deployment in a given area are subject to local definition by the relevant authorities[1]. In the case of the European airspace, the technical details associated with ELS and EHS are defined in the regulation and translated into the CS-ACNS (it must be noted that for ADS-B it mandates only a subset of the ICAO ADS-B version 2 parameters).

Main steps of modifications of the ICAO Annex 10 Volumes III and IV and the associated documents (Doc 9871 and Annex 6):

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 1 ICAO Mode S relevant document update

In parallel, ICAO Annex 6 was consistently modified to mandate ACAS and 25 ft altitude resolution on Commercial Air Transport as well as pressure-altitude reporting transponders for International General Aviation and Helicopters.

[1] ELS and EHS are not defined by the ICAO documents. They have been defined by the European regulations using two subsets of functionalities offered by the ICAO SARPS.

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.

Note: 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.

4.2 Changes from Amendment 77 to Amendment 85

In fact, before the publication of Amendment 85, a previous Amendment covered the Mode S aspects. This Amendment is Amendment 82 that took place in 2007.

4.2.1 Amendment 82 published in 2007:

Amendment 82 covers inter alia the Annex 10 Volume IV dealing with Mode S.

In complement to the Volume IV modifications it also introduces a modification of the Appendix to Chapter 5 in Annex 10 Volume III. This Appendix was removed from Annex 10 and inserted within Doc 9871 to lead to the Edition 1 of this document (“Technical Provisions for Mode S Services and Extended Squitter”). 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.

4.2.2 Amendment 85 published in 2010:

Amendment 85 covers inter alia the Annex 10 Volume IV dealing with Mode S.

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 85-4[2]), and at improving the robustness against radio-frequency interferences.

[2] See Annex 7 where the main Annex 10 Volume IV changes are listed and characterised.

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 switch[3], succesive 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); and
  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.

4.3. 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 foreward fit shall no longer reply to Mode A/C/S all-call interrogations (89-8).

[3] 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 operationaly transparent for ground radar non 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 polution 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.

A number of 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.

4.4. 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:

- The evolutions consist essentially in improvements and clarifications.
- The majority of modifications are relative to the reduction and prevention of RF pollution.
- The interoperability is maintained on the principle of backward capability.
- 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 robutsness 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 amendments bring 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)

5. The operational impact assessment of the various amendments

5.1. General operational considerations

In order to facilitate the transition between the classical SSR based surveillance service and the Mode S based surveillance service (ELS and EHS), the Mode S system (in this case the ground radar station) must use two interrogation methods :

- All-Call interrogation
- Selective interrogation

All call interrogations:

All-call interrogations are issued regularly as it is done with conventional SSR. Any Mode S transponder that is not yet 'locked out' will reply to an all-call interrogation, transmitting its unique 24-bit aircraft address, allowing to switch to Selective interrogation mode. This is needed, to ensure that the ground station acquires new aircraft not previously detected.

Once a Mode S transponder is recognised by the ground station, (and its track has been created with the surveillance chain), it switches to the 'locked out' status. At this stage the Mode S transponder does not answer to any all-call interrogations, it will then only respond to Selective interrogations. However, it will continue to respond to interrogations from other Mode S sensors with a dissimilar Identifier Code, to Mode 3/A sensors and to ACAS interrogations.

The lockout concept is one of the major features that radically reduce frequency pollution by reducing the reply rates.

Selective interrogations:

Selective interrogations use the unique 24-bit aircraft address. It is generated close to the azimuth where the aircraft is expected to be. Only the aircraft addressed will reply to this interrogation, with its aircraft identification, altitude and Mode A code (assuming one has been assigned).

So the first advantage of Mode S is associated with the selective interrogation feature that eliminate the collision of transponders answers (known as garbling) and also allows the downlink of airborne specific parameters that could be used for enhancing the ATM services (e.g. anticipate the aircraft turn in the radar data processing tracking tool, or getting key information like selected altitude to detect misinterpretation of clearance and thus increasing safety)

5.2 Elementary Surveillance evolutions

The main improvement associated with the introduction of Mode S Elementary Surveillance is the capability to identify automatically an aircraft unambiguously and uniquely by using a 24 bits address associated with the aircraft frame itself. This automatic identification is essential in the global surveillance function chain to correlate the Mode S information with the flight plan information. Based upon this correlation it allows the selective interrogation of the Mode S aircraft using the predicted aircraft position provided by the flight data processing system.

These informations are stable since the introduction of Mode S in Annex 10. All the evolutions regarding ELS that have been included in Annex 10 have not changed the content and mechanism

to collect these basic information. Due to this stability any Mode S transponder compliant to any one of the ICAO Annex 10 amendments will behave correctly and transparently for the surveillance chain.

Some additional changes have been introduced in order to increase the Mode S receiver robustness in presence of interfering signals. These aspects are considered in section 5.5 on “1090 MHz frequency pollution limitation considerations”

5.3. Enhanced Surveillance evolutions

Associated with the selective interrogation is the capability to downlink airborne parameters: the Downlink Aircraft Parameters (DAPs). This feature corresponds to the EHS capability. When an aircraft is capable to downlink the 8 parameters presented in the following table it is considered Mode S EHS capable.

Note: if the parameter ‘Track Angle Rate’ cannot be provided, ‘True Air Speed’ should be used instead.

BDS Register	Basic DAP set (if “Track Angle Rate” is available)	Alternative DAP set (if “Track Angle Rate” is not available)
BDS 4,0	Selected Altitude	Selected Altitude
BDS 5,0	Roll Angle	Roll Angle
	Track Angle Rate	
	True Track Angle	True Track Angle
	Ground Speed	Ground Speed
		True Airspeed
BDS 6,0	Magnetic Heading	Magnetic Heading
	Indicated Airspeed (IAS) /Mach number Note: IAS and Mach number are considered as 1 DAP even if technically they are 2 separate ARINC labels. If the aircraft can provide both , it must do so).	Indicated Airspeed (IAS) /Mach number Note: IAS and Mach number are considered as 1 DAP even if technically they are 2 separate ARINC labels. If the aircraft can provide both , it must do so).
	Vertical Rate (Barometric rate of climb/descend or baro-inertial)	Vertical Rate (Barometric rate of climb/descend or baro-inertial)

Table 2 List of essential DAP required for EHS service

Regarding the various BDS presented in the table above, no content nor format changes have been introduced in the different ICAO Annex 10 Amendments since Amendment 77. Therefore it is clear that aircraft fitted with Mode S transponder compliant with any of these Annex 10 Amendments would behave seamlessly from the surveillance chain point of view.

Nevertheless, it must be noted that the SPI IR requires the “Barometric Pressure Setting” to be downlinked as part of the EHS. This parameter is identified in the ICAO SARPS but it was not required by AMC 20-13 or by Doc 7030.

The figure below illustrates the “BDS Swap” problem of synchroneous interrogations and wrong DAP identification. This is the major defect that is corrected by the BDS Swap change in Amendment 89.

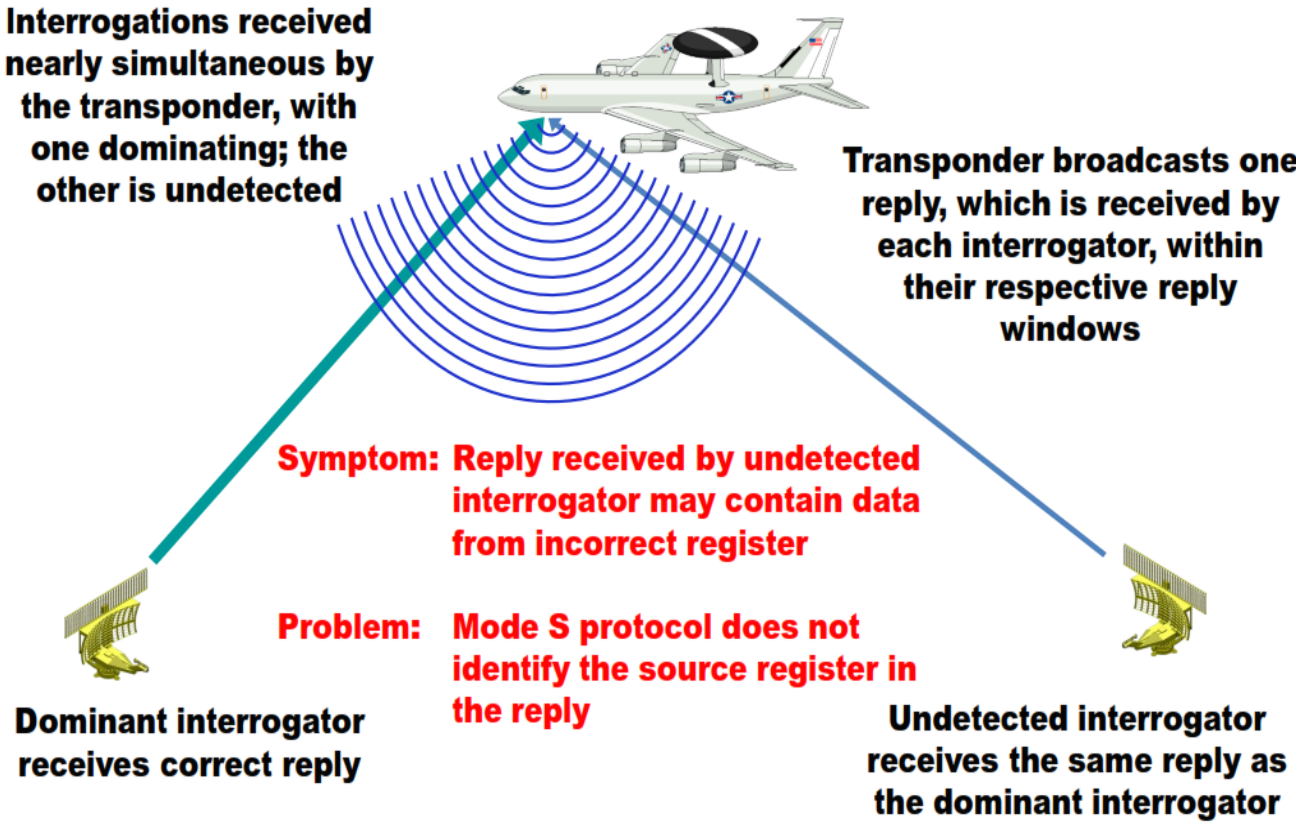

Figure 2 BDS Swap mechanism

BDS swap is a defect that has been observed in high density Mode S interrogators area. It must must be corrected because it impacts the efficiency of the overall surveillance chain. The defect correction will contribute to :

- Avoid false conflict detection and alert and thus minimizing false alarms and improve the airspace access management
- Swap phenomenon being typically a one-scan event only, meaning that correct data will be refreshed within few seconds, discarding also good data has little effect due to the ATM automation that coast through data absence

But using incorrect data can mislead controllers and/or automation including incorrect indications of changes in acceleration or flight path. Basic mitigations are provided by ATM system, but it can take several radar processing cycles to recover the correct situation.

To be noted that this new function is backward compatible with existing systems and that it is transparent for the system not implementing it yet.

5.4. ADS-B evolutions

ADS-B (Mode S Extended Squitter) has evolved regularly during the cycle of ICAO Annex 10 changes from Amendment 77 to Amendment 89. These evolutions have been summarised through the introduction of three Extended Squitter versions, named version 0, 1 and 2.

The evolutions associated with these three versions (Version 0 being the baseline) are presented in a complete comparison table in Annex 5. The detailed analysis of these parameters and their comparison with ELS/EHS parameters will be done in the second study (SC 002-2016).

The main changes associated with the new ADS-B versions (i.e. 1 & 2) are mainly dealing with the format and structure of the data rather than the data themselves but also with the information qualifier (NIC/NAC) that contribute to provide an appropriate level of integrity to the information broadcasted by the Extended Squitter. The changes that take place with version 1 and version 2 were essentially of two types:

1. Relocation of an existing Register field to another field in the same register or in an other register (format change type),
2. Duplication of an existing field within another register,
3. Introduction of new items that were not included in the previous version.

Version 2 introduces significant changes from the previous versions mainly regarding the following elements:

Register 05:

Introduction of the “NIC Supplement-B” replacing the former “Single Antenna Flag”. This new information is required by the EASA CS-ACNS in the ADS-B section.

Register 61:

The scope of information have been extended with version 2 to include the “Mode A code” and “Threat Identity Data”. They are required by the EASA CS-ACNS in the ADS-B section.

Futhermore “Aircraft status Message - Emergency/priority status” field has been replaced by “Aircraft Status Message - ACAS RA Broadcast”[4]

Register 62:

This is the register that was significantly changed with version 2. New data have been included (Autopilot Engaged, VNAV mode Engaged, LNAV mode Engaged, Altitude Hold Mode, Approach mode). None of these new information are required by the EASA CS-ACNS regarding Mode S. Other new items required by the EASA CS-ACNS in the ADS-B section have been added.

Register 65:

This register has been also significantly changed with version 2. New fields were added but they are not mandated by the EASA CS-ACNS on Mode S (1090 ES IN, UAT IN, Horizontal Reference Direction (HRD). Other new items required by the EASA CS-ACNS regarding ADS-B as: have been added:

[4] This last field is not required by EASA CS-ACNS on Mode S Extended Squitter

The majority of these changes consist in reallocation of field within Register to cope with new format of information and in addition of new informations.

The comparison of the information provided to the surveillance chain through ELS/EHS on one hand and through ADS-B on the other hand will be addressed in details in the deliverable associated with the second Special Contract dealing with such comparison (SC 002-2016).

The initial ADS-B ground surveillance applications using directly the ADS-B messages from aircraft are presented in Annex 6.

5.5. 1090 MHz frequency pollution limitation considerations

5.5.1. General considerations

Secondary radar works by transmitting an interrogation signal on 1030 MHz to which the transponder replies on 1090MHz. There are several modes of interrogation. For civil ATC, modes A,C and S are important.

1090 Mhz frequency is currently used for SSR Mode A/C replies and Mode S communication (ELS-EHS replies and ADS-B broadcasts) by civilian aircraft and some of military IFF modes.

- The uplink signal (interrogation) is a simple pulse encoding (Mode A/C) or a Differential Phase Shift Key modulation (Mode S / TCAS) on 1030 MHz.
- The downlink signal (replies, unsolicited squiters) is a simple pulse encoding (Mode A/C) or Pulse Position Modulation (Mode S / TCAS / ADS-B)

Originally only Mode A & C were available. Mode A and Mode C being not addressed, every transponder receiving a Mode A or Mode C interrogation will reply. These simultaneous replies causes two 1090 MHz frequency interference problems, known as garbling and FRUIT.

FRUIT:

False Replies Unsynchronised to Interrogator Transmission (FRUIT) is caused by replies that are triggered by other radars than the basic one used to track it. When multiple radars operate in an area, transponders can be forced to answer to other radars interrogations and conversely the radar could be polluted by a reply to another radar. These false replies could lead to wrong range estimation and in addition to confusions on the altitude reporting (there is no way to identify the nature of the reply (mode A or mode C).

Garbling:

Caused by the overlap of replies from multiple transponders within the same radar beam. A transponder replies on 1090 MHz with a number of pulses. For Mode A & C, there are at most 12 pulses between a set of framing pulses. When multiple aircraft reply to the same interrogation, these pulses mix up makes difficult to find out which transponder sent which pulse. This leads to false altitudes or false squawk codes that must be filtered out in the Radar Data Processing system (RDPS) on the ground. The result of this garbling mechanism is a serious decrease of the surveillance efficiency.

The FRUIT pollution today is mainly generated by Mode A/C replies. FRUIT is expected to grow almost linearly with traffic growth unless significant de-commissioning of SSR takes place.

FRUIT on 1090 MHz depends on:

- SSR/Mode S ground interrogators
  - ✓ Fixed ground civil surveillance infrastructure
  - ✓ Fixed and tactical military systems
- aircraft traffic density and ACAS/ADS-B equipage

L-band (i.e. 1030 and 1090 MHz) saturation has been a problem for a long time and it is the main reason to deploy Mode-S SSR in the congested areas. It substitutes initial all-call by a "roll-call", thus selectively interrogating aircraft instead of calling all aicraft within the radar beam.

Many discussions among the ATM stakeholders have taken place during the last decade in order to rationalise the radar Mode S infrastructure, in particular by sharing common radar for cross-border surveillance. Addition of new radars in already congested areas is made very difficult by spectrum protection regulations.

Multi lateration system could be also a good mitigation to the frequency occupancy issue by reducing the number of specific interrogations and relying on the Extended Squitter broadcast to get a high rate independent position elaboration on the ground.

There are some geographical areas where the 1090 MHz frequency is already very busy (e.g. Frankfurt area in Germany and the Los Angeles Basin airspace in the USA. Reduction of SSR's is only possible if all Mode A/C only transponders are phased out. Currently, Mode A/C operation is using a lot of the capacity on 1090MHz and is the nominal mode in a very large part of the European region.

5.5.2. First Mode S benefits

Mode S was introduced to overcome these Mode A/C problems. Mode S requires more sophisticated radar and transponder.

- Most Mode S interrogations are addressed; the interrogation contains the unique 24 bit address of the aircraft it is interrogating. This reduces the probability of garbling since other aircraft will not reply
- Unaddressed Mode S interrogations will solicit replies that contain the address of interrogator (radar). This prevents FRUIT since the radar can verify that the reply is correctly addressed.
- Unlike Mode A/C which does not have any error checking, a Mode S reply contains a 24 bit CRC check code.
- Mode S Altitude and identity (squawk) replies have their own identifier so they can be distinguished.
- Mode S radars can be operated in clusters and coordinate between them who is interrogating which aircraft at which time. This further reduces the message load and garbling / fruit probability.

Despite all the enhancements, Mode S radars are still receiving garbled messages[5] and FRUIT, but are much better equipped to cope with it than a Mode A/C legacy radar due to the addressing and CRC checks.

Since TCAS works on the same frequency as secondary radar, radars could occasionally receive TCAS messages. But since these have another downlink format (DF 0, DF 16) they are filtered out in the RDPS.

Similarly, Mode S extended squitter (ADS-B) (DF 17 / 18) when received by the radar could be also filtered out in the RDPS.

Garbling remains a concern with Mode S. Nevertheless, last Mode S radar generation are more robust against garbling due to their narrow antenna beam width and advanced degarbling processing technics.

Other systems using Mode S like TCAS, ADS-B receivers and Wide Area Multi-lateration systems using omnidirectional antennas receive more often overlapping messages. These systems could filter them out using modern digital signal processors discriminating them by their respective signal strength.

To reduce the number of Mode A/C replies, Mode S radars will include an extra pulse when interrogating in Mode A or C, so that Mode S capable transponders will not reply to these A/C interrogations.

Additionally, the removal of all call interrogations will also alleviate the frequency congestion.

5.5.3. ADS-B contribution to 1090 MHz congestion

On top of these 1090 MHz traditional pollution mechanisms, it is anticipated that the 2020 ADS-B Mandate in certain airspaces (Mandate for European airspace and CONUS airspace), will increase the number of transmissions on the 1090 MHz frequency that will be highly congested in the future if no specific measures are taken.

Indeed, there are certain methods/precautions to limit this congestion like randomized broadcast timing (between 0.4 s and 0.6 s for Airborne Position for example).

The direct impact of ADS-B operations is an increase of the 1090 MHz usage. At the same time, it could lead to the decomitioning of Mode-S radars. It will also reduce the TCAS 1090 MHz frequency usage[6] with reduced interrogation rates (ACAS X), and it reduces the number of interrogations needed by Wide Area Multilateration (WAM) systems.

On the long term the impact of ADS-B will likely be positive. But during the transition period towards a full ADS-B environment, the increase of the 1090 MHz congestion will remain a concern due to the increase of the number of flights.

[5] a Mode S reply can be either short (56 bit) or long (112 bit). ADS-B messages are 112-bit long. Every bit transmission takes 1µs, and for each reply contains an 8µs preamble. So, a message takes either 64µs or 120µs. Every second, a Mode S transponder sends 1 unsolicited Short Squitter, and between 2 and 6 Extended Squitter when ADS-B equipped.

[6] It must be noted that TCAS exchanges are in some areas the most significant contributor to the frequency occupancy time. Introduction of ACAS-X will de facto strongly reduce such contribution.

5.5.4. Impacts of Annex 10 Amendments on the frequency congestion

Amendment 85 brought strenghtened requirements regarding the robustness of Mode S airborne receivers in order to make them less impacted by some RF interferences. These features have been captured in ED-73E EUROCAE standard.

Amendment 89 on top of the two previous relevant ones for Mode S is centred on the mitigations of future 1090 MHz frequency congestion. It covers mainly two evolutions:

1. Reduction of Mode S transponder replies to:
    a. Mode A/C interrogations
    b. Specific all-call Mode S interrogations
    c. broadcast of the full set of 1090 ES messages for surface aircraft.

    To this end, ICAO Annex 10 requires that, after 2020, new Mode S transponder equipment in aircraft foreward fit shall no longer reply to Mode A/C/S all-call interrogations .

2. For aircraft without squat switch, transponder capability to temporally not reply to Mode A/C and Mode S All-Call interrogations

These new ICAO requirements should be included in the new mandate targeted for 2020 regarding the forward fit case, because it is an essential step to safeguard the system in the long terms.

Regarding retrofit as far as the non compliance with these ICAO requirements have no impact on the surveillance chain itself and its performances, there is no urgency to require these capabilities.

6. Analysis of the relevant standards and their coverage of the various amendments

6.1 ICAO Annex 10 Volume IV implementation in Europe.

Based on the ICAO provisions described above, Europe has implemented steps by steps a number of subsets of the ICAO Annex 10 Volume IV requirements. According to the type of aircraft and of Airspace to enter in, aircraft may comply with different categories of standards covering:

- Mode A/C only (Surveillance with Altitude reporting)
- Mode S Elementary Surveillance (ELS)
- Mode S Enhanced Surveillance (EHS)
- ADS–B (1090 MHz Extended Squitter)

6.1.1 Mode A/C only (Surveillance with Altitude reporting)

In the past, Mode A/C only was made mandatory by many States in Europe in most Airspaces and for the majority of aircraft: EASA certification requirements were covered in ETSO-C74d. MODE S transponders need to have this capability as well (ETSO-C112 any revision.).

6.1.2 Mode S Elementary Surveillance (ELS)

Elementary Surveillance was initially defined by JAA TGL 13 and, starting from December 2011, by the European Commission IR 1027/2011 and, since December 2013, there is the EASA certification specification EASA CS-ACNS

It has been mandated by a number of European States in 2007. The European Commission IR 1027/2011 as amended by IRs 1028/2014 and 386/2017will mandate it by 2020 for given flights and aircraft categories in European airspaces.

6.1.3 Mode S Enhanced Surveillance (EHS)

Enhanced Surveillance was initially defined by EASA ACJ 20X11 and then AMC 20-13. Since December 2011 it is defined by the European Commission IR 1027/2011 and, since December 2013, by EASA CS-ACNS.

It has been mandated by a number of European States in 2007. The European Commission IR 1027/2011 as amended by IRs 1028/2014 and 386/2017will mandate it by 2020 for given flights and aircraft categories in European airspaces.

6.1.4 ADS–B (1090 MHz Extended Squitter)

1090 MHz Extended Squitter was defined in 2008 by EASA AMC 20-24 for specific Airspaces (Non-Radar Areas using ADS-B Surveillance (ADS-B-NRA)). From December 2011 it is defined by the European Commission IR 1027/2011.

It will become mandatory complying with the European Commission IR 1027/2011 and EASA CS-ACNS requirements by 2020 (IR 1027/2011 as amended by IRs 1028/2014 and 2017/386) for given flights and aircraft categories in European airspaces.

Other ADS-B mandates are also existing in other regions, the most important is the FAA mandate that is today synchronised with the European one, but with significant differences. More details will be provided in the second study (SC 2016-002).

6.1.5 Summary of ICAO Annex 10 implementation in the European framework

Each category is supported by a number of EASA regulations and industry standards (EUROCAE). The hierarchy of these documents is shown in the following table. Each layer adds its own relevant materials:

	ICAO Annex 10 <= Amdt 77	ICAO Annex 10 Amdt 77			ICAO Annex 10 Amdt 85
Airspace regulation (1)		European State regulations	European State regulations		European SPI 1207/2011+
	Mode A/C	ELS	EHS	ADS-B	A/C+ELS+EHS+ADS-B
Airworthiness (and OPS) regulations		TGL 13 Rev 1	AMC 20-13	AMC 20-24	CS-ACNS
EASA ETSOs	ETSO-C74c	JTSO-2C112b	ETSO-2C112b	ETSO-2C112b	ETSO-C112d (*) ETSO-C166b
Industry standards (2)	EUROCAE 1/WG9 /71	ED-73B ED-102	ED-73B ED-82A	ED-73B ED-102	ED-73E ED-102A

(*) The CS-ACNS refers to ETSO-C112d but a new version ETSO-C112e has been published in 2016 in anticipation of a future Annex 10 Vol IV amendment correcting multiple Comm-B broadcast deficiencies. Nevertheless this version does not cover all the required changes from Amendment 89 (i.e. “not answering to all call interrogations”).

Table 3 Links between regulatory materials and standards

Notes:

(1) The different categories generally result from Airspace regulations. Only European regulations are mentioned here but some regions of the world implement ADS-B according to AMC 20-24 or FAA AC 20-165 for example.

(2) Other ETSOs and EUROCAE documents are called particularly documents relative to the sources (ED-46 for Altimeter Coding) or relative to the GNSS sensor (ETSO-C129a, ETSO-C145/C146...).

Each category, except Mode A/C, is reviewed in the following sections from the standard point of view:

6.2 Previous regulations on ELS, EHS and ADS-B

They are all based on ICAO Annex 10 amendment 77. As the State Regulations were very high level (or missing for ADS-B) the first layer of EASA starts with the definition of the application. Then the successive layers of documents are in accordance with this amendment but they add airworthiness requirements and performance or safety requirements because ICAO Annex 10 provides mainly requirements for interoperability with ground radar or surrounding aircraft and does not provide requirements relative to performance.

6.2.1 ELS

TGL 13 Rev 1 defines ELS in accordance with Amendment 77, it calls JTSO-2C112b and adds safety requirements. For example, the consequences of errors or loss of transmission by the transponder of Aircraft ID, Altitude and Flight Status are classified “Minor”. It is not a quantified requirement but it will be used by the applicant to demonstrate the safety level. It is clearly specified that it is not a very demanding requirement because it is assumed that ELS will be used by controllers and subject to verification or check.

JTSO-2C112b calls EUROCAE ED-73B which ensures compliance with ICAO Annexe 10 Amendment 77.

ED-73B calls ED-14D for the Environmental Conditions but in fact, according to ETSO Subpart A, the ED-14 edition should depend upon the date of approval.

6.2.2 EHS

AMC 20-13 defines EHS in accordance with Amendment 77. In line with the State regulations, the transmission of Barometric Pressure Setting is not mandatory. It adds safety requirements: with the same limitations than for ELS, the consequences of errors or loss of transmission of the EHS parameters are Minor.

It calls JTSO-2C112b and ED-73B. They are consistent with Amendment 77. Same remark as for ELS concerning the Environmental Conditions.

6.2.3 ADS-B

AMC 20-24 specifies ADS-B in accordance with Amendment 77. It was initially intended for certification of ADS-B for use in the “ADS-B NRA” (ADS-B for non-radar environment) application defined by EUROCAE ED-126. AMC 20-24 provides performance requirements (latency, aircraft

position...). The requirement for the integrity of the processing chain for aircraft position is 10^{-5}/FH. The requirement for the continuity of the overall ADS-B system is 2.10^{-4}/FH.

AMC 20-24 calls ETSO-2C112b ED-73B and ED-102 which are consistent with Amendment 77.

6.2.4 (EU) N° 1207/2011 regulation

The European (EU) N° 1207/2011 regulation provides the detailed definition of ELS (which includes Mode A/C), EHS and ADS-B. Concerning the aircraft side the requirements are based on a selection of ICAO Annex 10 Amendment 85 requirements with some refinements (Annex II of this regulation). ADS-B version 2 is selected. Its ads a number of performance requirements:

- continuity of the transponder functionality supporting the Mode S protocol: 2.10^{-4} / FH (surprisingly it is largely more demanding than the value required by the previous ELS definition by TGL 13); There is no integrity requirement.

- ADS-B : latency, continuity of the transponder functionality supporting the ADS-B protocol (2.10^{-4}/FH), integrity of the transponder system supporting ADS-B and integrity of some sources.

When ADS-B is present, the regulation adds new requirements that ELS and ADS-B use the same sources for the following parameters: SPI, emergency status, pressure altitude, barometric vertical rate, (MCP/FCU) selected altitude, barometric pressure setting and ACAS active resolution advisoriesThose requirements were not included in AMC 20-24.

There is a non-airworthiness requirement (Article 7.1 of this regulation) requiring a check at least every two years that a number of data transmitted by ELS, EHS and ADS-B are correct.

The EASA CS-ACNS provides the necessary airworthiness requirements. There is no reference to a specific ICAO Annex 10 amendment but the compliance with amendment 85 is ensured via the ETSOs which are called and finally the EUROCAE MOPSs:

- Mode A/C only: ETSO-C74

- ELS: the CS-ACNS requires a “remote” qualitative probability for continuity which is consistent in airworthiness words with the 2.10^{-4}/FH requirement in the SPI but makes the requirement more stringent. It calls ETSO-C112d (or ETSO-C112e) which calls EUROCAE ED-73E

- EHS: the qualitative probability requirement for continuity of the transmitted parameters is less stringent (Probable). ETSO-C112d (or ETSO-C112e) and EUROCAE ED-73E are applicable.

- ADS-B: the integrity requirements for the critical parameters are specified consistenly with the SPI requirements (major failure condition). The continuity requirement is identical to the ELS one (remote qualitative probability). ETSO-C166b and ETSO-C112d (or ETSO-C112e). They respectively call EUROCAE ED-102A and ED-73E

ED-73E and ED-102A ensure compliance with ICAO Annex 10 Amendment 85 and Doc 9871 Version 2 but in addition ED-73E contains some requirements in anticipation of Amendment 89:

- a number of requirements contribute to the reduction of frequency loading.

  However the Amendment 89 requirement supressing the transponder replies to Intermode Mode A/C/S all-call interrogations as of 2020 is not included in ED-73E.

- The Amendment 89 requirement adding Data Parity with Overlay Control as of 2020 for new equipment is part of ED-73E (with immediate applicability). It solves the “BDS swap” issue (see above) which was of concern for European ANSPs.

- The Amendment 77 requirements for aircraft without squat switch were modified by Amendment 85. The drawback was to modify the on-the-ground Status broadcast to surrounding ASAS when the ground forces transponder to send Surface Position Messages. Amendment 89 comes back to the Amendment 77 situation: the ground command no more impact the on-the-ground Status and in addition the transponder is forced to temporally not reply to Mode A/C and Mode S All-Call interrogations.

6.3 Additional relevant standards

6.3.1 OSED/SPR documents

Industry (EUROCAE and RTCA) has also produced the “Operational Services and Environment Description” (OSED) and associated “Safety and Performance and Interoperability Requirements” (SPR) documents to support ADS-B ES operational usage. They have two roles:

- the first goal of these documents is to ensure that compliance with SPR will satisfy the expected operational objectives when deployed in a real environment. SPR allocates requirements to airborne system and ground system (Safety Performance and Interoperability Requirements - SPR) in order to perform new operations. It is based on a reference environment (airspace, traffic...) and a description of the new operations (Operational Services and Environment Description - OSED). The goal of the OSED is to ensure that new aircraft and ground system/function compliant with the SPR will fulfil the operational objectives when implemented in a real environment close to the reference environment.

- the second goal is to facilitate the mandatory Safety Assesment that must be conducted by ANSP before providing operations associated with a given SPR standard. ANSPs can use the OSED/SPR document as a basis to perform their own safety assessment while taking into account their specific real environment.

EUROCAE/RTCA has developed several OSED/SPR documents in relation with surveillance services:

a) <u>For surveillance in Non radar airspace:</u>

   - Safety Performance and Interoperability Requirements for ADS-B in Non Radar Airspace (ADS-B NRA), EUROCAE ED-126 / RTCA DO-303, 2006

b) <u>For surveillance in Radar airspace:</u>

- Safety Performance and Interoperability Requirements for ADS-B in Radar Airspace (ADS-B RAD), EUROCAE ED-161 / RTCA DO-318, 2009

c) For surveillance on the Airport surface:

- Safety Performance and Interoperability Requirements for ADS-B for Airport Surface Surveillance (ADS-B APT), EUROCAE ED-163 / DO-321, 2010

All those documents are consistent with the current surveillance standards. They have been used by ICAO as a basis to define ADS-B Version 2 and by the European Commission to allocate to aircraft and to associated ground systems a number of performance and safety requirements that have been explicitly mentionned in the (EU) N° 1207/2011 Regulation.

6.4 Summary of the existing links between Regulations and Standards

The above analysis shows the European regulations (Commission Regulation 1207/2011, EASA regulation and industry standard documents) are consistent with the ICAO requirements. They have implemented the requirements defined by ICAO with in some specific cases necessary additional performance, safety and airworthiness requirements taking into account the European targeted operations.

They rely on successive ICAO Annex 10 Volume IV amendments (77, 82 and 85), but these ICAO changes have in general no impact on the surveillance function and operational associated separations as defined by the European (EU) N° 1207/2011 Regulation except for ADS-B where the application currently defined by the regulation requires Version 2, while initial European implementations were based on version 0 or 1 .

The purpose of the majority of ICAO changes was to improve the robustness of the Mode S system:

- reduction of the frequency loading,
- robustness improvement of transponders to radio-frequency interferences,
- improvements of protocols following in-service experience,
- clarifications to avoid manufacturer misunderstandings...

It seems that none of the changes covered by the various ICAO Annex 10 Volume IV relevant amendments (from Amendment 77 to amendment 89 that is in force since 2014) is safety critical or critical for interoperability.

As a consequence it is certainly desirable to implement the most recent amendments but there is no urgency to complete it. It should be noted that transponders compliant with amendment 85 include a number of improvements that are defined by amendment 89 due to the anticipated publication of ED-73E (Mode S transponder MOPS). However this standard version does not implement the suppression of replies to Mode A/C/S all-call interrogations as required by 2020 by ICAO for the new installations. Again the compliance to this specific requirement is essential for long terms protection of Mode S services (reducing the frequency usage load), but does not justify a short terms obligation for upgrading all already certified Mode S transponders equipped aircraft.

7. Analysis conclusions

The analysis of the various changes made to ICAO Annex 10 Volume IV regarding Mode S (i.e. from Amendment 77 to Amendment 89) have shown the followings :

1. No operationnaly significant changes have been made regarding the basic Mode S modes (ELS and EHS),
2. Significant changes made on Mode S Extended Squitter mode (ADS-B OUT) moving from version 0 to version 2.

7.1 ELS/EHS evolutions:

This study is not addressing the comparison between ELS/EHS and ADS-B regarding the nature of the information downlinked by these two modes of operation. This analysis will be covered in the second study under SC 002-2016.

With the exception of several ICAO Annex 10 Volume IV changes aiming to reduce the Mode S frequency loading (i.e. 1030 and 1090 MHz), the other changes were bringing either clarification or correction of defects that have been observed during the full deployment of Mode S in some traffic dense areas (e.g. Europe).

The assesment of these changes leads to the conclusion that regarding ELS/EHS there is no operational impact on the surveillance service (and on the traffic separations associated to this service) that could be expected from Mode S transponders that were simply compliant with Amendment 77.

All the changes made regarding basic Mode S technology (e.g. more robustness required against interferences for the airborne receiver) are certainly useful in the long run but they are not affecting the service itself.

The correction of the “BDS swap issue” included in Amendment 89 is also useful for the overall efficiency of the surveillance chain and constitute a more robust baseline for the future.

Finally the changes introduced in Amendment 89 with the objective to limit the 1090 MHz transmissions to the strict minimum (i.e. no answer to all call interrogations) are also essential for the long terms protection of the service. Nevertheless, they have no impact on the service functions at that stage and there is no rationale to enforce all these actions except regarding forward fit equipage. The same is applicable to ground infrastructure that should also target toward a situation of full compliance but without need for synchronisation between air and ground side.

On an economical point of view, all the changes enforced by the various ICAO Annex 10 Volume IV amendments are providing benefits in the long terms but they don’t justify to enforce them at the same pace than the basic ELS/EHS functionilities especially in terms of retrofit. Indeed, they could lead to the complete change of the Mode S transponder to comply with the Amendement 85 dealing with increase receiver robustness. The non application of these changes for retrofit will not impact the service.

Conversely, it make sense to enforce these last requirements for new aircraft forward fit with new airborne Mode S transponders.

The same logic could be applied to ground infrastructure: this is the case for software evolutions of Mode S radars from the first generation that should be replaced in the next coming years. Therefore it could be reasonible to provide some extra delay in the revised IR to comply with these amendments when the ground infrastructure is reaching the renewing cycle windows.

7.2 ADS-B evolutions:

The study highlighs the fact that ICAO Annex 10 Volume IV Amendment 85 constitues the main important change for ADS-B mode by introducing ADS-B version 2 with Amendment 85. ADS-B IN services are not addressed in this study.

Version 2 constitutes a significant evolution compared with version 0: it covers much more parameters to downlink and includes new information quality/integrity indicators asociated with the aircraft position (NIC & NAC informations). A detailed analysis comparing this specific ADS-B parameter with the Mode S or WAM independent position will be provided in the SC 002-2016 study.

The current (EU) N° 1207/2011 Regulation is confusing because it seems to consider that any of the three potential technologies (Mode S radar infrastructure, Wide Area Multilateration infrastructure or ADS-B infrastructure) has the capability to provide the same performance in terms of surveillance service. This is obvioulsly not true and the future optimised solution could be indeed an association of each of them in order to provide the performance required for the intended traffic separations.

The possibility to provide surveillance services in low density airspace using a simple ADS-B infrastructure layer is still an option today. This means that in such typical airspace the effective traffic separation need is less demanding than the 5 Nm targetted in the IR. Only limited deployments are today operational in the ECAC area (part of the Iceland, Portugal and Norway airspaces) corresponding to low density areas.

The current situation in European airspace is such that the surveillance service, for the vast majority of the airspaces, is relying only on Mode S radars (even if there are a few initial deployment of WAM in some European areas[7]). At the time the initial (EU) N° 1207/2011 Regulation was developped less than 70 TMAs in the European areas where not served by SSR Mode A/C stations. It must be noted that these TMAs were characterised by a low IFR traffic and used only procedural traffic separation rules, these operational elements were not justifying the deployement of individual Mode A/C or Mode S radars to support the surveillance function.

These few TMAs were the first areas of potential application of ADS-B as alternate sensor solution to feed surveillance chain. The decision to mandate IFR airspace users (above a certain weight or speed) to equip with ADS-B was understood by many stakeholders as the fact that Mode S, WAM or ADS-B are equivalent technologies that provide the same service level in all European airspace. This seems not demonstrated so far. The second study will elaborate on this topic as it is a very significant driver to consider when revisiting the Regulation (EU) N° 1207/2011.

As explained above, today, the consensus among the European ANSPs seems to be more operationally driven: ADS-B clearly suffer from availability and continuity limitations that leads to consider that ADS-B could be a sole mean solution only in low density airspace while it could only be suitable complementary solution to a Mode S infrastructure layer or WAM layer in the other airspaces. Even in the USA with the large ADS-B mandate formulated by FAA, the strategy seems to be to get

[7] According to a recent Eurocontrol report, about 800 ground stations supporting ADS-B are operating today in Europe (a large majority are associated with Wide Area Multilateration stations)

a technological diversified infrastructure: ADS-B general coverage complemented by a basic Mode S network and associated with a primary radar coverage to face with other security threats.

The extension of ADS-B mandate to all airspace users (no more exemptions in terms of weight or speed or VFR traffic) under consideration in the Euroepan airspace, seems to be an excessive burden to these General Aviation user community since such requirement is only fully justified in the airspaces that are not covered today by radar services and for which there is no business case to move ahead (i.e. the 70 TMAs mentionned above). The modification of the IR regarding these airspace users should be proportionate and limited to these few non radar airspaces. By doing so the economical burden on this airspace users community should be strictly limited and thus reducing the number of concerned aircraft to be fitted with ADS-B capabilities.

Regarding forward fit of GA aircraft, this analysis does not apply. Indeed fitting new GA aircraft with avionic compliant with the last standards, as a baseline, will pave the way for long terms aircraft capability harmonisation.

8. Recommendations

The following recommendations have been developed as the result of the analysis contained within this deliverable. They are concentrating on the Mode S ELS/EHS functionalities. Recommendations regarding ADS-B functionalities will be provided in the second study (SC 2016-002).

The implementation of these recommendations should be considered along with the recommendations of the second study regarding ADS-B functionalities.

The following recommendations addresses the operational impacts on the surveillance function and the associated traffic separation service, of aircraft fitted with Mode S transponders compliant with ICAO Annex 10 Volume IV amendments 77. It is assumed that the reference baseline is constituted by the current IR requirements and the associated recognised means of compliance.

8.1 Recommendation 1:

Aircraft forward fit shall be compliant with the last evolutions of Annex 10 in order to ensure that the defects observed with previous requirements are fixed and also that all measures intended to protect 1090 MHz operations are implemented.

The next revision of ED-73 (i.e. version F) expected to be released by 2019 could be the new baseline for Mode S transponder standard (ELS/EHS functions) for forward fit. This is still an open point, but this new revision of ED-73 should cover, inter alia, some new requirements from Amendment 89.

Such recommendation should be extended to all new aircrafts, including recommendations for GA aircraft coming on the market. It is recommended to set up the application date as soon as possible (i.e. 2020 expecting the publication of ED-73F in 2019).

The same recommendation applies to new ground installations (Mode S radars or WAM), they need to comply with the last changes contained in Amendment 89.

8.2 Recommendation 2:

Aircraft retrofit should be treated with more flexibility respecting the following principle:

Aircraft already fitted with Mode S transponders compliant with ICAO amendment 77 (i.e. compliant with ED-73B), regarding Mode S ELS/EHS, do not create operational impact on the ground surveillance chain and associated separation.

The retrofit of such aircraft to comply with the last ICAO amendment (supposed to be covered by ED-73F that is expected by 2019) should be considered, in association with the parallel need regarding ADS-B, as a medium terms objective for global harmonisation and protection of the 1090 MHz frequency.

The same recommendation applies to ground installations upgrades (Mode S radars or WAM). Some flexibility must be given to make them in an economical acceptable way.

Annex 1

Summary of Elementary and Enhanced Surveillance capabilities of Mode S

Mode S Elementary Surveillance (ELS)

Functionality

Mode S ELS provides the following functionality ("Basic Functionality"):

- Automatic reporting of aircraft identity. This is the aircraft call sign that is automatically presented to the controller
- Altitude reporting in 25ft intervals (subject to aircraft capability)
- Transponder capability report - (enable ground systems to identify the data link capability of the transponder)
- Flight status (airborne / on the ground)
- SI code capability (capacity to operate within a Surveillance Identifier (SI) code ground environment).

Note: Basic functionality with SI code capability is the minimum level permitted for operations in European airspace

Benefits

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 A/C code assignment. Mode S is the primary means of correlating radar tracks with Flight data processing system 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** efficiency (i.e. Short Term Conflict Alert). 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/efficiency of safety nets. These improvements should reduce the number of nuisance alerts and enhance the integrity of separation assurance.
- **Increased target capacity**. To handle current and forecast increases in traffic, Mode S radars can process many more aircraft tracks (approximately double the number) than conventional MSSR installations.

Mode S Enhanced Surveillance (EHS)

Functionality

Mode S EHS provides ELS functionality features (described in the previous section) complemented with downlinked aircraft parameters (DAPs)[8] among which the essential as follows:

- **Selected Altitude** - the flight level which is manually selected by the pilot. “Selected Altitude” parameter provides an indication of the actual selected altitude at the aircraft level 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 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

[8] Provision for 255 registers (BDS registers) to be connected to aircraft sensors or storing aircraft parameters. Responding to an interrogation requesting a specific BDS register (using its number), the transponder sends back a reply containing only the BDS register value.
DAPs (Downlink Aircraft Parameters) data cover the following domains: Avionics configuration information, Aircraft identification information, Intent parameters (Selected Altitude), State parameters (Ground Speed, Heading, Roll Angle, etc.).

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. 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 its lack of stability (significant variations caused by several factors, such as turbulence, small but rapid aircraft vertical movements, etc.)
- **Barometric pressure setting:** The provision of this information allows the ATC controller to check that the current altimeter setting of the aircraft is consistent with the last clearance given in terms of altitude or level. This is an additional safety net against wrong barometric pressure setting.
- **TCAS downlinked resolution advisories**.

Benefits

In addition to the Mode S ELS benefits, identified above, 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. ATM system enhancements and/or the display of downlink aircraft parameters obviate the need for certain voice communication exchanges (e.g. voice reports of heading or indicated speed)".
- **Safety enhancement**. Access by controllers to aircraft intent DAPs, such as "selected altitude" or "Baro pressure setting" enable cross-checking of climb/descent instructions and helps the early identification of potential level bust incidents or detection of wrong altimeter setting potentially leading to CFIT.
- **Improved trajectory estimation for Trajectory Based Operations (TBO)**

Annex 2

Extracts from Regulation (EU) No 1028/2014 amending Regulation (EU) No 1207/2011

(1) Article 5 is amended as follows:

(a) Paragraph 4 is replaced by the following:

‘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 June 2016 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 June 2016 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.’

(b) Paragraph 5 is replaced by the following:

‘5. Operators shall ensure that:

(a) by 7 December 2017 at the latest, 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) by 7 June 2020 at the latest, 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 June 2016 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) by 7 June 2020 at the latest, 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 June 2016 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.'

(2) In Article 8, paragraph 2 is replaced by the following:

'2. Member States shall ensure that, by 7 June 2020 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) In Article 14, paragraph 1 is replaced by the following:

'1. Aircraft of specific types with a first certificate of airworthiness issued before 8 June 2016 that have a maximum take-off mass exceeding 5 700 kg or a maximum cruising true airspeed greater than 250 knots that do not have the complete set of parameters detailed in Part C of Annex II available on a digital bus on-board the aircraft may be exempted from complying with the requirements of point (c) of Article 5(5).'

Annex 3

Mode S Transponder level per ICAO

ICAO Annex 10 identifies 5 levels for Mode S transponder. These five levels are detailed hereafter (this is an extract of ICAO annex 10 Volume IV chapter 2

1. **Level 1**

Level 1 transponders shall have the capabilities prescribed for:

a) Mode A identity and Mode C pressure-altitude reporting;

b) intermode and Mode S all-call transactions;

c) addressed surveillance altitude and identity transaction;

d) lockout protocols;

e) basic data protocols except data link capability reporting;

f) air-air service and squitter transactions.

Note. Level 1 permits SSR surveillance based on pressure-altitude reporting and the Mode A identity code. In an SSR Mode S environment, technical performance relative to a Mode A/C transponder is improved due to Mode S selective aircraft interrogation.

2. Level 2

Level 2 transponders shall have the capabilities of Level 1 and those prescribed for:

a) standard length communications (Comm-A and Comm-B);

b) data link capability reporting;

c) aircraft identification reporting; and

d) data parity with overlay control for equipment certified on or after 1 January 2020.

Note. Level 2 permits aircraft identification reporting and other standard length data link communications from ground to air and air to ground. The aircraft identification reporting capability requires an interface and appropriate input device.

3. Level 3

Level 3 transponders shall have the capabilities of Level 2 and those prescribed for ground to-air extended length message (ELM) communications.

Note: Level 3 permits extended length data link communications from ground to air and thus may provide retrieval from ground-based data banks and receipt of other air traffic services which are not available with Level 2 transponders.

4. Level 4

Level 4 transponders shall have the capabilities of Level 3 and those prescribed for air-to ground extended length message (ELM) communications.

Note: Level 4 permits extended length data link communications from air to ground and thus may provide access from the ground to airborne data sources and the transmission of other data required by air traffic services which are not available with Level 2 transponders.

5. Level 5

Level 5 transponders shall have the capabilities of Level 4 and those prescribed for enhanced Comm-B and extended length message (ELM) communications

Note: Level 5 permits Comm-B and extended length data link communications with multiple interrogators without requiring the use of multisite reservations. This level of transponder has a higher minimum data link capacity than the other transponder levels.

6. Extended squitter

Extended squitter transponders shall have the capabilities of one of the 5 levels, the capabilities prescribed for extended squitter operation and the capabilities prescribed for ACAS cross-link operation. Transponders with these capabilities shall be designated with a suffix “e”.

Note: For example, a level 4 transponder with extended squitter capability would be designated “level 4e”.

Annex 4

Mode S transmitted parameters

Transmitted parameters

The airborne Mode S transponders transmit different types of data (ICAO definitions):

a) Direct data:

This is the set of parameters required for surveillance

1.) Fixed direct data
- aircraft address
- maximum airspeed
- registration marking if used for flight identification

2.) Variable direct data
- Mode C altitude code
- Mode A identity code
- on-the-ground condition
- aircraft identification if different from the registration marking
- SPI condition

b) Indirect data:

They are data transmitted (or received) by the transponder which do not affect the surveillance function.

Mandatory parameters are for Level 2 Transponders:
- the capability reports;
- the aircraft identification protocol (register 20);
- for ACAS-equipped aircraft, the active resolution advisory (register 30).

Optional parameters (when required):

a) downlink aircraft parameters (DAPs):
- Register 40 - Selected vertical intention
  - MCP/FCU selected altitude
  - FMS selected altitude
  - Barometric pressure setting minus 800 mb
  - MCP/FCU mode
  - Target altitude source
- Register 50 - Track and turn report
  - Roll angle
  - True track angle
  - Ground speed

- Track angle rate
- True airspeed

- Register 60 - Heading and speed report
  - Magnetic heading
  - Indicated airspeed
  - Mach
  - Barometric altitude rate
  - Inertial vertical velocity

b) Extended Squitter transmissions

The three versions transmit the data contained in registers:

05	Extended Squitter Airborne Position
06	Extended Squitter Surface Position
07	Extended Squitter Status 1.0 s
08	Extended Squitter Identification and Category
09	Extended Squitter Airborne Velocity
0A	Extended Squitter Event-Driven Information
61	Extended Squitter Aircraft Status
62	Target State and Status Information
63-64	Reserved for Extended Squitter
65	Extended Squitter Aircraft Operational Status

Note: Although BDS registers 07_{16} and $0A_{16}$ are not conveying ADS-B data items their implementation is needed to complement the ADS-B protocol.

Annex 5

ADS-B transmitted parameters comparison between the three standardised versions

Note:

- Red: Version 0 or 1 parameters which are different from Version 2.
- **Bold**: parameters of Version 2 which are required by IR 1207/2011 and by EASA CS-ACNS
- Underlined: parameters of Version 2 which are conditional.

Register 05_{16} Airborne Position Message

Version 0	Version 1	Version 2
Airborne Position Message	Airborne Position Message	Airborne Position Message
Surveillance Status	Surveillance Status	**Surveillance Status**
Single Antenna Flag	Single Antenna Flag	**NIC Supplement-B**
Altitude	Altitude	**Altitude**
Time (T)	Time (T)	**Time (T)**
CPR Format (F)	CPR Format (F)	**CPR Format (F)**
CPR Encoded Latitude	CPR Encoded Latitude	**CPR Encoded Latitude**
CPR Encoded Longitude	CPR Encoded Longitude	**CPR Encoded Longitude**

Register 06_{16} Surface Position Message

Version 0	Version 1	Version 2
Surface Position Message	Surface Position Message	Surface Position Message
Movement	Movement	**Movement**
Ground Track Status	Heading/Ground Track Status	**Heading/Ground Track Status**
Ground Track	Heading/Ground Track	**Heading/Ground Track**
Time (T)	Time (T)	**Time (T)**
CPR Format (F)	CPR Format (F)	**CPR Format (F)**
CPR Encoded Latitude	CPR Encoded Latitude	**CPR Encoded Latitude**
CPR Encoded Longitude	CPR Encoded Longitude	**CPR Encoded Longitude**

Register 07_{16} Extended squitter status

Version 0	Version 1	Version 2
Extended squitter status	Extended squitter status	Extended squitter status
Transmission rate Subfield (TRS)	Transmission rate Subfield (TRS)	
Altitude Type (Baro/GNSS)	Altitude Type (Baro/GNSS)	

Register 08_{16}	**Aircraft Identification and Category Message**	
Version 0	**Version 1**	**Version 2**
Aircraft Identification and Category Message	Aircraft Identification and Category Message	Aircraft Identification and Category Message
Aircraft Category	ADS-B Emitter Category	**ADS-B Emitter Category**
Identification Characters #1-#8	Identification Characters #1-#8	**Identification Characters #1-#8**

Register 09_{16}	**Airborne Velocity Message**	**Velocity over Ground**
Version 0	**Version 1**	**Version 2**
Airborne Velocity Message - Velocity over Ground (Subtypes 1and 2, Normal/Supersonic)	Airborne Velocity Message - Velocity over Ground (Subtypes 1and 2, Normal/Supersonic)	Airborne Velocity Message - **Velocity over Ground** (Subtypes 1and 2, Normal/Supersonic)
Subtype	Subtype	**Subtype = 1/2**
Intent Change Flag	Intent Change Flag	Intent Change Flag
NUC_R	NAC_V	**NAC_V**
E/W Velocity	E/W Velocity	**E/W Velocity**
N/S Velocity	N/S Velocity	**N/S Velocity**
Vertical Rate Source	Vertical Rate Source	**Vertical Rate Source**
Vertical Rate	Vertical Rate	**Vertical Rate**
Difference from Barometric Altitude	Difference from Barometric Altitude	**Difference from Barometric Altitude**

Register 09_{16}	**Airborne Velocity Message**	**Airspeed**
Version 0	**Version 1**	**Version 2**
Airborne Velocity Message - Airspeed (Subtypes 3 and 4, Normal/Supersonic)	Airborne Velocity Message - Airspeed (Subtypes 3 and 4, Normal/Supersonic)	Airborne Velocity Message - **Airspeed** (Subtypes 3 and 4, Normal/Supersonic)
Subtype	Subtype	**Subtype =3/4**
Intent Change Flag	Intent Change Flag	Intent Change Flag
NUC_R	NAC_V	NAC_V
Heading Status Bit	Heading Status Bit	Heading Status Bit
Heading	Heading	Heading
Airspeed Type	Airspeed Type	Airspeed Type
Airspeed	Airspeed	Airspeed
Vertical Rate Source	Vertical Rate Source	**Vertical Rate Source**
Vertical Rate	Vertical Rate	**Vertical Rate**
Difference from Barometric Altitude	Difference from Barometric Altitude	**Difference from Barometric Altitude**

Register $0A_{16}$ Event-driven Message

Version 0	Version 1	Version 2
Extended squitter event-driven information	Extended squitter event-driven information	Extended squitter event-driven information
Variable	Variable	Variable

Register 61_{16} Aircraft Status Message Emergency Status and Mode A Code

Version 0	Version 1	Version 2
Extended squitter emergency/priority status	Aircraft Status Message - Emergency/priority status	Aircraft Status Message - Emergency Status and Mode A Code
Subtype	Subtype = 1	**Subtype = 1**
Emergency State	Emergency State	**Emergency/Priority Status**
		Mode A Code

Register 61_{16} Aircraft Status Message ACAS RA Broadcast

Version 0	Version 1	Version 2
N/A	Aircraft status Message - Extended squitter ACAS RA Broadcast	Aircraft Status Message - ACAS RA Broadcast
	Subtype =2	**Subtype = 2**
	Active Resolution Advisories	**Active Resolution Advisories**
	RACs Record	**RACs Record**
	RA Terminated	**RA Terminated**
	Multiple Threat Encounter	**Multiple Threat Encounter**
	Threat Type Indicator	**Threat Type Indicator**
	N/A	**Threat Identity Data**

Register 62_{16}	Target State and Status Message	
Version 0	**Version 1**	**Version 2**
N/A	Target state and status information	Target State and Status Message
	Subtype = 0	**Subtype = 1**
	Vertical Data Available/Source Indicator	**SIL Supplement**
	Target Altitude Type	Selected Altitude Type
	Target Altitude Capability	MCP/FCU Selected Altitude ***or*** FMS Selected Altitude
	Vertical Mode Indicator	Barometric Pressure Setting
	Target Altitude	Selected Heading Status
	Horizontal Data Available/Source Indicator	Selected Heading Sign
	Target Heading/Track Angle	Selected Heading
	Target Heading/Track Indicator	**Navigation Accuracy Category Position (NACP)**
	Horizontal Mode Indicator	**Navigation Integrity Category Baro**
	NAC_P	**Source Integrity Level**
	NIC_{BARO}	**Status of MCP/FCU Mode Bits**
	Capability/Mode Codes Emergency/Priority Status	Autopilot Engaged
		VNAV Mode Engaged
		Altitude Hold Mode
		Approach Mode
	Source Integrity Level	**TCAS Operational**
		LNAV Mode Engaged

Register 65_{16}	Aircraft Operational Status Message	While Airborne
Version 0	**Version 1**	**Version 2**
Extended squitter aircraft operational status	Extended squitter aircraft operational status	Aircraft Operational Status Message - While Airborne
	Subtype = 0	**Subtype = 0**
En-Route Operational Capabilities	Airborne Capability Class Codes	**Airborne Capability Class Subtype = 0**
TCAS/ACAS Operational	Not-ACAS	**TCAS Operational**
CDTI Operational	CDTI	1090 ES IN
	Air Referenced Velocity Report Capability	**Air Referenced Velocity Report Capability**
	Target State Report Capability	**Target State Report Capability**
	Target Change Report Capability	**Trajectory Change Report Capability**
		UAT IN
	Airborne Operational Mode Subtype	**Airborne Operational Mode Subtype = 0**
	ACAS RA active (coding)	**ACAS RA Active**
	IDENT Switch Active	**IDENT Switch Active**
	Receiving ATC services	
		Single Antenna Flag

		System Design Assurance
	Version Number = 1	**Version Number = 2**
	NIC Supplement	**NIC Supplement-A**
	$NAC_{\cancel{P}}$	**NAC_P**
	Barometric Altitude Quality (BAQ)	**GVA**
	Source Integrity Level	**Source Integrity Level**
	NIC_{Baro}	**NIC_{Baro}**
		Horizontal Reference Direction (HRD)
		SIL Supplement

Register 65_{16}	**Aircraft Operational Status Message**	**On the Surface**
Version 0	**Version 1**	**Version 2**
N/A	Extended squitter aircraft operational status	Aircraft Operational Status Message - On the Surface
	Subtype = 1	**Subtype = 1**
	Surface Capability Class Codes	**Surface Capability Class Subtype = 0**
	CDTI	1090 ES IN
	B2 Low	B2 Low
		UAT IN
		NACv
		NIC Supplement-C
	Length/Width Codes	**Length/Width Codes**
	Airborne Operational Mode Subtype	**Surface Operational Mode Subtype = 0**
	ACAS RA active (coding)	**TCAS RA Active**
	IDENT Switch Active	**IDENT Switch Active**
	Receiving ATC Services	
		Single Antenna Flag
		System Design Assurance
	Position Offset Applied	**GPS Antenna Offset**
	Version Number = 1	**Version Number = 2**
	NIC Supplement	**NIC Supplement-A**
	NAC_P	**NACp**
	Source Integrity Level	**Source Integrity Level**
	Track Angle/Heading	**Track Angle/Heading**
	Horizontal Reference Direction (HRD)	**Horizontal Reference Direction (HRD)**
		SIL Supplement

Annex 6

Initial ADS-B ground surveillance applications

The following ground based applications are based upon ADS-B messages usage:

- ADS-B in Non Radar Airspace (ADS-B NRA)
- ADS-B in Radar Airspace (ADS-B RAD)
- ADS-B for Airport Surface Surveillance (ADS-B APT)

ADS-B NRA

This application is one candidate to provide ATM surveillance services in areas where there is no radar infrastructure (either SSR or Mode S). It provides the capability the support 5 Nm separation between traffic providing that the traffic density remains low.

The technical and operational requirements are defined in a Safety, Performance and Interoperability Requirements (SPR) document published by EUROCAE (ED-126).

ADS-B RAD

This application is one candidate to provide ATM surveillance services in areas where there is no complete radar infrastructure (either SSR or Mode S). It provides the capability the support 5 Nm separation between traffic by mitigating the holes of radar coverage in the area and thus providing a continuous surveillance environment.

The technical and operational requirements are defined in a Safety, Performance and Interoperability Requirements (SPR) document published by EUROCAE (ED-161).

ADS-B APT

This application is one candidate to provide ATM surveillance services on airport surface. It could be the sole surveillance mean for airport surface movement or be a complementary sensor included in an ASMGCS infrastructure. It provides or contribute to the surveillance function at airport surface level (i.e. ASMGCS level 1 function).

The technical and operational requirements are defined in a Safety, Performance and Interoperability Requirements (SPR) document published by EUROCAE (ED-163).

Annex 7

Annex 10 Volume IV changes

This Annex provides a list of the main changes in ICAO Annex 10 Volume IV from amendment 77 to amendment 89.
Requirement clarifications or corrections, editorial modifications, modifications relative to TIS-B, Ground stations, Multilateration, ACAS or non-transponder devices are not considered.

Amendment 82

N°	Change description	Impacted paragraphs	Comment	Type of change
82-1	Changes to “quantization of pressure altitude reporting” to ensure that both ground surveillance systems and ACAS get the best possible data to improve altitude tracking.	2.1.3.2.5	For aircraft without 25 ft source.	Improvement
82-2	For completness, addition of ACAS cross-link requireement to Extended Squitter Transponders capability.	2.1.5.1.6	Already required by ED-73B when ACAS is present	Clarification
82-3	Additional material to ensure that non transponder devices that transmit extended squitters conform to all of the 1090 MHz radio frequency (RF) signals in space requirements of Mode S transponders.			N/A
82-4	New requirements to minimize the number of unsollicited replies when receiving low level continuous wave (CW) interference	3.1.1.7.8.1 3.1.2.10.3.5.1		Frequency loading reduction
82-5	Addition of a performance requirement (correct replies to at least 90 per cent of the interrogations) in presence of low level continuous wave (CW) interference	3.1.2.10.1.1.4		Robustness
82-6	Inclusion of a reserved format for military. Without such a format the military would use the civil formats with the possibility of creating more fruit interference and other undesirable impacts.			Frequency loading reduction
82-7	Addition of a new paragraph concerning “data link capability report” to specify which bits must be zeroed by the transponder when the transponder/subnetwork interface fails or is not connected.	3.1.2.6.10.2.2.3		Protocol improvment
82-8	Addition of a requirement to state that transponder insertion of barometric altitude data in “ACS subfield” shall take place when “ATS subfield” has the value of ZERO.	3.1.2.8.6.3.1.3		Protocol improvment
82-9	Modification of the on-the-ground condition requirements and of the squat switch validation.	3.1.2.8.6.7 3.1.2.6.10.1.2 3.1.2.8.7.3.3.5	Further modifications and counter modifications in subsequent amendements. See §4.3 third bullet.	On-the-ground issue.

Amendment 85

N°	Change description	Impacted paragraphs	Comment	Type of change
85-1	SI code capability for level 1 transponder was not clearly stated. The requirement has been made explicit.	2.1.5.1.7	ED-73E OK.	No impact
85-2	This change adds a specification for transponder processing to correctly recognize the S1 pulse used by ACAS to detect Mode A/C aircraft. Requirement added because some low-end receivers were not compliant. It results in an unnecessary increase of the FRUIT rate.	3.1.1.7.4 3.1.2.1.4.1 3.1.2.1.5.1.2		Frequency loading reduction
85-3	Maximum replies rate relaxation (some implementations were not fully compatible in different regions).	3.1.1.7.9	Alignment on ED-73E.	No impact.
85-4	Limitation of transponder spurious replies of Mode A/C generated by low level Mode S interrogations. Mandatory as of 2011 for new certified transponders.	3.1.2.10.1.1.5	Hardware modification.	Frequency loading reduction
85-5	This change clarifies the intent of the SARPs in the setting of the AQ bit in the RI field by revising 3.1.2.8.4 to be consistent with 3.1.2.8.2.2.	3.1.2.8.4	ED-73E OK.	
85-6	Addition of a requirement for retriggering of Temporary alert condition.	3.1.2.6.10.1.1.2		Protocol improvement
85-7	On-the-ground condition modifications	3.1.2.5.2.2.1 3.1.2.6.1.4.1		On-the-ground issue. Further modifications and counter modifications in subsequent amendement See §4.3 third bullet.
85-8	Validation of a reported surface condition by all capable platforms.	3.1.2.6.10.3.1	Further modifications and counter modifications in subsequent amendement. See §4.3 third bullet	On-the-ground issue.

Amendment 89

N°	Change description	Impacted paragraphs	Comment	Type of change
89-1	Transponder interface requirements to minimize crew errors (control accessibility)	2.2	Already in ED-73E	Aircraft installation
89-2	Addition of requirements that Flight ID be displayed to the crew with a simple action. It further requires that Flight ID be able to be entered by the crew with a simple action independent of any other parameters similar to Mode A Code entry.	3.1.2.10.5.1.4		Aircraft installation
89-3	Addition of data parity overlay control as of 01/01/2020.	2.1.5.1.2 New 3.1.2.3.2.1.5 3.1.2.6.1.3 & 4 New 3.1.2.6.1.4.1 (h & i) New 3.1.2.6.11.2.5 Tables 3-3, 3-4 & 3-6 Figure 3-8 + Note 5	Already in ED-73E	BDS swap issue
89-4	Addition of capability for the ground to command a transponder without automatic on-the-ground status capability to process interrogations and transmit extended squitter transmissions the same as aircraft with automatic on-the ground capability.	3.1.2.5.2.2.1 3.1.2.6.1.4.1 (f) New 3.1.2.6.1.4.2 &3 3.1.2.6.10.1.2 3.1.2.6.10.3 3.1.2.8.6.7 3.1.2.8.7.3.3.5		Frequency loading reduction On-the-ground issue
89-5	Requirement that a transponder process commands for both non-selective and multisite lockout in the same interrogation for both II and SI Codes. To avoid nuisance replies to ATCRBS-only all-call interrogations that are the result of misinterpretation of a narrow P4 pulse that is widened due to multipath, or a low-level Mode S interrogation. The change is required to permit the ground to command lockout to II=0 and normal lockout for either an II or SI Code in a single interrogation.	3.1.2.6.1.1 3.1.2.6.9.1.1 3.1.2.6.9		Frequency loading reduction
89-6	Requirement modification to ensure the compatibility of the two types of modulation currently in use.	Figure 3-1 3.1.2.1.1 3.1.2.1.4.2.1		Interoperability improvement
89-7	Transponder requirements for compatibility with the new 1090ES ADS-B Version 2 formats and protocols for extended squitter.	Several		
89-8	Requirement for new transponders certified on or after 1 January 2020 to no longer reply to Mode A/C/S all call interrogations.	3.1.2.1.5.1.1 3.1.2.4.1.3.2.1		Frequency loading reduction

	Such useless RF pollution could reach 20% of the Mode S messages transmitted on 1090 MHz RF channel.			
89-9	Addition of a SARPs requirement to limit the maximum number of all call replies triggered by an interrogator.	3.1.2.11.1.2	Ground Station requirement	N/A
89-10	Recommendation for passive acquisition	3.1.2.5.2.1.4.2	Ground Station requirement	N/A

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