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Cooperative surveillance DAPs/Registers

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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 aircrafts.

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.

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 (SSR) 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 by ICAO as the transport layer standard in the 90's of the last century. This functionality has been de facto ignored in the development of Mode S avionics.

Mode S Enhanced Surveillance (EHS) and Extended Squitter (ADS-B) functions are providing basic and complementary information to improve the safety and efficiency of the ATM surveillance process. These two functions are considered at first glance as equivalent technologies that can be used to provide the same surveillance service at ANSP level, but it is more and more clear that it is not the case. There is a need to make an objective comparison of these capabilities. Furthermore ADS-B solution provides much more parameters than those provided by EHS.

This study will make a comparison of these various information, starting with the key parameter that is the aircraft position and evaluating the operational benefits associated with the other parameters.

2. Scope of the study

The intention and objective of this study is to assist EASA in revising 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 regulation imposes today to a large extend of the airspace users, to fit their fleet with Mode S ELS/EHS capabilities on one hand consistent with a radar based[1] surveillance infrastructure and with ADS-B V2 capabilities on the other hand.

Due to between, A detailed assesment of these sets of capabilities is made to identify the key differences and to analyse the advantages and disadvantages of each of them with regards to their operational usage.

This study is composed of two steps:

a.) The first step is providing a comparison of the functional capabilities associated with the ELS/EHS and ADS-B Mode S capabilities in terms of information as follows:

1. The basic information transmitted by aircraft to the ground based surveillance chain[2] (ELS)

2. The additional airborne information transmitted by aircraft to the ground based surveillance chain, that is covered by Enhanced Surveillance (EHS), including the assessment of performance improvements for the aircraft tracking or the separation safety

3. The specific additional information that could be provided by ADS-B and the assessment of performance improvements for the aircraft tracking or the separation safety.

This step of the study will also categorise these various parameters in the three following categories:

a) The essential parameters which constitute the basic set of Mode S information,
b) The complementary information that have been considered as providing benefits in terms of safety and efficiency,
c) The additional information[3] that could be considered as useful in association with operational concepts other than surveillance (i.e. ADS-B IN services).

To be noted that among all these parameters a filter will be used to only consider the relevant ones to support a ground based surveillance and separation function

b.) The second step of the study will consolidate the list of parameters, selected from the essential and complementary ones, that must be provided to get the expected level of improvements in the surveillance chain. All the other parameters (i.e. excluding the essential ones identified before) will be analysed in terms of benefits for the current surveillance chain. All the parameters will be presented in a matrix

[1] This study does not address the case of WAM with regards to the parameter update rate, but it is assumed that in general a WAM infrastructure is combined with an ADS-B ground infrastructure (stations and data communication network).

[2] A description of the ground surveillance chain is provided in section 5

[3] To be noted that carry on a Mode S transponder with the full capability does not mean that all the information will be effectively downlinked to the ground system, if the access to airborne parameter from other avionics is not physically implemented on the aircraft

to facilitate the comparison an to associate them with potential operational improvements resulting from their usage in the surveillance chain on the ground:

- Impact on the traffic separation minima
- Impact on safety
- Impact of ATM efficiency
- Link with future ATM improvements foreseen within the SESAR programme.
  To be noted that SESAR programme mainly focused on future applications that imply ADS-B IN capability. This aspect will not be covered by this study because they will impose another set of aircraft equipage on top of the one intended by the SPI regulation.

3. Scope of the Deliverable 2.

The study will provide a single report that will be issued in two steps:

1. D1 has been already delivered and a formal review with EASA representatives has already taken place.
2. D2 contains the D1 content updated as the result of the review meeting and a set of recommendations.

4. Parameter comparison between ELS/EHS and ADS-B

4.1. General remarks

Mode S data transmission capability has been organised through the allocation of a typical information to a specific register. This method has been used in order to simplify the interaction between ground Mode S radar and airborne Mode S transponder. The ground Mode S radar is requesting in its addressed call the information to be download simply by mentioning the BDS register number. This mechanism is illustrated in the following figure.

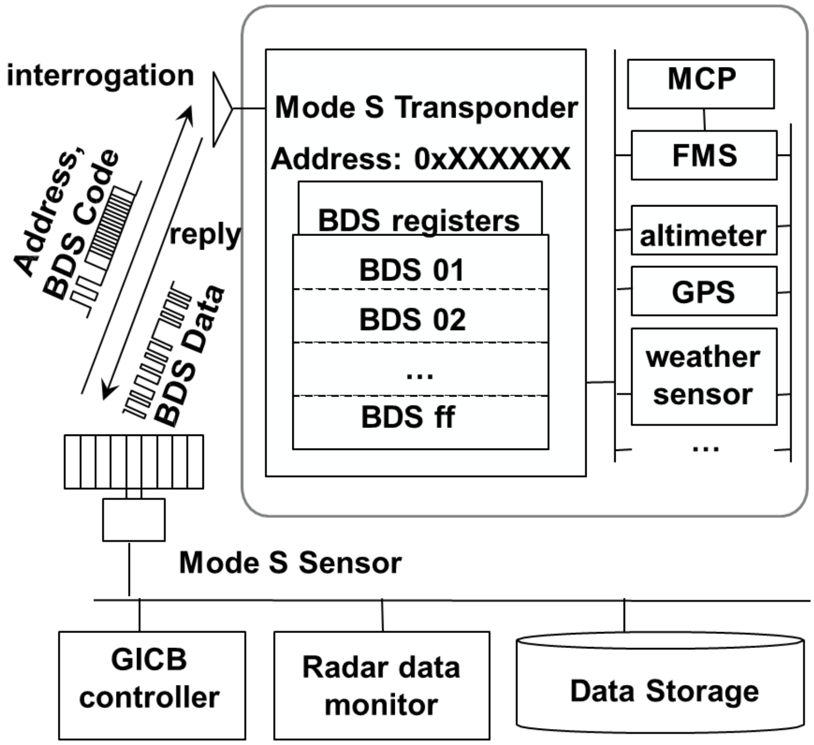

Figure 1 Mode S parameter transmission mechanism

In the detailed analysis provided in this deliverable, the parameters are considered independently from the register structure mentioned above to simplify the understanding. The parameter designations are contained in table 3.

The airborne Mode S transponders transmit different types of data per ICAO definitions. They are classified as direct (fixed or variable), indirect and optional. Details are provided in Annex 1.

The following Table 1 is providing the full list of parameters that can be provided by either ELS/EHS or by ADS-B version 2 (common parameters and specific parameters) and their respective status vis a vis IR 1207/2011 and EASA CS-ACNS. It provides some details on the way the parameters are transmitted.

This table does not address the operational usage of these parameters, this aspect will be covered in section 5.

- Parameters recommended by the CS-ACNS are mentioned
- Parameter name in green means that ADS-B and ELS/EHS provide identical information,
- Parameter name in yellow indicates transmission of the parameter by both Mode S ELS/EHS and ADS-B version 2, but with some discrepancies,
- Parameter name in blue indicates parameters that are covered by Mode S ELS/EHS and not by ADS-B version 2.

(C) means: conditional parameter. It is followed by the condition.

Parameter generic name	ELS	EHS	ADS-B Version 2
24-bit ICAO aircraft address	In All-call replies and Acquisition Squitter (DF11) every 1 s.		AA field broadcast in all Extended Squitter messages.
Mode A identity code	ID field in Identity replies (DF5 and DF21) A change is announced in field FS of DF 4/5 and 20/21.		In Register 61_{16} broadcast by Aircraft Status Messages. Broadcast rate: 0.5 s or 5 s A change is announced in the Surveillance Status subfield of Airborne Position Squitter.
Pressure altitude	AC field in Altitude replies (DF4 and DF20)		In Register 05_{16} broadcast by Airborne Position Message. (using the same source as for ELS) Broadcast rate: 0.5 s.
Pressure altitude Quality Indicator			NIC_{Baro} in Registers 65_{16} and 62_{16} broadcast by Aircraft Operational Status Message while Airborne. Broadcast rate: 0.8 s to 5 s.
Flight status (on the ground or airborne)	FS field in Altitude and Identity replies (DF4/5 and DF20/21)		Airborne Position message or Surface Position Message are sent per the status. Broadcast rate: 0.5 s or 5 s.
Capability (Level 2, On-the-ground)[4]	Field CA in Acquisition Squitter		CA field in every Extended Squitter

[4] Not required by SPI but mandatory per Annex IV 2.1.5.4.1

Parameter generic name	ELS	EHS	ADS-B Version 2
Data link capability report - ACAS capability - Mode S subnetwork version number - Specific services capability - Aircraft identification capability - Squitter capability - Surveillance identifier code capability - Common usage GICB capability report (indication of change capability)	Ground Mode S[5] can request the transmission of register 10_{16} "Data link capability report". Transmission in Comm-B replies DF20/21. Following a register change, the transponder announces it to Ground Mode S station through Altitude and Identity replies (DR field in DF 4/5 and 20/21)		
Common usage GICB capability report	On Ground Mode S request. Transmission of Register 17_{16} through Comm-B reply (DF20/21)		
Aircraft identification	In DF 5 (register 20_{16} content) An aircraft identification change is announced to Ground Mode S through Altitude and Identity replies (DR field in DF 4, 5, 20 or 21.)		In Register 08_{16} broadcast by Aircraft Identification and Category Message. Broadcast rate: 5 s or 10 s.
Special position indication (SPI)	FS field in Altitude and Identity replies (DF4/5 and DF20/21)		In Register 05_{16} (Surveillance Status Subfield) broadcast by Airborne Position Message. Same source as for the same parameter specified for ELS. Broadcast rate: 0.5 s.
Emergency status (general emergency, no communications, unlawful interference)	Through FS field in Altitude and Identity replies (DF4/5 and DF20/21) and the specific Mode A codes (Emergency, Radio communication failure, Unlawful Interference)		In Register 61_{16} broadcast by Extended Squitter Aircraft Status Message (Subtype 1: Emergency/Priority Status and Mode A Code). Conditions corresponding to the 3 Mode A values use the same source as for ELS. There are additional optional conditions. Broadcast rate: 0.5 s or 5 s Emergency condition is announced in Airborne Position Message (Surveillance Status subfield).

5 In this table « Ground Mode S » covers both Mode S radar station or active Wide Area Multilateration system

Parameter generic name	ELS	EHS	ADS-B Version 2
ACAS active resolution advisories	The transponder announces in field DR in Altitude and Identity replies (DF 4/5 20/21) an ACAS report is available in register 30. **(C)**: when the aircraft is equipped with TCAS II		In Register 61_{16} broadcast by Extended Squitter Aircraft Status Message (Subtype 2: 1 090 ES TCAS/ACAS RA Broadcast). Same source as for the same parameter as for ELS **(C):** when the aircraft is equipped with TCAS II Broadcast rate: 0.5 s or 5 s.
Transponder type/part Number	Those parameters are recommended by the CS-ACNS.		
Transponder software revision number	Those parameters are recommended by the CS-ACNS.		
ACAS unit part Number	Those parameters are recommended by the CS-ACNS.		
ACAS unit software revision number	Those parameters are recommended by the CS-ACNS.		
ADS-B version number			In Register 65_{16} broadcast by Aircraft Operational Status Message (equal to 2) Broadcast rate: 0.8 s or 2.5 s.
ADS-B emitter category			In Register 08_{16} broadcast by Aircraft Identification and Category Message. Broadcast rate: 5 s or 10 s.
Horizontal position	SSR: Slant range and azimuth of aircraft with respect to the radar location. WAM: 3D position.		In Register 05_{16} or 06_{16} broadcast by Airborne Position Message or Surface Position Message. Broadcast rate: 0.5 s or 5 s.
Horizontal position quality indicators			NIC Airborne: Airborne Position Message type + supp A et B NIC Surface: Surface Position Message type + supp A et C NICsupp-A is in 65_{16} NICsupp-B is in 05_{16} NACp: in 62_{16} and 65_{16} SIL: in 62_{16} and 65_{16} SDA: in Register 65_{16} (Airborne Operational Mode or Surface Operational Mode)
Geometric altitude			Either directly in the Airborne Position Message or indirectly using the Difference from Barometric Altitude subfield in the Airborne Velocity Message. Broadcast rate: 0.5 s.
Geometric altitude accuracy indicator (GVA)			In Register 05_{16} broadcast by Airborne Position Message. Broadcast rate: 0.5 s.

Parameter generic name	ELS	EHS	ADS-B Version 2
Velocity over ground		Transmission on Ground Mode S request of register 50_{16} through Comm-B reply (DF20/21): - ground speed - true track angle	In Register 09_{16} broadcast by Airborne Velocity Message. Broadcast rate: 0.5 s. Or in Register 06_{16} (heading/ground track field and Ground Speed in movement Field) broadcast by Surface Position Message. Broadcast rate: 0.5 s or 5 s. CS-ACNS: heading is the preferred solution
Velocity over ground accuracy indicator			NACv: in Register 09_{16} broadcast by Airborne Velocity Message. Broadcast rate: 0.5 s.
Vertical rate		Transmission on Ground Mode S request of register 60_{16} through Comm-B reply (DF20/21): - vertical rate (barometric or baro-inertial)	In Register 09_{16} broadcast by Airborne Velocity Message: - barometric vertical rate using the same source as for EHS when the aircraft is required and capable - or GNSS vertical rate Broadcast rate: 0.5 s.
Track angle rate		Transmission on Ground Mode S request of register 50_{16} through Comm-B reply (DF20/21): - track angle rate **(C)**: if available. If not: true airspeed	
Roll angle		Transmission on Ground Mode S request of register 50_{16} through Comm-B reply (DF20/21): - roll angle	
Airspeed[6]		Transmission on Ground Mode S request of register 60_{16} through Comm-B reply (DF20/21): - indicated airspeed (IAS) or Mach number	Airborne in case of a loss of GNSS horizontal: Airspeed in Register 09_{16} broadcast in Airborne Velocity Messages (Subtypes 3 and 4: Airspeed and Heading)
Heading		Transmission on Ground Mode S request of register 60_{16} through Comm-B reply (DF20/21): - magnetic heading	- Airborne in case of a loss of GNSS horizontal: Heading in Register 09_{16} broadcast in Airborne Velocity Messages (Subtypes 3 and 4: Airspeed and Heading) - On the ground: Heading or Ground track in Register 06_{16} broadcast by Surface Position Message. Broadcast rate: 0.5 s or 5 s. CS-ACNS: heading is preferred.

[6] The SPI does not require Airspeed and Heading for ADS-B (except Heading on the ground)

Parameter generic name	ELS	EHS	ADS-B Version 2
MCP/FCU Selected altitude		Transmission on Ground Mode S request of register 40_{16} through Comm-B reply (DF20/21): - MCP/FCU selected altitude	MCP/FCU selected altitude in Register 65_{16} broadcast by the Target State and Status Message. Same source as for EHS **(C)**: when the aircraft is required and capable to transmit this data item via the Mode S protocol. Broadcast rate: 0.8 s or 2.5 s.
FMS Selected Altitude		In addition to the MCP/FCU Selected altitude the CS-ACNS recommends the provision of FMS Selected Altitude in register 40_{16} through Comm-B reply (DF20/21).	The FMS Selected Altitude may be transmitted instead of MCP/FCU selected altitude in Register 65_{16}. Broadcast rate: 0.8 s or 2.5 s.
MCP/FCU mode bits - VNAV Mode - Altitude Hold Mode - Approach Mode		The CS-ACNS recommends the provision of those parameters in register 40_{16}	The Status of MCP/FCU mode bits provided in register 62_{16}. If the following data are available, they should be provided: - Autopilot Engaged - VNAV Mode Engaged - Altitude Hold Mode - Approach Mode - LNAV Mode Engaged Broadcast rate: 1.25 s.
Barometric pressure setting		Transmission on Ground Mode S request of register 40_{16} through Comm-B reply (DF20/21): - barometric pressure setting (minus 800 hP)	Barometric pressure setting (minus 800 hP) in Register 62_{16} broadcast by the Target State and Status Message. Same source as for EHS **(C)** when the aircraft is required and capable to transmit this data item via the Mode S protocol Broadcast rate: 1.25 s.
Coded aircraft length and width			Aircraft length and width in Register 65_{16} broadcast while on the surface in the Aircraft Operational Status Message. Broadcast rate: 0.8 s or 2.5 s.
Global navigation satellite system (GNSS) antenna offset			In the Surface Operational Mode field of Register 65_{16} broadcast with on the surface by in the Aircraft Operational Status Message. Broadcast rate: 0.8 s or 2.5 s.

Table 1 Transmitted parameter comparison

4.2 ELS parameters

The basic functionalities associated with ELS mode are in the table 1 presented in the previous section 4.1 (with details in column ELS).

The most important parameters are:

- 24-bit ICAO aircraft address: the unique aircraft address attached physically to the aircraft frame
- The Mode A identity code: the current code (Mode A/C) allocated to the flight
- aircraft identification: it is the aircraft call sign used for the flight which is automatically presented to the controller
- Pressure altitude: the pressure altitude is coded with a 25ft intervals
- Flight status (airborne / on the ground): provide to the ground systems the information on the status airborne on the ground
- Emergency status (general emergency, no communications, unlawful interference): notification of an emergency
- ACAS active resolution advisories: notification of the execution of an ACAS RA

Additional parameters are also covered historically by ELS (they could be less relevant when associated with EHS or ADS-B):

- Transponder capability: enable ground systems to identify the data link capability of the transponder
- Data-link capability: provide many information regarding the transponder hardware and software capabilities
- Common usage GICB capability report: list of supported GICB registers
- SI code capability: to indicate the capability of operating within a Surveillance Identifier (SI) code ground environment.

To be noted that even if such parameters are made available from the aircraft point of view, they are not widely used today by the ground surveillance system due to the limited Mode S infrastructure deployed in the eastern part of Europe and due to the ATM system capabilities not yet fully capable of EHS usage.

Conversely, the provision of ELS/EHS parameters potentially transmitted is also subject to the availability of them on the aircraft.

To be noted that ground Mode S station should be able to handle the GICB capability report to identify the right software version of the interrogated transponder. Nevertheless, some ground stations are not respecting this requirement and thus they can receive wrong information from older Mode S transponders that are using the old labels for the various register.

4.3 EHS parameters

The enhanced surveillance functionalities, in addition to the ELS basic functionalities, contribute to increase the ATM safety and to improve globally the performances of the ground surveillance chain by using complementary information from aircrafts.

Thirteen major EHS parameters are described in the following sections and they will be analysed in the section 5 regarding the potential operational benefits they can bring to the ATM ground surveillance chain.

These parameters appear in the Table 1 presented in section 4.1 (EHS column)

EHS parameter	IR SPI	CS-ACNS	
	Mandatory	Mandatory	Recommended
MCP/FCU Selected altitude	X	X	
FMS selected altitude			X
Barometric pressure setting	X	X	
MCP/FCU Mode bits			X
Roll angle	X	X	
True Track angle	X	X	
Ground speed	X	X	
Track angle rate	X (a)	X(a)	
True air speed	X (a)	X(a)	
Magnetic heading	X	X	
Indicated airspeed	X	X	
Barometric altitude rate	X (b)	X(b)	
Inertial vertical velocity	X (b)	X(b)	

(a) Only one of the two parameters is transmitted: True air speed is send in place of Track angle rate if this last one is not available.
(b) Only one of the two parameters is transmitted

7 Parameters in orange are mandatory
2 Parameters in blue are mandatory but can be provided by two different ways
2 Parameters in green are recommended by CS-ACNS

Table 2 List of EHS parameters regulatory status

It must be mentioned that regarding VFR flights, EHS parameters are generally not available without significant avionic upgrade. Taking into account the VFR restricted flights profiles within a given airspace (typically class E, F or G), none of these parameters that could be provided by this airspace user population seem essential for the surveillance system and the traffic separations.

4.3.1 Mandatory parameters

4.3.1.1 MCP/FCU Selected altitude:

This is the altitude selected by the crew into the Mode Control Panel (MCP) or Flight Control Unit (FCU), that becomes an active command for the aircraft's autopilot system. The selected level is normally the "cleared level" by ATC.

The display of the altitude selected by the crew on the controller screen gives him the ability to intervene where, for whatever reason, this selected altitude does not match the altitude of the clearance. This greatly reduces the chance of a level bust.

This parameter is required by the IR and by CS-ACNS.

4.3.1.2 Barometric pressure setting

This is the QNH or standard pressure setting in the aircraft. It could be used to detect mismatches between aircraft QNH settings and that expected by ATC.

It is required by the IR and by EASA CS-ACNS under the condition "the aircraft is required and capable to transmit this data item via the Mode S protocol".

4.3.1.3 Roll angle

This angle indicates that the aircraft is banking in general this is associated with the execution of a change in its heading.

4.3.1.4 True Track angle

This is the angle between the track (course over ground or path) of the aircraft and true north.

4.3.1.5 Ground speed

This is the speed of the aircraft relative to the ground surface.

4.3.1.6 Magnetic heading

This is the aircraft heading relative to the magnetic North.

4.3.1.7 Indicated airspeed

This is the aircraft speed (IAS) as displayed to the crew on the airspeed indicator. It represents also the aircraft speed relative to the air but the value depends upon the air density i.e. the altitude.

4.3.2 Mandatory parameters with option

4.3.2.1 Track angle rate or True air speed

The track angle is the rate of change of the track angle.

The true air speed is the actual aircraft speed relative to the air.

The track angle rate is the basic parameter but it can be replaced by true airspeed in association with the Roll angle if track angle rate is not available.

4.3.2.2 Barometric altitude rate or Inertial vertical velocity

The barometric altitude rate is the vertical rate that is provided by the barometric pressure computer that characterises the rate of climb or descent.

The inertial vertical velocity is the vertical rate that is provided by the inertial computer that characterises the rate of climb or descent.

One of these two parameters must be transmitted.

4.3.3 Parameters recommended by CS-ACNS

4.3.3.1 FMS selected altitude

This is the level selected by the flight management system and can include levelling off that may occur due to economic or other constraints.

This parameter provides, a priori, similar information to “MCP/FCU selected altitude” parameter presented above. ICAO Annex 10 leave the choice between both, EASA CS-ACNS recommend to transmit this parameter in addition to the “MCP/FCU selected altitude” parameter when available.

Nevertheless, there are some ambiguities and differences that could have an operational impact. This is addressed in the following section 4.5.

4.3.3.2 MCP/FCU Mode bits

This parameter provides the information on engaged auto pilot mode.

It is not a mandatory parameter either from the IR or EASA CS-ACNS. Nevertheless, EASA CS-ACNS recommend to transmit this parameter when available.

4.4. ADS-B parameters

Several changes have been made with the introduction of the ADS-B versions 1 and 2. The analysis of ADS-B parameters is conducted using only ADS-B version 2.

The list of register and associated parameters provided through ADS-B Version 2 are presented in details in Annex 2.

It must be noted that activities are on going at EUROCAE, RTCA and ICAO to prepare a version 3 of ADS-B with several new parameters introduced. In particular due a strong push from the FAA and US industry, ADS-B is now proposed to be a mean to downlink meteorological information to the ground.

Such move is not the most welcome to prevent the 1090 MHz frequency from overloading. This subject should be followed with a great attention.

4.5. Comparison between ELS/EHS and ADS-B parameters

As the main difference between ELS/EHS and ADS-B is the way the horizontal position of aircraft is obtain, the comparison of this feature is provided in a specific section (§ 4.6).

4.5.1 Parameters transmitted by both ELS/EHS and ADS-B

Although transmitted differently many parameters are transmitted by both systems, as:

- 24-bit ICAO aircraft address,
- Mode A identity code,
- Pressure altitude,
- Flight status (on the ground or airborne),
- Capability (Level 2, On-the-ground),
- Aircraft identification (aircraft identification in the flight plan or the registration marking)
- SPI
- Emergency status
- ACAS Active Resolution advisories
- Velocity over ground
- Vertical rate.
- MCP/FCU Selected altitude
- FMS Selected altitude
- MCP/FCU Mode
- Barometric Pressure Setting

The 24-bit ICAO aircraft address plays a specific and essential role for the association/correlation of surveillance tracks with corresponding flight plans.

The way each other parameter is transmitted in the two modes ELS/EHS or ADS-B is described in Table 1. Even if the principles and timings are different, ADS-B has been defined in such a way that the ADS-B update rate is at least as good as the ELS/EHS one, but very often much higher.

The meaning of the parameters transmitted in ELS/EHS mode or ADS-B mode are either identical or very close.

The European regulation requires that Pressure altitude, SPI, Emergency status (specifically the Mode A codes of emergency), ACAS active resolution advisories, Vertical rate, MCP/FCU Selected altitude and Barometric pressure setting are provided by the same source for ELS/EHS and ADS-B.

4.5.1.1 Pressure altitude

This is one of the parameter that is dependent from aircraft alone. Even in the so call independent cooperative concept (SSR or Mode S ELS) it is the major non independent key parameter. So there is no significant difference between Mode S and ADS-B regarding this parameter.

It was expected that WAM technology could provide an independent altitude (geometrical) determination using multilateration, but the achievable accuracy does not satisfy the performance need. Nevertheless, the use of such independent information provided by WAM could allow the detection of major pressure altitude errors.

Nevertheless, a difference is that the Pressure altitude transmitted by ADS-B is qualified by the Barometric Altitude Integrity Code (NIC_{BARO}) parameter (see § 4.5.3).

4.5.1.2 Flight Status

The Flight Status which informs whether the aircraft is on the ground or airborne raises several operational issues with aircraft without air-ground switch.

It must be noted that the implementation of an air-ground switch is not always feasible on some aircraft and the use of vertical and ground speed cannot be suitable to determine the flight status (in particular for GA aircraft).

4.5.1.3 MCP/FCU Selected altitude and FMS Selected altitude

The goal of the “MCP/FCU Selected altitude” and “FMS Selected altitude” is to transmit the “Target altitude” that the aircraft is flying to. It is defined in the ICAO Doc 9871 as follows: “*Target altitude shall be the short-term intent value, at which the aircraft will level off (or has levelled off) at the end of the current manoeuvre”*. There are guidance materials in part D of this ICAO document considering some specific avionics architectures but it is not guaranteed that those parameters have absolutely the same meaning for each aircraft. It is difficult to establish a definition of the “Target altitudes” enough accurate to ensure that the meaning of the transmitted parameter is identical for all the avionics architectures. Provisions should be taken to ensure that the meaning is identical and unambiguous both for the avionics world and the ground surveillance world. They could be more closely related to the clearance definitions.

ELS (register 40_{16}) can transmit simultaneously “MCP/FCU Selected altitude” and “FMS Selected altitude”. The IR requires the first one but the CS-ACNS recommends adding the second. In this case the Target Source field should indicate the data source that the aircraft is currently using.

ADS-B format (register 62_{16} in the Target State and Status Message) transmits either “MCP/FCU Selected altitude” or “FMS Selected altitude”. There is a specific bit to indicate the source used.

It should be noted that there are many aircraft (VFR but even some IFR) that have no capability to selected altitude. This should not have significant operational impacts on ATM and can be mitigated.

4.5.1.4 Navigational accuracy category velocity

For the same reason than for the horizontal position, a quality indicator (Navigational accuracy category velocity - NACv) is associated to the velocity over the ground.

4.5.2 Parameters transmitted by Mode S ELS/EHS and not covered by ADS-B

The following parameters are transmitted by Mode S ELS/EHS but are not covered by ADS-B:

- Data link capability report,
- Common usage GICB capability report,
- Track angle rate,
- Roll angle,
- Airspeed and Heading

The two first parameters in the list above are very specific to Mode S functional capabilities associated with EHS, so there is no issue with their non-transmission through ADS-B.

4.5.2.1 Airspeed and Heading

Airspeed and Heading are transmitted by EHS. They are normally not transmitted by ADS-B except if Velocity over ground is not available

4.5.2.2 Track angle rate and roll angle

Regarding track angle rate and roll angle, these parameters are useful in EHS to identify, without delay, that an aircraft heading change is occurring and to use this for improving the ground tracker process. The fact that it is not transmitted by ADS-B could be justified by the higher transmission rate of the aircraft horizontal position that facilitates its filtering without the need to anticipate the detection of a trajectory change (turn initiation). The interest of such parameters is assessed in section 5.

4.5.3 Parameters provided by ADS-B and not by ELS/EHS

The following parameters provided by ADS-B and not by ELS/EHS:

- ADS-B emitter category (including “Large”, “High Vortex Large” or “Heavy”)
- Pressure altitude Quality Indicator: NIC_{Baro}
- Geometric altitude

- Coded aircraft length and width
- GNSS antenna offset.

The Pressure altitude Quality Indicator, NICBaro, reports whether, in case of Gilham code altitude source, it has been cross-checked against another source[7].

Geometric altitude is provided by the source for horizontal position. It is the height above WGS-84 ellipsoid. A quality indicator “Geometric Vertical Accuracy” (GVA) is associated to this parameter characterizing the 95% accuracy.

The last two parameters are specific to airport surface applications (i.e. A-SMGCS level 2). They facilitate the data fusion of various sensors regarding aircraft position and thus improve the quality of the aircraft positioning.

4.6 Horizontal position

The horizontal position provided by Mode S SSRs complying with ELS-EHS is measured by the radar system in terms of slant range and azimuth with respect to the radar site. The principle is the same as for the legacy Mode A/C radars (even it has been significantly improved thanks to the mono-pulse antenna technology).

On the opposite, surveillance based on ADS-B aircraft messages conveying the horizontal position in terms of latitude and longitude elaborated by the aircraft positioning and navigation systems relies on completely different principles involving several segments (space, aircraft, ground segments).

The use of the two very differentiated aircraft horizontal position for surveillance purpose has been analysed in depth at various levels (e.g. ICAO, Eurocontrol, FAA and EUROCAE/RTCA)[8].

Several features were considered:

- Accuracy
- Integrity
- Continuity
- Update rate
- Update probability
- Latency.

The following sections are providing some details on those different features, to clearly identify the differences. The approaches are fundamentally different because a radar is a close system and the

7 Due to the 25 ft mandate for Air Transport aircraft, those aircraft are no more equipped with altimeters using Gilham outputs. However even if it not recommended by the regulation and if most aircraft have now digitalised outputs, other aircraft may use Gilham codes which caused a lot of incidents in the past.

8 - EUROCAE Working Group 51, in close cooperation with RTCA and in the framework of the FAA-Europe Requirement Focus Group. The selected reference operational context was the provision of separation service with 5 NM separation En-Route and 3 NM in terminal.
- ICAO document “Doc 9924 — Aeronautical Surveillance Manual. 1st edition, 2010” on the use of SSRs, WAM and ADS-B.
- ICAO circular “ICAO Cir 326 — Assessment of ADS-B and Multilateration Surveillance to Support Air Traffic Services and Guidelines for Implementation. 2012”.

performances can be predetermined. They mainly depend upon the radar system performances (and upon a minimum cooperation of airborne Transponders, at least correct pulse timing and shape).

On the opposite ADS-B involves several systems (space GNSS system, aircraft avionics and ground systems). For accuracy, integrity and continuity the three systems are involved and moreover, one of them, the GNSS constellation characteristics can change in time and are not under the responsibility of Air Navigation Services. The GNSS system itself is standardised by ICAO (ICAO Annex 10 Volume I, 3.7 and Appendix B). The signals characteristics, performances of satellites ranging, data format... are accurately defined but the position performances are guaranteed with availability figures which are not compatible with aviation needs (for example 99% for GPS accuracy average location and 90% at worst case location - ICAO Annex 10 Volume I, 3.7.3.1.2) because they are based on a minimum guaranteed constellation of 24 satellites. The real number of satellites deployed by the US DoD is larger (31 currently, 27 targeted) but the horizontal position performances cannot be predetermined or allocated, so they need to be estimated and predicted in real time. For the update timing characteristics only the airborne and ground systems are involved. Requirements have to be allocated to the airborne side and the ground side.

4.6.1 Accuracy

The determination of aircraft horizontal position by Mode S SSRs is based on the measurement of the aircraft azimuth and distance. Consequently, the along-range accuracy and the cross-range accuracy are significantly different. ICAO do not provide SSR performance requirements but Europe has minimum performance requirements to be achieved by modern mono-pulse Mode S SSR in the ECAC States[9]. It is considered that they are as follows (ED-126 and ED-161):

- 95% azimuth accuracy: 0.127 degrees
- 95% distance accuracy: 137 meters.

The cross-range accuracy is highly dependent upon the distance of the aircraft from the radar site:

- 200 NM: 820 m
- 60 NM: 246 m
- 33 NM: 137 m
- 15 NM: 62 m.

For comparison with ADS-B it is convenient to consider an horizontal accuracy 95% radius:

- 200 NM: 970 m
- 60 NM: 308 m
- 33 NM: 171 m
- 15 NM: 171 m.

The accuracy aspects of the horizontal position transmitted by aircraft through ADS-B are totally different. In Europe, Regulation (EU) N° 1207/2011 requires that aircraft:

- have an horizontal position primary data source “at least compatible with GNSS receivers that perform receiver autonomous integrity monitoring (RAIM) and fault detection and exclusion (FDE), along with the output of corresponding

[9] SUR.ET1.ST01.1000-STD-01-01, “EUROCONTROL Standard Document for Radar Surveillance in En Route Airspace and Major Terminal Areas,” March 1997.

measurement status information, as well as integrity containment bound and 95 % accuracy bound indications."

- transmit in ADS-B messages real time quality indicator information. For accuracy, it is NACp, which provides a 95% Horizontal Accuracy Bound:

NACp value	95% Horizontal Accuracy Bound
0	≥ 18 520 m (≥10 NM)
1	< 18 520 m (10 NM)
2	< 7 408 m (4 NM)
3	< 3 704 m (2 NM)
4	< 1852 m (1 NM)
5	< 926 m (0.5 NM)
6	< 555.6 m (0.3 NM)
7	< 185.2 m (0.1 NM)
8	< 92.6 m (0.05 NM)
9	< 30 m
10	< 10 m
11	< 3 m

Table 3 NACp value and corresponding Horizontal accuracy 95% bound

The GNSS receiver requirements are specified by the CS-ACNS based on ETSO-C129a or ETSO-C196 or ETSO-C145/ETSO-C146 with additional qualification requirements (AMC1 ACNS.D.ADSB.070 and Appendix H Part 5).

4.6.2 Integrity

The integrity is characterized by the probability of position error greater than a given value without alerting within the Time to Alert (10 s).

There is no formal integrity requirement for Mode S SSRs because the position determination is the prime function of the Mode S radar itself with a functional cooperation from the airborne transponder. The EUROCONTROL Surveillance Standard has only a requirement on "jumps" more than 1 degree azimuth or 700 meters range that are the drivers of the radar design itself. Their probability should be less than 5.10-4 (ED-161 Annex B).

Concerning ADS-B two types of integrity impact are considered:

- without on-board failure. In the case of GNSS the origin could be a failure of the satellite constellation.

  The Regulation (EU) N° 1207/2011 and EASA CS-ACNS requires a "Source Integrity Level" equal or less than 10-7 per flight hour. It is the probability of a position error greater than the Containment Radius (Rc) encoded by the Airborne Navigation Integrity Category (NIC) value transmitted by aircraft.
- due to on-board failure (position source, Extended Squitter protocol part of the transponder and interconnecting avionics).

  The Regulation (EU) N° 1207/2011 and EASA CS-ACNS require a probability of false or misleading position information or related quality indicators less than 10-5 per flight-hour (remote probability corresponding to the Major failure condition).

Radius Containment Rc (horizontal position integrity containment bound) encoding:

NIC value	Radius Containment (Rc)
0	Rc > 37 040 m (20 NM) or unknown
1	Rc < 37 040 m (20 NM)
2	Rc < 14 816 m (8 NM)
3	Rc < 7 408 m (4 NM)
4	Rc < 3 704 m (2 NM)
5	Rc < 1 852 m (1 NM)
6 (NIC Supplement codes A,B = 1,1)	Rc < 1 111.2 m (0.6 NM)
6 (NIC Supplement codes A,B = 0,0)	Rc < 926 m (0.5 NM)
6 (NIC Supplement codes A,B = 0,1)	Rc < 555.6 m (0.3 NM)
7	Rc < 370.4 m (0.2 NM)
8	Rc < 185.2 m (0.1 NM)
9	Rc < 75 m
10	Rc < 25 m
11	Rc < 7.5 m

Table 4 NIC value and associated Radius Containment

Concerning ADS-B it is worth noting that the European Regulation provides only an obligation of means and not a requirement for a given accuracy or integrity containment. The reason is that the performance of position provided by GNSS is dependent upon the receiver but the most important factor is the GNSS constellation status, specifically the number of satellites and the geometry of the constellation. The avionics manufacturers and the ANSP in charge of surveillance do not master this last key aspect.

Today on-board GNSS receivers are based only on GPS. Based on the receiver requirements provided by the Regulation (EU) N° 1207/2011 and the EASA CS-ACNS, the proportion of time (availability) a given NACp or NIC values are reached can be pre-determined based on assumptions concerning the GPS satellite constellations (number of satellites and geometrical aspects).

Notes:

a) the CS-ACNS makes references[10] to the requirements for surveillance operations in radar environment provided by the “ADS-B-RAD Safety and Performance Requirements/Interoperability document” (EUROCAE ED-161) but this document requires for some operations NACp=8 or NIC=7 (§3.3). Those values cannot be reached 100% of the time, depending on the current GPS constellation (see chapter 5 below).

There are two notes in the CS-ACNS stating:

[10] We understand there are no formal requirements in the CS-ACNS to comply with the requirements in section 3.3 (Aircraft domain safety and performances requirements) of the ADS-RAD SPR ED-161. However, these documents including some NACp and NIC values is often mentioned in Appendix H (Guidance on 1090 MHz Extended Squitter ADS-B Out)

- ✓ "The minimum NACp values required for the ADS-B-RAD application can be found in Table 20, in Part 3 of Appendix H. This value is met through the horizontal position source requirements defined in CS ACNS.D.ADSB.070."
- ✓ "The minimum NIC values required for the ADS-B-RAD application can be found in Table 20, in Part 3 of Appendix H. They are met through the horizontal position source requirements defined in CS ACNS.D.ADSB.070."

As the maximum NACp and NIC values in Table 20 are respectively 7 and 6 they cannot be met 100% of time with the guarantied 24 satellites GPS constellation and even with a 27 satellites constellation (see chapter 5).

b) the NACp and NIC parameters are upper bounds that are determined in real time by the GNSS receivers. In fact, the actual performances are significantly better. For example, ICAO Annex 10 Vol I (§ 3.7.3.1) states that the GPS horizontal position error (95%) shall not exceed 17 m 95% at the worst site. Unfortunately, as explained above, the availability of this value is only 99% of time and even 90% in the worst case.

4.6.3 Continuity

Continuity of position is characterized by the probability that the required position performance is provided without unscheduled interruption, if it was available at the initiation of the intended operation. It is considered that SSR continuity is better than 0.99966 per hour (1 - 3.3 10-4). The continuity of airborne Mode S transponders is generally 10-3 per flight-hour (Minor classification).

Concerning ADS-B position there are three causes of loss of position continuity:

- two are linked to the GNSS system:
  a. the risk of complete failure of the GNSS system (i.e. GPS today) or of interferences
  b. the risk performance (NACp or NIC) no more complies with the required values.

  They impact multiple aircraft.

- one is linked to the on-board GNSS receiver continuity. Regulation (EU) N° 1207/2011 requires a 2.10-4 per flight-hour continuity and the EASA CS-ACNS has translated it in the more stringent requirement of 10-5 per flight-hour.
  Only one aircraft is impacted.

4.6.4 Update interval and Update probability

For ADS-B, update interval is the time interval within which there is a 95% probability of receiving at least one ADS-B message update from an aircraft.

Update probability is the probability that a message transmitted by aircraft is received by a ground station within the update interval;

For Mode S SSRs, the update intervals are linked to the radar sweeps in a mono radar environment (typically between 5 and 8 seconds). Multi-radar operations improve largely the update intervals regarding the ELS parameters as a result of multi radar tracker algorithm. This is the dominant situation in Europe (at least in the core area). In the European core area with a typical 3 to 5 Mode S SSRs in visibility the update rate of the position could reach 2 seconds in the best conditions.

EHS additional parameters, the situation is different since only one Mode S SSR is initiating the request for the download of a specific register (see limitation known as BDS swap issue that was analysed in SC001 report).

For ADS-B the position messages are transmitted, typically, twice per second. The actual update is indeed lower due to the garbling effect (overlaps of ADS-B random transmissions). Other information may be spread between several messages with different update intervals. So the update rate is generally higher for all parameters in ADS-B mode than in Mode S SSR mode.

4.6.5 Latency

Latency is the amount of time it takes to deliver data end to end.

For SSRs it is considered latency is less than 2 seconds.

For ADS-B position, a distinction is made between the total end to end latency and the uncompensated latency (the remaining latency after compensation based on the Time of Applicability). For the horizontal position the Regulation (EU) N° 1207/2011 and EASA CS-ACNS requirements are:

- total latency <= 1.5 second in 95 % of all transmissions;
- uncompensated latency <= 0.6 second in 95 % of the cases and <= 1 second in 99.9 % of all transmissions.

4.6.6 Source position independence

When aircraft position is determined by Mode S SSRs (or WAM), the source of horizontal position used for surveillance is independent of the source used by each aircraft for the navigation function. Furthermore, when Multi-radar are used the computed aircraft position is the consolidation of multiple independent measurements.

On the opposite, when the aircraft positions are provided by ADS-B there is a risk to use the same source for surveillance and aircraft navigation. It could be a cause of common point of failure for navigation and ATC surveillance functions.

4.6.7 Comparison synthesis

The comparison between ELS/EHS horizontal position and ADS-B horizontal position performed in this section has shown that most of the ADS-B horizontal position performances are equivalent or better than the ELS/EHS one. However, there are two significant differences:

- ADS-B position is not only “dependent” upon the aircraft avionics. It is also highly dependent upon the GNSS (i.e. GPS today) system. The guarantied availability is low and the real availability depend upon the GNSS constellation but the GNSS constellation is neither under the responsibility of the receiver manufacturer nor under the responsibility of the ANSP in charge of surveillance in a given Airspace. Therefore, the availability of required performance due to the GNSS constellation could be a critical point.

- The GNSS position source could be a common point of failure for aircraft navigation and surveillance.

5. The operational usage of the various downlinked parameters

In this section, ELS/EHS parameters will be analysed, from the point of view of their operational usage by ATC, to identify the most interesting ones. This initial filtering will be used to make a comparison with ADS-B provisions. The basic ELS parameters are not analysed in this study considering that they are the necessary baseline for EHS functions.

Considering the effective usage of ELS/EHS parameters, by the European ANSPs, provides a solid ground to assess the operational interest of the parameters accessible via ELS/EHS or via ADS-B.

After this analysis, a comparison between ELS/EHS parameters and ADS-B parameters will be made to confirm that the same parameters could be available whatever technology is used.

A special consideration will address the most critical difference between Mode S ELS/EHS and ADS-B regarding the aircraft horizontal position determination, due to the fundamental differences as described in the previous section 4.6. The following table 5 provides a global synthesis of the differences between Mode S, WAM and ADS-B highlighting the notion of dependence/independence, that are fundamental to understand the above mentionned difference between ADS-B and the other solutions (i.e. Mode S or WAM).

In the following table the terms “cooperative” and “dependent” shall be understand as follows:

- Dependent: data are provided by systems external to the ground surveillance means (aircraft or GNSS).
- Cooperative: data are elaborated by ground surveillance means but it needs aircraft cooperation.

A surveillance means is qualified as dependent when the acquisition of horizontal position of aircraft is dependent.

A surveillance means is qualified as cooperative when the acquisition of horizontal position of aircraft is cooperative.

Surveillance means	Aircraft identification	Pressure Altitude	Horizontal position	Additional parameters
PSR			Independent Non-cooperative	
SSR Mode S (ELS+EHS)	Dependent (Aircraft)	Dependent (Aircraft)	Independent Cooperative	Dependent (Aircraft)
WAM	Dependent (Aircraft) (1)	Dependent (Aircraft) (1)	Independent Cooperative	Dependent (Aircraft) (1)
ADS-B	Dependent (Aircraft)	Dependent (Aircraft)	Dependent (Aircraft + GNSS)	Dependent (Aircraft) (2)

(1) Active WAMs with Mode S aircraft or passive WAMs with ADS-B aircraft.
(2) Geometric altitude and in some case Velocity over Ground should be provided by GNSS

Table 5 Mode S, WAM and ADS-B comparison

Surveillance system output (flight consolidated tracks) is primarily used by the traffic separation function.

The En route and TMA separations criteria used are:

- 3 Nm for TMA operations
- 5 Nm for En Route operations
- 10 Nm for En Route oceanic operations

The final approaches separation criteria used are:

- 2.5 Nm for the final approach leg
- Locally defined separation criteria for dependent runways

For airport surface movement surveillance, there is no separation criteria as such yet defined due to the shared responsibility between ground ATCO and aircraft crew members. Specific surveillance functions are defined (i.e. ASMGCS level 1) that cover:

- Traffic Awareness on airport surface

In complement to these separation functions, the surveillance system output is also used by various specific safety nets:

For airport surface:

- Runway incursion associated with ASMGCS surveillance function (ASMGCS level 2)

For En route and TMA:

- Minimum Safety Altitude Warning (MSAW) for En Route and TMA
- APP path monitoring for approaches
- Area Proximity Warning (APW) and Airspace Infringement Management
- Short Term Conflict Alert (STCA) to mitigate non-detected separation violation by the ATCO

The following analysis is concentrating upon the main separation function. It also considers the ATCO display that is used to provide the controller with relevant parameters associated with a given flight. These parameters could be permanently displayed or displayed on request of the ATCO (using a specific HMI interaction). This is the case for the selected altitude parameter that could be considered as a safety barrier against human error in the level or altitude selection.

It is considered that the major surveillance requirement is to ensure safe separation of traffic. All complementary parameters (provided either by ELS/EHS or by ADS-B) are contributing to the improvement of the surveillance service but not to the achievement of the traffic separation requirements.

5.1. Operational benefits of ELS/EHS parameters currently used by ANSP surveillance system

The figure 2 below describes the “ground surveillance chain”. It is composed of three major elements:

- The sensors (Mode S stations, WAM stations, ADS-B stations and a common data communication network),
- The data processing,
- The ATM client function (separation function, safety nets or other ATC tools).

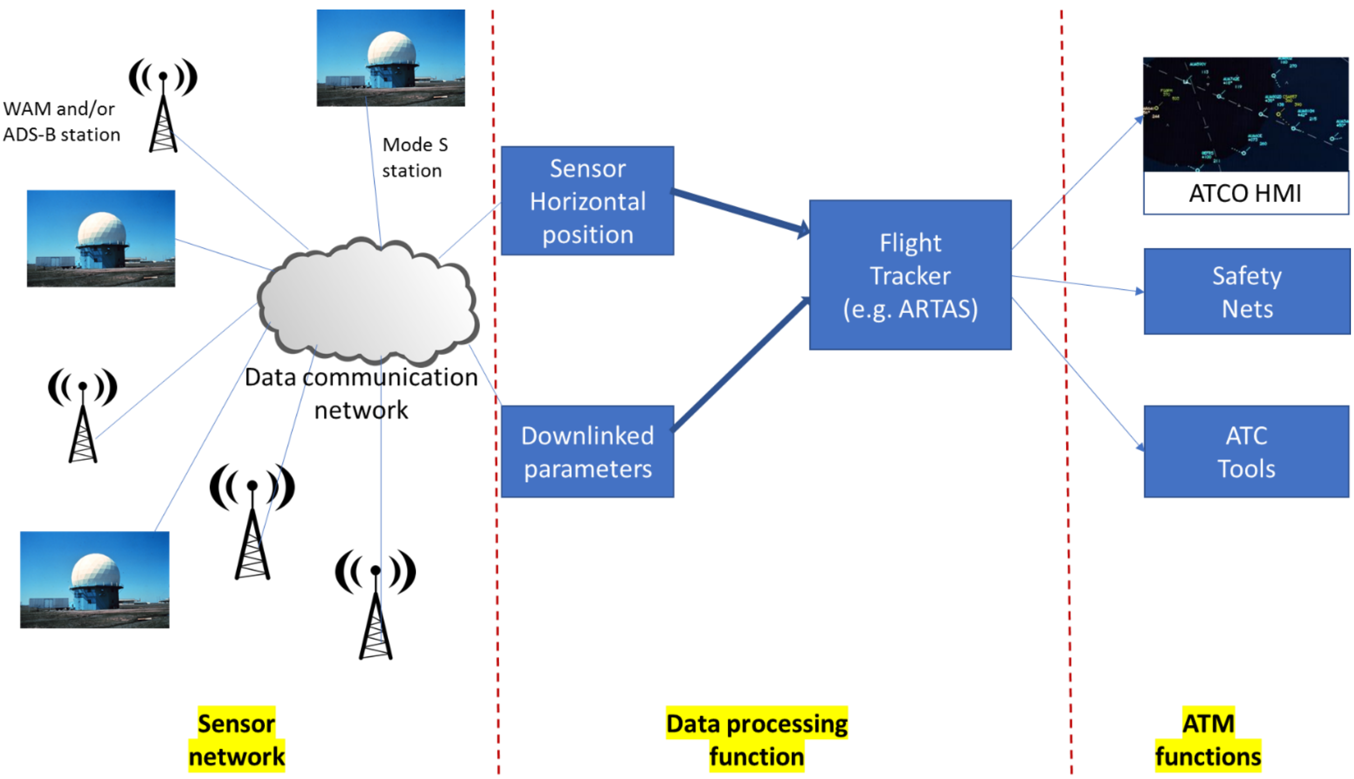

Figure 2 Ground Surveillance Chain description

The parameters that are provided by ELS/EHS (or by ADS-B) can be used either as input to the automated ATM tools (i.e. the tracking function as heart of the ground surveillance chain) or as information that can be displayed on the ATCO HMI. In this last case the information could be permanently displayed or following ATCO selection at the flight label level.

Based upon a recent survey made by Eurocontrol and presented to a Surveillance Modernisation Sub Group meeting in September 2016, the usage by European ANSP of the EHS parameters is summarised in the table below.

EHS parameter usage by ANSP			
Parameter	Extracted	Displayed	Used for automation
MCP/FCU Selected altitude	14	12	8
FMS selected altitude	1		
Barometric pressure setting	9	4	4
MCP/FCU Mode bits	3	1	
Roll angle	5	2	1
True angle	6	3	1
Ground speed	6	2	1
Track angle rate	6	2	1
True air speed	5	2	
Magnetic heading	13	11	1
Indicated airspeed	13	11	2
Mach number	8	7	1
Barometric altitude rate	13	10	1
Inertial vertical velocity	9	5	

Table 6 ANSP usage of EHS parameters

From the survey above it appears clearly that only a few EHS parameters are widely used by ANSPs to improve the performance of their ground surveillance chain (i.e. safety and efficiency).

The following sections will analyse only the key parameters (highlighted in the above table in green or orange). For each parameter the operational benefits will be analysed. A comparison with alternative ADS-B provision will be made for each of these parameters.

5.1.1 Selected altitude

Selected altitude data is presented as either a flight level or an altitude, depending on surveillance system settings.

The selected altitude DAP has the potential to help in “level bust” prevention as it provides the opportunity to alert ATC if there has been any misinterpretation of the altitude/level clearance. The analysis of level bust occurrences carried out by NATS some years ago showed that the following factors are being preventable:

- Correct pilot “read-back” followed by incorrect action;
- Incorrect pilot read-back by correct aircraft;
- Pilot read-back by incorrect aircraft.

NATS demonstrated that, following the implementation of Modes S and usage of selected altitude parameter, 63% reduction in the level of risk exposure, associated with the above causal factors, expressed as the severity of the consequent level bust, was achieved.

The selected altitude shows intent only, and therefore cannot be used for separation purposes. Indeed, there are may be occasions where despite the flight crew complying with the ATC clearance, the selected altitude is not consistent. This is the case during SID/STAR procedures in Terminal area evolutions or during final approaches (the selected altitude could be made to cover the missed approach procedure).

The display of selected altitude to controllers can have additional safety benefits, for example in highlighting call-sign confusion.

This is therefore a **useful complementary parameter.**

To be noted that this parameter is also transmitted by ADS-B.

5.1.2 Magnetic Heading

This is the aircraft heading relative to magnetic north. Display it to controllers reduces R/T exchanges to request such information to the crew. The Magnetic Heading has the potential to improve horizontal maneuver recognition, either by the controller or by the surveillance data processing systems, via monitoring of heading changes.

Heading is also used by ATCO in specific clearances to modify the aircraft trajectory in case of need for traffic separation: the clearance is often a new heading request.

This is therefore a **useful complementary parameter**.

This parameter is normally not transmitted by ADS-B except if Velocity over ground is not available.

5.1.3 Indicated airspeed (IAS) and Mach-number.

Presenting the IAS to controllers facilitate the traffic separation provision tasks while reducing the R/T and controller workload. This is also the parameter used by ATCO for speed constraint clearance. Therefore it is considered as a **useful complementary parameter**.

This parameter is normally not transmitted by ADS-B except if Velocity over ground is not available.

5.1.4 Vertical rate (barometric rate of climb / descent)

This parameter is used operationally by several ANSPs. It provides an indication that the aircarft is potentially changing of level or altitude and also provides the ATCO with an idea of the vertical profile followed by the aircraft.

It is recognised as a useful parameter to display on ATCO screen. Therefore, it is considered as a **useful complementary parameter**.

This parameter is also transmitted by ADS-B.

5.1.5 Ground Speed and True Track Angle

They represent the module and the direction of the calculated aircraft ground velocity. The aircraft ground velocity is also calculated by the surveillance fligth tracking processing systems based upon the filtering of positions.

The usage of this information associated with the Track angle rate, the Roll angle and the True airspeed could provide serious improvements to the simple derivation from aircraft position measurements. This is true for SSR Mode S infrastructure with a limited number of overlapping radar coverages.

Despite the situation in the core area of Europe, characterised by a multi radars infrastructure, the usage of these parameters has been implemented by several ANSPs.

To be noted that this parameter is also transmitted by ADS-B. In the case of ADS-B due to the update rate of the position, there is less interest with such parameter, even if theoritically the same type of improvement is also provided by this mean.

For these reasons, they are **useful complementary parameters**.

5.1.6 Roll angle, True Airspeed and Track Angle Rate

These flight technical parameters could be used to enhance the radar tracking capability and/or tactical trajectory prediction by the ground ATC systems. Either the Roll Angle, in conjunction with the True Airspeed, or the Track Angle Rate, in conjonction with the ground speed, can be used by the surveillance data processing systems to improve the recognition without delay of route changes and avoid the latency of Kalman filter: this increases aircraft tracking accuracy.

The usage of such parameters increase tracking performance (particularly at the edges of the radar systems' range) and to improve recognition of horizontal maneuver by monitoring changes in track angle.

Therefore, they are considered as **useful complementary parameters**.

To be noted that two of these parameters ("Roll angle" and "Track Angle Rate") are not transmitted by ADS-B because the update rate of the aircraft position is high enough to identify any change in the aircraft trajectory.

5.1.7 TCAS downlinked resolution advisories.

This information displayed to the controller could also reduce the R/T activities and provide a quicker awareness of emergency manoeuvre from aircraft following a TCAS RA.

Therefore, it is considered as a **useful complementary parameter**.

To be noted that this parameter is also transmitted by ADS-B.

5.1.8 Flight status (airborne / on the ground)

Several issues have been reported by ANSP at major airport regarding the lack of reliability of this parameter when used within A-SMGCS system to contribute to the runway incursion protection.

These issues are directly linked with aircraft that are not fitted with air/ground switch sensor but using a combination of airborne parameters including the speed to generate this flight status parameter.

Actions could be needed to improve the situation that is directly linked with airport operation safety (i.e. runway incursion).

5.2 Aircraft horizontal position

As seen in the previous chapter a part of the ADS-B horizontal position requirements of the European regulation have been derived by comparison with SSRs performance. The general idea was to get performances at least as good as the one provided by SSRs. However, two fundamental differences have been identified:

- ADS-B is not only “dependent” upon the position provided by the aircraft avionics. This position is also highly dependent upon the GPS system. The guarantied availability is low and the real availability depend upon the GNSS constellation but the GPS constellation is neither under the responsibility of the receiver manufacturer nor under the responsibility of the ANSP in charge of surveillance in a given Airspace. However, the availability of performance due to the GPS constellation could be a critical point.
- The GPS position source could be a common point of failure for aircraft navigation and surveillance.

Their consequences depend upon the operational scenarios considered.

- For example, ED-126 has considered 5NM and 3 NM separation in medium traffic density based only on ADS-B.
- ED-161 has analysed five operational scenarios based on the combined use of SSR and ADS-B in a reference environment reflecting a medium to high traffic density environment:
    - 5 NM separation services in En-Route;
    - 3 NM separation service in TMA;
    - 2.5 NM separation in-trail on approach;
    - 2 NM dependant parallel approach;
    - independent parallel approach.
- ED-163 has analysed the surveillance context on the airport surface.
- It could be mentioned also the concept of operation FAA is currently implementing.

Those documents represent a set of possible operations which could be totally or partly supported by ADS-B. However European ANSPs may implement operations outside this list.

They are all based on comparisons with Mode S SSR-based surveillance, considering that their performances are appropriate. The assumptions made when comparing SSR and ADS-B operations may have significant impact on the result:

- ED-126 was established in 2006 on the assumption that 5 NM separation is performed within the entire Mode S SSR coverage (i.e. 200 NM away from the SSR where the accuracy is 970 m).
- In the subsequent documents, it was decided that 5 NM separations in dense areas are performed only within a 60 NM range around the SSR. This new assumption is certainly valid for the core area of Europe where Mode S infrastructure provides a multi radar overlapping coverage (i.e. Mode S individual raw positions being consolidated in a multi radar tracker). Consequently, the ADS-B accuracy requirement was set to 308 m instead of 970 m. It explains why the ED-126 requirements are far less stringent than in the subsequent documents (ED-161 and ED-163).

5.2.1 ED-126 Operational context

ED-126: has determined that the horizontal position performance provided by aircraft ADS-B should be as follow (ED-126 § 3.4.2.1):

	95% accuracy	**NACp**	**Rc**	**NIC**
5 NM separation En-Route	<0.5 NM (926 m)	>= 5	< 2 NM	>=4
3 NM separation in TMA	< 0.3 NM (555 m)	>=6	< 1 NM	>=5

Table 7 NACp and NIC associated with ED-126

5.2.2 ED-161 Operational context

ED-161 has determined that the horizontal position performance provided by aircraft ADS-B should be as follow (ED-161 § 3.3.2.1):

	95% accuracy	**NACp**	**Rc**	**NIC**
5 NM separation En-Route	< 308 m	>=7	< 1 NM	>=5
3 NM separation in TMA	< 171 m	>=8 (*)	< 0.6 NM	>=6
2.5 NM separation in-trail on approach	< 171 m	>=8 (*)	< 0.2 NM	>=7
2 NM dependent parallel approach	< 171 m	>=8 (*)	< 0.2 NM	>=7
independent parallel approach	< 121 m	>=8	< 0.2 NM	>=7

(*) As 171 m is very close to the NACp = 7 threshold (185 m) a NACp value equal to 7 could be considered.

Table 8 NACp and NIC associated with ED-161

5.2.3 ED-163 Operational context

ED-163 is requiring the most demanding accuracy, driven by the misleading position error threshold value of 22.5 m in the along-track direction. It has been determined that a 10 m 95% accuracy would be enough.

	95% accuracy	**NACp**	**Rc**	**NIC**
Surface surveillance	<10 m	>= 10		

Table 9 NACp and NIC associated with ED-163

The document recognizes in § 3.4.2.1.3 that this NACp value cannot be obtained with a high availability. Instead of relying on a quality indicator reported by Aircraft which is an upper bound whilst the actual accuracy is in the order of 2 to 3 meters it suggests an alternative solution where the real-time GPS performance is monitored on the ground. The difficulty is that there is no assurance that aircraft are using GPS then criteria are suggested to check that the ADS-B aircraft position is GPS-based.

5.2.4 FAA Operational context

The FAA requires as of 2020:

	95% accuracy	NACp	Rc	NIC
CONUS operations	<0.05 NM (92 m)	>= 8	< 0.2 NM	>=7

Table 10 NACp and NIC FAA requirements

5.2.5 Horizontal position requirement feasibility

Concerning the feasibility of such requirements, it is dependent upon the actual GPS constellation but it is important to note that there is no international standard defining the actual GPS constellation. There is only a commitment of the US government on the minimum capability which is reflected in ICAO Annex 10 Volume I (Attachment D, Guidance material on GNSS, § 4.1.4.2):

> "*Twenty-four operational satellites will be maintained on orbit with 0.95 probability (averaged over any day), where a satellite is defined to be operational if it is capable of, but is not necessarily transmitting, a usable ranging signal. At least 21 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.98 probability (normalized annually). At least 20 satellites in the nominal 24 slot positions must be set healthy and must be transmitting a navigation signal with 0.99999 probability (normalized annually*)."

Several simulations have been performed in the past, to assess the feasibility of such requirements using different assumptions on the number of GPS satellites or satellite geometry. The usage of assumptions with more than 24 GPS satellites, are under the responsibility of the ANSPs.

A recent simulation was performed by European experts[11] addressing the usage of "SBAS or RAIM for ADS-B positioning".

They have considered two sets of GPS constellations:

- 24 satellites constellation close to the minimum commitment of United States[12];
- 27 satellites constellation which should be the nominal constellation.

The GPS receiver has been considered as compliant with the current European regulation. It is assumed it is "Selective Availability aware" (it is an optimistic hypothesis because for now only a part of aircraft flying in Europe have such GPS receivers and this is not mandated by IR 1207/2011) and not SBAS capable.

The results show that:

[11] "SBAS and RAIM analysis for ADS-B mandates" by Mikael Mabilleau, Daniel Salos, Eric Vallauri and Benoit Roturier

[12] In fact, the simulation does not consider the possibility to have less than 24 satellites because the authors believe less than 24 satellites would not have a high probability. In case of deployment this hypothesis would be made by the ANSP at its own risk. The decision should probably be approved by the regulatory authority.

- The combination NACp>=7 and NIC >= 6 corresponding to the "2.5 NM separation in-trail on approach" and "2 NM dependent parallel approach" as defined in ED-161 scenarios cannot be reach 100% of the time and in all regions of Europe.

  With the minimum GPS constellation of 24 satellites, the availability ranges from 97% to 100% of time according to the region. Only a small part of Europe benefits from a 100% availability.
  With the 27 satellites GPS constellation, it ranges from 97.5% to 100%. Approximately half of the Europe area benefits from the 100% availability.

- The combination NACp>=8 and NIC >= 7 corresponding to the FAA requirements cannot be reach 100% of the time and in all regions of Europe.

  With the minimum GPS constellation of 24 satellites, the availability ranges from 88% to 98% of time according to the region. Only a small very part benefit from 100%.
  With the 27 satellites GPS constellation, it ranges from 98% to 100%. The 100% availability is reach only in a small part of Europe.

Globally a 100% availability cannot be guaranteed in all regions of Europe for the scenarios corresponding to TMA or approach operations.

The required level of availability will be determined by the ANSPs in charge of the surveillance considering the concept of operations and the mitigation means implemented. In the ED-161 document the assumption was made that aircraft were compliant at the beginning of operations then this aspect was not addressed.

The NACp or NIC unavailability's are predictable. Mitigations means based on operational limitations are possible even if it is not a satisfactory solution.

Considering their specific surveillance infrastructure, traffic environment and concept of operation the FAA has determined that à 99.9 % availability similar to radar availability would be necessary. As it cannot be guaranteed neither with the 24 GPS satellites constellation nor with a 27 GPS satellites constellation, FAA recommends the use of SBAS (or the use of prediction tools informing operators that they cannot fly in airspaces in which the requirement applies).

However, some recent trials have demonstrated[13] that with the current 31 GPS satellites constellation the 99.9% availability for NIC >=7 could be reached by most of high end aircraft. It generally corresponds to aircraft equipped with SA-aware GPS receivers. Unfortunately, the current 31 GPS satellites constellation is an exceptional situation. The GPS constellation should converge towards 27 satellites.

5.2.6 Summary of operational impacts of the ADS-B horizontal position

Those results show that for each kind of planned operations the requirements in terms of NACp and NIC as well their associated availability should be carefully analysed by the ANSP in charge of the operations in the considered airspace.
The main problem is the institutional issue because the ANSP does not master the GPS constellation specifically the number of GPS satellites which drives the availability of performances. There is only an official commitment from the US government to maintain at least 24 GPS satellites in operations.

The simulations mentioned above demonstrated that this guarantied configuration is not capable of 100% availability for the European combination (NACp>=7 and NIC >= 6) nor the FAA combination

[13] ICAO ADS-B SITF/15 IP10 "Performance of current ADS-B version 2 systems" 14/04/2016.

(NACp>=8 and NIC >= 7). If a better availability is required, the ANSP in charge of the Airspace should made assumptions on the GPS constellation on its own responsibility.

The second significant difference mentioned in section 4.6 is that the GPS position source could be a common point of failure for aircraft navigation and surveillance. Traditionally the air traffic control principles are based on the independence of aircraft navigation and surveillance. Then it is unlikely that an aircraft could lose navigation and surveillance simultaneously. In some concepts of operations ground vector provided by air traffic controllers are mitigations means covering loss of navigation capability. Surveillance may also detect slowly increasing navigation errors.

These benefits would be completely lost in case of surveillance using only ADS-B data because it combines the aircraft navigation and the surveillance capabilities. Even in case of ADS-B combined with SSRs or WAM the impact of the potential common point of failure should be analysed. It could be the case when implementing Performance Based Navigation with low RNP levels.

ICAO warn the States on this issue in different documents (ICAO Cir 326 — Assessment of ADS-B and Multilateration Surveillance to Support Air Traffic Services and Guidelines for Implementation. 2012" § 1.7 and "ICAO Doc 9924 — Aeronautical Surveillance Manual. 1st edition, 2010" § 7. Independence of Navigation and Surveillance).

It should be noted that those two issues are difficult to be properly addressed by standards and regulations if they are limited to the surveillance domain.

For example, as far as we know the "EUROCONTROL Specification for ATM Surveillance System Performance (EUROCONTROL-SPEC-0147) March 2012" can be used in Europe to define the minimum performance of the surveillance system to comply with IR 1207/2011. It has been developed as a generic technology independent specification. As such the surveillance system is considered, in isolation of the other ATC supporting functions (e.g. communication and navigation), as a whole -it could be constituted of SSRs and/or WAM and/or ADS-B). If ADS-B is one of the surveillance components, there are two consequences:

- the role of the external navigation space segment (i.e. GNSS) with its potential impact on availability is not considered.
- the common point of failure between surveillance and the navigation system for some aircraft is not addressed.

The situation is the same for the "Safety and Performance Requirements document for a generic surveillance system supporting Ait Traffic Control Services (GEN-SUR SPR)" document currently under development at EUROCAE.

Similarly the scope of the Regulation (EU) N° 1207/2011 (requirements for the performance and the interoperability of surveillance) is the surveillance domain. It requires ANSPs to perform, as a baseline requirement, a safety assessment of the surveillance function with respect to the contemplated traffic separation minima (article 9(2)). This safety assessment could be understood as limited to the constituents identified in article 2 of the regulation and thus ignoring the global environmental context:

- airborne surveillance systems, their constituents and associated procedures;
- ground-based surveillance systems, their constituents and associated procedures;
- surveillance data processing systems, their constituents and associated procedures;
- ground-to-ground communications systems used for distribution of surveillance data, their constituents and associated procedures.

The two major issues, associated with the aircraft horizontal position as provided by ADS-B, are not addressed by a surveillance performance-based approach because communication, navigation are addressed as contributors to the global traffic separation function.

Inter-domains issues can be addressed only when the safety assessment is performed for a given airspace environment as required by ICAO (Annex 11) and EASA (Part-ATM/ANS.OR). Then, the interrelations between the different support components (C, N, S) and associated ATM procedures are examined, leading to the identification of the necessary mitigation means and potential minimum separation limitations due to all the contributing systems, including those that are not managed by the ANSP itself (i.e. GNSS satellite number).

5.3. Parameter update rate comparison and operational implications

Another aspect to consider when comparing Mode S ELS/EHS and ADS-B is the update rate of the downlinked parameters.

At the beginning of the development of ADS-B technology, one significant advantage was the high update rate provided for the key parameters (i.e. of the order of the second) compared with the Mode S ELS/EHS that implies a systematic interrogation to get the parameter.

ADS-B update rates are generally still much higher that those of Mode S SSR in the mono radar case.

In Europe, with the wide deployment of multiradars data fusion technology (i.e. ARTAS product developped by Eurocontrol) and the progressive deployment of a multi layers radar coverage (at least three radars covering any piece of airspace in the european core area), the strong limitation of mono Mode S radar has been removed. Today in these european airspace due to the multiradar infrastructure, the update rate of the key parameters has been progressively increased and is now lower than 2 second, relatively close from the ADS-B update rate (at least in the european core area where the infrastructure is highly redundant).

This is true for the aircraft position parameter. This increase of the update rate in the ground surveillance chain has also minimised some initial deficiencies of Mode S (mono radar), like the need to anticipate a change in the aircraft route to avoid the reaction latency of the tracking Kalman filter.

5.4. ADS-B complementary parameters and their potential role

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.

Additional parameters that could transmitt ADS-B are indeed supporting specific applications in addition to the basic surveillance function associated with traffic separation.

One application is the Advanced Surface Management Guidance and Control System (ASMGCS) through the provision of several geometrical informations on the antenna locations on a given aircraft that could optimise the quality of the aircraft position used in the ASMGCS various functions. Only ADS-B broadcast parameters can provide such improvement.

The other set of applications that could benefit from these additional ADS-B parameters are the so call ‘ADS-B IN” services (e.g. Flight Interval Management service).

This study is not addressing these aspects that could bring extra benefits to the choice of ADS-B technology.

This study has not addressed the ongoing activities at ICAO level towards a version 3 of Extended Squitter. Some new proposals should be carefully monitored because they could result in over usage of the scare 1090 MHz resource. (i.e. transmission of meteorological information using Mode S extended squitter).

6. Analysis summary

This study has been analysing the differences between the two essential operating modes of Mode S technology (i.e. ELS/EHS and ADS-B) in terms of surveillance performances, content of information exchanges and update rate of this information.

The analysis was driven by operational considerations, taking into account the specificities of the European area constituted of a large high density of traffic area, and medium to low density traffic areas mainly at its periphery.

6.1 Considerations on the performance differences

6.1.1 Aircraft horizontal position performance comparison

A significant part of the study has been devoted to investigate the major difference in terms of performance between the classical ground based radar (or WAM) infrastructure solution (i.e. ELS/EHS) and the ADS-B solution for which the performance is essentially provided by the onboard navigation function.

a) In the Mode S ground radar case (as well in the WAM case), the performance is totally deterministic and predictable by design and it is independent from the other ATM support functions (i.e. Navigation or Communication) with the exception of the vertical dimension that is completely dependent on airborne information. The performance can be easily mastered by the ANSP that provides the surveillance and separation services.

b) In the ADS-B case, the performance is mainly achieved on board and is completely linked with the quality of the navigation position. In the majority of cases the navigation position is the GNSS position (today this means GPS L1 frequency alone with aircraft augmentation or SBAS augmentation). So the performance is totally dependent on an external system on which neither the aircraft nor the ANSP have any control concerning the satellite constellation i.e. the availability of performances.

Due to the uncertainty and the lack of guaranties concerning the GNSS constellations, the GNSS performance could be a limiting factor for ADS-B. [14]

The analysis indicates that the GNSS performances could be a strong limiting factor for ADS-B sole solution for the majority of the European airspace. Nevertheless, it could be an acceptable solution for low traffic density airspace, associated with appropriate separation minima to cope with GNSS performance degradations, via a safety assesment case, as mentioned in section 5.2.6.

6.1.2 Common failure mode issue

Futhermore, it should be recognised that ADS-B sensor for surveillance and traffic separation, represents a common mode of failure (i.e. navigation function and surveillance function), in the case of GNSS outages.

[14] ADS-B aircraft horizontal position has been improved with version 2 with the introduction of the NIC and NAC indicators that provide a quality level of the position information.

The most critical case is the complete GNSS outage over a given area: in this case the risk to loose both navigation capability (i.e. RNP 1 in particular) and surveillance function allowing safe traffic separation could be a serious issue that must be addressed during the operational concept validation for a given airspace configuration[15].

Such event is becoming more and more probable when considering solar pulses occurences and their strong impact on GNSS signals (significant perturbations during several hours have been observed or are predicted for large regions[16]).

6.1.3 Need for safety assessment case to drive the surveillance infrastructure selection

It is important that, this understanding of the basic limitations of ADS-B, be shared between the whole aviation community. Based upon such understanding, surveillance function and technology should be selected on the basis of the operational needs that could be rather different in a large region like Europe. The technology choice should be driven by operational needs, that is to say that for high density traffic area, the solution could be a mix of classical Mode S radar infrastructure (or WAM as an interesting alternative to radar stations) and ADS-B to ensure that there is no common mode of failure in case of GNSS outage.

It has been noted that standardisation and regulation devoted to a specific domain (i.e. surveillance in this case) are not the most appropriate tool to cover the two major issues raised above with regards to the aircraft horizontal position provided by ADS-B. Performance-Based regulation associated with surveillance could face the same difficulty.

The only way to cope with such difficulty is to impose a safety assessement case covering all the contributing components including the external ones (i.e GNSS).

The evolution of the SPI regulation should reinforce the requirement for a global multi-domain safety assessment case associated with airspace specificities, when introducing ADS-B as one of the ground surveillance chain sensor, identifying the mitigations (that could be separation increase) to cover the worst case of GNSS outages.

6.2 Information exchange commonalities and differences between ELS/EHS and ADS-B.

This study has shown that nearly all parameters provided through ELS/EHS mechanisms were also provided by ADS-B with some exceptions.

The parameters that are not transmitted by ADS-B (“Roll Angle” and the “Track Angle Rate”), and provided by EHS, are mainly used by ground flight tracking systems to improve the tracking accuracy during aircraft turns by anticipating them: this is essential in the case of single radar surveillance infrastructure. Due to the very high refreshment rate provided by ADS-B (i.e. aircraft horizontal position), such parameters are not necessary because aircraft turns are identified in nearly real time in association with “Heading” parameter.

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[15] To be noted that in the EASA Opinion regarding PBN implementation in Europe, that is today under consideration at EC level, the introduction of RNP 1 operations is conditioned by a separation provision based upon a surveillance function not dependent on the GNSS.

[16] GNSS and the ionosphere by Anna Jensen and Cathryn Mitchell (GPS world February 2011)
Sursauts radio-solaires et perturbation des signaux GPS by Mériem Imache (Thesis Université Paris Diderot)
Effect of intense December 2006 solar radio bursts on GPS receivers by Alesandro Cerruti (American Geophysical Union)

ADS-B on the other side is providing several complementary parameters (e.g. A-SMGCS geometrical information enabling an efficient fusion of data positions from various sensors associated with specific aircraft antenna locations), but they are not necessary to provide the surveillance and separation function. These complementary parameters are mainly useful for new applications (e.g. ADS-B IN applications) or specific operational needs (i.e. ASMGCS).

There are still some difficulties to reconcile the parameters defined for EHS and the similar ones defined for ADS-B when they are not identical. ICAO should address such issue in order to avoid any misinterpretation of them in the development of the technical solutions. The areas where such clarification is required are: the aircraft speed, the various ways to get the selected level, etc.

Finally as identified in the previous section, there is still an issue to provide a reliable flight status (airborne or ground) for the aircraft not fitted with the proper switch. Several attempts have been made to correct this point in ICAO Annex 10 Volume IV (from amendment 77 to Amendment 89) with move in one direction and finally the return at the initial situation, but the implementation of this status parameter is not yet fully correct and this could lead to safety net inhibition (i.e. inefficient runway incursion detection algorithm). It should be fixed as soon as possible.

As a conclusion regarding this comparison, ADS-B is providing all the necessary informations as via ELS/EHS (with few exceptions explained above). The main advantage of ADS-B parameters provision is the much higher rate of refreshment compared with a mono radar Mode S case. In case of multiradar infrastructure, such advantage is less obvious due to the increased refresh rate achieved through a multiradar infrastructure.

It must be noted that activities are on-going to define and standardise a Version 3 of ADS-B Extended Squitter. These evolutions will cover additional parameters or information exchanges including meteorological informations.

6.3 Update rate

The last point of comparison regarding Mode S ELS/EHS and ADS-B is the refresh rate of the downlinked parameters.

Regarding this point, it is a clear significant advantage for ADS-B, that allows a quicker detection of changes and a more reactive position filtering, if compared with mono radar surveillance system.

In case of multi radar infrastructure and the generalisation of advanced tracker like ARTAS, this advantage is less apparent due to the refreshment rate improvement provided by the multi-radar environment.

In the case of an hybrid infrastructure (i.e. one or two radar or WAM coverage layers, complemented by an ADS-B layer), the benefits are cumulated (robustness and independence of the surveillance function and high refreshment rate of key parameters). This is probably the more realistic solution for the large part of the European airspace.

In summary, ADS-B provides a high refreshment rate for all basic information needed for surveillance and traffic separation. Nevertheless, this advantage cannot compensate the major issue highlighted in section 6.1. The benefits of high refreshment rate of key parameters can be achieved using an hybrid surveillance infrastructure (i.e. WAM and ADS-B that could reduce the 1090 MHz frequency loading).

7. Conclusions and recommendations

The analysis conducted in this study indicates that ADS-B provides the same parameters than ELS/EHS (with limited exceptions), with a much higher refresh rate, and other useful parameters (e.g. aircraft antenna relative positions used for A-SMGCS).

The majority of the additional parameters to basic ELS ones (barometric altitude, Mode A/C code and unique 24 bits address) are provided by any of the potential technologies (i.e. Mode S stations, WAM or ADS-B).

This information is useful to improve the quality of the ground surveillance tracking chain. It can be used directly by the data processing function that generates the flight tracks to be displayed on ATCO HMI or displayed directly (for some of them) on the ATCO HMI upon following an ATCO selection (avoiding to continuously display information not necessary for the ATCO task).

ADS-B provides additional information that is not available from other technologies in support of airport surface surveillance (i.e. A-SMGCS level 1&2[17]). This information improves the aircraft position determination within the data fusion function using aircraft positions depending on various aircraft antennas.

The most significant difference between these various technologies (i.e. classical Mode S radar, Mode S WAM or ADS-B) is the aircraft horizontal position determination.

The essential difference between ELS/EHS and ADS-B is way the aircraft horizontal position is determined. This is the most important driver to select the sensors to be used in ground surveillance chain. Such decision shall be driven by the actual operational requirements for the considered airspace, with a special attention to the traffic separation necessary to accommodate the expected traffic. The additional parameters should be considered as a second decision layer to improve the overall ground surveillance chain performances.

The current (EU) N° 1207/2011 on surveillance performance and interoperability regulation requires the aircraft fitting with full Mode S ELS/EHS and ADS-B v2 capabilities: it gives the impression that it undertakes a transition from classical Mode S radar based surveillance towards an ADS-B surveillance based sole solution.

The study just indicates that it cannot be so straightforward. Probably that the long term surveillance infrastructure for the large majority of the European airspace will be an hybrid solution based upon Mode S radars or WAM on one hand and ADS-B on the other hand, while in some areas ADS-B solution could be selected where traffic density does not require reduced distance between aircraft.

These considerations should be the main drivers for the future evolution of the European Regulation in terms of surveillance.

Consequently, the following recommendations are proposed;

[17] Levels seem not to be used anymore for ASMGCS. Level 1 corresponds to the ground surface surveillance function while level 2 corresponds to the runway incursion safety net

7.1 Recommendation 1:

Based upon the development of concepts of operations for the different types of environment in Europe, a safety assessment embracing all the CNS and ATM aspects should be encouraged. The results of such assessment would constitute the basis on which a revision of European Surveillance and ADS-B regulation shall be elaborated.

In the meantime, the surveillance regulation should clearly require ANSPs to assess their operational requirements considering the actual traffic density in their considered airspace and the traffic separation needed. Based upon such assessment, the surveillance infrastructure should be determined and specific airspace requirements should be formulated. .

7.2 Recommendation 2:

Considering the main benefit provided by ADS-B (i.e. the higher refresh rate of information and provision of additional parameters) to the ground surveillance chain and the additional benefit for the ASMGCS functions, it is recommended to require all new aircraft to be fitted with ADS-B v2 capabilities in addition to basic Mode S ELS/EHS capabilities when intended to operate in European controlled airspace.

7.3 Recommendation 3:

It is recommended to consider the retrofit of aircraft regarding the ADS-B v2 capabilities in addition to basic Mode S ELS/EHS capabilities with caution and to address it in a flexible way, considering that it is absolutely necessary only where ADS-B solution is foreseen as a sole solution, while elsewhere it is only providing an additional sensor layer.

7.4 Recommendation 4:

There are still some difficulties to reconcile all the parameters defined for EHS and the similar ones defined for ADS-B when they are not identical. Such clarifications should be made at ICAO level.

ICAO should address such issue in order to avoid any misinterpretation of them in the development of the technical solutions. The areas where such clarification is required are: the aircraft speed, the various ways to get the selected level, etc.

7.5 Recommendation 5:

There is still a safety issue regarding the provision of a reliable flight status information (airborne or ground) for aircraft that are not fitted with the proper switch: appropriate feasible solution should be quickly develop to fix this defect and avoid safety net failure (i.e. inefficient runway incursion detection algorithm). It should be fixed as soon as possible.

7.6 Recommendation 6:

Activities are ongoing at EUROCAE, RTCA and ICAO to prepare a version 3 of ADS-B with several new parameters introduced. In particular due a strong push from the FAA and US industry, ADS-B is now proposed to be a mean to downlink meteorological information to the ground.

Such move is not the most welcome to prevent the 1090 MHz frequency from overloading. This subject should be followed with a great attention.

7.7 Recommendation 7:

The use of passive acquisition of Downlinked parameters (i.e. combination of WAM and ADS-B) should be encourraged as far as it could provide an effective reduction of the 1090 MHz frequency loading.

Annex 1

Mode S transmitted parameters

Transmitted parameters

The airborne Mode S transponders transmit different types of data:

a) Direct data:

This is the set of parameters required for surveillance

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

2.) Variable direct data
- the Mode C altitude code
- the Mode A identity code
- the on-the-ground condition
- the aircraft identification if different from the registration marking
- the 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
  b) MCP/FCU selected altitude
  c) FMS selected altitude
  d) Barometric pressure setting minus 800 mb 27-39
  e) MCP/FCU mode bits 48-51
  f) Target altitude source bits 54-56

- Register 50 - Track and turn report
  g) Roll angle 1-11
  h) True track angle 12-23
  i) Ground speed 24-34

j) Track angle rate 35-45
k) True airspeed 46-56

- Register 60 - Heading and speed report
  l) Magnetic heading 1-12
  m) Indicated airspeed 13-23
  n) Mach 24-34
  o) Barometric altitude rate 35-45
  p) Inertial vertical velocity 46-56

BDS Registers and link with Mode S service level

q) 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 2

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/Priority 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/Priority Status and Mode A Code
Subtype	Subtype = 1	**Subtype = 1**
Emergency State	Emergency State	**Emergency State**
		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	
	Horizontal Mode Indicator	
	NAC_P	**Navigation Accuracy Category Position (NACp)**
	NIC_{BARO}	**Navigation Integrity Category Baro (NIC_{BARO})**
	Source Integrity Level (SIL)	**Source Integrity Level (SIL)**
		Status of MCP/FCU Mode Bits
		Autopilot Engaged
		VNAV Mode Engaged
		Altitude Hold Mode
		Approach Mode
		TCAS Operational
		LNAV Mode Engaged
	Capability/Mode Codes	
	Emergency/Priority Status	

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_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

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