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Agenda Item 1: Strategic issues that address the challenge of integration, interoperability and harmonization of systems in support of the concept of "One Sky" for international civil aviation
1.1: Global Air Navigation Plan (GANP) – framework for global planning
d) Surveillance roadmap

SURVEILLANCE ROADMAP

(Presented by the Secretariat)

1. INTRODUCTION

1.1 Introduction

1.1.1 The *Global Air Traffic Management Operational Concept* (Doc 9854) presents the ICAO vision of an integrated, harmonized and globally interoperable air traffic management (ATM) system bringing substantial safety and capacity benefits. Surveillance systems are fundamental components of any ATM system and will be required to support both current services and the more demanding future operational improvements that are defined in the ICAO aviation system block upgrades (ASBUs).

1.1.2 The objective of surveillance is to provide information on an aircraft position, identification and intent in all phases of flight. As such, surveillance systems are key enablers for a safe, efficient and cost-effective ATM service.

1.1.3 Not too long ago, the surveillance techniques available to air navigation service providers (ANSPs) were limited to secondary surveillance radar (SSR), SSR Mode-S and primary surveillance radars (PSR). However, technological developments such as automatic dependent surveillance – broadcast (ADS-B) and wide area multilateration (WAM) have recently reached maturity for operational deployment.

1.1.4 In parallel, new performance targets and associated operational requirements are emerging such as increasing traffic densities and changes to the composition of the aircraft fleet with the introduction of very light jets (VLJs) and unmanned aircraft systems (UAS). Furthermore, global interoperability, civil/military coordination, and cost and radio frequency spectrum efficiency considerations continue to remain key requirements.

1.1.5 In preparation for the Twelfth Air Navigation Conference (AN-Conf/12), the focus has been put on the ASBUs which describe in a stepwise approach the operational ATM improvements towards the global ATM operational concept. To support further refinement of the ASBU approach it is necessary to have a clear appreciation of when the necessary surveillance enablers will be available for widespread operational deployment and the activities that must be undertaken to achieve such readiness.

1.1.6 The surveillance infrastructure must adapt to meet these changes. Local implementations will be tailored to meet local demands by exploiting recent technological developments and using an increasing number of surveillance techniques. A significant change is that the avionics carried on-board an aircraft must become a fully integrated element of the surveillance infrastructure to support the provision of airborne information. Surveillance systems will thus have to take into account and be assessed together with an increasingly diverse range of avionic components such as positioning systems, traffic computers and cockpit display systems, as well as transponders.

1.2 Purpose and scope

1.2.1 This information paper complements the global air navigation plan (GANP) surveillance roadmap to provide comprehensive high-level guidance concerning the anticipated evolution and availability of the techniques used by the surveillance infrastructure to meet the changing operational environment. It addresses ground-based surveillance, surveillance of airport surface and surveillance used to support air-air applications.

1.2.2 The surveillance roadmap indicates which surveillance techniques will be available, and at which point in time, over the next twenty years. It provides an indication of drivers for change and how the different surveillance techniques will be used over time in support of existing operational services and future improvements introduced by the ASBU as well as their timescales.

1.2.3 The scope of this roadmap does not cover weather radar, wake vortex detection or debris detection. Its focus is on the surveillance sensors and the supporting avionics. It identifies the need for supporting legislation and a support infrastructure but does not address operational procedures or system components such as controller tools.

1.2.4 The milestones of this roadmap reflect the timeframes used within the ASBU: Block 0 (available now), Block 1 (from 2018), Block 2 (from 2023) and Block 3 (from 2028 and beyond). The modules may be subject to further elaboration. Changes to dates and requirements may become apparent during the refinement of the modules. The impact of these modules on the surveillance infrastructure will need to be considered.

2. AVAILABILITY OF AERONAUTICAL SURVEILLANCE TECHNIQUES

2.1 Introduction

2.1.1 Surveillance information can be provided using a range of different techniques. The techniques selected by a surveillance provider will depend upon a variety of factors including avionic equipage in the region, the operations performed and the nature of the terrain and environment. This section provides an indication of which techniques are or will be available during the different ASBU periods of time defined by ICAO.

2.1.2 The surveillance service delivered to users may be based on a mix of three main types of surveillance: independent non-cooperative surveillance; independent cooperative surveillance; and dependent cooperative surveillance as defined in the ICAO *Aeronautical Surveillance Manual* (Doc 9924).

2.2 Independent non-cooperative surveillance

2.2.1 Primary radars are currently the main existing independent non-cooperative surveillance systems. They include PSR, surface movement radar (SMR) also known as airport surface detection equipment (ASDE). Spectrum pressure and cost drivers will result in a reduction of conventional PSR. In addition, changing aircraft characteristics resulting in reduced radar cross sections (use of composite materials, etc.) may place increasing demands on PSR to detect intrusion into controlled airspace by non-cooperative aircraft or aircraft experiencing an avionic failure.

2.2.2 Multi-static primary surveillance radar (MSPSR) technology is a new type of independent non-cooperative surveillance currently under development which expected to have several advantages (see Table 1). MSPSR technology consists of using several transmitters and receivers in a multi-static mode to detect aircraft. MSPSR are expected to become available in the Block 1 period of time.

2.2.3 Non-cooperative independent surveillance is foreseen to continue to provide safety mitigation rather than providing the principal source of surveillance data for separation services.

Technique	Development status and Operational Availability	Comments
SMR	Readily available.	Also known as ASDE (airport surface detection equipment).
PSR	Readily available.	Under spectrum pressure. Conventional PSR might not be able to detect aircraft expected with lower cross section. Technological developments support improved driver technology and signal processing capabilities.
MSPSR	Technical feasibility proven. Operational requirements for civil applications to be developed. Operational availability expected for Block 1.	Private venture funded R&D expected to lead to commercially available systems within Block 1 timescales. Low altitude surveillance (e.g., <10 000 ft) achieved by exploiting transmitters of opportunity. Spectrum efficient even in active configurations. Wind farm and general clutter resilience. Active MSPSR could meet more demanding performance requirements.

Table 1. Summary of independent non-cooperative surveillance technique availability

2.3 Independent cooperative surveillance

2.3.1 Conventional SSR (Modes A and C) has been the key enabler for air-ground surveillance since the 1950s. However, the use of conventional SSR alone is in decline due to technical and costs issues which can be addressed by other solutions.

2.3.2 SSR Mode S is an available solution to upgrade and/or replace conventional SSR and provides backward compatibility to address the changing environment. Mode S protocol is specified in Annex 10 — *Aeronautical Telecommunications*, Volume IV — *Surveillance and Collision Avoidance Systems*, message formats in the ICAO *Manual on Technical Provisions for Mode S Services and Extended Squitter* (Doc 9871) and transponder minimum operational performance standard (MOPS) in RTCA DO-181/EUROCAE ED-73. With the availability of aircraft identification through Mode S elementary surveillance (ELS) and other airborne parameters through Mode S enhanced surveillance (EHS), SSR Mode S is also paving the way for advanced applications requiring air-ground information.

2.3.3 Multilateration (MLAT) technique is a new technique providing independent cooperative surveillance. Its deployment is made easier by the use of airborne Mode S equipment capability with the spontaneous transmission of messages (squitters). In this case the signal transmitted by aircraft is received by a network of receivers at different locations. The use of the different times of arrival at the different receivers allows an independent determination of the position of the source of signals. This technique can be passive and use the existing transmissions made by the aircraft or be active and trigger replies in the manner of Mode S SSR interrogations. MLAT systems have been initially deployed on airports to provide surveillance on the surface but are now used to provide surveillance over WAM.

2.3.4 The deployment of such systems is already taking place during Block 0, initially to cover areas where the use of conventional SSR is difficult, costly or does not provide required performance. The deployment of WAM will extend with the deployment of ADS-B as the WAM infrastructure contains an ADS-B infrastructure.

Technique	Development status and Operational Availability	Comments
SSR Mode A/C	Readily available. SARPs available.	RF inefficiency and poor performance in very high traffic density airspace contribute to current phase out activities in some Regions.
SSR Mode S	Readily available. SARPs available. Transponder MOPS available.	Provides aircraft derived data (ELS & EHS) and superior performance compared with SSR Mode A/C. Increasing deployment foreseen in short term in very high traffic density and for local areas; however, reduction in longer term for complete coverage due to ADS-B availability.
Multilateration	Readily available SARPs available Ground system specification available	Passive and active configurations available. Complements ADS-B deployment and/or ASDE at some airports

Table 2. Summary of independent cooperative surveillance technique availability

2.4 Dependent cooperative surveillance

2.4.1 ADS-B is recognized as one of the important enablers of several of the ATM operational concept components including traffic synchronization and conflict management (AN-Conf/11, Recommendation 1/7, 2003). It can support 3.5 NM separation minima provided suitable airborne equipage is carried by aircraft.

2.4.2 The transmission of ADS-B information (ADS-B OUT) is already used for surveillance in some non-radar areas (Block 0). It will continue to be more widely deployed during Block 1 to also support detection in radar environment. While the technique is available the actual wide operational deployment is determined by wide spread installation of suitable avionics platform. This is why relevant mandates have been published in various regions (e.g. Australia, Canada, Europe, United States).

2.4.3 ADS-B OUT SARPs (ICAO Annex 10, Volume IV and Doc 9871) and MOPS (RTCA DO-260B/ EUROCAE ED-102A) are available. Equipage rate is growing together with Mode S, ACAS and ADS-B OUT mandates. It is pointed out that ADS-B OUT, V.2 also provides for ACAS RA DOWNLINK information in support of monitoring activities currently only possible in SSR Mode S coverage.

2.4.4 ADS-B is dependent upon having a source of required positional accuracy (such as GNSS today).

2.4.5 With the widespread deployment of ADS-B OUT, it is expected that airborne surveillance applications would be developed in direct support of airspace users (reduced or no involvement of ATC). This will require aircraft to be equipped with surveillance systems that are able to use the surveillance information broadcast by other aircraft or airport surface vehicles. This is known as ADS-B IN and enables various applications such as airborne traffic situational awareness, applications, interval management applications and possibly airborne separation and airborne self-separation. For those new applications, the operational concepts and constraints associated with using ADS-B for separation assurance are still subject to R&D work and the need for future ADS-B OUT/IN will be expected to be defined for use during Block 2 timescale.

2.4.6 ADS-B IN Standards and Recommended Practices (SARPs) and MOPS are available for Block 0. It is important to note that ADS-B equipment is only one enabler of some applications and additional systems might be required such as controller-pilot data link communications (CPDLC) capability, cockpit display of traffic information (CDTI). A draft PANS-OPS procedure on the operational use of ADS-B traffic display is being considered.

2.4.7 Oceanic airspace (or remote) is taking advantage of ADS-C to support separation provision from the ground with existing separation minima while ADS-B supports ITP (reduced) separation minima for flight level changes.

2.4.8 The use of satellite receivers for oceanic ADS-B surveillance (satellite ADS-B) is being studied and depending on the cost benefit analysis this technique could become available after 2020 during Block 1 timescales (See 3.8).

Technique	Development status and Operational Availability	Comments
ADS-B OUT	SARPs available. Avionics MOPS available. Operation supported by regional mandates on aircraft equipage.	Provide cost effective and efficient means of surveillance supporting a wide range of new applications proposed within ASBU concept. The technologies are ready with the main constraint being the deployment of appropriate avionics on-board aircraft. Widespread use in dense airspace expected from 2020.
ADS-B IN	SARPs available for initial application (Block 0).	Enables airborne traffic situational awareness and may support delegation of responsibility to pilot for separation and self-separation. Initial deployment of ADS-B IN will be conducted on a voluntary basis with increasing deployment encouraged through benefits from airborne surveillance applications (e.g. ITP).
ADS-C	Readily available.	The surveillance service of ADS-C could potentially be augmented by ADS-B through satellite after 2020.

Table 3. Summary of dependent cooperative surveillance technique availability

2.5 Data fusion

2.5.1 Surveillance is likely to be provided using a combination of different surveillance techniques. This requires an appropriate function to provide a seamless interface between the surveillance sensors, each with specific characteristics, and the end users (controller and tools). Current mechanisms such as data fusion or multi-sensor trackers will need to be adapted.

2.6 RF link congestion management

2.6.1 1030/1090 MHz should remain the worldwide radio frequency (RF) bands used to support cooperative aeronautical surveillance including ADS-B throughout the different block upgrade periods.

2.6.2 The global use of these RF bands allows a cost effective interoperable system. These bands are shared by different applications including military applications and optimizing the use of 1090 MHz is important. Significant optimization of 1030/1090 MHz is achievable through the use of improved ACAS surveillance, the reduction in the use of radars because of ADS-B and passive WAM, the removal of the old SSR sliding window-based systems, reduction in the use of Mode A/C and through radar clustering and data sharing.

2.6.3 It is recognized that future ADS-B applications will potentially require additional capacity to convey necessary data elements to achieve expected benefits. In order to provide additional capacity without further contributing to the RF congestion, an increase of the 1090ES capacity is being prepared by ICAO by adding phase modulations on the same signals opening the possibility to multiply the throughput on 1090 MHz RF band if necessary while keeping full compatibility in a mixed environment.

2.6.4 Compared to the recent past, the 1030/1090 MHz channel is carrying additional data and no longer only altitude or limited indication of identity (Mode A code). The criticality of this information must be assessed in the ATM system to determine the need for backup and diversity systems. The mix of different links such as VHF data link Mode 4 (VDL Mode 4) or Universal Access Transceiver (UAT) to support ADS-B operations is possible. However, such an approach introduces a degree of system complexity by requiring multiple band receivers or by requiring additional ground function to rebroadcast the data received from one link onto the other link (ADS-R) and in some instances uses elements of spectrum that are already heavily utilized. Nevertheless, VDL Mode 4 and UAT may be deployed on a local or regional basis.

3. GROUND AND AIRBORNE SURVEILLANCE INFRASTRUCTURE ROADMAP

3.1 Current surveillance infrastructure

3.1.1 Today (Block 0) aeronautical surveillance is primarily based on independent cooperative surveillance systems using 1030/1090 MHz RF bands (SSR and SSR Mode S) complemented by non-cooperative systems (PSR or SMR), MLAT systems on surface, and ADS-C in oceanic areas. Initial ADS-B operational use has started in a limited number of areas.

3.2 Drivers for change

3.2.1 In addition to addressing the eleven ICAO Key Performance Areas (KPAs) as defined in ICAO *Manual on Global Performance of the Air Navigation System* (Doc 9883), a wide range of drivers are contributing to the manner in which the surveillance infrastructure would need to operate in the future. Drivers specific to the surveillance environment include:

a) increasing traffic densities;

b) new construction techniques for aircraft and new types of aircraft (VLJs and UAS) may place new requirements both for ground surveillance (integration of UAS in non segregated airspace) and for airborne surveillance (support to “detect and avoid”);

c) increasing use of secondary and tertiary airports;

d) new operational improvements stemming from initiatives (SESAR, CARATS, NextGen, etc.);

e) obsolescence of old/existing technology and the availability of new technologies and techniques offering superior performance at reduced cost;

f) introduction of spectrum charging schemes; and

g) RF congestion – the frequency spectrum (1030/1090 MHz) allocated to aeronautical safety and regularity of flight is, in certain airspace, already heavily congested by non-optimized civil and military systems.

3.3 Evolution of future surveillance infrastructure

3.3.1 It can be predicted that surveillance in 2030 will be achieved using the techniques currently available, based on cooperative surveillance systems using 1030/1090 MHz RF bands (SSR Mode S, WAM and ADS-B) complemented, where necessary, with some form of independent non-cooperative means of detection such as conventional PSR or MSPSR.

3.3.2 The important trends of the next twenty years will be that:

a) different techniques will be mixed in order to obtain the best cost benefit depending on local constraints; and

b) the airborne part of the surveillance system will become more important in the total surveillance system and should be globally interoperable in order to support the various surveillance techniques which will be used.

3.3.3 The surveillance techniques established over recent years will thus form the foundations for ASBU Blocks 1, 2 and 3 and will support the demanding separation minima required to achieve those foreseen operational requirements. Whilst refinements to capabilities may be identified in the course of the development of the operational improvements it is anticipated that the surveillance infrastructure currently foreseen could meet all the demands placed upon it. However, the timely provision of changes should be carefully managed to minimize the burden on aircraft operators and maintain interoperability with military and State authorities.

3.4 Migration of functionality from ground to air

3.4.1 The most significant difference between the surveillance infrastructure of the recent past and that which will be established to support Block 3 is a shift in functionality from the ground-based sensors to a comprehensive suite of avionics supporting a range of demanding surveillance applications. The position and other airborne parameters, including short-term intent indication, will be provided by the airborne part of the surveillance system (ADS-B OUT) and will also be directly used by other aircraft (ADS-B IN) to support new surveillance applications. Airborne surveillance applications also represent an important change in perspective from current air traffic control (ATC) practices.

3.4.2 To enable this evolution and migration of functionality a corresponding development in the support infrastructure is necessary. The resolving of design anomalies within a transponder or related avionics component installed on hundreds or even thousands of aircraft will be more difficult and time consuming to achieve than resolving similar issues on a more limited number of ground-stations. To mitigate this, the shift of functionality must therefore also be accompanied by a corresponding shift in responsibility and activity by all partners involved in surveillance. More demanding standardization, certification methodologies and regulation will help address the issue in its early stages; however, provision must be foreseen to address anomalies that are identified when in operational service. Activities to analyze the performance of avionics and transponders will be required. Conformance monitoring should be established.

3.5 **Increasing choice of surveillance techniques**

3.5.1 A less apparent but equally significant difference stems from the availability of a broad range of surveillance techniques available to ANSPs.

3.5.2 ANSPs providing separation services will need to make decisions regarding which technique best matches the specific needs of their local environment, their terrain and a host of other characteristics.

3.5.3 In general, the expected trend will be to keep an independent cooperative layer together with the new dependent cooperative surveillance provided by ADS-B. However, in this case 100 per cent equipage of ADS-B is required.

3.5.4 Combinations of independent and dependent cooperative surveillance means will bring benefits in terms of cost and performance. For example, composite MLAT/ADS-B systems are widely offered by industry and are being deployed by ANSPs in Europe and worldwide. They would also bring the requirement for the appropriate data fusion system.

3.6 **Better in-band spectrum management**

3.6.1 A common attribute that all the new surveillance techniques offer is one of improved spectrum efficiency. By rationalizing the surveillance infrastructure and by deploying, in an appropriate manner, spectrum efficient systems, the cost and the need for a second data link to support 1030/1090 MHz operations will be obviated.

3.6.2 The airborne collision avoidance system (ACAS) is one of the major contributors to the 1090 RF band usage and must therefore be optimized using, for example, hybrid surveillance making use of passive techniques to reduce congestion.

3.6.3 Rationalization of the surveillance infrastructure in areas of high RF density is necessary. Such measures may include the removal of spectrally inefficient Mode A/C type systems, deployment of modern sensors, increased sharing of data between surveillance service providers (civil/civil and civil/military) and improved management of Mode S interrogators. Increasing the capacity of 1090ES using a phase modulation technique provides provisions for future surveillance needs (see 2.6.4).

3.7 **Change to the operational environment**

3.7.1 The increasing traffic densities and more demanding performance and safety targets are placing greater demands upon the surveillance infrastructure.

3.7.2 By 2028 it is anticipated that most aircraft, including non-powered visual flight rules (VFR), UAS and military, will be equipped with cooperative surveillance avionics. Some platforms are unlikely to be required to meet the same demanding performance specifications as those foreseen for commercial aircraft. The operational requirements, specifications and means of certification of these reduced capability systems are to be further developed for the various types of airspace users.

3.7.3 The introduction of UAS into operations in controlled airspace is expected to happen within Block 1 (after 2020). Although the UAS roadmap is not included in GANP, the ICAO Unmanned Aircraft Systems Study Group (UASSG) is currently working on the integration of such platforms within controlled airspace and has developed UAS guidance material (ICAO Circular 328) to support States in this issue. There are three matters, namely detect and avoid, flight profiles and equipage requirements that may impact upon surveillance components.

a) a detect and avoid function will be required to avoid all obstacles in the flight path. This function must be compatible with current collision avoidance systems, i.e. ACAS. However, UAS platforms cover a broad spectrum of size, weight and performance envelopes. Smaller UAS may not be capable of carrying or powering the SSR transponder. Some larger UAS platforms may not be capable of complying with ACAS evasive manoeuvres. Consequently, new systems and possible associated procedures will need to be developed;

b) the flight profile or performance envelope of some UAS may also impact upon the performance requirements of the surveillance infrastructure. Some UAS will fly above the altitude of normal manned aircraft and will impact upon current separation minima only during ascent and descent phases of flight. Other large UAS will operate non-conventional missions flying at slow speed, not necessarily conducting point-to-point operations. The difference in speed and the manoeuvrability characteristics of such UAS may therefore impact upon tracking algorithms and controller support tools. The impact will need to be assessed in a timely manner; and

c) ATC may introduce a specific user requirement regarding confirmation of whether an aircraft is manned or unmanned. Such information could be broadcast from UAS equipped with ADS-B or transmitted via Mode S. The receipt and processing of such data will place new requirements upon the surveillance infrastructure.

3.7.4 Whilst spectrum charging, the mandatory carriage of transponders and a need for cost efficiencies will drive a reduction in the use of conventional PSR, it is anticipated that some form of non-cooperative surveillance technique will be retained where deemed to be operationally necessary. This will be used to mitigate against avionic failures and support the identification of the presence of aircraft intruding, accidentally or deliberately, into controlled airspace. It is likely that changes to the materials from which aircraft are manufactured will result in a reduction to their radar cross sections (RCS) – the detection of small aircraft with an RCS that is lower than for today’s fleet of aircraft could place increasing demands upon non-cooperative surveillance systems. MSPSR, subject to successful development and validation, is likely to fulfil this requirement.

3.8 Possible solution for remote area surveillance (satellite ADS-B)

3.8.1 As mentioned in 2.4.8, subject to further development the use of ADS-B receivers located on low earth orbit satellites could provide a means for ATM surveillance in all volumes of airspace, initially in regions such as oceanic or remote areas, in which it is currently difficult or even impossible to provide through conventional ground-based systems.

3.8.2 The use of satellite receivers for ADS-B surveillance is being evaluated by several manufactures aiming for the near-tem implementation. The technology would provide extraordinary cost benefit for all airspace users.

3.8.3 This space-based surveillance capability will be evaluated during the Block 0/1 timeframe for technical feasibility. The technical assessment will address the integration with other enabling technologies (communications and navigation) as well as trade-off studies to evaluate technical alternatives. These will be coupled with a regional or State business case to determine whether to proceed with this technology for implementation in the Block 2 timeframe. If the business case and operational needs can be met through such a technique then this has the potential to complement or replace many surveillance services currently achieved using ADS-C.

3.9 **Increasing use of airborne parameters**

3.9.1 Modern surveillance systems (and the tools they support) provide benefits in terms of safety through the use of airborne information automatically downlinked by surveillance systems. For example, it could bring the following advantages:

a) clear presentation of callsign and flight level;

b) improved situational awareness;

c) use of certain down linked aircraft parameters (DAPs) and 25 ft altitude reporting to improve radar tracking algorithms;

d) display of vertical stack lists;

e) reduction in radio transmission (controller and pilot);

f) improve management of aircraft in stacks; and

g) reduction in level busts.

3.9.2 The current trend is to make more use of the short-term intent information (which is already made available with Mode S systems for enhanced surveillance). However, future operational improvements are expected to impose requirements for the transmission of longer term intent information. Avionics architecture should therefore be designed to provide such information to the surveillance system.

3.10 **ACAS**

3.10.1 ACAS is implemented worldwide (aircraft with a maximum take-off mass greater than 5.7 tons or with a maximum approved passenger seating configuration of more than nineteen are required to equip) and can already benefit from ADS-B through a technique known as hybrid surveillance, a combination of ACAS active Mode S interrogations with ADS-B. This option can bring benefit to the RF environment without affecting ACAS performance.

3.10.2 B0-101 Improved ACAS has the potential to bring additional significant operational and safety benefits to the implementation of ACAS (TCAS version 7.1) by the introduction of two optional functions: auto-pilot/flight director (AP/FD) connection and altitude capture (AltCapt). Plans for a new collision avoidance system are also proposed (see B2-101 “new collision avoidance systems”) to ensure the adaptation to future ATM environments.

4. **CONCLUSION**

4.1 The Conference is invited to take note of the information provided in this paper in consideration of the surveillance roadmap in the Global Air Navigation Plan.

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