BENEFITS AND TECHNOLOGICAL IMPACTS OF THE FUTURE ATM SCENARIO FOR CIVIL AND MILITARY AIRCRAFT

Giovanni Antonio Di Meo

Politecnico Di Torino
Corso Duca Degli Abruzzi 24
10129 Torino - Italy
giovanni.dimeo@polito.it

Giovanni Medici

Politecnico Di Torino
Corso Duca Degli Abruzzi 24
10129 Torino - Italy
giovanni.medici@polito.it

Sergio Chiesa

Politecnico Di Torino
Corso Duca Degli Abruzzi 24
10129 Torino - Italy
sergio.chiesa@polito.it

Nicole Viola

Politecnico Di Torino
Corso Duca Degli Abruzzi 24
10129 Torino - Italy
nicole.viola@polito.it

Antonella Cavallo

Alenia Aermacchi S.p.A
Corso Marche 41
10146 Torino - Italy
antonella.cavallo@alenia.it

Abstract. The aim of the work is to analyze benefits the future ATM scenario delineated by SESAR research program and to assess which are the technological impacts requested to avionic architectures for implementing SESAR innovative functionalities. Both civil and military aircraft have been analyzed considering that civil-military interoperability in the future ATM scenario is a key-element of SESAR concept of operations. By using SESAR public documentation an analysis of operational scenario has lead to the consideration of SESAR Key Performance Areas (KPA's), which represent the ATM performance benefits. Available information on civil and military air traffic and fleets has been reported in order to understand the traffic volumes and the number of platforms interested by the new SESAR functionalities and benefits. The result of the work is the analysis of impact on civil and military aircraft avionics of functionalities of the future ATM delineated by SESAR. In addition, considerations on the requested technological impact versus expected benefits have been reported in the conclusions. The authors assumed that the best solution to the avionic functional implementation problem is not a retrofit solution but a solution based on the upgrade of existing avionic equipments. The reason is that an upgrade solution could be more attractive in terms of costs for end users.

Keywords. SESAR, ATM, Avionics, Civil-Military Interoperability.

1 Introduction

SESAR (Single European Sky ATM Research) is a research project co-financed by the SJU, the European Community and EUROCONTROL. The aim of SESAR is to realize a reformation of ATM (Air Traffic Management) rules and procedures in order to realize the following goals as indicated in the SESAR ATM Master Plan [1]:

- Enable a 3-fold increase in capacity which will also reduce delays, both on the ground and in the air;
- Improve safety performance by a factor of 10;
- Enable a 10% reduction in the effects flights have on the environment and;
- Provide ATM services to the airspace users at a cost of at least 50% less.

The realization of SESAR goals is based on pillars called Key features [1] here reported:

- *Moving from an airspace to trajectory based operations* so that each aircraft achieves its preferred route and time of arrival;
- *Collaborative planning* so that all parties involved in flight management from departure gate to arrival gate can plan their activities based on the performance the system will deliver;
- *Dynamic Airspace Management* through enhanced coordination between civil and military authorities;
- *New Technologies* providing more accurate airborne navigation and optimized spacing between aircraft to maximize airspace and airports capacity
- *Central role for the human,* widely supported by advanced tools to work safely without undue pressure.

Key Features and Target Goals represent the starting point of the whole SESAR program structure. The analysis of Key Features and Target Goals lead to the development of innovative ATM procedures and advanced functionalities which are then tested during flight test campaigns. Furthermore, by analyzing Key features of SESAR and in particular the Dynamic Airspace Management it is possible to understand that the future ATM scenario, delineated by SESAR concepts of operations, shall consider the presence of military aircraft within the airspace into a collaborative environment. This leads to consider also military aircraft in the analysis performed in this paper. The need for ATM interoperability between civil and military aircraft is confirmed by Eurocontrol in its "Introduction to Mission Trajectory" [2] where the concept of Mission Trajectory (MT) is introduced for military operations. MT, in parallel with Business Trajectory (BT) for civil aircraft, is elaborated and agreed for each flight obtaining as a result a 4D trajectory[1] that the user agrees to fly and the Air Navigation Service Provider (ANSP) agrees to facilitate. It is possible to anticipate that a crucial aspect for ATM interoperability of military aircraft consists in the benefits that SESAR scenario can assure compared with the technological implementation impact requested to military aircraft avionic systems; further considerations will be conducted in following chapter of the paper.

The work presented in the paper considers, at first, the SESAR scenario together with the data of civil and military air traffic and fleets in order to understand the traffic volumes interested by SESAR innovations. Military air traffic data are fundamental in order to understand which are the selected SESAR functionalities (i.e. Capacity Levels) whose implementation is considered on military aircraft avionic systems. Furthermore, it is possible to anticipate that SESAR functionalities planned to be implemented on military aircraft are a subset of those planned for civil mainline aircraft due to the higher traffic volume. Capacity Levels are functionalities grouped basing on their complexity and

[1] Each waypoint of the trajectory is unambiguously defined by: latitude, longitude, altitude and Requested Time of Arrival (RTA).

implementation date. The technological impact of implementation of Capacity Levels both on civil and on military aircraft has been considered in order to identify modifications necessaries for assuring capacity levels. Figure 1 shows the process followed for the described analysis.

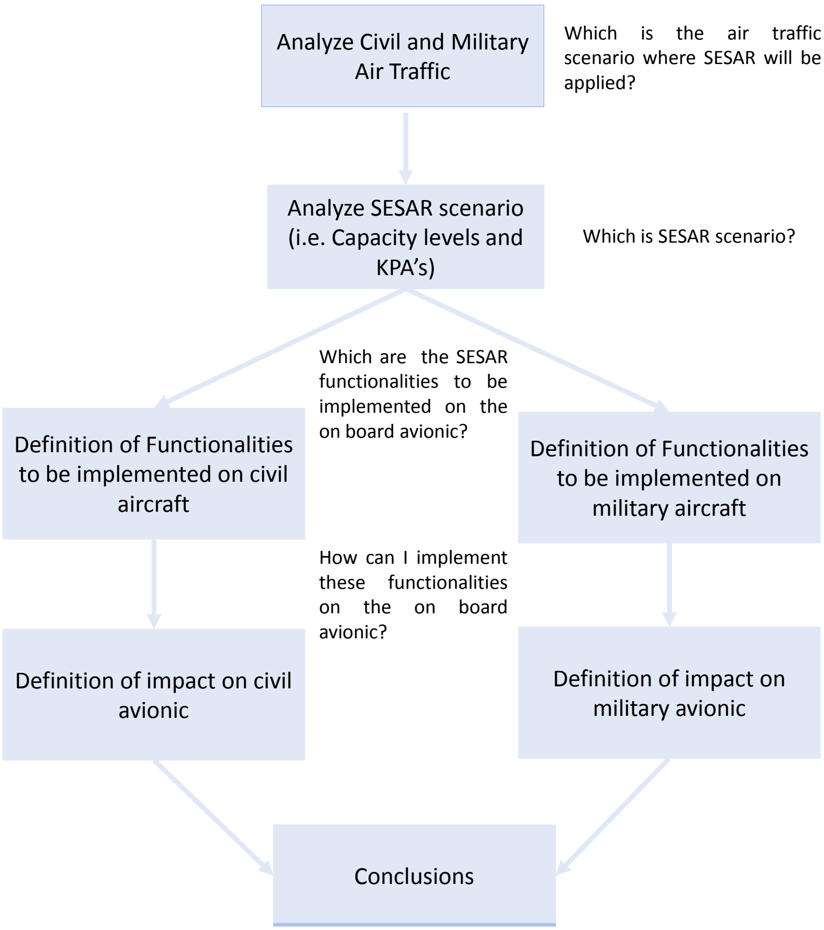


Figure 1: Paper work flow

2 Civil – Military: a need for interoperability

The need for integration of military aircraft into a collaborative ATM scenario leads to the necessity to solve the problem of making the military aircraft systems interoperable with the Air Traffic Management framework. It is obvious that the nomenclature civil and military is very generic. In particular, by adding details, it is possible to consider that in accordance to SESAR Master Plan [1] the civil categories interested by SESAR are mainline and regional. Moreover, military aircraft identified by SESAR Master Plan are: Transports, Fighters and Trainers. The reason behind these choices is clear by analyzing the fleet and air traffic composition of civil and military aircraft in Europe.

As a general disclaimer, the presented statistic data are related to year 2009 and 2010 and the authors assume that they are still representative of the actual situation of civil and military aircraft fleets and of civil and military GAT (General Air Traffic).

2.1 Civil and Military Fleets in Europe

Aircraft fleets in Europe are important indicators to consider in SESAR research program, considering this gives the feedback on the number of aircraft potentially interested by the identified avionic upgrades in order to acquire a higher Capacity Level. As a consequence, fleet composition is above all an economic indicator which gives a feedback on the returns of research investment. The following statistics have been realized by using as data sources Eurostat statistics [3] for civil commercial fleet and Eurocontrol statistics reports for military fleet [4]. Results are showed in the following tables and figures.

Civil Commercial Aircraft category	Number of aircraft
Passenger aircrafts with less than 50 seats	620
Passenger aircrafts with 51 to 150 seats	1.252
Passenger aircrafts with 151 to 250 seats	1.637
Passenger aircrafts with more than 250 seats	420
Other	2.329
TOTAL	6.258

Table 1: European Civil Commercial Aircraft category composition 2009 (source: EUROSTAT)

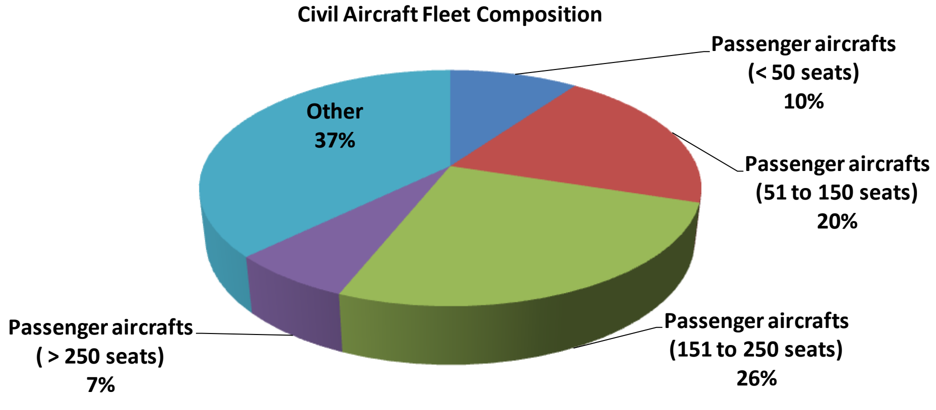


Figure 2: European Civil Commercial Aircraft category composition 2009 (source: EUROSTAT)

Military Aircraft category	Number of aircraft
Transport-type	1173
Fighters	3167
Trainers	1868
Other	353
TOTAL	6561

Table 2: European Military Aircraft category composition 2010 (source: EUROCONTROL)

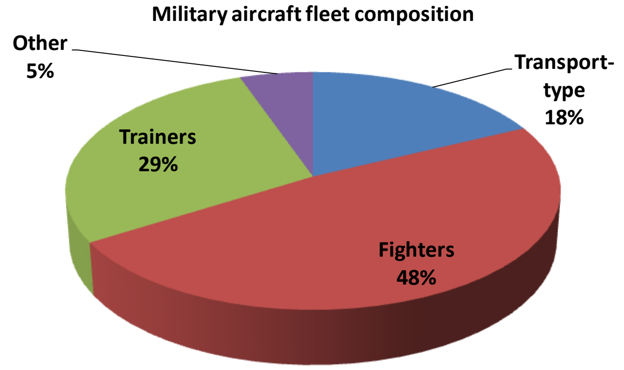


Figure 3: European Military Aircraft category composition 2010 (source: EUROCONTROL)

As already said, the composition of European Military and Civil fleets allow to understand which are the aircraft categories potentially interested by SESAR avionic updates and their size in terms of numbers of platforms. In particular, it is possible to notice in Figure 2 that more than 50% of civil fleet is composed by passenger aircraft with more than 50 seats. It is to notice that passenger aircraft with more than 50 seats correspond to the most of Regional2 and the whole Mainline category. Figure 3 shows that, as expected, the 95% of the military aircraft fleet is composed by Transport, Fighter and Trainer aircraft. Furthermore, particular attention should be paid to the absolute number of civil and military platforms. It has to be noticed that the number of military platforms (i.e. Transport-type, Fighter and Trainer) potentially interested by SESAR avionic updates could be nearly two-fold of the potentially interested civil platforms (i.e. Passenger aircraft with more than 50 seats).

2.2 Civil and Military Air Traffic

The Air Traffic volumes represent an important parameter of the analysis because it allows to acquire a feedback on the aircraft categories which will have an higher impact on the ATM system. Air Traffic volumes, divided by aircraft categories, provide an indicator on the effectiveness of the introduction of the new functionalities on the overall ATM performance. It has to be noticed that, as far as military flights are concerned, the most part of flights today are performed in OAT (Operational Air Traffic) in segregated airspace. Eurocontrol [4] estimates that only 20% of military flights are performed in GAT (General Air Traffic) in a non-segregated airspace. The reason of this is the need for military aircraft to fly in segregated areas for training operations together with the lack of interoperability between ATM system and military avionics in accordance with what stated in [5]. Air Traffic data for civil commercial aircraft and for military aircraft are presented in the following graphs

[2] Some Regional aircraft have less than 50 seats (e.g. ATR 42)

and tables. The authors used as data sources Eurostat statistics [3] for civil Air Traffic and Eurocontrol statistics for military Air Traffic [4].

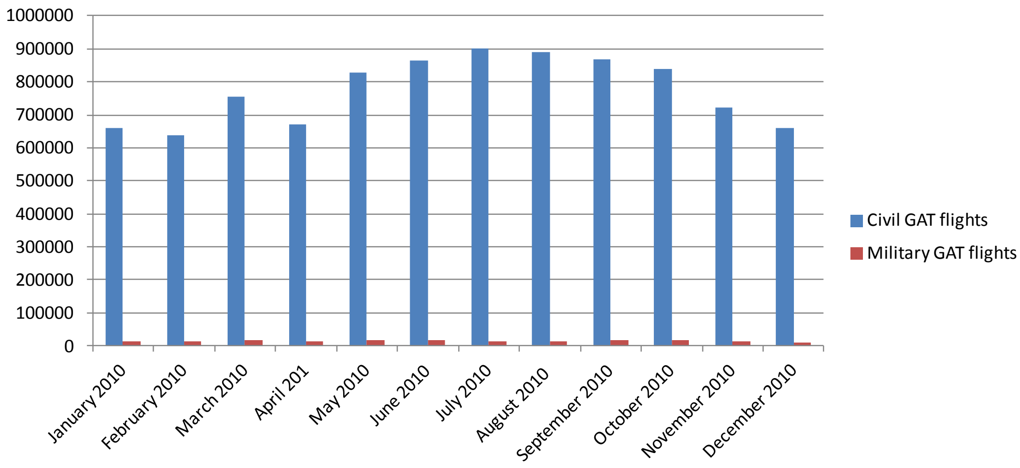


Figure 4: European Civil and Military General Air Traffic 2010 (source: EUROCONTROL)

Air Traffic	Number of flight
Civil Commercial Air Traffic GAT	9295454
Military Air Traffic GAT	178042
Military Air Traffic OAT[3]	712168

Table 3: European Military Aircraft category composition 2010 (source: EUROCONTROL)

As it is possible to see the most of the European Air Traffic is composed by Commercial flights. Military GAT is about the 2% of the Civil GAT but, as already said, the most part of military flights are flown in OAT. Military OAT has been estimated to be the 80% of the total military air traffic in accordance with Eurocontrol [4]. It is so possible to approximate that globally (i.e. OAT + GAT) the military air traffic is about the 9% of the Commercial GAT. Furthermore, it is interesting to examine also the composition of Military and Civil GAT's. Results are showed in the following graphs.

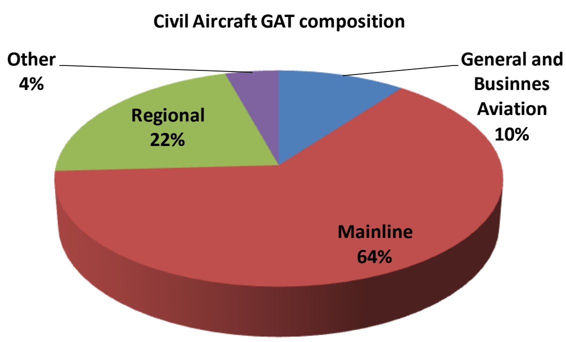


Figure 5: Civil General Air Traffic composition 2009 (source: EUROSTAT)

[3] Estimated Value by considering that Eurocontrol estimates that 80% of military flights are flown in OAT [4]

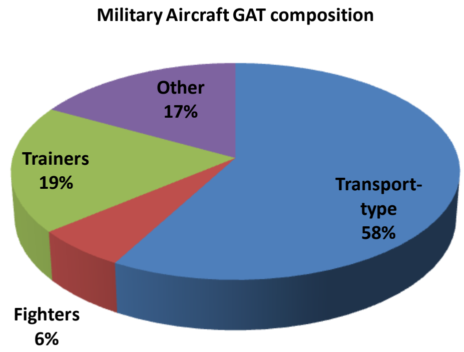


Figure 6: European Military General Air Traffic composition 2010 (source: EUROCONTROL)

As it is possible to see in Figure 5, the 86% of the Civil Air Traffic is flown by Regional and Mainline aircraft. This result together with the results on the civil commercial fleet of the previous paragraph confirms and justifies the main focus of SESAR on Regional and Mainline aircraft. General Aviation and Business Aviation is also considered in SESAR, but with restrictions generated by the reduced Air Traffic flow.

As far as military aircraft are concerned Figure 6 shows that Transport-type, Fighters and Trainers compose the 83% of Military GAT. This result together with the results on the military fleet presented in the previous paragraph confirms and justifies the main focus of SESAR on Transport, Fighter and Trainer aircraft.

3 SESAR Scenario

This chapter is intended to briefly analyze SESAR structure in order to understand how from Key Feature and Target Goals SESAR develops Key Performance Areas (KPA) where benefits are quantifiable. KPA's directly descend from previously mentioned Target Goals and Key Features. Figure 7 summarizes the SESAR structure which could be useful in order to better understand the logic flow of the following paragraphs.

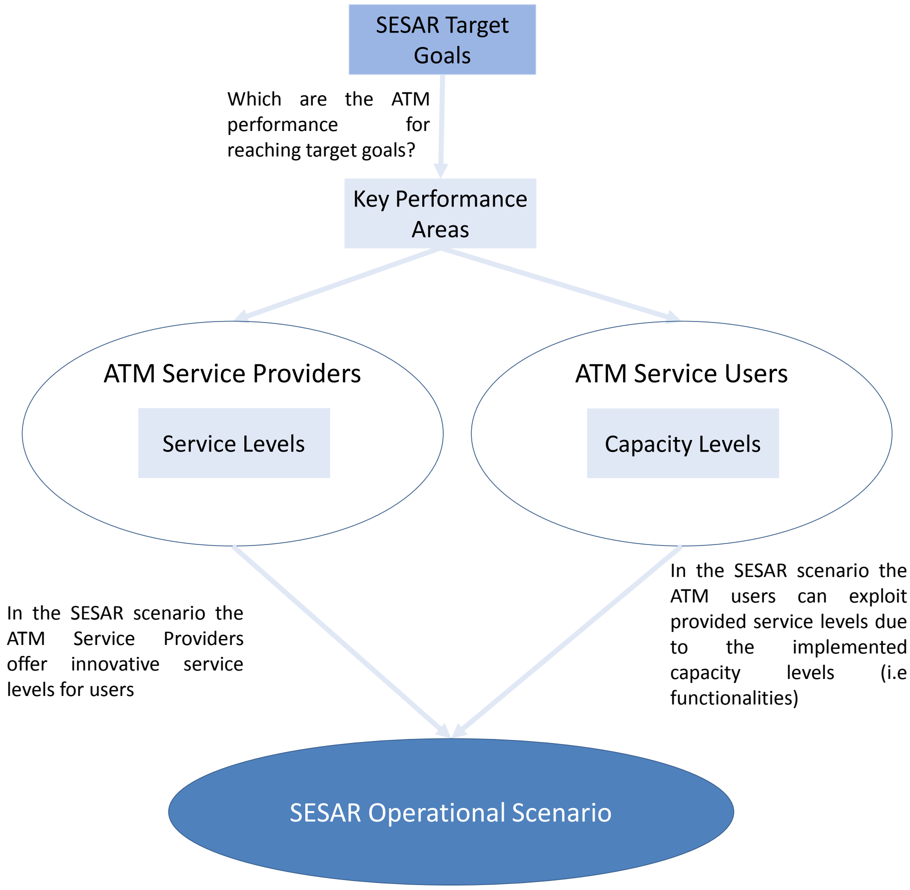


Figure 7: SESAR concept flow

3.1 Key Performances Areas (KPA's)

Key Performance Areas are those areas where SESAR ATM performances (i.e. KPI) are grouped. SESAR MasterPlan [1] identifies the following Key Performance Areas:

- Capacity: In accordance with the political vision and goal, the ATM target concept should enable a 3-fold increase in capacity which will also reduce delays, both on the ground and in the air (en-route and airport network), so as to be able to handle traffic growth wellbeyond 2020.
- Cost Effectiveness: The working assumption for the Cost Effectiveness target is to halve the total direct European gate-to-gate ATM costs from €800/flight (EUROCONTROL Performance Review Report 2005) to €400/flight in 2020 through progressive reduction. Notwithstanding this 2020 target, continuing cost improvement should be sought after 2020.
- Efficiency: This KPA addresses the necessity to fly a 4D trajectories shared and agreed between aircraft and ANSP's.

- Flexibility: This KPA addresses the ability of the ATM system and airports to respond to "sudden" changes in demand and capacity: rapid changes in traffic patterns, last minute notifications or cancellations of flights, changes to the agreed Business Trajectory (pre-departure changes as well as in-flight changes, with or without diversion), late aircraft substitutions, sudden airport capacity changes, late airspace segregation requests, weather, crisis situations, etc.
- Predictability: This KPA addresses the ability of the ATM system to ensure a reliable and consistent level of 4D trajectory performance. In other words: across many flights, the ability to control the variability of the deviation between the actually flown 4D trajectories of aircraft in relationship to the agreed Business Trajectory.
- Safety: This KPA addresses the risk, the prevention and the occurrence and mitigation of air traffic accidents.
- Environmental Sustainability: As a first step towards the political objective to enable a 10% reduction in the effects flights have on the environment in term of:
    - Achieving the implicit emission improvements
    - Minimizing noise emissions and their impacts for each flight

3.2 Capability Levels

The notion of ATM Capability Level is used as the top-level, System-wide basis to establish the performance characteristics with which all components (covering both those on-board aircraft and within the ground-based systems) of the future European ATM System will be linked and will assure ATM performances. SESAR has defined six levels, which will progressively be deployed; Figure 9 shows the time scale for the first three Capability Levels as reported in the SESAR Master Plan [1]. The Figure reports only the first three Capability Levels because they are those interested by the performed analysis which is a short to medium term analysis. Capability levels are associated with Stakeholder systems, procedures, human resources etc. Upgrading a Stakeholder to a higher capability level means deployment of new enablers, and this requires investments (costs). SESAR Master defines also Service levels associated with Capability Levels. They are operational services offered by a service provider and consumed by a service user. Upgrading a service to a higher service level means deployment of operational improvement steps, and this leads to benefits (performance improvements). Service Level and Capability Level time scales are identical.

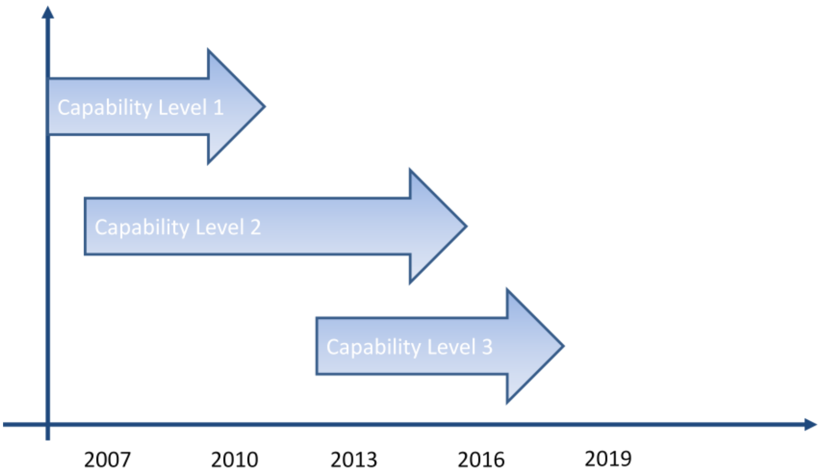


Figure 8: Capability levels with their time scale

Capability Levels are so groups of functionalities which share the same time scaled implementation in order to together assure performance goals (i.e. KPI) belonging to above mentioned

Key Performance Areas (KPAs). Each capability level together with its service level assure step by step important performance goals in the Key Performance Areas (KPA's) which together assure a step by step reaching of ambitious SESAR performance discussed in the introduction chapter. Table 4 is extracted by SESAR Master Plan [1] and it gives more details on first three Capability Levels.

	Functionality	Description
Capacity Level 1	Precision Navigation	Implementation of 2D-RNP, steep and curved Approaches, CDA/CCD and use of auto throttle to reduce noise; Cruise Climb modes for use en-route to allow climb as weight is reduced; in addition; precision approaches (such as APV/Baro-VNAV, LPV or RNP AR) with vertical guidance for aircraft regularly operating on secondary airport (not ILS equipped).
	ATSAW	Air broadcast of aircraft position/vector. Receive other aircraft position/vector. This enablers the implementation of ATSAW-AIRB, ITP, VSA and SURF applications.
	ACAS linked to AP/FD:	Deploy upgrade of the ACAS to provide vertical speed guidance through autopilot or flight director display in case of resolution advisory.
	Secure CPDLC	Deploy secure CPDLC Datalink services complementing voice communications (but not replacing them).
Capacity Level 2	Initial 4D	Functionality of 4D Trajectory Management concerning: • Controlled Time of Arrival (CTA) – time constraint on a defined merging point associated to an arrival runway; • Precision Trajectory Clearances (PTC-2D), and Trajectory Control by Ground Based Speed Adjustment; • Uplink of ATC constraints and downlink of 4D data.
	Navigation enhancement	Navigation performance enhancement basing on fusion of data coming from more constellations.
	ASAS Spacing	New Separation mode concerning aircraft autonomous time spacing maintain for queue management
	Expand Datalink services	Update Datalink communication system to process uplink of Datalink clearances for taxi route, ASAS, Brake To Vacate, and AIS/Meteo data, as well as uplink/downlink of Meteo data.
	Airport Communications	Introduce new airport wireless Datalink (802.16 based) capability
	EVS	Enhanced vision (EV) of terrain and runway on head up display (HUD) in Low Visibility Conditions to facilitate approach and ground operations.
Capability Level 3	Full 4D Trajectory	Full implementation of 4D Trajectory management concerning in addition to Initial 4D: • data sharing; • ground broadcast of Uplink of AIMS/Meteo data (wind grids); • auto taxi (optimising speed adjustment according to the cleared taxi route) and auto brake (making it impossible for an aircraft to cross a lit stop bar) to support automatic prevention of runway incursion; • Multiple Controlled Times of OverFly (CTOs, in addition to CTA): time constraint management on several point of the trajectory.
	ASAS Separation	More advanced Airborne Separation mode where the role of separator is temporarily delegated to aircrew to maintain airborne separation.
	Precision landing	Introduction of GBAS Cat III for landing and exploiting technology for sub-metric surface movement positioning.
	Navigation Enhancement	Improvement of vertical navigation to fly pre-defined route 3D-PTC.

Table 4: European Military Aircraft category composition 2010 (source: EUROCONTROL)

4 Analysis of implementation impact

Previous paragraphs have described which are the SESAR functionalities which will assure a certain Capability Level. It is obvious that implementation of functionalities in Table 3 has a direct impact on the aircraft avionic systems. More in particular it is possible to assert that SESAR functionalities call for a development of:

- Communication System: to assure air-ground data link communication as a substitution of air-ground voice communication
- Navigation System: to assure enhanced navigation performances and supporting high automation flight procedures (e.g. Initial 4D where autonomous time navigation is requested)
- Surveillance System: to assure situational awareness on the surrounding air traffic to the flight crew
- Cockpit and more in general HMI: to accommodate SESAR functionalities on the cockpit elements (e.g. displays and control panels)

The aim of this chapter is to analyze the impact of SESAR functionalities on the above mentioned aircraft systems; necessity to hardware or software updates will be identified. The authors are conscious that the identification of hardware and software updates or modifications in order to accommodate SESAR functionalities strongly depend on the considered platform, however it is possible to deduce relevant guidelines for the functionalities implementation also by considering "generic" avionic architectures representing modern civil and modern military avionics. In the following paragraphs, at first, a generic avionic architecture for civil and military categories is described, then the impact of SESAR functionalities on avionics are analysed in order to identify guidelines for their implementation.

4.1 Civil aircraft avionics

Civil avionic system study has been based on a literary review of *Avionic Handbook* [6] and *Civil Avionics System* [7]. Modern civil avionic systems concern an integrated architecture where integration is performed among the equipments by digital data buses. Typical data buses used on commercial civil avionics are:

- ARINC 429 (A429)
- ARINC 629 (A629)
- Avionics Full Duplex Ethernet (AFDX) based upon commercial Fast Switched Ethernet (FDX) technology and adopted for the Airbus A380

Integrated avionic concerns benefits in terms of weight reduction and system flexibility in event of necessity of reconfiguration of data flows. It is to notice that integrated avionic flexibility is a key element in order to reduce the impact of new functionalities implementation.

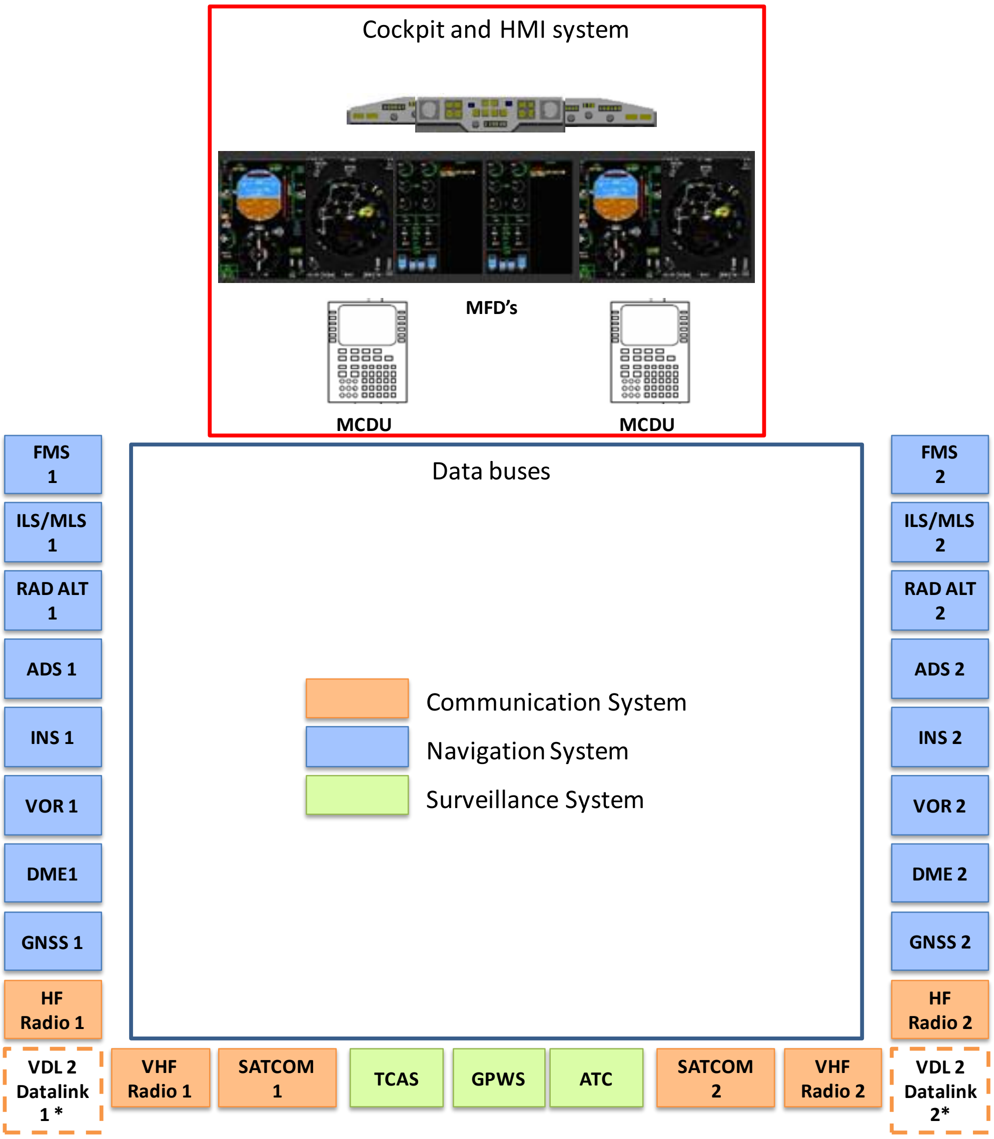
Communication System of considered civil aircraft (i.e. Mainline and Regional) is typically based on HF, VHF and SATCOM radios for allowing voice communication in Line of Sight (LOS) and Beyond Line of Sight (BLOS). Data link communication is assured by digital VHF radios compliant with VDL-Mode 2 (DO-281A) only on mainline aircraft compliant with FANS 1/A [8]. Regional aircraft typically slightly differ from the here reported description because SATCOM is often optional and digital VHF radio are compliant with Aircraft Communications Addressing and Reporting System (ACARS) (not with VDL-Mode2).

Navigation System is based on a redundant Flight Management System (FMS) which represents the computational unit of the navigation system. The FMS is fed by data coming from navigation radios (i.e. VOR and DME), precision approach radios (i.e. ILS and optionally MLS), air data system

(ADS), inertial navigation system (INS), Global Navigation Satellite System (GNSS) and radar altimeter (RADALT). The interface between the FMS and the flight crew is represented by the MCDU. FMS implement advanced flight guidance mode (i.e. LNAV and VNAV) coupled with AP/FD on mainline. The coupling of advanced flight guidance modes with FCS is often optional on regional aircraft.

Surveillance System is typically composed by Ground Proximity Warning System (GPWS) for ground collision avoidance and Traffic Collision Avoidance System (TCAS) for air collision avoidance. ATC Transponder typically compliant with Modes A, C and S is implemented for responding to ATC interrogation. No particular difference is possible to find between mainline and regional aircraft as far as Surveillance system is concerned.

Figure 9 graphically shows a generic civil avionic architecture.



* Available on mainline compliant with FANS 1/A

Figure 9: Generic civil aircraft avionic architecture

4.1.1 Implementation impact for civil avionics

The implementation of SESAR functionalities on the above mentioned civil avionic architecture concerns a technological impact due to the necessity to perform updates on the avionic systems guidelines The following paragraph describes the results of a matching activity between the SESAR functionalities divided by CL's, described on paragraph 3.2, and the civil avionic architecture, described in paragraph 4.1, in order to obtain guidelines for the implementation of SESAR functionalities. The hypothesis done is that civil aircraft are interested by all SESAR functionalities. This hypothesis is consistent with SESAR Master Plan [1].

4.1.1.1 Capability Level 1

	Communication	Navigation	Surveillance	Sensors	Cockpit
Precision Navigation	N/A	Implement management of new functionalities into Flight Management System	N/A	Implement baro-vnav or SBAS to support precision approaches	Implementation of HMI on PFD in order to assure that the pilot is aware of updated flight navigation precision
ATSAW	N/A	N/A	Update Mode S transponder to support the implementation of 1090 ADS-B OUT and 1090 ADS-B IN	N/A	Implementation on HSI of a proper HMI for surrounding traffic visualization
ACAS linked to AP/FD:	N/A	Integrate indications coming from ATSAW and TCAS with FCS	N/A	N/A	Enhance TCAS Human Machine Interface on PFD.
Secure CPDLC	Implementation of secure CPDLC[4] applications on VHF Digital Radios (VDL-Mode 2 protocol)	N/A	N/A	N/A	Modification of existing MCDU interface in order to allow accomodate insertion/recieving of CPDLC messagaes

Table 5: Impact of CL1 functionalities on civil avionics

[4] ACM, ACL, AMC, DCL

4.1.1.2 Capability Level 2

	Communication	Navigation	Surveillance	Sensors	Cockpit
Initial 4D	Implementation of 4DTRAD CPDLC and ADS-C applications on VHF Digital Radios (VDL-Mode 2 protocol).	Implementation of RTA mode on flight director /autopilot and on FMS in order to allow the aircraft to be steered on the waypoint by respecting the requested time constraint	N/A	Implement GNSS for navigation precision augmentation	Modification of existing MCDU interface in order to allow accommodation of insertion/reception of CPDLC messages Implementation on HSI and on PFD of a proper HMI for assisting the pilot in the RTA function.
Navigation enhancement	N/A	N/A	N/A	Implement dual constellation receivers for navigation precision augmentation	N/A
ASAS Spacing	Implement ASAS data link clearances in VHF Digital Radios (VDL-Mode 2 protocol)	Implementation of ASPA mode on FMS and on AP/FD in order to allow the aircraft to achieve and maintain the requested spacing	Updates and modifications for ATSAW are sufficient	N/A	Modifications for ATSAW should be enhanced with implementation on additional symbols for ASPA mode management
Expand Datalink services	Enhancement of data link applications implemented on VHF Digital Radios (VDL-Mode 2 protocol).	N/A	N/A	N/A	Modification of MCDU for composition/reception of data link messages is necessary.
Airport Communications	Introduce new airport wireless data link (802.16 based) capability	N/A	N/A	N/A	No particular modification requested. The whole HMI should be integrated with data of airport wireless data link.

EVS	N/A	N/A	N/A	N/A	Installation of an HUD where not available, integration of flight control data and navigation data

Table 6: Impact of CL2 functionalities on civil avionic

4.1.1.3 Capability Level 3

Functionality	Communication	Navigation	Surveillance	Sensors	Cockpit
Full 4D Trajectory	Expanded Data link enhancement of Capability Level 2 should be sufficient	Implementation of Multiple Time constraints management on FMS. More advanced speed control law shall be implemented in FCS in order to manage Multiple Time Constraints	N/A	Implement GNSS for navigation precision augmentation	Initial 4D HMI enhancement for integration of new data visualization and new procedure.
ASAS Separation	Implement ASAS data link clearances in VHF Digital Radios (VDL-Mode 2 protocol)	Implementation of ASAS mode on FMS and on AP/FD in order to allow the aircraft to achieve and maintain the requested spacing	Updates and modifications for ATSAW are sufficient	N/A	Modifications for ASPA should be enhanced with implementation on additional symbols for ASAS Separation mode management
Precision landing	N/A	N/A	N/A	Implement ILS CAT III compliant where not already available	N/A
Navigation Enhancement	N/A	N/A	N/A	Implement GNSS for navigation precision augmentation	N/A

Table 7: Impact of CL3 functionalities on civil avionic

4.2 Military aircraft avionics

The following information and details on the military avionics are taken from the study "*Initial Study to Determine Feasibility of Navigation Equivalent Verification of Compliance for State Aircraft Against ATM Navigation Standards"* commissioned from Eurocontrol to FDC [9] and from the study *"Feasibility Studies on the Integration of Military Ground and Aircraft Systems in the SESAR Concept and Architecture"* commissioned by Eurocontrol to Altran [10].

Modern military avionic systems concern an integrated architecture where integration is performed among the equipments by digital data buses. As already said, integrated avionic concerns benefits in terms of weight reduction and system flexibility in event of necessity of reconfiguration of data flows. Typical data buses used on military avionics are:

- MIL-STD 1553B
- STANAG 3910
- ARINC 429 (A429)

Voice communications for GAT flights employ VHF radios compliant with 25 kHz channel spacing below FL195 and 8.33 kHz channel spacing above FL195. Transport aircraft are also equipped with UHF radios for tactical purposes and HF radios for Beyond Line of Sight communications. Military aircraft communication systems are typically equipped with MIDS radios based on Link 16 (STANAG 5516) networks (optional for Transport-type) for data link communication. Link 16 is based on TDMA (Time Division Multiple Access) technology with anti-jamming and security capabilities. Modern aircraft compliant with civil certifications (e.g. C-27J JCA and A400M) concerns provisions for digital VHF radios compliant with VDL-Mode 2 (DO-281A).

Military aircraft implement on a Mission Computer (MC) military navigation modes in order to perform their typical missions. Modern military Transport-type aircraft like C-27J and A400M enhance basic navigation function of MC with two fully redundant FMS where civil navigation modes are implemented. The FMS and MC are fed by data coming from navigation radios (i.e. VOR, TACAN and DME), precision approach radios (i.e. ILS and optionally MLS), air data system (ADS), inertial navigation system (INS or LINS), Global Positioning System Precise Positioning Service (GPS PPS) and radar altimeter (RADALT). The interface between the FMS and the flight crew is represented by the MCDU on transport-type and by Glare Shields (GS) on Fighter and Trainers.

Surveillance System is typically composed by Ground Proximity Warning System (GPWS) for ground collision avoidance and Traffic Collision Avoidance System (TCAS) for air collision avoidance. IFF typically is compliant with civil modes (i.e. A, C and S) for responding to ATC interrogation and with military modes (1, 2, 4 and 5) for military friend or foe interrogations.

Figure 10 graphically shows a generic military avionic architecture.

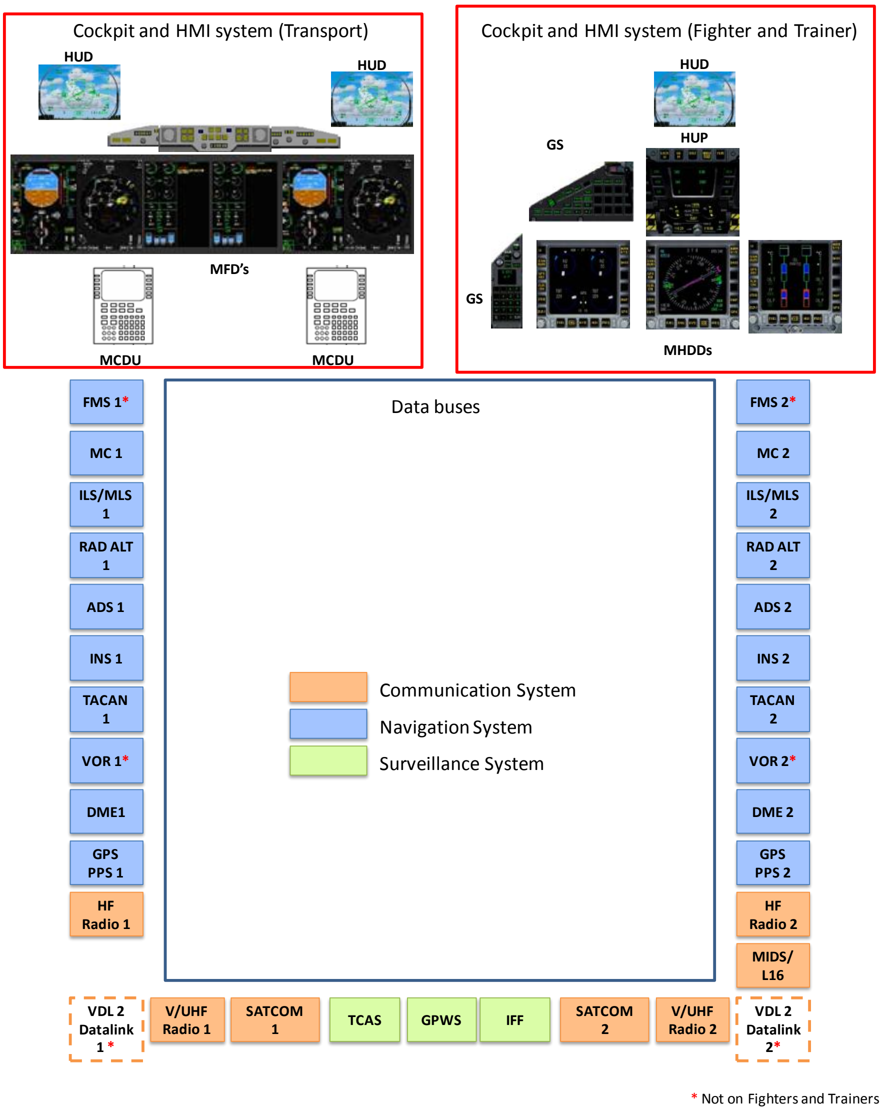


Figure 10: Generic military aircraft avionic architecture

4.2.1 Implementation impact for military avionics

The implementation of SESAR functionalities on the above mentioned military avionic architecture concerns a technological impact. As for civil aircraft, it is possible to identify guidelines for implementation of SESAR functionalities for military avionic architecture. In the military case the hypothesis done by the authors is that military aircraft are interested not by all SESAR functionalities but by a subset. This subset is defined by considering operational scenario which civil and military aircraft agree to share. Examples can be the en-route phase of a military transfer flight or a landing on a crowded TMA for transport aircraft. This hypothesis is consistent with SESAR Master Plan [1] and Eurocontrol *Introduction to Mission Trajectory* [2]. The following paragraph describes the results of a matching activity between SESAR functionalities, divided by CL's, described on paragraph 3.2, and military avionic architecture, described in paragraph 4.2, in order to obtain guidelines for the implementation.

4.2.1.1 Capability Level 1

	Communication	Navigation	Surveillance	Sensors	Cockpit
Precision Navigation	N/A	Implementation of new algorithms in MC/FMS for supporting new navigation modes	N/A	Extended use of GPS PPS and LINS sensors for enhancing navigation precision	Implementation of HMI on PFD in order to assure that the pilot is aware of updated flight navigation precision
ATSAW	N/A	N/A	Update IFF Mode S transponder to support the implementation of 1090 ADS-B OUT and 1090 ADS-B IN	N/A	Implementation on HSI of a proper HMI for surrounding traffic visualization
Secure CPDLC	Implementation of secure CPDLC[5] applications on VHF Digital Radios (VDL-Mode 2 protocol) where available or on encrypted radios (e.g. MIDS L16)	N/A	N/A	N/A	Modification of existing Digital VHF or MIDS L16 interfaces in order to accommodate CPDLC messages visualization and pilot insertion

Table 8: Impact of CL1 functionalities on military avionics

4.2.1.2 Capability Level 2

	Communication	Navigation	Surveillance	Sensors	Cockpit
Initial 4D	Implementation of 4DTRAD CPDLC and ADS-C applications on VHF Digital Radios (VDL-Mode 2 protocol) where available or on encrypted radios (e.g. MIDS L16)	Implementation of RTA mode on AP/FD and on MC/FMS in order to allow the aircraft to be steered on the waypoint by respecting the requested time constraint	N/A	Extended use of GPS PPS and LINS sensors for enhancing time estimations	Modification of existing Digital VHF/ MIDS L16 interface in order to accommodate CPDLC messages visualization and pilot insertion. Implementation on HSI and on PFD of a proper HMI for assisting the pilot in the RTA function

[5] ACM, ACL, AMC, DCL

ASAS Spacing	N/A	Implementation of ASPA mode on AP/FD and on MC/FMS in order to allow the aircraft to achieve and maintain the requested spacing	Updates and modifications for ATSAW are sufficient	N/A	Modifications for ATSAW should be integrated with implementation on HSI and PFD
EVS	N/A	N/A	N/A	N/A	HUD typically already available.

Table 9: Impact of CL2 functionalities on military avionic

4.2.1.3 Capability Level 3

	Communication	Navigation	Surveillance	Sensors	Cockpit
Full 4D Trajectory	Expanded Datalink enhancement of Capability Level 2 should be sufficient	Implementation of Multiple Time constraints management on MC/FMS. More advanced speed control laws shall be implemented in FCS in order to manage Multiple Time Constraints	N/A	Extended use of GPS PPS and LINS sensors for enhancing time estimations	Initial 4D HMI enhancement for integration of new data visualization and new procedure.

Table 10: Impact of CL3 functionalities on military avionic

5 Conclusions

SESAR is a research program concerning ambitious goals for the enhancement of the European Air Traffic Management (ATM) in order to realize the Single European Sky concept. The ambitious goals can be reached only if all the stakeholders participate in reaching it. SESAR represents a reformation for both civil and military use of airspace. Civil and Military air traffics will be requested to be more and more integrated and interoperable. The paper, at first, analyzed statistical data on the civil and military fleets and air traffic by showing that, as expected, even if the military air traffic volume is lower than civil one, the number of military platforms potentially interested by SESAR functionalities could be surprisingly higher than the civil one. This fact could be economically interesting for military aircraft manufacturers and as consequence could assure SESAR ATM performances to military aircraft whose flights are today performed almost totally in OAT. The paper analyzed the impact of SESAR functionalities of CL1, CL2 and CL3 on generic civil and military avionic architectures obtaining as a result guidelines for their implementation. However, this represents the starting point in the solution of the avionic implementation of SESAR functionalities on civil and military platforms. More significant and detailed results can be obtained by performing an implementation study dedicated to a particular aircraft platform. The next step of the performed work is to develop software and hardware requirements for the implementation of SESAR functionalities. It has to be noticed that this paper does not deal with the civil-military interoperability aspects regarding communication protocols and navigation performances. These aspects shall be studied in order to assure civil and military communication protocols and navigation performances to be interoperable (e.g. civil communication on VDL Mode 2 is not intrinsically interoperable with military communication on Link 16 network). For more details on these aspects and possible solutions, the authors recommend the reference paper *Interoperability of Military Aircraft Versus Future Air Navigation System (FANS)* [5].

Acronyms

2D	2 Dimensional
3D	3 Dimensional
4D	4 Dimensional
4DTRAD	4D Trajectory Data link
ACARS	Aircraft Communications Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ADS	Air Data System
ADS-B	Automatic Dependent Surveillance - Broadcast
ADS-C	Automatic Dependent Surveillance - Contract
AFDX	Avionics Full Duplex Ethernet
AIRB	Airborne
AIS	Airborne Information Service
ANSP	Air Navigation Service Provider
AP/FD	Autopilot/Flight Director
APV	Approach with Vertical guidance
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATM	Air Traffic Management
ATSAW	Airborne Traffic Situational Awareness
BLOS	Below Line of Sight
BT	Business Trajectory
CCD	Continuous Climb Departure
CDA	Continuous Descent Approach
CL	Capacity Level
CPDLC	Controller Pilot Data link Communication
CTA	Controlled Time of Arrival
CTO	Controlled Time Over Fly
DME	Distance Measurement Unit
EV	Enhanced Vision
EVS	Enhanced Vision System
FANS	Future Air Navigation System
FCS	Flight Control System
FDX	Fast Switched Ethernet
FMS	Flight Management System
GAT	General Air Traffic

GBAS	Global Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GS	Glare Shield
HF	High Frequency
HMI	Human Machine Interface
HSI	Horizontal Situation Indicator
HUD	Head Up Display
IFF	Interrogator Friend or Foe
ILS	Instrument Landing System
ILS	Instrumental Landing System
INS	Inertial Navigation System
ITP	In Trail Procedure in Oceanic airspace
KPA	Key Performance Area
KPI	Key Performance Indicator
LINS	Laser Inertial Navigation System
LNAV	Lateral Navigation
LOS	Line of Sight
LPV	Localizer Procedure with Vertical guidance
MC	Mission Computer
MCDU	Multipurpose Control Display Unit
MHDD	Multifunction Head Down Display
MIDS	Multi Functional Information Distribution System
MLS	Microwave Landing System
MT	Mission Trajectory
OAT	Operational Air Traffic
PFD	Primary Flight Display
PPS	Precise Positioning Service
PTC	Precision Trajectory Clearances
RADALT	Radar Altimeter
RNP	Required Navigation Performance
RNP AR	Require Navigation Performance Approval Required
RTA	Required Time of Arrival
RTA	Required Time of Arrival
SATCOM	Satellite Communication
SBAS	Satellite Based Augmentation System
SESAR	Single European Sky ATM Research
SJU	SESAR Joint Undertaking
SL	Service Level
SURF	Surface
TACAN	Tactical Navigation
TCAS	Traffic Collision Avoidance System
TMA	Terminal Maneuver Area
VDL	VHF Data link
VHF	Very High Frequency
VNAV	Vertical Navigation
VNAV	Vertical Navigation

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Alenia Aermacchi S.p.A.

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