INTEROPERABILITY OF MILITARY AIRCRAFT VERSUS FUTURE AIR NAVIGATION SYSTEM (FANS)

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Abstract

The aim of the work is to study the problem of civil-military interoperability in a future Air Traffic Management environment defined by the research project SESAR (Single European Sky ATM Research) in Europe. The result of the work has been the evaluation of the potential impact of the civil-military interoperability directly on the avionic architecture of modern military Transport, Fighter and Trainer aircraft. The study has been conducted at first analyzing the Mission Trajectory concept which represents the operational scenario where the military aircraft shall operate in the SESAR concept. From operational to functional level of the analysis particular attention has been paid to SESAR Initial 4D functionality. Functional analysis of Initial 4D has been conducted in order to identify potential requirements for the avionic architecture. Result of the study is the analysis of technical solutions for military avionic architecture in order to cope with Initial 4D requirements. The authors assumed that the best solution to the interoperability 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 military end users.

1 General Introduction

SESAR (Single European Sky ATM Research) is a research project funded by Eurocontrol and European Community. 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 [7]:

- 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 [7] 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.

By analyzing Key feature 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. 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.

1.1 Mission Trajectory

The SESAR target concept of operation is a trajectory-based concept. All partners involved in the Air Traffic Management will share in real time all relevant trajectory information through an '*ad-hoc'* created network called SWIM (System Wide Information Management). In accordance with what Eurocontrol/DCMAC affirms in its *"Introduction to the Mission Trajectory"* [4] a Business Trajectory (BT) for civil aviation or a Mission Trajectory (MT) for military operation is elaborated and agreed for each flight, resulting in a trajectory that user agrees to fly and the Air Navigation Service Provider (ANSP) agrees to facilitate. It is to be highlighted that BT and MT are 4D Trajectory so that each waypoint of the trajectory is unambiguously defined by: latitude, longitude, altitude and Requested Time of Arrival (RTA).

The most relevant peculiarity of Mission Trajectory is the possibility to consider Areas Reserved (ARES) for military activities (e.g. firing, training and air refueling) as a part of the whole 4D Trajectory agreed with ANSP's. Military aircraft will fly their 4D Trajectory in ARES only where requested by specific military activities, the remaining part of the Trajectory will be shared with Air Traffic Control (ATC).

Eurocontrol/DCMAC [4] identifies 3 categories of Mission Trajectory Management and 1 exceptional type in order to take into account the great diversity of military air operations. In particular, these categories are:

- Category 1: it implies the possibility to share all information about the flight during all planning cycles and during the flight. This first category assumes Business and Mission Trajectory to be similar to each other;
- Category 2: it implies the possibility to share all the relevant information about the flight during flight planning but only a part of them during the flight. This category imply the possibility that part of the flight is performed in Areas Reserved (ARES) due to particular military needs (e.g. firing, training and air refueling);
- Category 3: it doesn't consider the possibility to share relevant trajectory information, nor during flight planning phase nor during the flight itself. This category implies that the whole flight is performed in ARES;
- Category 4 (exceptional): it doesn't consider the possibility to share relevant trajectory information, nor during flight planning phase nor during the flight itself. The difference with Category 3 is that in this case the military mission involved is performed for national security reasons so additional confidential measures are adopted.

The concept of Mission Trajectory so delineated by Eurocontrol/DCMAC [4] is a powerful basis in order to realize a civil-military interoperability environment where military users will share with civil relevant trajectory information in order to participate to the airspace reformation of SESAR when particular military confidentiality issues are not concerned.

It is to be noticed that Mission Trajectory concept concerns innovative flight procedures and consequent on-board functionalities defined by SESAR. The complete set of ATM procedures and functionalities in order to realize a minimum and sufficient level of Civil-Military interoperability is wide and its fixing is ongoing in the SESAR research program. At the moment one of the fixed SESAR procedures identified for a minimum interoperability level is the Initial 4D. This paper is focused on the investigation of impact on the military avionic architecture of the on-board functions requested by the Initial 4D procedure. This impact has been investigated for military Transport, Fighter and Trainer aircraft. Evaluation of the accommodation of Initial 4D on the existing Human Machine Interface (HMI) is considered as a future development of the work. Figure 1 summarizes the process followed.

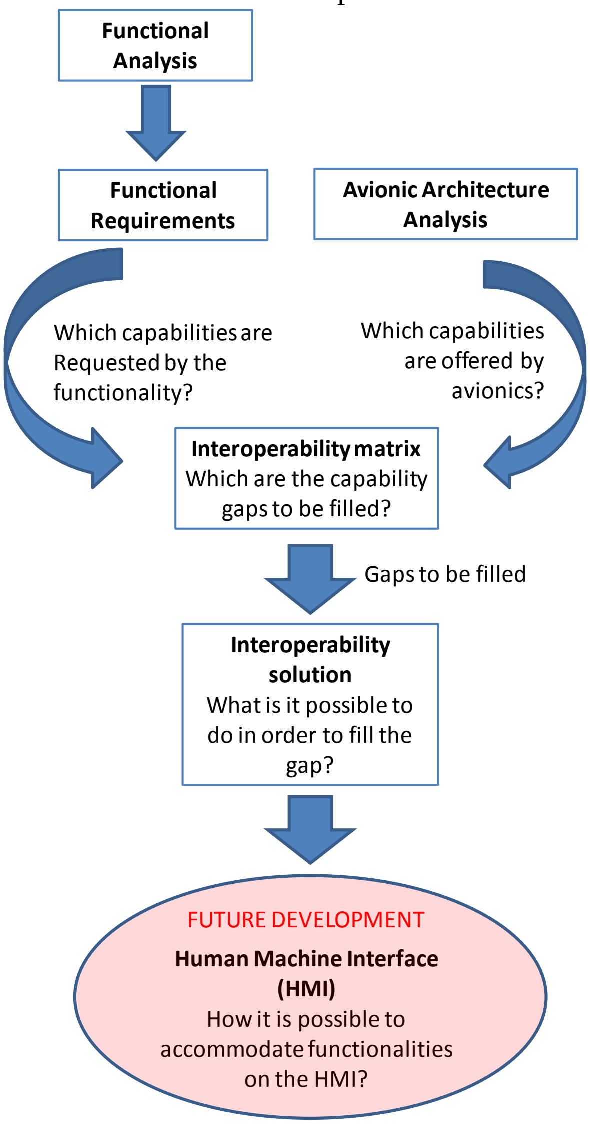

Fig. 1. Interoperability analysis process

1.2 Initial 4D

In accordance with what asserted by *SESAR – WP 9 Description of Work (DoW)* [2] 4D Trajectory Management is an aircraft function that enables to build, guide, predict and communicate a 3D trajectory where all waypoints are described also by a time constraint. In SESAR target concept Initial 4D is the first implementation step of 4D Trajectory Management.

Initial 4D is a flight procedure which applies in the final en-route and Terminal Maneuver Area (TMA) within the Arrival Manager (AMAN) Horizon. In accordance with the description of Initial 4D found in [1] and [3] it is possible to decompose the nominal flight procedure in the following steps:

- The aircraft downlink via ADS-C EPP report [8] its preferred 4D Trajectory composed by a waypoints defined by latitude, longitude, altitude prediction and time prediction. Speed prediction and aircraft gross weight are additional information to be downlinked;
- The Air Traffic Control (ATC) ground system receives the downlinked 4D Trajectory and a dedicated tool is used in order to establish if it is possible or not to accommodate user preferred trajectory;
- A 3D route clearance is uplinked to the aircraft via CPDLC [8]. This clearance is in order to communicate if the ATC can accommodate aircraft preferred 3D route or modifications to aircraft preferred 3D route are requested;
- After the 3D route is synchronized between the aircraft and the ground, the Flight Management System (FMS) of the aircraft estimates on a single defined waypoint of the Trajectory, ETA (Estimated Time of Arrival) maximum and ETA minimum. ETA maximum and ETA minimum represent the time interval where the aircraft is confident to overfly the defined waypoint. Defined waypoint where ETA maximum and ETA minimum shall be estimated by FMS is the Initial Approach Fix (IAF)

[3]. ETA maximum and ETA minimum are downlinked via ADS-C ETAmin/max report [8];
- The ATC receives downlinked ETA minimum and maximum values and determines a Single Time Constraint on the IAF to assign to the aircraft. The Single Time Constraint takes the name of Required Time of Arrival (RTA). The ATC uplink via CPDLC [8] the assigned RTA;
- The aircraft receives the assigned RTA and automatically uploads it into the FMS. If the crew agrees with the received RTA value, they activate the RTA function in the FMS;
- The RTA function steers the aircraft on the IAF by adjusting aircraft speed so that RTA value is respected with a given tolerance of ±10 seconds[1] [3];

The description of Initial 4D flight procedure allows to determine which are the required airborne functionalities in order to enable Initial 4D in accordance with [1] and [3]. It is obvious that the following requirements are not the real Initial 4D requirements but these have been grouped and summarized for the paper purposes:

- REQ-01: Data link supporting 4DTRAD (4D Trajectory Data Link) services on ADS-C and CPDLC applications as defined by RTCA SC-214 EUROCAE WG-78 SPR Version H [8]. It is to be noticed that air-ground data link communication will be supported by VDL – Mode 2 as far as physical, link and network layer are concerned [10];
- REQ-02: Automatic upload of uplinked received clearances into the Flight Management Unit;
- REQ-03: Computation of reliable time estimates (i.e. ETA min and ETA max) on defined waypoints for trajectory negotiation;
- REQ-04: RTA function coupled with Flight Control System (FCS) in order to steer the aircraft on defined waypoint with an accuracy of ±30 seconds if the waypoint is in en-route or ±10 seconds if the waypoint is in TMA;
- REQ-05: Navigation Database compliant with ARINC 424.

These required functionalities are key elements in order to evaluate impact of Initial 4D on military avionics.

2 Military Avionic Architecture

A first step in order to examine impact of Initial 4D is to analyze typical military avionic architecture. Considered categories of military aircraft are: Transport, Fighter and Trainer. These categories have been chosen basing on the composition of European military fleet published on Military Statistics by Eurocontrol in 2011 [9]. Figure 2 summarizes results of this statistics.

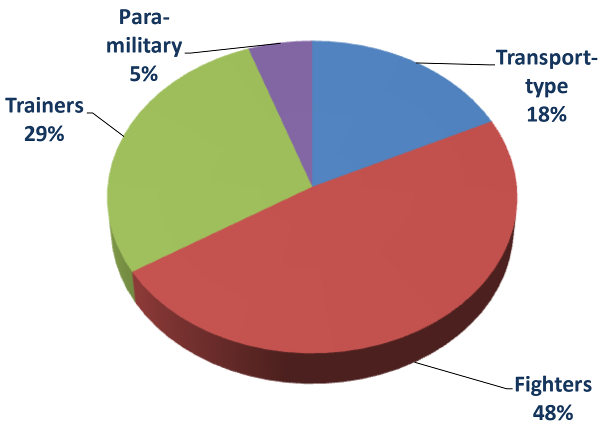

Fig. 2. Military aircraft fleet composition – 2011

It is important to remark that the necessity to study an interoperability solution for specific military platforms (i.e. Transport, Fighter and Trainer) is driven by the military aircraft fleet composition but it is weighted by the percentage of GAT (General Air Traffic) military flight per category published by Eurocontrol [9].

[1] Time tolerance for RTA function is ±10sec if the waypoint is in TMA ±30sec if the waypoint is in En-route. In the considered case IAF is in the TMA so ±10sec time tolerance is applied.

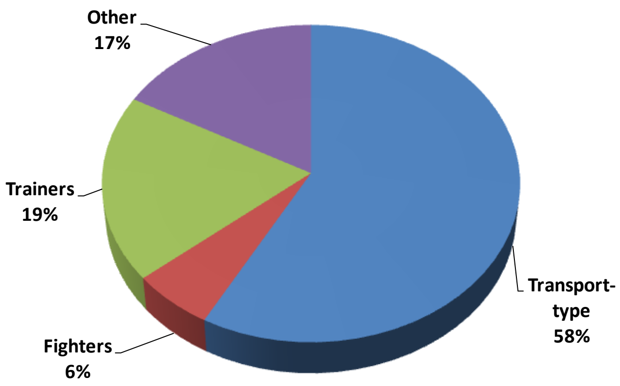

Fig. 3. Military GAT per aircraft type - 2011

Figure 3 allows to understand the importance of Civil-Military Interoperability for Transport aircraft whose flights represents more than 50% of the total military GAT flights.

The results of the analysis of military avionic architecture is presented in the followings paragraphs. Only Communication and Navigation systems are taken into account because Initial 4D functionality has an impact mainly on these systems of the on-board CNS (Communication Navigation Surveillance system).

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 [5] 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 [6].

2.1 Transport-type

Transport-type are those military aircraft used by national air forces for tactical and strategic transportations. This category of aircraft is distinguished by high capacities of the cargo bay and high take-off and landing performance on a wide variety of surfaces. Some examples of modern transport-type military aircraft are:

- Alenia Aermacchi C-27J Spartan
- Airbus A400M
- EADS CASA C-295M
- Boeing C-17 GlobeMaster

Fig. 4. Alenia C-27J Spartan

2.1.1 Communication

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 Below Line of Sight communications.

On board military Transport aircraft communication systems are optionally equipped with MIDS radios based on Link 16 (STANAG 5516) networks for data link communication. Link 16 is based on TDMA (Time Division Multiple Access) technology with anti-jamming and security capabilities. Modern aircraft compliant also with civil certifications (e.g. C-27J and A400M) concern provisions for digital VHF radios compliant with VDL-Mode 2 (DO-281A).

2.1.2 Navigation

Modern military Transport-type aircraft like C-27J and A400M are equipped with two fully redundant FMS which enhance basic navigation capabilities of a common military Mission Computer. As a result, a modern military Transport aircraft concerns navigation performances similar to civil ones. Estimation of arrival times on waypoints is possible in order to give the pilot an early-late indication in comparison with pilot inserted desired time of arrival. Time indications do not directly feed Flight Control System but the pilot must manually steer the aircraft in order to achieve the desired time on the waypoints.

Navigation database compliant with ARINC 424 is embedded into the FMS of a modern Transport-type aircraft.

Transport-type aircraft concern equivalent or better positioning performance than civil mainline aircraft due to the coupling of GPS PPS (Precise Positioning Service) receivers and advanced LINS (Laser Inertial Navigation System).

2.2 Fighter

Fighters are those military aircraft whose main role is to cope with the national air forces needs for air-to-air and air-to-ground defense. This paper considers only 4th Generation Fighter due to the limited information available on 5th Generation Fighters. Some examples of European modern 4th generation Fighters are:

- Eurofighter Typhoon
- Dassault Rafale
- Saab Gripen

Fig. 5. Eurofighter Typhoon

2.2.1 Communication

As for Transport-type, Fighters employ during GAT flight VHF radios with 25 kHz and 8 kHz of channel spacing for voice communications. UHF radios are used for tactical purposes.

Data link communications are supported by MIDS radios based on Link 16 (STANAG 5516) network. Radios based on Link 22 (STANAG 5522) networks (compatible with Link 16 networks) are also used. No provision for VHF digital radios compliant with VDL-Mode 2 (DO-281A) exists.

2.2.2 Navigation

Modern Fighters are not equipped with an FMS compliant with typical civil navigation modes. Navigation function is implemented on a Mission Computer where military navigation modes are available to perform typical fighter missions. No full redundancy of the navigation functionalities of Mission Computer often exists. Estimation of arrival times on waypoint is possible as for Transport aircraft but time indications do not directly feed Flight Control System: the pilot must manually steer the aircraft in order to achieve the desired time on the waypoints.

Modern fighters typically do not concern a navigation database compliant with ARINC 424. A limited number of waypoints are stored in the Mission Computer during the mission preparation phase on ground through a Mission Support System.

As for Transport aircraft, also Fighters concern better positioning performance than civil mainline aircraft due to the coupling of GPS PPS receivers and advanced LINS (Laser Inertial Navigation System) or FINS (Fibre optic Inertial Navigation System).

2.3 Trainer

Trainer aircraft are those aircraft dedicated to the training of the fighter pilots. It is to be noticed that Trainer category concerns a wide variety of aircraft categories, each corresponding to the training level which it is necessary to achieve. This paper only deals with Trainers employed for the most advanced training level which allows the pilot to be able to operate operational fighters. Their strong similarities with fighter aircraft often lead manufacturers companies to propose also a *'light-fighter'* version of these aircraft.

Most relevant examples of advanced trainers are:

- AleniaAermacchi M-346 Master
- KAI T-50 Golden Eagle

Fig. 6. AleniaAermacchi M-346

2.3.1 Communication

As for Transport-type and Fighters, Trainers employ during GAT flight VHF radios with 25 kHz or 8 kHz for voice communications.. UHF radios are used for tactical purposes in air to ground or air to air ways of communication.

Standard data link communication is uncommon on this aircraft category. Except the installation for training purposes of the standard AACMI (Autonomous Air Combat Maneuvering Instrumentation system) pod (all different AACMI version are typically guaranteed), a dedicated data link may be adopted for embedded simulation data exchange between multiple aircraft, while simulation of MIDS radios based on Link 16 (STANAG 5516) network are provided on board for training purposes.

2.3.2 Navigation

As for Fighters, modern Trainers are not equipped with an FMS where common civil navigation functions are implemented. Flight Management function is performed by a Mission Computer performing different avionic functions. Available navigation modes are very similar to those on fighters. Often could exist a No “full” redundancy of all functionalities of the Mission Computer even if the navigation function is designed to be a redundant function by adoption of different choices for the management of the Autonomous or Radio Navigation modes. Estimation of time of arrival on waypoints is possible. Time indications do not directly feed Flight Control System but the pilot must manually steer the aircraft in order to achieve the desired time on waypoints in both conditions during a normal navigation toward a waypoint or during a pre-planned flight plan.

Modern Trainers typically do not concern a navigation database compliant with ARINC-424. As for Fighters, a limited number of waypoints are stored in the Mission Computer during mission preparation phase on ground through a Mission Support System.

Positioning performance strongly depends on the availability of GPS PPS receivers which are optionally available on the avionic architecture of a Trainer.

3 Interoperability matrix

After the analysis of Initial 4D requirements and of the military avionic architecture of most diffused military aircraft categories, it is possible to compile the interoperability matrix in Table 1. Interoperability matrix highlights which are the gaps to be filled in order to assure Initial 4D compliance versus considered military aircraft. It is obvious that each gap concerns a dedicated technological solution analyzed in paragraph 4 of this paper.

The following color coding is applied in the interoperability matrix:

- Green: the requirement is already satisfied by the on-board avionic architecture. No modification required.
- Yellow: the requirement is satisfied by the on-board avionic architecture with minor modifications (e.g. software upgrade, existing hardware integration)
- Orange: the requirement could be satisfied by on-board avionic architecture with major modifications (e.g. new software design, hardware adaptation and modification)
- Red: the requirement cannot be satisfied due to serious technical issues, onerous to be solved.

As it is possible to notice, for each requirement an allocated equipment has been identified. Technical solutions of identified gaps are described in paragraph 4 of the paper. Technical solution coding has been used in the Interoperability matrix in order to keep traceability between identified gaps and technical solution in paragraph 4. The coding is written with the following logic:

Sol.[platform_type].[requirement_number] (1)

Where:

- *platform_type*
  - TR = Transport-type
  - F = Fighter
  - T = Trainer
- *requirement number* indicates the functional requirement which the solution refers to.

	Transport-type	Fighter	Trainers
REQ-01: Data link supporting 4DTRAD (4D Trajectory Data Link) data link services on ADS-C and CPDLC applications as defined by RTCA SC-214 EUROCAE WG-78 SPR Version H [8].	Allocated equipment: VHF Digital Radios and Communication Management Unit (CMU) Transport-type aircraft already implement or concern provisions for VDL Mode 2 digital radios compliant with ADS-C and CPDLC applications of 4D TRAD service.	Allocated equipment: MIDS/Link 16 Data link Fighter aircraft implement MIDS radios not compliant with 4DTRAD services. For technical solution please refer to (Sol.F.1) in paragraph 4.	No allocated equipment Trainer aircraft are typically not equipped with digital radios for supporting data link communications. The installation of a dedicated equipment is not under consideration.
REQ-02: Automatic upload of uplinked received clearances into the Flight Management Unit.	Allocated equipment: FMS This requirement concerns the integration of existing equipments. For technical solution please refer to (Sol.TR.2) in paragraph 4.	Allocated equipment: MC This requirement concerns the integration of existing equipments. For technical solution please refer to (Sol.F.2) in paragraph 4.	Allocated equipment: MC This requirement concerns the integration of existing equipments. For technical solution please refer to (Sol.T.2) in paragraph 4.
REQ-03: Computation of reliable time estimates (i.e. ETA min and ETA max) on defined waypoints for trajectory negotiation.	Allocated equipment: FMS Transport-type aircraft are equipped with an FMS able to compute a single reliable time estimation ETA on waypoints defined in the planned route. Estimation of both ETA minimum and ETA maximum and the consideration of Meteorological data is not implemented. For technical solution please refer to (Sol.T.3) in paragraph 4.	Allocated equipment: MC Fighter aircraft Mission Computer implements the possibility to compute reliable time constraints. The absence of dedicated redundant FMS for navigation allows to evaluate as orange the interoperability. For technical solution please refer to (Sol.F.3) in paragraph 4.	Allocated equipment: MC Trainer aircraft Mission Computer implements the possibility to compute reliable time constraints. The absence of dedicated redundant FMS and the possible absence of a precise positioning system (i.e. GPS PPS) for navigation allow to evaluate as orange the interoperability. For technical solution please refer to (Sol.T.3) in paragraph 4.
REQ-04: RTA function coupled with Flight Control System (FCS) in order to steer the aircraft on defined waypoint with required accuracy.	Allocated equipment: FMS The FMS should convert time estimation of RTA function in speed commands for FCS. For technical solution please refer to (Sol.TR.4) in paragraph 4.	Allocated equipment: MC The MC should convert time estimation of RTA function in speed commands for FCS. For technical solution please refer to (Sol.F.4) in paragraph 4.	Allocated equipment: MC The MC should convert time estimation of RTA function in speed commands for FCS. For technical solution please refer to (Sol.F.4) in paragraph 4.
REQ-05: Navigation Database compliant with ARINC 424	Allocated equipment: FMS Transport-type FMS implement navigation database compliant with ARINC 424.	Allocated equipment: MC Modern Fighters do not concern a navigation database compliant with ARINC-424. For technical solution please refer to (Sol.F.5) in paragraph 4.	Allocated equipment: MC Modern Trainers do not concern a navigation database compliant with ARINC-424. For technical solution please refer to (Sol.T.5) in paragraph 4.

Table. 1. Interoperability matrix

4 Interoperability solutions

This paragraph analyzes which are the interoperability solutions in order to fill the technological gaps highlighted in the interoperability matrix in Table 1. Solution coding described in (1) is used in order to keep traceability with interoperability matrix.

4.1 Transport-type

Sol.TR.1: No existing gap and no need for technological solution.

Sol.TR.2: REQ.02 calls for an enhanced integration between navigation and communication system. Modern Transport-type aircraft concern an integrated avionic architecture where integration is based on full duplex data buses compliant with MIL-1553B standard. An enhanced integration among communication and navigation system for the automatic upload of uplinked clearances in the FMS can be achieved with a software update of the bus controllers responsible of data flows on data buses where communication and navigation equipments are connected.

Sol.TR.3: FMS of Transport-type aircraft typically concerns the calculation of a single reliable ETA on a defined waypoint. Initial 4D require the estimation of two reliable ETA (i.e. ETA maximum and ETA minimum) and Meteorological data shall be taken into account in the estimation in order to maximize reliability. These gaps can be solved by a software update of FMS.

Sol.TR.4: RTA function of Initial 4D calls for an integration of time guidance modes in the aircraft Flight Control System. Time guidance mode should use existing auto-throttle autopilot in order to adjust the speed for time constraints respecting. The FMS when RTA function is engaged should provide speed commands to auto-throttle autopilot based on the time of arrival error on the waypoint. A new dedicated software functions should be designed and implemented in the FMS. Integration of this function with FCS is not problematic due to the already integrated avionic architecture based on MIL-STD 1553B data buses.

Sol.TR.5: No existing gap to be filled, FMS of Transport-type aircraft already implements a navigation database compliant with ARINC 424.

4.2 Fighter

Sol.F.1: Fighter aircraft implement data link radios compliant with Link 16 and Link 22 encrypted network. This category of data link application are used for tactical purposes and at the moment they are not compliant with ADS-C and CPDLC applications defined by RTCA and EUROCAE [8]. SESAR WP 9.20 is in charge of implementation of ADS-C and CPDLC applications on MIDS/Link 16 [2]. The technical solution proposed is to use as a physical and link layer for 4DTRAD Air-Ground communications MIDS/Link 16 military data links. A dedicated Ground Gateway investigated by SESAR WP 15.2.8 shall provide J-Series messages decryption and filtering for a Ground-Ground communication with ATC [11]. This solution is feasible but modification to the STANAG 5516 should be necessary in order to implement new J-Series messages for ADS-C and CPDLC applications.

Sol.F.2: REQ.02 calls for an enhanced integration between navigation and communication systems. Modern Fighter aircraft concern an integrated avionic architecture where integration is realized with full duplex databuses compliant with MIL-1553B standard or STANAG 3910 (e.g. Eurofighter Typhoon). An enhanced integration among communication and navigation system for the automatic upload of uplinked clearances in the FMS can be achieved with a software update of the bus controllers responsible of data flows on databuses where communication and navigation equipments are connected.

Sol.F.3: MC of Fighter aircraft concerns the estimation of a single reliable ETA on a defined waypoint. As for Transport Type a software update should be necessary in order to allow the estimation of two ETA values on a defined waypoint (i.e. ETA minimum and ETA maximum) by taking into account also Meteorological data. The incomplete redundancy of navigation functions on separate units could have a negative impact on reliability of time estimations.

Sol.F.4: Considerations about technical solution for fighter aircraft are similar to those done for Transport-type aircraft. Please refer to *Sol.TR.4*

Sol.F.5: As already said, Fighter aircraft does not implement a navigation database compliant with ARINC-424 and updatable with the AIRAC (Aeronautical Information Regulation and Control) cycle. The implementation of a Jeppesen navigation database in the Mission Support System is under consideration but it is not sure that this would be sufficient to solve the issue due to the limited number of waypoints storable on the Mission Computer.

4.3 Trainer

Sol.T.1: Trainer aircraft are typically not equipped with digital radios for supporting data link communications. The installation of a dedicated equipment is not under consideration for reason of space in the avionic bay.

Sol.T.2: REQ.02 calls for an enhanced integration between navigation and communication systems. Modern Trainer aircraft concern an integrated avionic architecture where integration is realized with full duplex databuses compliant with MIL-1553B standard or equivalent. An enhanced integration among communication and navigation system for the automatic upload of uplinked clearances in the FMS can be achieved with a software update of the bus controllers (typical function carried out by Mission Computer) responsible of data flows on databuses where communication and navigation equipments are connected. As a warning it shall be noticed that this enhanced integration should concern the presence of a digital radio supporting data link communications (see *Sol.T.1*) compliant with VDL-Mode 2.

Sol.T.3: MC of Trainer aircraft concerns the estimation of a single reliable ETA on a defined waypoint. As for Fighter a software update should be necessary in order to allow the estimation of two ETA values on a defined waypoint (i.e. ETA minimum and ETA maximum) by taking into account also Meteorological data. The incomplete redundancy of navigation functions could have a negative impact on reliability of time estimations. The possible absence of GPS PPS receivers could have a negative impact on the accuracy of time estimations.

Sol.T.4: Considerations about technical solution for Trainer aircraft are similar to those done for Transport-type aircraft. Please refer to *Sol.TR.4*

Sol.T.5: As for Fighter, Trainer aircraft does not implement a navigation database compliant with ARINC 424. Even in this case it is under consideration the implementation of Jeppesen navigation database on the Mission Support System but it is not sure it could be sufficient to solve the issue due to the limited number of stored waypoints in the Mission Computer.

5 Conclusions

SESAR is a research program concerning ambitious goals for 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 also for military use of airspace because military air traffic will be requested to be more and more integrated and interoperable with civil air traffic. This interoperability has an important impact on the military avionic architecture which will be requested to comply also with civil specifications and flight procedures.

The paper analyzed the impact of Initial 4D on the military avionic architecture of Transport-type, Fighter and Trainer.

Interoperability solutions have been proposed in order to fill the technical gaps between military avionic capabilities and Initial 4D required functionalities.

The implementation impact of the interoperability solutions is modest for Transport-type. The reason is the availability of two fully redundant FMS unit and civil VHF Digital Radios compliant with VDL Mode 2 on Transport-type aircraft. It is not to be forgotten that this category of aircraft often concerns models which have already successfully concluded the civil certification process (e.g. C-27J).

The implementation impact of interoperability solutions is high for fighter aircraft. The reasons are: the absence of fully redundant navigation units, the absence of a navigation database compliant with ARINC 424 and the need to upgrade MIDS/Link 16 data-link in order to support ADS-C and CPDLC.

As far as Trainer aircraft are concerned the absence of a data-link radio able to support Air-Ground data sharing strongly limits Initial 4D capability of Trainer aircraft. It is not under consideration the installation of a dedicated data link radio in the avionic bay. A more accurate feasibility assessment is strongly recommended in order to assess feasibility of SESAR civil-military interoperability for Trainer aircraft.

The final result of the work is that Transport-type and Fighter interoperability is feasible considering Initial 4D function. Trainer interoperability shall be further investigated in order to evaluate feasibility.

The next development of this work will be the study of accommodation of Initial 4D function on the existing Human Machine Interface of military platforms. Even in this case no retrofit solution will be considered but only the upgrade of available displays and control panels in the cockpit.

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