SAFETY ASPECTS OF UAS INTEGRATION IN PAN-EUROPEAN AIRSPACE

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ABSTRACT

In parallel to the ever increasing air traffic in Pan-European airspace, another aeronautical platform seeks approval to share the airspace with civil aviation; that with no pilot on-board the aircraft – the Unmanned Aircraft System (UAS). The introduction of UAS into civil airspace, under auspices of the Air Traffic management and its services, will generally coincide with anticipated growth of the air traffic with high rate, thus putting additional pressure before UAS community. In same time, different security and safety aspects need to be addressed and positively resolved, mainly in relation to Sense and Avoid functions of UAS, as well as general acceptance of specific nature of UAS flight within ATM procedures and safety protocols.

KEY WORDS

Unmanned Aircraft Systems. UAS. Air Traffic Management. Air Navigational Service. Air Traffic Control. Air Traffic. Non-segregated Airspace. Communications. Ground Control Station. TCAS.

1. INTRODUCTION

The airspace environment witnesses the emergence of Unmanned Aircraft Systems (UAS) with an almost geometrical progression. New aeronautical mission profiles and operational requirements have driven the development of large number of different UAS designs, with increasing system complexities involved. Although initially envisaged as a military means, and operated in respective manner, the achieved technological breakthroughs have effectively migrated into the civil domain, opening new frontiers for an extensive amount of possible civil UAS applications. Meanwhile, UAS have grown in size and their capacity of performing an autonomous operation, in which they have mimicked the various aspects of manned aviation to quite a large degree. But in order to fulfill their ever increasing mission spectrum, they should be given green light to spread from segregated airspace into controlled one, which they then will share with manned aviation.

The UAS industry is among the largest growing in the field of aeronautics, with total number of different UAS more than doubled in the period between 2005 and 2010 [1]. But, in parallel to anticipated integration of UAS in non-segregated airspace, the conventional air traffic will grow with similar rate. Eurocontrol estimates there will be 16.9 million IFR movements in Europe in 2030, which is 1.8 times more than in 2009 [2]. The growth will average 1.6%-3.9% annually and will be faster in early years, especially in Eastern Europe [3]. With these prospects in sight, it is safe to assume that UAS integration into civil airspace, without their full compliance with respective operational routines and procedures of manned aviation, would have a degrading effect on overall air traffic safety. The question that arises here is whether the technology involved is mature enough to allow for this process to start.

The purpose of this paper is to demonstrate; within given Air Traffic Management (ATM) environment, what are the critical safety issues that may determine the pace of UAS integration in Pan-European Airspace.

2. UAS IN NON-SEGREGATED AIRSPACE

The use of UAS is at this point almost exclusively limited to confined (segregated) volumes of airspace due to the absence of appropriate protocols needed for their integration into the auspices of ATM system. Nevertheless, the UAS community and different institutional stakeholders have so far demonstrated firm intention to find modalities that will provide unlimited access for UAS to the controlled airspace. In doing so, many aspects of safe and secure integration must be achieved, while their adaptation to ATM procedures will play the most significant role. Moreover, if UAS are to integrate with other airspace users, they must fit in with those other users and with current procedures, rather than existing ATM being required to adjust to accommodate UAS [4]. Besides procedural, many other aspects will have to be dealt with, including regulatory frameworks and airworthiness, pilot training and certification but also socio-economic issues; such is public acceptance of removing a man from the cockpit of an airborne asset, with remote control loop in charge of flight. Main processes for integration of UAS in European airspace are depicted in *figure 1*.

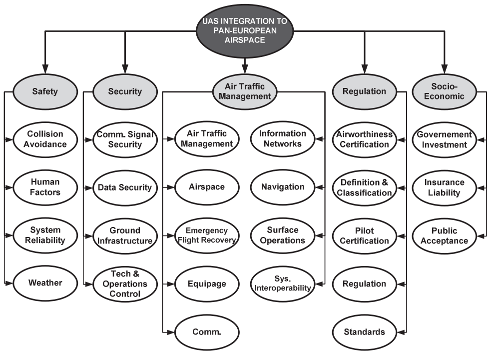

Figure 1: UAS integration main processes
Source: A. Gheorghe, E. Ancel, Unmanned Aerial Systems Integration to National Airspace System

Before UAS start to negotiate their access to the civil airspace, they should be systematically and functionally recognized in terms of regulations. Every sub-system of UAS has to be certified in airworthiness. Similarly, operators should be certified in the similar fashion. Different classifications in regards to size, airframe, flight characteristics and other are needed to facilitate these processes. Few institutions have adopted certain specifications in regard to airworthiness, that correspond to fixed wing UAS with operating mass of 150 kg and more, and these are namely EASA in its policy document [5], and NATO in its standardization document [6]. Both have derived their specification on the equivalence basis of already established EASA CS-23 certification specification codes that correspond to manned aircrafts.

In terms of air operations, many efforts exist in setting different sets of operational requirements, i.e. Eurocontrol specifications in [4] that tend to demonstrate that risk to other airspace users from military UAS operations would be no greater than from manned military Operational Air Traffic (OAT) in non-segregated airspace and would be reduced as far as possible. Eurocontrol in its overly pragmatic approach derives its specifications under condition that UAS should carry similar functionality for flight, navigation and communication as required for manned aircraft.

In order to achieve the same level of separation and collision avoidance functionality as it is the case for manned aircraft, UAS should be design in such a way that it effectively offsets the partial deprivation of situational awareness that is provided with a pilot inside the airframe. This could be done both procedurally and by increasing on-board systems functionality. Since some of the specific procedural actions cannot be performed by UAS, i.e. following other air traffic under ATC instruction, this is where UAS capacity of performing autonomous actions comes in play. The same applies in other instances such is loss of communication between UAS and Ground Control Station, or some other critical system failure that precludes the remote command and control function of the aircraft. In any case, UAS should have the ability of autonomous operation in secondary mode, which would clear the possibility of mid-air conflict by maneuvering different preprogrammed patterns.

As the most important functions of ATC/ANS is provision of separation between different airspace users, both in lateral and vertical plane, it is clear that this will also present a crucial requirement for UAS, and subsequently for the safe conduct of air operations. But while the responsibility for separation provision lies on the ATC where the radar surveillance is provided, it is for pilot-in-command to provide separation from other users by virtue of available means of navigation and collision avoidance systems, in case when radar separation is not available for any reason.

At this point, there is no empirical data that would indicate that situational awareness achieved through the remote operation of UAS, as is, would not have a degrading effect on the safety of flying UAS as OAT in non-segregated airspace. It seems that human factors in operation of UAS are an aspect not yet researched to the extent that would yield precise requirements and technical specification for appropriate human-machine interface designs, although some specifications do exist at present time (NATO STANAG 4586). Such designs should account for sensory deprivation of the UAS operator, as opposed to the pilot in the manned aircraft. The only input in that regard is highly limited visual reference in a narrow field of view, conveyed through the means of data-link. Data-link, furthermore, may suffer from signal latencies that may further diminish situational awareness in that particular regard. Sensory cues that are lost therefore include ambient visual information, kinesthetic/vestibular input, and sound [7].

Lastly, the most intriguing technological domain pending operational confirmation may be the ability of UAS to see and avoid conflicting traffic by means of on-board sensory layout. This function is further elaborated in chapter 3.

3. SENSE AND AVOID FUNCTION OF UAS

The emerging issue of UAS integration in the controlled airspace is its ability to avoid mid-air collisions with other air traffic. In order to do that, UAS have to be able to sense, detect, and avoid that traffic. Considering the robotic nature of UAS, this consideration will not only attract technical, but also ethical discussion on the subject. In the manned aviation, pilot on board supervises the VFR flight and responds with actions to extraordinary developments, including possible conflicts with other aircraft. His situational awareness may be amplified by means of collision avoidance systems, i.e. TCAS (Traffic Collision Avoidance System). In case of unmanned aircraft, the functional requirements of separation provision and collision avoidance functions will have to be achieved in respect to the same safety criteria as for manned aircraft, but without a pilot on board. Consequently, sense and avoid systems for UAS will have to be more versatile and autonomous than those in conventional aviation.

In today's airspace, several safety layers exist to minimize the probability of an airborne collision [8]. In the first layer, airspace structure and respective flight rules form procedural mechanism for collision avoidance. ATC provides surveillance and control functions that effectively form the second safety layer. Identification of cooperative aircraft via transponder, and respective functions of TCAS equipment serve as third layer. Finally, the ability to see and avoid traffic forms the fourth layer of safety. All of the aforementioned layers in civil airspace are shown in *figure 2*. Although it doesn't fall into the remit of this paper, it is worth mentioning that collision avoidance also applies to actions in avoidance of other obstacles, i.e. trees, buildings and terrain.

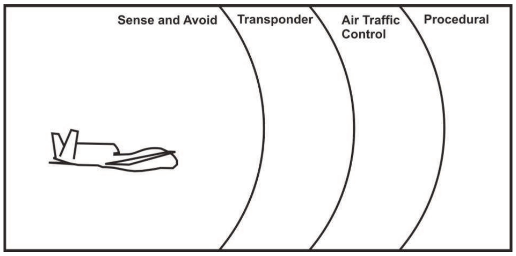

Figure 2. Safety layers in airborne collision avoidance
Source: Author

Safety requirements of Sense and Avoid systems will be derived from appropriate safety metrics, which in this case are represented as a rate at which the mid-air collision occurs. This is also referred to as Target Level of Safety (TLOS). For TLOS to be derived, some authors have used the statistical data of general aviation accidents in which two aircraft were involved in mid-air collision, regardless of the size of fatalities [9]. With that approach, the baseline rate could be established at $1x10^{-6}$ accidents in 100000 flight hours (table 1.) However, although numbers of accidents of UAS do not indicate that TLOS is even remotely achieved, it is important to understand that these accidents are entirely represented through various collisions with obstacles and/or ground, and not with other aircraft in mid-air. Further research is needed to establish more precise baseline for mid-air collisions, which is the primary domain of Sense and Avoid systems operation.

Table 1: Comparison of average accidents between UAS and manned aircraft per flight hour

Number of UAS accidents in 100000 flight hours	**Number of accidaents in manned aviation in 100000 flight hours**
Predator (MALE) $3,2x10^{-4}$	**F-16 Fighting Falcon** $3x10^{-6}$
Pioneer (MR) $3,3x10^{-3}$	**General Aviation**
Hunter (MRE) $5,5x10^{-4}$	**Regional Aviation** $1x10^{-7}$
	Larger Airliners $1x10^{-8}$

Source: Defence Science Board Study on Unmanned Aerial Vehicles and Uninhabited Combat Aerial Vehicles

The most comprehensive and operationally usable postulation of TLOS so far is seen in NATO document [10] which derives functional requirements for UAS Sense and Avoid operating in non-segregated airspace. According to this postulation, baseline probability of mid-air collision $\left({}^{\Delta}MAC\right)$ for UAS with MTOW of 150 kg and above should be no less than $5x10^{-9}$ per flight hour in airspaces classes A to D. For all other operations in airspace classes E, F and G $\left({}^{\Delta}MAC\right)$ should be equivalent, or better than, which is acceptable TLOS for conventional aviation in respective classes of airspace.

According to NATO capability group on UAS, apart from TLOS as derived above, Sense and Avoid systems on UAS should also comply with two basic operational functions in order to allow for operations in non segregated airspace. These are:

- Collision avoidance, which applies when the separation provision has failed and an imminent risk of collision exists. It applies at all times, in any class of airspace under any flight rules.
- Separation provision, which is the routine act of keeping aircraft apart, in order to mitigate the risk of collision.

On the basis of these two functions, a number of specific functional requirements are further proposed in order to obtain the desired level of technological and technical capacity of UAS operating in non-segregated airspace. Once again, Sense and Avoid systems are surrogate of human See and Avoid capability which functions in orchestra with TCAS systems. Having said this, functional requirements should account for any latency in relaying relevant flight data to pilot on ground, or should have substantial level of autonomy to act without input from the remote operator for any given contingency during the flight.

4. ATM ASPECTS OF UAS INTEGRATION

First and utmost difference in regards of UAS operations from the ATM perspective is the geographical relation between the Ground Control Station (GCS) and the ATM cell that is in charge of traffic separation en route. In case of manned aviation, this relation is relative to the position of the aircraft and is handled by respective Air Navigational Service (ANS) authority via various communication links (data/voice). In case of UAS operations, on the other hand, GCS remains stationary in relation to the ATM network. In the same time, UAS airborne platform is critically dependant on the input from the ground operator, regardless of the level of its capacity to perform flight mission in autonomous fashion. As today's ATM is not readily network centric-based, this puts a pressure on relying communication in case UAS will fly between multiple airspace sectors and switch between several ANS authorities, respectively. It is essential that any ANS communication relay between the UAS and the GCS meet the performance requirement applicable for that airspace and/or operation, as determined by the appropriate authority. As with manned aviation and to reduce the potential of external interference, this will necessitate the use of designated frequency bands [11].

Communicating with different ANS nods will not be an issue when it comes to aerodrome operations. These are very well an important segment of ATM system in large and need to be dealt with accordingly. Procedures, such is Standard Instrument Departure (SID) or Missed Approach Procedures, would not substantially differ when it comes to UAS. One of the problems that are not yet solved, though, is presented through incapacity of UAS to conform to specific instructions from ATC that encompass visual recognition of near traffic. Example of this situation is a situation when a pilot of general aviation is instructed to follow another airplane inside the traffic circuit, in aerodrome VFR conditions. Logically, with absence of a pilot on-board, UAS would not be able to comply with such instruction, posing a threat to other aircraft.

Although it is widely accepted that integration of UAS into controlled airspace will in no circumstances condition any specific adjustment from the ATM side, it should be noted that development of the future ATM system could account for specific aspects of UAS operations and consequently facilitate their integration. To understand that, it is important to recognize one major aspect of today's ATM system, which is set to be largely modernized. It is the rigidness of its configuration which is also a complex collection of independent systems interconnected by very different technologies from geographically dispersed facilities [12]. Under assumption that the future ATM system will be more network centric-based system, such future arrangements would conveniently address the aforementioned issues with heavy communication loads that UAS operations would bring into ATM system. This way, it is safe to assume that the migration of today's complex and dispersed ATM towards a network centric arrangement would largely facilitate the introduction of UAS operations into Pan-European airspaces.

5. CONCLUSIONS

In present, there is no solid evidence that UAS would be able to address all the safety and security requirements of the operational flying within the controlled airspaces of the European states. In any case, not without operational confirmation of the security protocols, as well as technology related issues of the Sense and Avoid systems installed on UAS. Assuming that other aspects, such are airworthiness standards, regulatory framework and pilot licensing will not present critical issue, there still exists a set of issues related with general acceptance of the remote pilot within the control loop of the aircraft that shares the airspaces with civil airliners. It is no coincidence that ATM community puts a significant emphasis on the designation of the operator that is responsible of the aircraft during all segments of flight, regardless of its actual position relative to UAS.

Although network centric approach in design of future ATM system would largely mirror the design of UAS itself, and in this regard would facilitate the introduction of UAS into controlled airspaces, it is paramount that designated communication bandwidths remain allocated for UAS operations. If those aspects are positively achieved, few issues would remain opposed to migration of UAS into non-segregated airspace, including airspaces of classes A to D.

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BIOGRAPHIE

Tomo Bagaric was born in 1975 in Zagreb. He has graduated on the Faculty of Transport and Traffic Sciences in Zagreb in 2000, in the area of Aeronautics. With military training background, he joined Croatian Air Force in 2001 as a staff officer in the field of Intelligence. During his professional career he was deployed in NATO operations in Afghanistan and NATO Headquaters in Brussels, Belgium, where he was primarily engaged in intelligence-related but also in capability development issues. During this time he was also Croatian representative to NATO Joint Capability Group on Unmanned Aircraft Systems (UAS) on its plenary meetings. He has published a number of articles concerning the development of UAS. At this time, he is still on his mandate in Brussels.

Ms. **Sanja Steiner**, Ph.D., was born 1964 in Zagreb (Croatia). She graduated in 1988 at the Faculty of Transport and Traffic Sciences in Zagreb, Air Traffic study. In 1995 she acquired the Master's degree within the post-graduate study "Multimodal transport" at the Maritime Faculty, University of Rijeka. In 1998 she acquired the Doctoral degree in the field of technical sciences by the University of Zagreb. Since 1988 she has been employed at the Faculty of Transport and Traffic Sciences, University of Zagreb. In 2005 she was elected full professor. Since 2008 she has been head of Air Transport Department. Apart from lecturing activities at the undergraduate, graduate and doctoral studies at University of Zagreb and as visiting professor at University of Sarajevo (BiH), Ms. Steiner is active in scientific research work. She was participating as principal researcher or researcher in ten scientific projects. Since 2007 she is chairing national scientific programme Harmonization of Transport System within Context of Sustainable Development, and within it she is principal researcher in project Strategic Planning of Air Transport Development. Since 2007 she has been appointed by Ministry of Sciences and Education as national representative for transport within administration structure for European Commision Seventh Framework Programme of research and tehnology development. The previous scientific work done by Ms. Steiner includes complex research in the fields of air transport technology and safety, air transport policy and the applied projects of strategic development of the Croatian transport system. She has lectured at numerous conferences in Croatia and abroad and published several dozens of papers in the scientific and technical publications. She has published several course materials and authorised lectures, as well as a university course book Air Transport Safety Elements and Elements of Transport Policy (in Croatian), published by University of Zagreb. The five scientific books have been edited by Ms. Steiner, of which four have been published by Croatian Academy of Sciences and one by University of Sarajevo. Ms. Steiner is a member of the Flight Safety Foundation European Advisory Committee FSF EAC, professional member of Air Traffic Control Association ATCA (2002 nominated for Director for Europe and Africa), and vice-president of Scientific Council for Traffic of the Croatian Academy of Sciences and Arts. She is a member of the editorial/scientific board of the international scientific journal Promet-Traffic-Transportation and Transport Problems in edition of Silesian University of Technology.

The Adriatic Corridor establishing in European air route network is the most important result of Ms. Steiner professional contribution in domain of applied scientific research. Recent work done by Ms. Steiner is oriented towards transport policy harmonization and air traffic management within the processes of European Union enlargement.