

An approach to assess the safety of ADS-B based Unmanned Aerial Systems

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Abstract— The increasing demand for the use of unmanned aerial systems (UAS) in various social and economic applications have pressed aviation authorities to draw up rules and regulations that permit the release of such aircraft in non-segregated airspace. However, issues related to the safety of air traffic operations arise when considering the possibility of coexistence of manned and unmanned aircraft simultaneously. Thus, surveillance plays a key role in monitoring and controlling air traffic in new scenarios. The positional information provided by the Automatic Dependent Surveillance - Broadcast (ADS-B), originally designed to improve situational awareness for pilots and support controllers in air traffic management, interacts with the Sense and Avoid Systems (S&AS) of the UAS in order to avoid exposure to events of loss of separation (AIRPROX) and collisions. This paper presents a qualitative approach to assess safety when using ADS-B systems integrated with UASs in aeronautical operations. In addition, the possibility of using a methodology previously applied on manned systems for assessing safety on UASs is discussed. A new testing platform (PiPE-SEC) is presented as a possible solution for this safety evaluation.

Index Terms—ADS-B, Unmanned Aerial System, Air Safety, Surveillance

I. INTRODUCTION

FOR years, aviation has rapidly advanced in technology. Regarding all the changes, aviation organizations and manufacturers have found themselves faced with new safety issues along with ever-changing safety requirements. Unmanned Aircraft system (UAS) is not different. In fact, safety in this area is more than a concern. With no onboard pilot, complex operating systems, and ever-changing avionics as well as continuous software updates, safety emerges as one of the major obstacles for integrating UAS into non-segregated airspace [1].

Because the demands for civilian Unmanned Aerial Systems (UASs) have increased in the past several years, there has been a significant pressure on aviation regulators to develop and to implement the standards and regulations for the management of UAS operations. Despite the existence of

technologies that could facilitate the integration and operation of UASs in non-segregated airspace, several issues involving UAS safety conditions along with airworthiness independent of application remain a concern. As cited by [2] *apud* [3], Dr. Wilson Felder, the Director of the William J. Hughes Technical Center of the FAA, in his keynote addressed to ICUAS 2012, “*identified five challenges of UAS integration as procedural, technical, aircraft safety, crew credentials and public acceptance*”. These technical challenges are very significant, although Sense and Avoid Systems (S&ASs) remain one of the largest obstacles towards safe integration of UAS into airspace; hence, this key element is routinely singled out as the limiting factor in UAS to airspace integration [2].

Be it is a manned or unmanned system, the three mandatory activities to operate an aircraft (flight, navigation and communication) that should be assumed by any person or any computer-based system in command of an aircraft [4]. As a result, any UAS designed for non-segregated airspace must conform to existing airspace regulations regarding both collision detection and resolution efforts.

The Automatic Dependent Surveillance-Broadcast (ADS-B), a surveillance technology defined in the concept of Global Air Traffic Management (Global ATM), has been under development and implementation for almost a decade before its recent adoption [5]. Even though this technology was primarily developed for improving situational awareness for manned aircrafts, in the same way, it has appeared as a potential solution for UASs regarding the Sense and Avoid issue which is an inherent characteristic of this system [7].

According to [6], ADS-B can be considered one of the most important underlying technologies to transform air traffic control from the current ground-based system (such as Radar and VOR-DME systems) to a satellite-based system by conferring precision and reliability of satellite-based surveillance (GNSS-based position) to the skies, allowing the safe reduction of the mandatory separation between aircrafts. The complete ADS-B system will allow pilots to see and to avoid weather disturbances, air traffic, and terrain with the most up-to-date flight information, providing an unparalleled level of situational awareness contributing to the improvement of flight safety and flight operations [7]. ADS-B also provides greater coverage, since ADS-B ground stations are much easier to place than Radar systems. As a result, remote areas without Radar coverage

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are now covered by ADS-B. The Federal Aviation Administration (FAA) anticipates compulsory compliance for ADS-B to be complete by 2020 for the majority of aircraft in the North-American airspace [5]. In this scenario, ADS-B appears as a practical requirement for UASs for use in S&ASs. “*The improvement in situational awareness for pilots greatly increases safety*” [6].

According to FAA [8], small UASs (SUASs) for civil and commercial operations are likely to grow most quickly because of their versatility and relatively low initial and operating costs, unlike most manned aircraft and larger UASs. These versatile platforms can be utilized in a large number of ways. Besides obvious applications such as law enforcement and search and rescue operations, SUASs can be effectively used in monitoring applications such as agriculture, fire detection, and infrastructure (oil/gas pipelines and power lines). Scientific and research applications of SUASs are equally numerous, ranging from remote sensing of soil moisture, invasive weed control, wildlife monitoring and geological surveys. In this scenario, it is essential for UAVs that use the same airspace as manned aircraft not to increase safety risks of the existing aeronautical operations [4].

There are several strategies (architectures) in the use of data from an ADS-B system into an UAS. In [2], some of these possible configurations that can be employed while integrating ADS-B system with a UAS are presented. The same article addresses and discusses issues and implications that the integration of these two systems, in its different forms, can generate from the point of view of aircraft performance as well as flight safety.

This paper presents a qualitative approach for assessing safety in the usage of ADS-B systems integrated with UASs regarding aeronautical operations through the same safety assessment methodology proposed in [9], which evaluates safety in a both quantitative and qualitative approach (comparison between two different scenarios), so that the different integration strategies presented in [2] will be considered in the models to be simulated. The simulations seeking validation of models for the different scenarios proposed will be made using the Integrated Platform for Testing Critical Embedded Systems (PIpE-SEC [10]), a tool for simulating critical embedded systems in aviation which was proposed by the Safety Analysis Group at the University of São Paulo and that will be adapted for this purpose. The validation of the proposed models and new scenarios will allow, as the next step of the safety analysis of integration UAS into non-segregated airspace, running simulations on an accelerated manner which will provide data for more accurate conclusions to assess the safe integration of UAS into airspace.

This paper is organized as follows: section 1 gives the motivation and concerns involving the integration of UASs in a non-segregated air space. Section 2 presents the concept of Aeronautical Surveillance and the importance of using ADS-B into UAS. Section 3 presents the proposed safety

assessment methodology, including the possible tools applied for evaluating safety in the proposed scenarios. Section 4 discusses the challenges and future perspectives of the proposed approach. Lastly, Section 5 presents the final considerations and future work.

II. SURVEILLANCE TECHNOLOGIES

Before assessing the safety level in the integration of UAS into non-segregated airspace and evaluating the influence of different types of surveillance technologies in their operation, it is necessary to understand some concepts related to aeronautical surveillance and the technologies adopted.

A. What is Surveillance?

Aeronautical Surveillance System is defined in [7] as a system that “*provides the aircraft position and other related information to ATM and/or airborne users*” In general terms, surveillance is responsible for updating flight plans, improving estimates at future waypoints and also removing the workload for pilots reducing voice communication while they are in flight. Several surveillance technologies are suitable for delivering Air Traffic Control (ATC) services to separate aircraft that are currently available, such as radar technology and ADS-B. Fig. 1 shows how surveillance is inserted in ATC architecture.

Surveillance plays an essential role in Air Traffic Control (ATC). The ability to accurately and reliably determine the location of aircraft has a direct influence on the separation distances required between aircraft (i.e. separation standards) and, therefore, on how efficiently a given airspace may be utilized. In certain areas where there is no electronic surveillance, ATC relies exclusively on voice communication between pilots and Air Traffic Controllers (ATCo) to report aircraft position. Because of this, the separation distance between two or more aircraft have to be relatively large taking into account the uncertainty in the estimated position of the aircraft and the timeliness of the information. Conversely, ADS-B intends to improve the airspace performance, accommodating a higher density of aircraft when compared, for instance, to voice-based surveillance systems. It also allows aircraft vectoring for efficiency, capacity and safety reasons.

The main usage of surveillance in Air Traffic Management (ATM) is to monitor ATC expectations of aircraft movements based on clearances or instructions issued to pilots, and the actual trajectories of these aircraft indicating to ATC when expectations and trajectories do not match, providing an important safety function.

The demand to increase flexibility to airspace use either by manned or unmanned aircraft by reducing restrictions associated with flying along fixed routes requires improved navigation capability on board the aircraft. Equally, accurate surveillance is required to assist in the detection and resolution of any potential conflicts associated with the flexible use of the airspace which is likely to result in a more

dynamic environment.

Accurate surveillance can be used as the basis of automated alerting systems. The ability to actively track aircraft enables ATC to be alerted when an aircraft detected deviates from its assigned altitude or route, or when the predicted future positions of two or more aircraft conflict. It also supports minimum safe altitude warnings, danger area warnings and other similar alerts.

B. Why using ADS-B in UAS

Sense and Avoid Systems (S&AS) pose a significant challenge to UASs. The purpose of a S&AS function is to act in the place of a human pilot to detect and to resolve certain hazards (such as aircraft and other flying objects, as well as terrain and obstacles) to safe flight. Because there is no human pilot aboard in a UAS, the motivation of S&AS is not necessarily to preserve the aircraft but to prevent collisions with other traffic, with persons on the ground (in case of fall), or collateral damage to property.

Cooperative technologies, such as ADS-B, provide significant advantages to range, but will not be commonly adopted in the expected UAS operational airspace. Visual and other optical systems can be utilized for an approximation of a manned pilot's point of view, but pixel resolutions and bandwidth issues limit hazard identification range [2].

While not all aspects of S&AS can be addressed with current technology, the use of ADS-B in SUAS is currently a capable solution. The range, resolution, accuracy and update rate are all superior to other existing technology. The challenges to overcome with an ADS-B based system are not negligible, though. Cooperative technology suffers from reliance on widespread adoption and implementation costs. While ADS-B Out¹ is currently scheduled for adoption by 2020 through legislative mandates, its adoption is not currently widespread or required for aircraft flying at the low altitudes expected for UAS operations. However, as the technology improves, the integration of ADS-B into the Global ATM Airspace System completes the adoption of ADS-B based S&ASs and will improve a UAS operator's situational awareness as regards other air traffic. Specifically, it addresses a current weakness in the proposed operating procedures for SUAS operation.

The implementation of an ADS-B S&AS would enable the process of Conflict Detection and Resolution (CDR) to be accomplished sooner and would allow a UAS operator sufficient time to complete a self-separation or conflict avoidance maneuver. In some cases, a SUAS may be tasked to operate in a more congested airspace class, with permission of a local ATC. In these situations, ADS-B integration is necessary to gain sufficient situational awareness. SUAS operation in high air traffic areas requires close attention to air space management and control. This

¹ 'ASB-B Out' is an ADS-B system feature that enables the frequent broadcast of accurate aircraft position and vector data together with other information. [17]

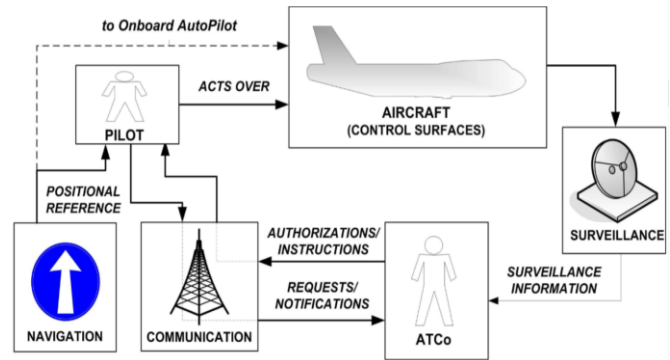


Fig. 1. Air Traffic Control architecture [14]

can be achieved by addressing all levels of conflict resolution strategies. By utilizing ADS-B as required by FAA laws, the outer levels of ATC management and self-separation layers are addressed.

Additional discussion is brought forth to the topic of the effects of introducing a new and likely heavily utilized class of aircraft to the ADS-B frequencies. The increased utilization of the two ADS-B frequency bands may result in an overly crowded system, especially in airspace segments where ADS-B information is most critical. Additional management from ATC would be required for supervising these operations as well.

Five different configurations for implementing an ADS-B S&AS for a SUAS were presented in [2] and are reproduced in Fig. 2 Each implementation has its advantages and challenges, although the preference for one or the other for a specific architecture depends on the technical aspects as well as on the context of the scenario.

III. SAFETY ASSESSMENT METHODOLOGY

A collision between aircrafts is the most important factor affecting the perceived aeronautic safety [11] for causing great social impact. Thus, guaranteeing the safety levels for air traffic services is related to the minimization of risks concerning the interaction of aircrafts, especially over factors that could affect their separation procedures. System parameters directly affecting the risk of collision are compiled in [12], such as: exposure time to aircraft separation losses; navigation systems performance of aircraft fleet; surveillance and navigation systems performance available for air traffic controllers (ATCo) and for aircraft fleet.

Hence, to fly a UAS in any airspace requires approval from the appropriate authorities, which tend to evaluate airworthiness and operational approvals according to existing regulations for aircraft, but some issues emerge as a result of the unmanned nature. Each of these approvals depends on a safety case, which must demonstrate that any foreseeable hazards would be controlled within an acceptable frequency [13].

It can be noticed that separation standards and safety are interdependent characteristics in air traffic systems, both

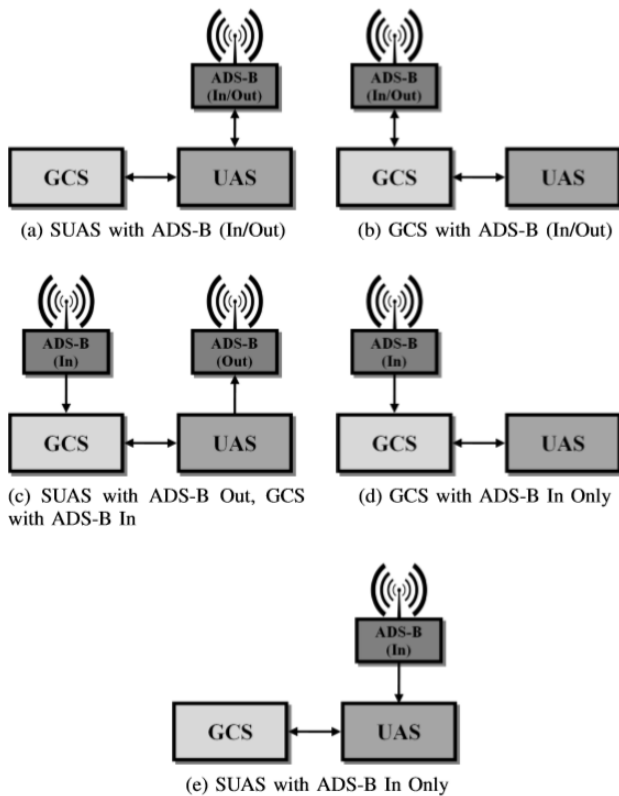


Fig. 2. Potential ADS-B Integration Configurations [2]

depending on the parameters influencing the levels of collision risks. Consequently, the current safety/risk assessment methods are, overall, applied to processes that determine the standard values of minima separation [9].

A critical step toward developing performance requirements will be performing safety assessment of S&AS. This will involve the determination of operational hazards – an example would be a midair collision – that could arise from the failure or incorrect performance of each function or data flow constituting S&AS. Examples of failure events arising from the surveillance system could include:

- 1) Aircraft not detected by surveillance system.
- 2) Aircraft detected late by surveillance system.
- 3) Aircraft detected with incorrect position or velocity.

The second and the third examples involve deeper analysis, since a ‘late’ or ‘incorrect’ detection may not cause a hazardous outcome with certainty, but would increase its likelihood. The relationship between the cause and the effect might depend on the design or technology involved. The analysis should consider not only failures in resolving collisions, but also incorrect maneuvers that ‘induce’ a collision where none would have otherwise occurred. This is a very real hazard, which could arise from various causes, including measurement error, human decision, limitations in the algorithm, or even the communications link to the aircraft [13].

A. Methodology

The “*Airspace Planning Methodology for the Determination of Separation Minima*”, used by the International Civil Aviation Administration (ICAO) [12], describes procedures and parameters to be considered in the airspace planning process, mainly for reducing separation values. It is composed of the following steps:

- 1) “*Identify the needs for change*” in the current system;
- 2) “*Describe the current system*”;
- 3) “*Determine the proposed system meeting the required needs*”;
- 4) “*Identify the Safety/Risk Assessment Method to be applied to the proposed system*”;
- 5) “*Evaluate Risk to the proposed system*” (applying the Safety/Risk Assessment Method ahead chosen);
- 6) “*Verify if the proposed system satisfies the safety criteria*”

Thus, any proposed system shall only be released to commercial operation if its safety levels are assessed (in phase 6), comply with its acceptable safety criteria (the Target Level of Safety to the system), set to the proposed system.

In [9], the safety of the ATC system was assessed considering two different scenarios in which the functional elements that must be considered to the model for assessing its risks are: Airspace (route configurations, airspace structure, aircraft flight plans and so on), Aircrafts (flight dynamics algorithms and aircraft performance characteristics), Navigation (characteristics of positional data provided to the aircraft), Communication (between controllers and pilots), Surveillance (estimative of aircraft positions provided to controllers), Air Traffic Controller (ATCo) (responsible for managing the safety separation values between aircrafts) and the aircraft Pilot. In both systems (the reference and the proposed ones), Airspace, Aircrafts, Pilots, Communication and ATCo models were the same. The differences adopted by the systems lay in the Surveillance and in the Navigation elements (systems related to the ADS-B):

- i. *In the Proposed System, navigation was based on the Global Navigation Satellite System (GNSS) and surveillance, on the ADS-B;*
- ii. *In the Reference System, navigation was based on the current VHF Omnidirectional Range / Distance Measure Equipment (VOR/DME) equipment and surveillance, on the radar system.*

The study presented in [14] focused on the relationship between the current surveillance paradigm (based on Radar, with strong characteristics of independence, determinism and synchronism), its ‘future’ paradigm (based on ADS-B, with strong characteristics of interdependence, randomness and asynchronism) and the level of exposure of aircraft to events of loss of separation (AIRPROX). It was concluded that the “*the exposure of the pairs of aircraft to separations smaller than 3.5 nautical miles (NM) – when the applied separation standard was 5 NM – was found to be reduced by approximately 93% as compared to the Reference System*”

(current ATC system)", improving aircraft adherence to flight plans and quality of surveillance information provided to the ATCo. It is important to notice that these studies were conducted considering scenarios with manned aircrafts only.

Within the proposed methodology [9], as seen, at least two scenarios must be considered: the reference one and the proposed one. In this study, the reference scenario to be adopted corresponds to the same scenario as that proposed in [9]. From there, the insertion of UAS in non-segregated airspace must be considered within the new scenarios proposed, adding and/or modifying those elements used in Vismari's study.

The first task is to update the model of the aircraft taking into account that a UAS consists of an unmanned aircraft (UAV) associated with a Ground Control Station (GCS). In the case of UASs, we can deal with 'automated' systems, whose tasks can be pre-defined by an instructor and/or by remote intervention of a GCS; or 'autonomous' systems which can achieve their goals without the intervention of a GCS, i.e. can execute decisions made by the Piloting Autonomous System (PAS) [4]. The aircraft level of autonomy will mainly affect its navigation aspects, especially influencing autopilot models, making them increasingly complex.

Other important aspects to be considered involve communication and surveillance (for this particular study, ADS-B). The adoption of digital communication technologies, such as Controller Pilot Data Link Communication (CPDLC) become compulsory within the new concept of Global ATM (previously known as Communication, Navigation and Surveillance/Air Traffic Management, or simply CNS/ATM) regarding the inclusion of UAS in conventional airspace [4]. Other features such as scanning, latency, availability of the communication channel, error rate, among others, should be considered when modelling new evaluation scenarios. Because it is supported by a digital data communication via Air Traffic Network (ATN), the ADS-B model also needs to change the message parameters of its respective model. This will be done by increasing the information fields in the ADS-B data packet, such as the 'projected-profile' (next waypoint, estimated flight level, etc.). Moreover, one can incorporate ADS-B 'future intention' information in the ATCo model for detection and conflict resolution to assess the impact of this parameter within the concept of safety of ATC. As in the case of the communication link, ADS-B scanning rates and latency should be altered to better represent data communication time variables. Besides the features inherent to ADS-B, another aspect that must be examined is the application architecture implementation of ADS - B within the S&AS. As seen in [2], there are several ways to integrate ADS-B with the UAS, each one with their own advantages and challenges to technical issues.

B. Modelling Validation

Society's risk perception of an unmanned aircraft within

the non-segregated airspace makes much stricter demands on UASs than on manned equipment, mainly for posing risks to the structure already established [10]. This makes it necessary to methodically cope, with factors related to the interaction of UASs with air traffic environment, be it for civilian or military applications. In this sense, the existence of methodologies and tools applied to the development, evaluation and validation of concepts and technologies used in unmanned aerial vehicle is vital, especially those that may have disastrous impact on the environment in which they operate. The operation of UASs, especially the autonomous type – where there is no direct human intervention in their operations – in areas where there is resource-sharing managed by humans (such as the air traffic control system) brings up numerous issues that must be resolved completely before its effective operationalization.

In this context, one of the tools suitable for such studies is the testing platform, called "Integrated Platform for Testing Critical Embedded Systems" (PIpE-SEC²) in Airspace which allows testing different models within the proposed scenarios as well as the aspects of design stage of the product UAS (unmanned aircraft) and aspects related to its operation within a social context (interaction of this unmanned aircraft with the environment). Consequently, this platform will assess and validate design concepts (requirements, algorithms, embedded technologies, etc.), operational procedures, tools and many other aspects that should be applied over these systems life cycle.

C. The PIpE-SEC

The Integrated Platform for Testing Critical Embedded Systems (PIpE-SEC) is a test tool, which is currently being developed by the Safety Analysis Group at the School of Engineering of the University of São Paulo (Poli-USP), that allows modeling and simulating air traffic operations, in real time, of the actual structural and behavior characteristics of the Air Traffic Control System (ATC), including the interaction between air traffic controllers (ATCos) and aircrafts, be they manned or computer-piloted vehicles. In this real-time simulated environment, through controlled tests, it is possible to evaluate and to validate the concepts

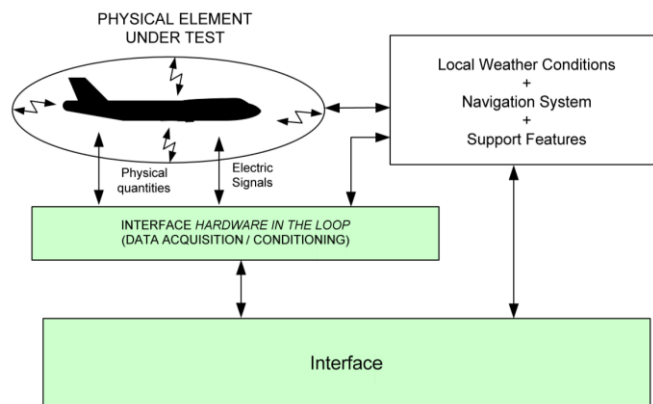


Fig. 3. Detailing of "Aircraft" (Ai) module under the HIL concept. [10]

intrinsic to the project of both manned and unmanned vehicles (especially the ones that are autonomous) and their interaction with the operational environment in which they are inserted, pondering the characteristics related to the technologies and to the procedures applied [10].

The main reason for adopting this platform is the possibility of testing UASs either through their computational models (where the UAS and the environment are computationally modeled and simulated) or through their actual physical prototypes (in which the variables read or provided by the actual physical UAS are considered in the computationally modeled and simulated environment), using the “Hardware In the Loop” (HIL) concept as shown in Fig. 3. As well as the HIL, the possibility of human action in the analysis process (known as the concept of “Human in the Loop”), makes PiPE-SEC essential for developing processes of critical embedded systems. In this context, PiPE-SEC is being adopted in order to seek validation of the proposed models and new scenarios when dealing with a qualitative approach. Models which were properly validated by the tool are now ready for accelerated simulation seeking a quantitative approach of safety analysis as presented in [14].

PiPE-SEC is composed of an Experiment Management Kernel (for controlling the execution of tests and data collection), through an Airspace Modeling and Simulation kernel and through Models of the involved Agents, that could be directly implemented in the software (computational models) or in the hardware (by the “Hardware in the Loop” concept). These kernels and their respective contexts in Airspace, especially in the Air Traffic Control System, are presented below. Fig. 4 shows the basic architecture of PiPE-SEC. More details about this specific tool can be found in [10].

IV. CHALLENGES AND FUTURE PERSPECTIVES

The level of safety demanded by society when using UASs will tend to be much higher compared to those for the manned vehicles, mainly because they may pose risks to an already set structure. The tolerance for accidents would be much lower, condemning the technology even before its

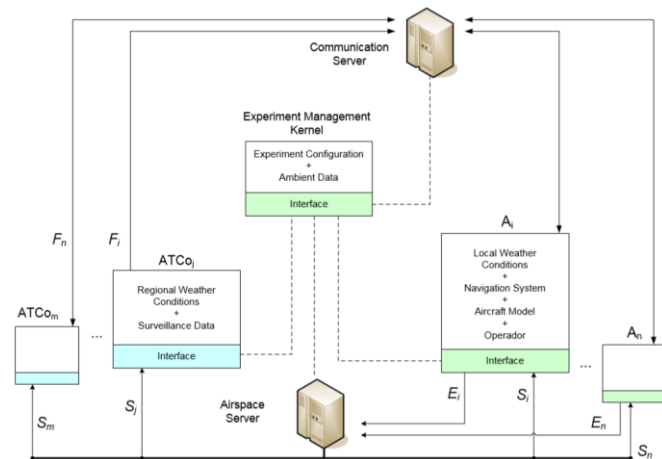


Fig. 4. Preliminary Architecture of PiPE-SEC [10]

benefits to humankind could be perceived [10]. Thus, before an unmanned or even remotely piloted aircraft can safely operate in the same airspace as other aircraft (manned or not), their operators have to demonstrate a high level of operational robustness and the ability to "sense and avoid" other air traffic.

By the safety premises pointed out and also considering the different technologies, methods and testing tools described before, several issues and challenges arise when trying to insert UASs into a non-segregated air space. Those concerns can be categorized as follows:

- 1) *Safe Airspace Operations:*
 - a) *Separation Assurance using ADS-B*
 - b) *4 Dimensional Trajectories*
 - c) *Ground Control Operations*
- 2) *Robustness to System Failures:*
 - a) *Lost Link Control*
 - b) *GNSS Unavailable*
 - c) *GNSS Unreliable*
- 3) *Uncooperative Air Traffic Detection*

Regarding the assessment of the levels of safety required for the operation of aircraft in non-segregated airspace, the analysis proposed in [9], combining absolute and relative methods, proved to be adequate since it combines the advantages of both. Any drawbacks found in this methodology are mitigated mainly because the system reference is usually a legacy system, i.e., which was previously simulated and validated or presents parameters and historical data from real systems already in operation.

In the specific case of ADS-B surveillance, as there are no large numbers of historical data involving the use of this system by UASs, the comparison can be made considering a reference scenario involving manned aircraft and in which the air traffic control adopts ADS-B as a system for surveillance. One can thus have a good sense of safety level at a particular location where the presence of UASs using metrics and data from other locations where ADS-B is already a reality exists.

Thus, it is imperative for the proposed models being submitted those criteria before being fully adopted in the operation of normal air traffic. Validating them by evaluating their behavior and especially their interactions with other systems of air traffic control is required in order that the occurrences of failures and deemed unsafe situations are minimized. Even if parts of the system analyzed show proper functioning, the interaction between them may generate the failures and unsafe situations previously mentioned [15].

With this, testing in a real-time simulated virtual environment offered by the PiPE-SEC becomes essential so that we can achieve the goal of approving any type of system, be it is manned or not, for use in conventional non-segregated airspace. Because of this important tool, it is possible to evaluate the behavior of UASs in different scenarios, including different architectures for the implementation and interaction with other air traffic control

systems and also check the different possible degrees of autonomy in a UAS.

Currently, there is no extensive documentation regarding the rules and standards for inserting UAS into the non-segregated airspace [4]. Because it is a new technological boundary within both civil and military aviation, it is necessary for governmental and aviation authorities to define the parameters and rules to be followed aiming at safe flying by the UASs.

V. FINAL CONSIDERATIONS AND FUTURE WORK

The International Civil Aviation Organization (ICAO) defines safety in [16] as

“the state in which the risk of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level through a continuing process of hazard identification and risk management”.

Based on this definition and in the global aviation context, the term safety is the feature of a particular system of not causing unacceptable risks of accidents or incidents involving aircraft.

Market demands for the use of unmanned aircraft in various civil and military applications are pushing the aeronautical authorities to establish standards and regulations in order to expedite the process of releasing this type of aircraft in non-segregated airspace. However, the perception of risk in our society regarding unmanned aircraft makes its project requirements even higher than manned ones [10]. Thus, regarding the integration of UASs in non-segregated airspace, a very careful assessment of their automated systems for navigation, communication and surveillance is needed. Besides the models in the system itself, it is necessary to evaluate their interaction, since, even though each individual part of these presents correct operation, the interaction between them can lead to potentially unsafe situations [15].

Regarding the surveillance system adopted by the new Global ATM concept, the Automatic Dependent Surveillance – Broadcast (ADS-B), there are several possible architectures for its interaction with UASs [2]. Each has more or less advantageous characteristics depending on the aircraft model used and also on their respective degree of autonomy. The unmanned aircraft can be either automatic, remotely commanded by human intervention, or autonomous, in which decisions and actions are taken on board the system itself.

There are several possible scenarios for interaction between ADS-B and UASs. In previous work, such as in [9], the impact of ADS-B on air traffic safety was evaluated and compared to systems whose surveillance was primarily based on radar technology. Thus, new parameters available in the ADS-B technology can be considered for evaluating the safety levels of air traffic control, such as the ‘projected-profile’, a field of ADS-B data package, which was not considered in previous analysis.

In order to maintain uniformity of analysis and to

establish a reliable comparison with previous work, the method to be used for the safety evaluation system will be the same proposed and used in [9]. This methodology combines ‘absolute’ and ‘relative’ methods proposed in [12] in which both quantitative and qualitative analyses are performed in a given system. It assesses whether the safety level is above an acceptable threshold value and also compares the system with another reference system, which is usually a legacy system already tested or in current operation.

The validation and safety assessment (in a qualitative approach) of each model as well as its interactions with the airspace makes it imperative to simulate those in a computer-based virtual environment. In such an environment, it is possible to assess how a particular model of the aviation system (be it used for navigation, communication or surveillance) interacts with other systems in a virtual computationally controlled airspace. This context makes the Integrated Platform for Testing Critical Embedded Systems (PIpE-SEC) play an import role in this evaluation, since it is a tool under development by the Safety Analysis Group at the School of Engineering of the University of São Paulo (Poli-USP) in order to provide a virtual environment for validation testing and evaluation of computer models of systems for air traffic control and air traffic management.

The adoption of this methodology and tools makes it possible to find the most suitable scenarios for the insertion of UAS together with other types of manned aircraft in order to, at least, keep the same level of safety currently adopted by the aviation authorities, mitigating risk situations inherent to the air traffic services.

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