**An Assessment for UAS Traffic Awareness Operations**

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# AN ASSESMENT FOR UAS TRAFFIC AWARENESS OPERATIONS

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## Abstract

*Technology evolution in the field of Unmanned Aircraft Systems (UAS) will affect the Air Traffic Management (ATM) performance regarding to new military and civil applications. UAS, as new airspace users, will represent new challenges and opportunities to design the ATM system of the future. The goal of this future ATM network is to keep intact (or improve) the network in terms of security, safety, capacity and efficiency level. On the other hand, most UAS are, at present, designed for military purposes and very few civil applications have been developed mainly because the lack of a regulation basis concerning their certification, airworthiness and operations. Therefore, UAS operations have always been solutions highly dependent on the mission to be accomplished and on the scenario of flight. The generalized development of UAS applications is still limited by the absence of systems that support the development of the actual operations. Moreover, the systematic development of UAS missions leads to many other operational risks that need to be addressed. All this elements may delay, increase the risk and cost in the implementation of a new UAS application.*

## 1 Introduction

There is great pressure in order to define the rules under which UAS will be able to fly inside non-segregated airspace. This initial effort has been already started, mainly due to military interest, leaded in Europe by EUROCONTROL in the UAV-OAT Task Force. UAV-OAT recently distributed the first public draft and collected comments about the document [2]. A similar process will eventually happen for civil UAS, thus leading to the real introduction of UAS as an available product for science, business, etc. EUROCONTROL and the FAA have similar philosophy about the integration problem: UAS should operate transparently to ATM and other airspace systems and users. However, even when restricted to the OAT scenario with an approved set of rules there are a number of open issues that must be addressed in order to obtain a successful UAS integration. Such situation will be extremely aggravated when UAS operational rules are introduced for the civil operation of UAS.

At present, the majority of manned flights correspond to commercial aviation dealing with persons/goods point to point transportation. On the contrary, the majority of potential UAS flight types may significantly differ from common manned flight types. Most common UAS potential mission is surveillance duties, requiring flexible and uncertain flight plans directly executed by computers with some supervision from UAS pilot. It is true that nowadays there are several general aviation manned aircraft performing this kind of missions, but its operation is mainly a man-directed process with little direct control from computers.

The introduction of this new type of unmanned traffic should not greatly affect ATM operations. However, UAS operation will be affected to large extends by its interaction with ATCs. Modern autopilots support pilots with replanning capabilities, but only for point to point operations. Mission re-planning of surveillance UAS due to the integration in the non-segregated ATM systems will require lots of automated support for the UAS Pilot if a timely response by him is required.

It is also true that we can imagine in the future scheduled cargo or even eventually passenger UAS flights. This means that UAS integration in civil airspace will balance in some way the "general aviation flight types" with the "commercial aviation flight types" affecting to ATM operations and involved systems. However, the real integration of such type of flight will not occur in the short term, and therefore its study can be delayed until further UAS operational experience is gained.

Nowadays, no assessment exists dealing with the necessity to coordinate UAS almost automatic operations, but monitored by human pilots, with automatic or human operations performed by other airspace users and by the different ATM actors. Moreover, with the advent of civil UAS, the degree of automation will significantly increase because civil users wonŠt be able to invest in extremely complex ground stations requiring multiple operators. Therefore the future integration of civil UAS should take into account relatively low cost but high automated vehicles.

Industry is currently designing and implementing the first family of *sense-and-avoid* systems [3]. Legally speaking these systems will allow the rightful operation of UAS in non-segregated airspace. However, the separation provision and collision avoidance is hierarchically divided from the ATC to the pilot-in-command to the UAS autonomous operation. Therefore it is true that sense and avoid is a technical topic that must be successfully resolved, but it is also true that the UAS - ATM - Manned Aircraft triple interaction must be also addressed from a technological point of view, but also from an operational point of view.

## 2 Assessment of UAS Operational Issues

### 2.1 Regulation and sense&avoid

Nowadays the introduction of UAS into non-segregated airspace if suffering by a number of both legal and technological factors. It is generally understood that the clarification of these issues will firmly clarify the future path of UAS inside the general aviation.

From a legal perspective, regulation needs to be clarified and consolidated at many levels (ICAO, EASA, FAA, etc.) [2, 10, 1]. Currently there is a high level of activity on this topic, that eventually will lead to the consolidation of a regulatory framework for UAS. Also, the assignment of radio-electrical spectrum to dedicated command & control and mission communications is being addressed [6], and eventually decisions will be taken at the upcoming ITU conference.

From a technological perspective, new communication devices will be needed to cope with the potential spectral bands assigned to UAS operation. Additionally, I huge effort will be needed to clarify how technology will cope with the see and avoid mandatory obligation on UAS. A large amount of research is currently being carried out to solve this particular aspect of UAS technology.

However, even though all this aspects are really relevant and are acting as bottlenecks on UAS development, the thesis of this work is that the magnitude of the previous problems is precluding the investigation of further aspects that will become relevant as soon of the first set of limiting factors is resolved.

### 2.2 Mission-oriented UAS

UAS have a great potential to support a wide variety of aerial monitoring applications. UAS may substitute manned aerial resources for cost/availability reasons; may cohabit with manned aerial resources in order to complement them; and even may allow addressing new monitoring scenarios in which manned platforms have never been introduced due to accessibility, complexity or risk. All these potential may be lost if all inherent risks in the UAS technology are not properly identified and addressed (see Figure 1).

The goal of UAS is to substitute manned aircraft in a number of aerial work scenarios. This is the first fundamental issue to take into account, UAS will not operate as point to point aircraft. Instead, UAS will possibly loiter over certain areas that may change over time. The main objective of the UAS Pilot in Command (PiC) being to attend to the commercial, security or scientific mission that the UAS is developing. Any change on the desired mission-oriented flight plan due to external interferences (ATC, traffic, etc.) will require the UAS PiC to redesign its operation to retake the tasks at hand prior to the undesired interruption. Therefore *mission support* is required at the UAS in order to automate the operation, but also on the ground so that the PiC or the operator could manage the operation.

The operation of the UAS goes beyond basic point to point navigation. The UAS pilot will need to manage the trajectories that the vehicle will need to follow. This **flight management** may include the selection of alternative trajectories to implement departure and approach operations, or the selection of specific routes to respond to an optimum route selection.

**Contingency reaction** is also one of the main bottlenecks that will need to be addressed. In case of any type of contingency, from the vehicle or due to a conflict, an immediate reaction is mandatory in order to don't miss any precious second. Due to the limited situational awareness of the PiC, we advocate for pre-planned contingency reaction schemes associated to the flight plan itself. Pre-planning for contingencies offers two main advantages: simplifies pilot decisions avoiding wrong selections due to the pressure of the circumstances, but also permits an automated contingency response in case the communication link between the ground and air segments is lost.

The desired goal by the UAS community is to allow them to operate in non-segregated airspace. Therefore, UAS will need to **interact with the ATC** and with other aircrafts if operating in VFR airspace. Which and how are the flight intentions that UAS should provide to ATM actors? How and when these intentions will remain valid for

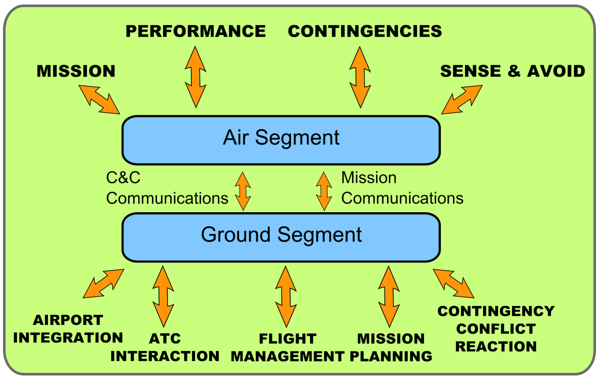


**Fig. 1** Overview of UAS Operational Open Issues

the UAS and how they will have to be re-planned in flight in order to accommodate variations on the final mission goals or to cope with variations induced by external events? Human factors are also considered crucial here. How the PiC will interact with the systems in order to react to these external events and how mission re-planning will be supervised by them?

Flight plan definition according to actual standards is considered to be quite vague; therefore ATC will have little detailed information about the intentions of UAS carrying out surveillance operations. Most details about actual operations will be defined prior and during the flight upon negotiation between both parts. On the other hand it will be assessed how sustained UAS operations will affect the current CFMU systems and which measures will be needed to accommodate this new kind of operations.

Especially interesting is also determine the amount of overload to PiC and eventually to the ATC and determine the type of tools that may help reducing such overload. In particular, tools to help keeping the situation awareness of the UAS pilot in order to clearly keep track of all PiC - ATC interaction, and tools to properly react to the ATC requests, conflicts or contingencies with immediate update of the UAS flight-plan and/or intentions.

## 3 UAS Mission Oriented Architecture

The UAS System Abstraction Layer (USAL) is the set of available services running on top of the

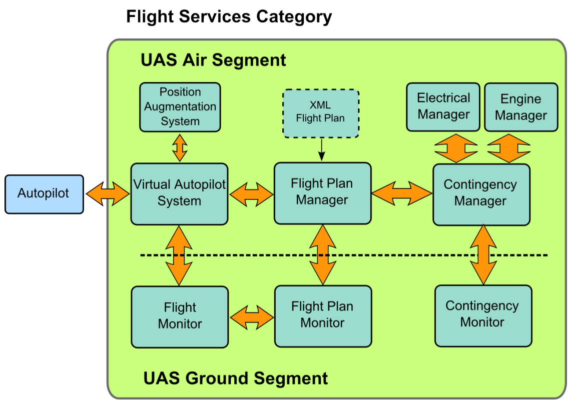


**Fig. 2** Overview of the Flight Services Category.

UAS system architecture to give support to most types of remote sensing UAS missions [4]. A number of specific services have been identified as "a must" in any real life application of UAS. The idea is to provide an abstraction layer that allows the mission developer to reuse these components and that provides guiding directives on how the services should interchange avionics information with each other. The available services cover an important part of the generic functionalities present in many missions.

The USAL services are divided in four categories accordingly to the role they play in the overall UAS operation: Flight Services, Mission Services, Awareness Services and Payload Services.

*Flight Services* are those in charge of the UAS flight operation. This includes the autopilot management, flight management, flight monitoring for the PiC and the flight contingency management.

*Mission Services* are those in charge of developing the actual UAS mission, controlling the payload and the area of surveillance, processing or saving the earth observation information and showing it to PiC or operator.

*Awareness Services* are in charge of the safe operation of the UAS with respect terrain avoidance and integration with shared airspace.

*Payload Services* are lower level services, not necessarily available to the end-users. They are like device-driver, this is, the facility services that abstract the details to access to the input, output and communication devices.

## 3.1 Flight Services

Flight services are a set of USAL applications designed to properly link the selected UAS autopilot with the rest of the UAS avionics [8]. The main services operated are the *Virtual Autopilot Service*, the *Flight Manager Service*, the *Contingency Service*, the *Flight Monitor Service*, the *Flight Plan Monitor Service* etc. (see Figure 2):

The *Virtual Autopilot Service* (VAS) is a system that on one side interacts with the selected autopilot and is adapted to its peculiarities. The VAS abstracts the implementation details from actual autopilot users. From the mission/payload subsystems point of view, the VAS is a service provider that offers a number of standardized information flows independent of the actual autopilot being used.

The *Flight Plan Manager* (FPM) is a service designed to implement much richer flight-plan capabilities on top of the available autopilot capabilities. The FPM offers a virtually unlimited number of waypoints, waypoint grouping, structured flight-plan phases with built-in emergency alternatives, mission oriented legs with a high semantic level like repetitions, parameterized scans, etc. These legs can be modified by other services in the USAL by changing the configuration parameters without having to redesign the actual flight-plan; thus allowing the easy cooperation between the autopilot and the UAS mission.

The *Contingency Management* services are a set of services designed to monitor critical parameters of the operation (like battery live, fuel, flight time, system status, etc.). In case contingencies are detected, actions will be taken in order to preserve the security and integrity of the UAS: from flight termination, mission abort or system re-cycle.

The *Electrical and Engine Management* services are a set of services designed to gather data on the operation of the UAS electrical system and the propulsion system. Such information is relayed to the Contingency Manager to take the appropriate decisions.

The *Flight Termination System* is a system outside the USAL architecture, and it is in charge to deploy a parachute system in case the Contingency Manager requires it; also the parachute may be deployed in case a major USAL failure.

The *Flight Plan Monitor* is the HMI interface on the ground that provides high level flight management services that will exploit the advanced capabilities offered by the UAS oriented flight plan provided within USAL.

## 3.2 Awareness Services

A UAS is a highly instrumented aircraft and has no pilot on board. With these conditionings the more suitable flight rules for a UAS are IFR (Instrumental Flight Rules), however for remote sensing missions the advantages of UAS systems is precisely its capacity for flighting at any altitude, where VFR (Visual Flight Rules) aircrafts are found. UAS must relay on its instrumentation equipment to properly inform the pilot in command on the ground or substitute the pilot capacities in VFR conditions. The awareness services (see Figure 3) are responsible of such functionalities. Flight Services are in charge of the aircraft management in normal conditions while the Awareness Services are in charge of monitoring surroundings conditions and overtake aircraft management in critical conditions. In this case mission services come to a second priority, until flight conditions become again normal.

The *Awareness data fusion* (ADF) is a service designed to collect all available data about air vehicles surrounding our UAS, terrain and meteorological conditions. All this information can be obtained either by on board sensors or even through an external provider.

The *Tactical/Strategic Conflict Detection* service will analyze the fused information offered by the ADF in order to detect potential collision conflicts with objects/terrain/bad climate. Depending on the type of conflict, different types of reaction procedures will be activated. While reaction is executed it will keep monitoring than the conflict is really being avoided.

The *Tactical/Strategic Reaction* services, will implement avoidance procedures according to the severity of the conflict. Tactical reaction is designed in such a way it can overtake the Flight Plan Manager in order to execute a radical avoidance maneuver. Once completed, the FPM will regain control. An strategic reaction will command the FPM to slightly modify its selected flight plan trying to avoid the conflict but at the same time retaining the original mission requested by the Mission Manager.

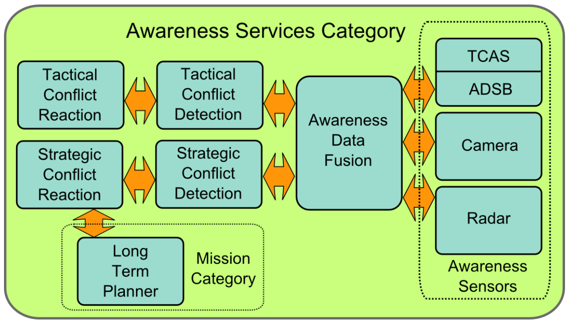


**Fig. 3** Overview of the Awareness Services.

# 4 UAS Flight Plan Specification

The flight plan is a document that contains the navigation instructions for the UAS [7, 5]. In our proposal the flight plan is a self-contained description of the main flight plan, but also contains options for take-off and landing operations as well as alternatives for emergency situations (see Figure 4).

**Stages** constitute high-level building blocks for flight plan specification and are used to group together legs that seek a common purpose. They correspond to flight phases that will be sequentially executed: Taxi, TakeOff, Departure, En-Route, Mission, Arrival, Approach and Land.

A stage may have more than one final leg, for instance, a take off stage may end at different points depending on the selected take off direction. Also, a stage may have more than one initial leg as could be the case for departure procedures that start at different positions depending on the chosen take-off direction.

A **leg** specifies the flight path to get to a given waypoint. In general, legs contain a destination waypoint and a reference to their next. Most times legs will be flown in a single direction, but

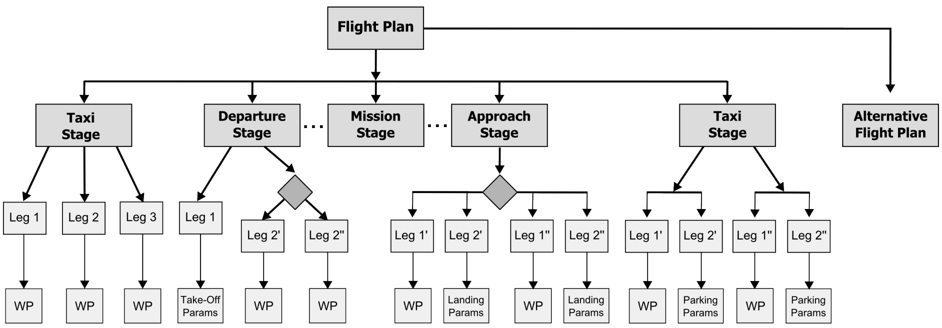


**Fig. 4** A flight plan is composed of stages, legs, waypoints and parameters to be used by the FCS.

within iterative legs reverse traversal is also supported.

There are four different kinds of legs. Basic legs that specify basic tradditional primitives; Iterative legs that allow for specifying repetitive sequences; Intersection legs that provide a junction point for legs which end at the same waypoint, or a forking point where a decision on what leg to fly next can be made; and Parametric legs that specify legs whose trajectory can be computed given the parameters of a generating algorithm, e.g. a scanning pattern.

A complex trajectory may involve iteration, thus the inclusion of iterative legs. An iterative leg has a single entry (i.e. its body can be entered from a single leg), a single exit and includes a list with the legs that form its body. Every time the final leg is executed an iteration counter will be incremented. When a given count is reached or an specified condition no longer holds the leg will be abandoned proceeding to the next one.

Intersection legs are used in situations where there is more than one possible path to follow and a decision needs to be made. This leg type contains a list with the different alternatives and a condition for picking one of them. Intersection legs are also used to explicitly indicate where two or more different paths meet. Together with parametric and iterative legs, intersection legs provide a powerful means for adapting the flight as best suited to the ongoing mission circumstances.

With parametric legs complex trajectories can be automatically generated from a reduced number of input parameters. If the actual values of these parameters change, the resulting trajectory will be dynamically recomputed. Eventually a complete enough library of different parametric legs will be available so that a wide range of missions can be performed. With the use of parametric legs two goals are achieved. First, complex trajectories can be generated with no need to specify a possibly quite long list of legs. Second, the UAS path can dynamically adapt to the mission requirements.

Analysis of the potential contingency situations and planning the correct reaction is a critical task to be carried out by any airplane to guarantee its safe operation. Pilot's reactions to any kind of incidences that may occur in-flight, like engine malfunctions, loss of electrical power, hydraulic failure, unexpected weather, etc; are critical and will determine the fate of the flight in case such contingency occurs.

## 5 In Flight Contingency Management

Contingency management relates to the capability of the system to monitor its health status, detect anomalies and react accordingly. During a pre-flight phase (also known as flight-dispatching) all reasons that may lead to a deviation from the expected UAS behavior are identified and assigned a pre-defined reaction. Once the UAS is in flight, its operation is continuously monitored to check whether its behavior is maintained within nominal status. If some deviation is detected a pre-defined reaction is triggered causing other USAL flight and mission services to modify its operation.

Contingencies can be grouped according to the four categories established by the USAL.

*Flight Contingencies* which may have an impact on the UAS ability to execute the flight plan. Some examples include the UAS performance not satisfying certain minimums, estimated flight time for completing the mission exceeding UAS autonomy or any malfunction in flight-critical subsystems. *Payload Contingencies* in case a given payload element fails some predefined actions may need to be taken. These category refers mainly to sensors and other hardware elements used for acquiring data. *Mission Contingencies* when a component belonging to the mission category, e.g. storage or data processing, fails and the system is unable to go back to normal operation. *Awareness Contingencies* when the required levels of situational awareness are not guaranteed.

Depending on the criticality of the contingency the response may consist in trying to fix the problem, perform the mission in degraded conditions or a partial or complete cancellation of the mission. The USAL introduces a contingency architecture (implemented by the Contingency Manager)[5], that is built by two components: the Health Monitor (HM) and the Contingency Intelligent Control (CIC). The HM gathers and processes the information needed to take a contingency decision. The CIC is in charge of deciding the proper response or set of responses for dealing with a particular contingency. The CIC classifies the contingency into three categories: Minor, Hazardous and Catastrophic.

Catastrophic Contingencies includes all contingencies which interrupt the UAS flight or a safety landing. In practice it means loss of the platform. For example: a structural defect in the fuselage, in the autopilot or a flight management failure. In order to respond to these contingencies, it is considered an emergency component aggregated to our architecture called *Flight Termination System* (FTS). This system will be triggered by the catastrophic category. The FTS commonly will be composed by parachute system [9]. The main objective is to guarantee that the potential impact to the ground of the UAS will not fatally damage any person or infrastructure.

Hazardous Contingencies includes all contingencies which reduce the aircraft airworthiness. This lack of airworthiness may put in danger the mission success or sometimes develop into catastrophic contingency. Also this category is composed by those contingencies which make impossible the mission objectives, as for example any failure in the payload needed for the mission. This component has different reactions in front of these contingencies.

*Go Home*: The UAS will be sent directly to its final destination and the mission will be aborted. *Go Home by Alternative Flight Plan*: The UAS will flight back home. If the emergency situation in critical enough, it may be needed an alternative path which description is composed by alternative paths; these paths are managed by the Flight Plan Manager. *Go Better Alternative Runway*: A UAS flight plan presents different landing possibilities. Due to its little size a lot of airfields may be suitable enough to ensure safety landings. This response is focused in finding the best alternative runway. *Go Closest Alternative Runway*: A landing site is needed as soon as possible in order to preserve the UAS platform. *Go to Flight Termination Field*: If the UAS cannot arrive to the closest runway, it must find somewhere to terminate the flight. The flight Plan Manager is the main service to implement hazardous contingency reactions.

The Minor Contingency category corresponds to anomalies or failures that interfere with normal mission execution without completely preventing it.

All flights require a single main flight plan, but additional emergency flight plans may be present to support the previously introduced contingency reaction scheme. The main difference between the main flight plan and emergency plans is that while the main plan includes the whole set of the aircraft's operations from take-off to landing, emergency plans only cover the finishing stages of a flight. The reason for not including all possible stages in an emergency plan is that they only get executed when something goes wrong during the mission, *i.e.* when the aircraft is already flying.

## 6 Conclusions and Future Work

This paper has reviewed a number of open issues that still limit the integration of UAS in non-segregated airspace. These limiting issues related to the fact that UAS operate as mission-oriented vehicles rather than point to point transportation. In order to address this factors, an UAS oriented architecture has been introduced. This architecture supports the development of mission-oriented flight-plans with embedded alternatives to manage departure and approach operations. The architecture also supports embedded contingency reactions so that the PiC can supervise semi-automatic reactions, or the UAS can automatically react as pre-planned in case the link between ground and air segment is lost. Future work will address the analysis of the automatic reaction to both tactical and strategic aerial conflicts, and how the mission-oriented flight path can be retaken after conflicts are resolved.

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