

Evaluating technologies and mechanisms for the automated/autonomous operation of UAS in non-segregated airspace

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Abstract—This paper focuses on several aspects of the UAS-ATM interaction that have not been previously addressed: separation assurance, contingency reaction and lost link procedures; as well as the evaluation of the trade-off between automated and autonomous UAS operations. These aspects will definitely determine the effectiveness of the UAS integration performing the aforementioned surveillance missions. Our research intends to investigate such relationships and how current ADS-B or future technology may support them. Beyond the conceptual perspective, a simulation environment is being developed to provide functional and quantitative measures to the study of the UAS-ATM interaction. UAS operations are modeled and reproduced in great detail through a wide set of real-time simulations. UAS behavior is being coupled with an ATC simulation environment that will allow to explore the UAS behavior to contingencies, conflicting traffic and ATC requests in real time.

I. INTRODUCTION

At present the majority of flights correspond to manned 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. Surveillance is the most common UAS mission, requiring flexible and dynamically changing flight plans directly executed by on-board flight management systems supervised by the UAS pilot. Nowadays there are general aviation manned aircraft performing this type of mission, but its operation is a minority and its always a man-directed process with little automation involved in it. UAS may exponentially increase this type of operations, placing a larger pressure into the ATM system.

Technology evolution in the field of UAS will affect ATM. 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 [1].

Once introduced, 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.

UAS will have to co-exist with both IFR and VFR traffic and follow the minimum performance criteria required by SESAR [2]. Hence, all this potential may be lost if the inherent risks of the UAS technology are not properly identified and addressed. To accommodate this, UAS operation will be affected to large extends by its interaction with ATCs and surrounding traffic; requiring immediate reactions by a pilot with limited situational awareness. Industry is currently investigating, designing and implementing the first family of sense-and-avoid systems [3]–[5]. Legally speaking, these systems will allow the rightful operation of UAS in non-segregated airspace, but almost no experience exists on how to comply with ATM requirements.

The separation provision and collision avoidance is hierarchically divided from the ATC to the pilot 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 - aircraft interaction must be addressed from a technological point of view, but also from an operational point of view.

Which and how are the flight intentions that UAS should provide to ATM actors? How and when these intentions will remain valid for 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? Can ADS-B be used as the basic surveillance mechanism? Human factors are also considered crucial here. How pilots will interact with the systems in order to react to these external events and how mission re-planning will be supervised by them?

Current autopilots only support re-planning capabilities oriented to point to point operations. Also, they don't support any of the UAS operational peculiarities (like their remote operation, performance differences, required valance between automation and autonomous operation in case of lost-link situations). However, it is clear that mission re-planning of surveillance UAS due to the integration in the non-segregated airspace will require lots of automated or even autonomous

support for the UAS pilot if a timely and safe response by him is expected.

This paper reviews research currently underway, supported by the European Organization for the Safety of Air Navigation (EUROCONTROL) under its CARE INO III programme, to create an environment in which the interaction between a mission-oriented UAS and the overall ATM system can be fully, or at least, partially understood, quantified and evaluated. The UAS-ATM interaction being explored aims at:

- Understanding UAS as mission-oriented airspace users that will exploit automation and become autonomous at times.
- Focus on separation assurance rather than on conflict avoidance, although both phenomena will be considered.
- Formalize the interaction between UAS and ATM actors within nominal operations but also for separation assurance, in-flight contingency reactions and lost link situations.
- Study approach, depart and mission operations, in addition to en-route point to point.
- Consider an active role of the PiC under a highly automated environment designed to support him. However, a number of fully autonomous UAS operations will be also explored to support critical contingencies and lost-link situations.

The rest of this paper is organized as follows. Section II will justify the fact that UAS are mission-oriented vehicles that operate under different objectives when compared to traditional point to point aviation. Section III introduces a coherent contingency reaction model designed to integrate all types of in-flight emergencies, even in case of lost-link. Aspects related to trajectory uncertainty when reacting to contingencies are also discussed. Section IV outlines current investigations related to the UAS operation under loss of separation with conflicting traffic and the tools that the UAS pilot needs to respond to these situations. The simulation environment in which UAS operation and surrounding traffic are being evaluated is introduced in Section V. Finally, Section VI concludes the paper.

II. MISSION ORIENTED UAS OPERATION

The goal of UAS is to substitute manned aircraft in a number of aerial work scenarios [6]. 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. In addition to safety, the main objective of the UAS pilot 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 pilot 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 pilot can manage the contradictory objectives of its operation.

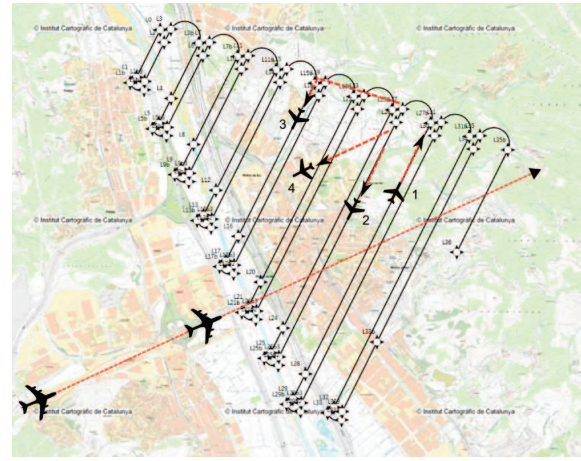


Fig. 1. Particularities of UAS surveillance operations when confronted to conflicting traffic.

Future UAS flight management systems may include the selection of alternative trajectories to implement departure and approach operations, the selection of specific routes to reach mission areas, and obviously the support to perform its surveillance duties. Contingency reaction is also one of the main factors that need to be addressed. In case of any type of contingency, related to the airworthiness of the UAS or due to a separation conflict, an immediate reaction is mandatory in order to avoid aggravating the situation. Moreover, autonomous reactions will be required in case an airworthiness contingency is combined with a lost-link.

Separation conflicts need also to be considered. Standard reactions will drive an airplane to separate from their intended trajectory, to retake it after the conflict has been cleared. UAS introduce new variables like the extreme difference in performance between them and the intruders, and the requirement for autonomous separation in case of lost-link. On top of this, UAS mission requirements will also be greatly perturbed by this type of separation maneuver originally designed for point to point aircraft. Figure 1 shows a paradigmatic scenario. UAS will mostly perform scanning operations that, in case of security missions (due to disasters, fire, etc) in areas where airspace segregation is not an option. In this example, a UAS may be flying away from another flight (1), but all the sudden turns around and induces an unexpected conflict due to the scanning pattern (2). Instead of being diverted to some undesired location (4) the UAS pilot may suggest the ATC to skip a number of scan lines (3), rather than just canceling the whole operation.

Nowadays little experience exists on UAS operation under the aforementioned situations. Recently, UAS have been employed as wildfire monitoring assets [7]. For the first time, during the October 2007 California fires a UAS participated in real-time wildfire surveillance activities. NASA's Ikhana UAS (a General Atomics Predator B) flew over the major Southern California wildfires. Ikhana flew a number of missions over several of the major Southern California wildfires from 24 October until 28 October 2007, capturing thermal-infrared

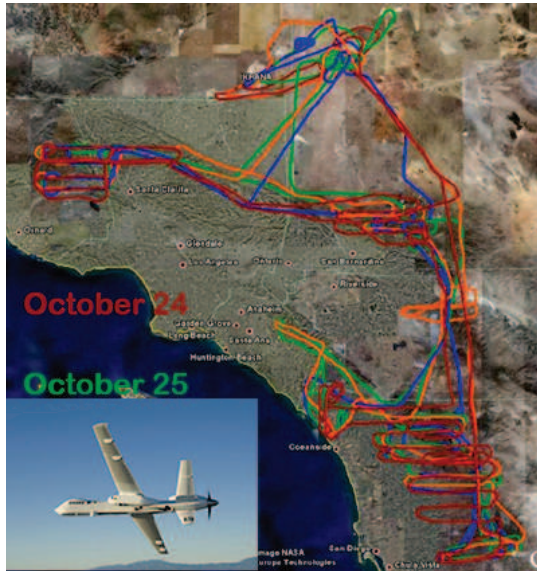


Fig. 2. Flight paths flown by NASA's Ikhana UAS over California's fire storm in year 2007.

imagery to aid fire fighters. Figure 2 depicts the complexity of the trajectories flown by the UAS –although all of them fully pre-planned to the dismay of the fire fighters that were requesting higher flexibility to cope with the fire evolution. Ikhana has repeated the same type of operation and thus has become a referent onto which experiences have to be extracted.

In order to reproduce this type of mission, previous work has introduced USAL [8], as a pre-designed architecture covering most critical aspects of UAS operation following well-established concepts of operation and self-limiting users modifications. USAL comprises a wide range of components, which are classified in four categories: Flight, Mission, Payload and Awareness. By providing pre-designed systems for these categories, users effort to implement the desired UAS application is reduced. To avoid offering a rigid architecture, the operation of most relevant USAL components is highly parameterizable to provide a reasonable level of flexibility and reconfiguration, but at the same time simplicity. USAL is being coordinated with ATM simulation environments to explore UAS operation in non-segregated airspace.

III. AN INTEGRATED CONTINGENCY MANAGEMENT

In order to guarantee the safe operation of a UAS the vehicle has to be verified to be airworthy at dispatching time. But in addition to flight dispatching for nominal conditions, planning for contingencies is also required. 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, loss of communications, subsystem malfunction, etc; are critical and will determine the fate of the flight in case such contingency occurs.

A. Categorizing UAS contingencies

Contingency reactions in manned aviation are mainly driven by the airplane manufacturer, with pre-analyzed contingency scenarios covered in the airplane documentation. Aircraft crew are trained to react to such conditions. Also, regulations define the way flight plans should be prepared and landing alternatives selected depending the type of airplane, flight and contingency.

However, managing contingencies on a UAS is a much more complex problem basically due to three reasons:

- Highly reduced situational awareness that the pilot in command should face preventing him to make the right decisions.
- The automated and complex nature of the vehicle may prevent a direct and immediate operation by the pilot on it. Natural pilot tendency will be to take manual control, which is prone to accident.
- Remote operation adds additional communication latency and the always present lost-link problem.

It is well known from the short history of UAS accidents that many of them are directly imputable to pilot errors when trying to manage an unexpected contingency without an adequate situation awareness. Moreover, new types of contingencies emerge from the specific nature of an UAS. In particular the loss of the command and control link, and the failure of the systems that should guarantee a safe integration in the airspace like TCAS or ADS-B subsystems.

In our research we introduce an structured approach to automate contingency reactions in UAS, keeping the pilot in the loop decision when possible; but relaying into an autonomous reaction when necessary [9]. Our objective is to classify the contingency sources and, up to a certain level, abstract their impact on the system operation. In this way, almost all system reactions to contingencies can be pre-planned. Then, if the contingency occurs, the required reaction can take place, producing a highly predictable reaction scheme and well determined trajectory, even in the case of lost-link.

Contingencies can be related to five aspects of the UAS operation: the flight, communications, the mission, the payload, and the airspace integration systems. According to the level of severity, the contingency reaction may involve a restricted cancellation of some parts of the UAS mission; up to a total mission cancellation with different levels of emergency returns to base. Following this structured scheme, the response to the contingency can be selected from a predefined but limited catalog of automated reactions that may reconfigure the UAS operation in all aspects.

In order to detect and react to on-board contingencies, some form of *Contingency Manager* (CM) should monitor the state of the UAS, and alert the pilot about contingency situations related to the specified areas:

- **Flight Contingencies:** Such as when the expected performance of the UAS does not satisfy certain minimums, power sources do not provide the required levels of electrical energy or fuel consumption does not behave

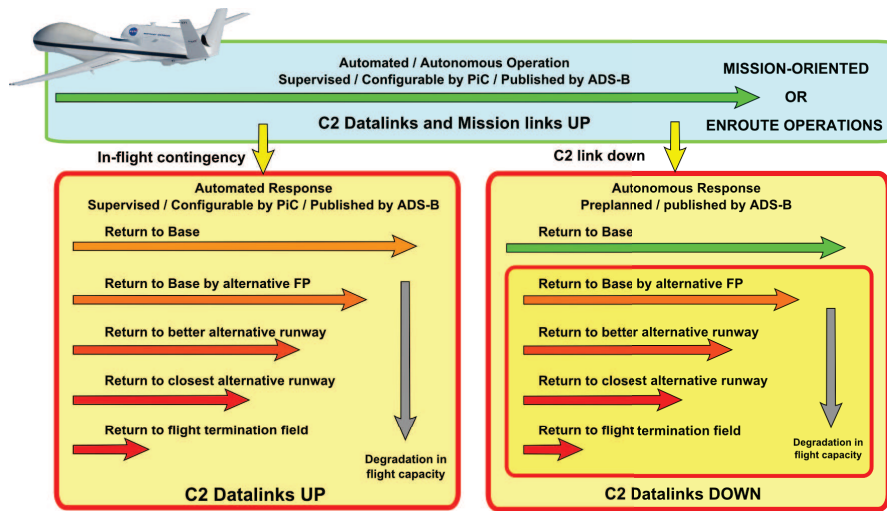


Fig. 3. The pre-planned reaction concept: alternative flight plans are employed according to the severity level of the contingency. The model is homogeneous for flight contingencies, but also for lost-link situations and other types of contingencies.

as expected. Flight contingencies may certainly reduce the capacity of the UAS to fly, thus requiring the early landing of the vehicle or even its flight termination. Remaining flight capability should be quantified either in flight time or distance.

- **Payload Contingencies:** If a given payload element fails, certain predefined actions need to be taken. If the payload element is critical for the mission, it is canceled or its objectives are reduced. If the contingency only partially affects the operation, the degraded conditions are annotated for further failures.
- **Mission Contingencies:** If the expected mission results are not achieved due to any unexpected situation, the mission objectives may be reduced or totally canceled. Neither mission or payload contingencies affect the airworthiness of the UAS, but they may induce a mission cancellation and therefore an early return to base.
- **Communication Contingencies:** Failure of the command and control link between the pilot and the UAS is considered one of the open problems that UAS must resolve before they access non-segregated airspace. Lost link may affect the UAS at many levels:
 - 1) A complete loss of both LOS and BLOS links.
 - 2) A loss of the BLOS link, but keeping the expectancy that the LOS link will remain operative once the UAS gets back in range.
 - 3) A loss of the LOS link while the BLOS link is operative, which means that control will be lost once getting close to the landing site.
- **Airspace Integration:** Failure of the systems that facilitate the safe integration of the UAS may also require specific reactions according to the level of criticality.
 - 1) Total loss of the ADS-B In/Out and even the transponder may render the UAS completely invisible to the surrounding traffic and surveillance

systems (except primary radars).

- 2) Loss of the ADS-B In systems will limit the capability of the UAS to autonomously detect and avoid conflicting traffic. The pilot may retain traffic information through ground services.
- 3) Loss of the transponder which renders the UAS invisible apart from the primary surveillance systems, or ground information relayed by the UAS pilot.
- 4) Loss of sense-and-avoid systems that limit the UAS capability to fly in VFR conditions

B. Pre-planned contingency reactions

Assuming the existence of a UAS *Health Monitor*, the CM will implement the contingency decision core. The CM evaluates all UAS pre-processed reaction options versus the actual state of the UAS and generates the pre-planned response so that the pilot can evaluate it, and eventually commit to it. If no response is received, or the contingency relates to a lost-link situation, the CM may immediately proceed to apply the reaction autonomously.

The CM classifies all contingencies in three categories: minor, hazardous and catastrophic; each category with different preplanned responses:

- The most important and restrictive category is the *catastrophic contingency*. The system enters in this state when the UAS cannot be safely recovered. So, we have to immediately terminate the flight but the same time ensure the safety. The CM will activate the Flight Termination System (FTS) [10]. In general, only really critical flight contingencies may lead to a catastrophic contingency. It is up to the dispatching phase to decide whether a lost link situation, or some other contingency can also be categorized as critical.
- *Hazardous contingencies* directly refers to situations in which the normal development of the UAS flight is at risk and the mission needs to be canceled. A timely

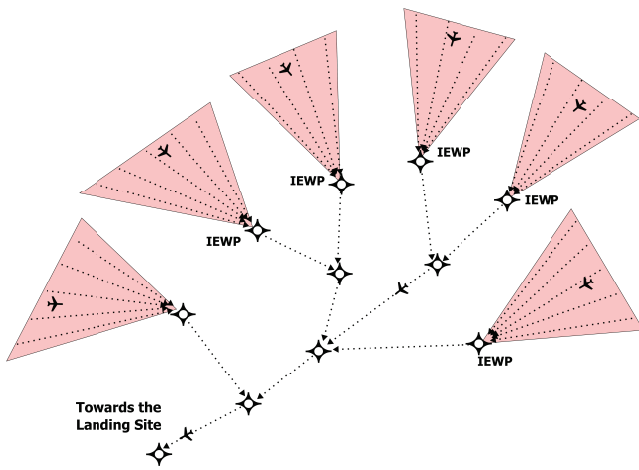


Fig. 4. Multiple initial WP allow reusing the same contingency flight plan and can be designed at convenience.

contingency reaction with the pre-determined operation decreases pilot workload and eventually save the UAS.

- *Minor contingencies* treat any anomaly or failure from which the UAS can be recovered. Generally speaking we refer to payload or mission related contingencies that do not affect the safety of the UAS flight.

1) *Hazardous Contingencies*: This category manages all contingencies which reduce the aircraft airworthiness or reduces its potential flight endurance. This lack of airworthiness immediately forces a mission cancellation and a timely reaction in order to avoid developing into a catastrophic contingency. The proper reaction to a hazardous contingency directly depends on its severity and therefore we propose to employ a increasingly radical set of alternatives that may match the contingency level. The reaction to hazardous contingencies is classified using the following levels:

- *Return to Base (RTB)*: In this response the UAS will be sent directly to its final destination and the mission will be aborted. The UAS damage is important enough and makes impossible the normal mission development.
- *Return to Base by Alternative Flight Plan (RTBAFP)*: In the dispatching phase, it is defined the flight plan to come back home. If the emergency situation is critical enough, it may be needed an alternative path to go back home. For example, the weather conditions have changed and the UAS airworthiness is in danger.
- *Return to an Alternative Runway (RAR)*: 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. The parameter in order to classify a runway as good can be the air traffic, number of runways, state of the airfield, etc.
- *Return to Closest Alternative Runway (RCAR)*: When the contingency is very restrictive, it is needed landing as soon as possible in order to preserve the UAS platform. This response is addresses to this type of contingencies.

- *Return to Flight Termination Field (RFTF)*: If the UAS cannot arrive to the closest runway, the UAS must find somewhere to terminate the flight. This place must guarantee that the potential impact to the ground of the UAS will not fatally damage any person or infrastructure [10].

Figure 3 outlines the pre-planned reaction concept. From its nominal mission-oriented flight plan, the UAS will select a sequence of contingency flight plans that fit given the level of degradation of the platform. This scheme properly fits within the lost link scenario, in which the UAS flight capability is not inherently degraded. In case a lost-link is couple with an airworthiness contingency that degrades flight capacity, the reaction sequence remain valid even though it must be executed autonomously by the flight management system. More complex failure scenarios (flight, communications and ADS-B at the same time) will require to define precedence relations that are currently being investigated.

Thus, contingency planning requires that for each flight plan segment, the best alternative landing sites to be identified. Approaching routes to each alternative field are pre-defined at dispatching time, and therefore the flight manager only needs to find a suitable *track* that identifies the closest initial approach point to the selected return route. Additionally, flight termination zones need to be identified. Usually, the closest termination zone will be chosen in case a catastrophic contingency develops. Obviously, the contingency approach procedures will strongly depend on the characteristics of each specific airport and need to be properly designed beforehand. Multiple strategies may exist depending on the level of desired automation or flexibility; e.g. the approach to that airport can be centralized in a single way point, and then the UAS be driven to the appropriate runway according to ATC decisions. The flight plan may contain a number of holding areas and decisions points as necessary. In case of executing a lost-link contingency procedure, a predefined number of holding iterations and branch decisions must be agreed and predefined into the flight plan so that it can be autonomously operated with a minimum level of uncertainty.

C. Uncertainty levels during contingency reactions

1) *Contingency flight plans*: Defining a contingency flight plan for each possible location of an aerial vehicle is totally unfeasible as its number will be infinite. The only reasonable solution is to define a discrete number of well defined contingency flight plans (that may be tailored to the different levels of criticality). Each one of these flight plans will offer a number of strategically located *initial way points*, with trajectories that converge to a main contingency route. We call this strategy the *funnel entry concept*. Figure 4 depicts a potential example of the funneling strategy. A large collection of initial waypoints exists, but all the resulting trajectories eventually converge into a single one, that will drive the UAS to the desired airfield or termination point. Trajectories have been agreed between the UAS operator and the ATM authorities beforehand. The pilot or the UAS (if an autonomous maneuver is necessary due to a lost link scenario) will turn into the

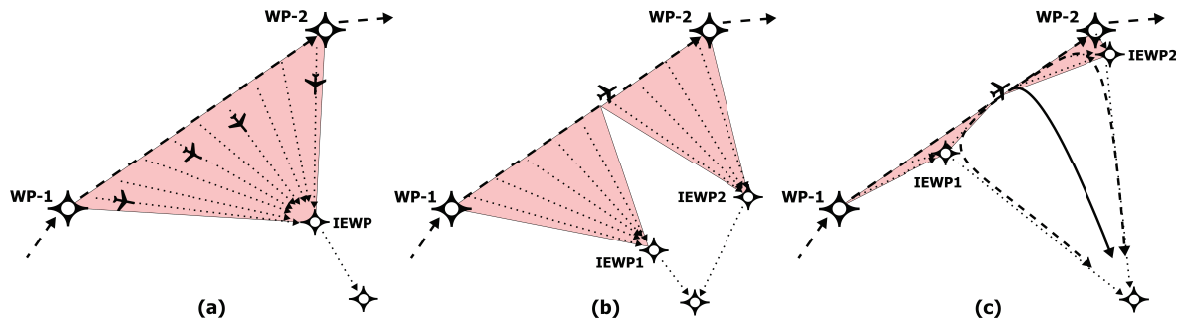


Fig. 5. Pre-planned reactions to contingencies may produce a trade-off between uncertainty and efficiency of the response.

appropriate initial waypoint, and from there adhere to the designed trajectory.

Funneling the UAS into the contingency flight plan reduces the design complexity, but on the other side introduces a level of uncertainty that has to be carefully considered during the flight plan design. Figure 5 depicts a number of scenarios to justify this assertion. Figure 5(a) shows that, once a contingency flight plan is activated, the UAS should turn to intersect the designed initial waypoint. However, given that the initial point is the same one for the whole length of a leg, there is a cone of uncertainty with respect the actual trajectory that the UAS will follow from the original flight plan. The actual trajectory will be determined by the location in which the contingency is detected and the associate reaction time.

Figure 5(b) shows that if more than one initial waypoint is assigned to the same leg, the cone of uncertainty is reduced, and the UAS may take the initial point that is closer to its actual position. If uncertainty has to be reduced to a minimum (as probably ATM authorities would like), one or more initial points can be located directly on top of the flight plan legs (see Figure 5(c)). However, this strategy has two negative effects: (1) reduces the flexibility of the scheme, as the same initial waypoint cannot be shared among multiple legs; and (2) the resulting trajectory may be longer than strictly necessary, and therefore can endanger the survivability of the UAS if the contingency is related to the UAS inherent airworthiness. Figure 5(c) shows that committing to any of the initial waypoints defined for that leg forces the UAS to follow a wider trajectory than strictly necessary.

This trade-off between uncertainty and efficiency of the contingency route not only depends on the placement of the initial waypoints, but also on the whole trajectory. If we explore in detail Figure (b) we can see that if the UAS in the figure takes a direct route to the closest initial waypoint (IEWP2), it will end up performing a longer trajectory than by taking IEWP1. Even though IEWP2 seems to be closer, the distance from the initial waypoints to the closest common waypoint is longer from IEWP2 than from IEWP1.

Figure 6 shows a complex contingency example current under evaluation. A mission oriented flight plan requires an extensive scan operation and its corresponding set of contingency reactions. In case of lost-link, one possible conservative strategy to be employed may extend the UAS trajectory along

the scan tracks to the initial contingency waypoints. Then all possible initial waypoints are funneled into an eastbound and west-bound trajectories, that eventually converge into the selected airfield. This strategy clearly extends the flight time under the lost-link condition, but limits to a minimum the amount of uncertainty. More direct strategies will result in unacceptable levels of uncertainty for the ATC.

2) *Flight time estimation*: Under this strategy, flight time estimation becomes crucial for two reasons. Firstly, it is mandatory to adjust the remaining fly capability in the UAS (due to its potentially degraded performance), to the estimated time that each contingency flight plan may require. If the UAS is not capable to complete the initially selected contingency flight plan, the pilot or the systems itself may have to revert to another plan better suited to the UAS capabilities. In the worst case it may need to commit itself to a flight termination procedure if no airfield can be reached within its remaining flight time. Secondly, in case of separation conflicts or a lost-link situation, having an accurate estimate of the UAS performance is crucial to predict its position and provide a better confidence on its operation.

A continuous update of the flight time estimation will maintain the uncertainty levels low, thus improving the quality of the decisions taken in case of contingencies. However, it will be necessary to evaluate the potential degradation of these predictions under the absence of new sources of information.

IV. AUTOMATING UAS SEPARATION ASSURANCE

Figure 7 summarizes the different mechanisms that are present in civil aviation aiming at minimizing the probability of collision with other aircraft. The two inner layers include the sense mechanisms and avoidance maneuvers that may prevent the aircraft from an imminent collision in case the minimum separation has been lost for any reason. Conversely, the outer three layers are devoted to ensure these minimum separations. Each layer is summarized as follows:

- **Non-cooperative collision avoidance** is the lowest level mechanism to prevent an imminent collision with aircraft, obstacles or terrain. In manned aviation, this relies entirely on the ability to *see and avoid*. Yet, the equivalent *sense and avoid* (S&A), for UAS, is one of the main issues that must be addressed before integrating them into civil airspace. Solutions can range from human

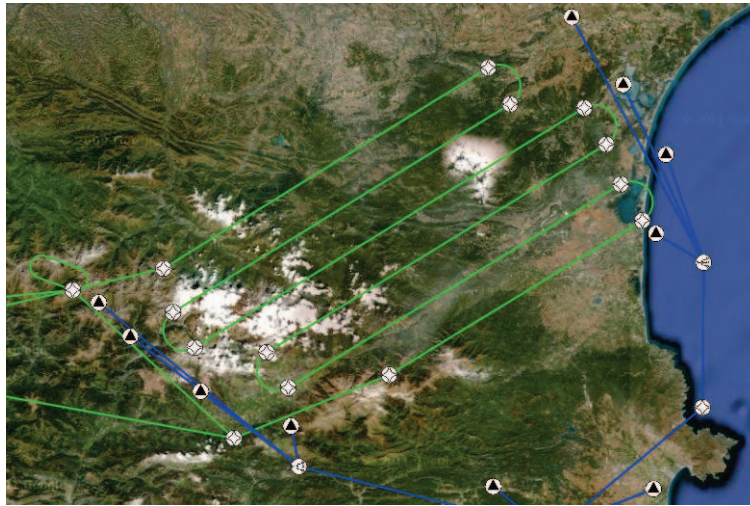


Fig. 6. Evaluation scenario of a mission-oriented flight plan and a minimum uncertainty contingency flight plan.

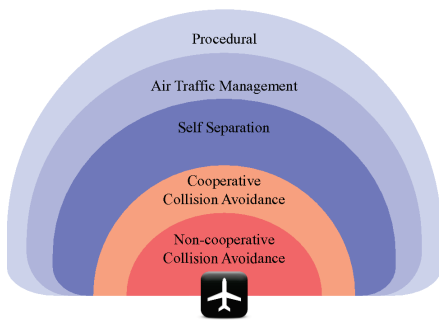


Fig. 7. Separation and collision avoidance mechanisms

observers, vision based on-board systems or radars, or ad-hoc ground surveillance radars as proposed in [13].

- **Cooperative collision avoidance** mechanisms form the following collision avoidance layer and contain all these systems and procedures between cooperative aircraft that can avoid imminent collisions. The well known Traffic Collision Avoidance System (TCAS), mandatory in manned aviation for certain type of aircraft, belongs to this category.
- **Self separation** is the lowest layer that can guarantee a minimum safe separation. See/sense and avoid systems play again an important role, which can be enhanced with different kinds of Airborne Separation Assistance Systems (ASAS), based for instance with Automatic Dependent Surveillance (ADS) applications.
- **Air traffic management (ATM)**, which includes air traffic services (ATS) and air traffic control (ATC), adds a very significant extra layer of protection, but very variable in function of the type of airspace.
- **Operational procedures** are the outermost layer in assuring separation with other aircraft (along with known obstacles and terrain). Here, we find not only navigation procedures but also aircraft operating procedures.

A. Characterizing UAS operations

Current UAS efforts have been greatly focused on the *sense and avoid* technology that should support collision avoidance for both cooperative and non-cooperative traffic. However, nowadays a loss of separation is considered an extremely dangerous situation that has to be avoided at any cost. Very little research exists, to the best of our knowledge, in that area.

Given the peculiar nature of the missions carried out by UAS, it is not reasonable to simply consider them as unmanned versions of traditional manned aviation. Clearly, UAS will follow similar routes as point-to-point commercial traffic, but only up to a certain extend. Beyond that, UAS will require operating outside traditional airways, or even intermixed in busy airways when their mission provides a benefit to the society that extends beyond the negative impact they may pose to commercial traffic. If we recall the example in Figure 1, it may be the case that a surveillance UAS needs to perform a critical surveillance operation close to or intermixed to an area in which dense commercial traffic exists.

UAS differ from manned point to point aircrafts due to a number of reasons that need to be understood, characterized and analyzed to evaluate their impact to the surrounding traffic:

- 1) UAS are aerial-work mission-oriented platforms; and therefore their operation cannot be easily confined to airways or airspace classes as point to point traffic.
- 2) UAS performance and dimensions greatly differs from other type of vehicles that may operate in the same airspace as UAS would like to do.
- 3) Pilot situational awareness is reduced compared to classical pilots and therefore longer reaction times should be expected in response to ATC requests, contingencies or other situations.
- 4) Given their long-endurance surveillance missions, UAS may prefer to grant preference to other traffic using separation maneuvers.

The goal of this research is to identify which operational

procedures should be employed by UAS pilots and evaluate systems that support and automate the operations and reduce the pilot workload. However, clearly different scenarios will be considered according to the phase of the operation in which the vehicle is involved.

For this study we are considering two large UAS that currently have been operated in scientific surveillance missions: NASA's *Global Hawk* and the *Ikhana Reaper*. Both vehicles have been partially integrated in the NAS and are relevant examples of two UAS classes that will provide great benefits if their operation could be integrated in European airspace. The classical Airbus A320 will be considered as intruder to establish comparisons.

B. En-route UAS operations

UAS flight to or returning from their mission area will probably follow the same routes that point to point manned traffic. Under this assumption, reactions to guarantee separation assurance either instructed by the ATC or by self-separation maneuvers may be similar to those employed by manned aircraft. However, performance differences should be taken into account in order to determine the particular flight envelope in which separation maneuvers need to be executed in order to be effective. Moreover, the separation maneuvers themselves may need to be more radical due to the UAS limited response capability (specially in terms of speed and vertical profile), and their higher sensibility to wind factor and/or wake vortex produced by conflicting aircraft.

Classical separation schemes [14] will be required to cope with this scenario, but additional factors need to be taken into account:

- Aircraft performance in general, but in the vertical profile specially, is extremely poor for UAS. That means that not only reaction times will be longer due to the remote nature of the situation, but separation distances will be longer to achieve.
- UAS being overtaken by faster traffic is a quite probable scenario that requires a decision with respect right of way. UAS may actively support that separation to avoid negative impacts to airspace capacity.

Figure 8 shows the classical separation scenario in which a UAS maneuvers to maintain separation to both facing or chasing traffic. Depending on intersection angles and speeds the UAS maneuver needs to be more radical if a 3/5 NM separation needs to be achieved. Current research activity focuses on angles, timing and turning parameters in order to support both automated and autonomous versions of the maneuver to be embedded in the flight management system. Flight plan reinsertion is also an open issue, given that original waypoints may need to be skipped due to the maneuver (as seen in Figure 8).

C. Mission UAS operations

Maintaining separation with conflicting aircrafts when the UAS is performing its mission phase adds a new dimension to the problem. Most times UAS will perform repeated scanning

patterns, and therefore standard separation maneuvers may have a strong negative impact in the efficiency of the operation. Our research sustains that detecting separation conflicts quite in advance will permit the UAS pilot to suggest separation maneuvers to its advantage. New types of separation reactions are being evaluated, including non-orthodox maneuvers that include:

- Scan track re-start from both an early position or even the initial waypoint (see Figure 9).
- Perform hold operations to gain separation time.
- Skipping scanning tracks in a non-consecutive scheme according to the dynamics of the separation conflicts.
- Extend scanning tracks beyond mission requirements to gain separation time between tracks.

Automating the maneuver selection and exact parameterization so that the UAS pilot can react properly remains to be investigated. Note, however, that this type of separation maneuver will be only employed when the UAS pilot is under command, but never under a lost-link situation (as mission should be canceled in that case).

Figure 10 shows the HMI interface designed to support the separation maneuver selection in our simulation environment. The pilot can preview two different maneuvers at the same time and update their parameters in real time. Once a maneuver is selected it must be committed so that the UAS flights it and later returns to the nominal flight plan. The image in the left hand corner shows the resulting trajectory as seen in the X-Plane simulator. Although not seen in the image, the interface offers information about the conflicting traffic, the area in which the intrusion will occur given the intentions of both aircraft, and predictions of the committed separation maneuver.

1) *The role of ADS-B:* ADS-B [11], [12] may be the perfect mechanism to alleviate the uncertainty problems when operating a UAS. Our research intends to offer a continuously updated flight intent to the ATM system, and to the surrounding traffic. ADS-B can be employed as a surveillance mechanism that could permit an active role of the UAS when maintaining separation with conflicting traffic. ADS-B can be also used to provide a much deeper understanding of the state and immediate intentions of the UAS; thus reducing the negative impact any in-flight emergency or a lost-link scenario. In that case, the UAS will need to perform autonomously through the predefined contingency reactions agreed with the ATM system. But the UAS should not be invisible to the system. Intentions and state could be continuously updated through ADS-B. Even if during a lost-link situation a flight contingency develops, which shortens the UAS flight time, any autonomous decision taken by the UAS will be known to the pilot and to the ATC. Additional research is currently underway to evaluate if the amount of information provided by ADS-B is sufficient for the ATC to properly manage either the contingency or a separation maneuver.

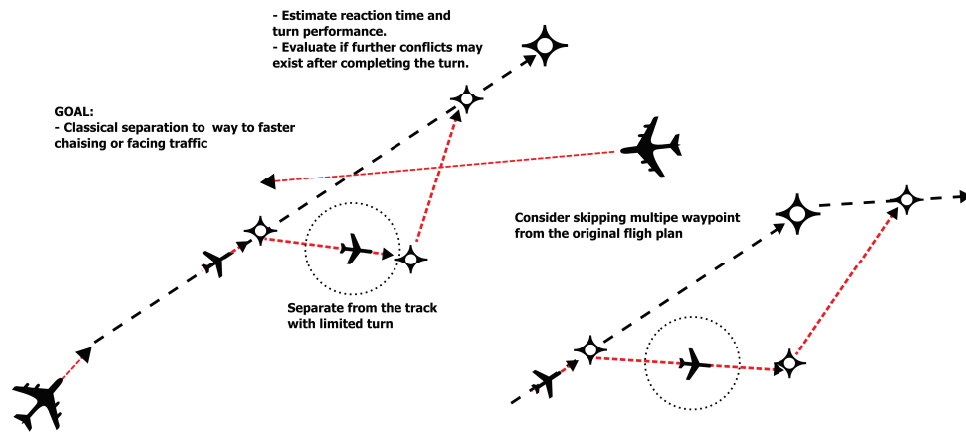


Fig. 8. Separation scenario in which a UAS maneuvers to maintain separation to both facing or chasing traffic

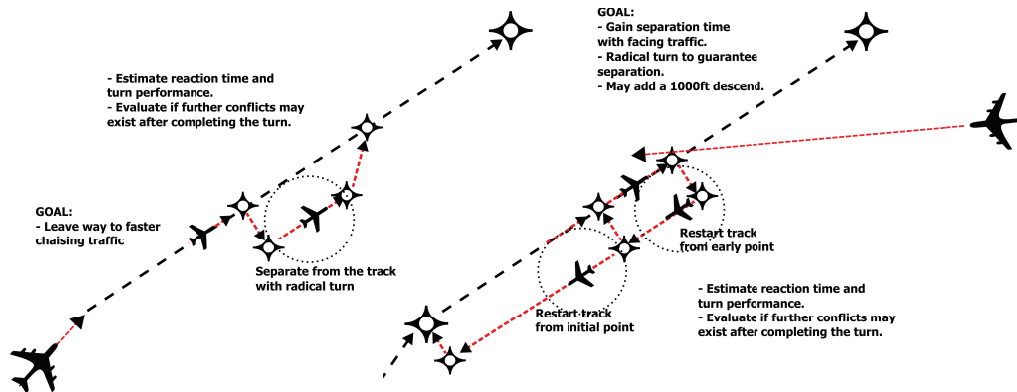


Fig. 9. Non-orthodox scan track re-start from both an early position or even the initial waypoint.

V. A UAS-ATM SIMULATION ENVIRONMENT

In order to evaluate the dynamic behavior of UAS and support UAS-ATC interaction, this research will complete the integration of the USAL architecture (UAS System Abstraction Layer) with eDEP (Early Demonstration and Evaluation Platform). USAL provides support to simulate most types of remote sensing UAS missions. USAL supports: Flight Services to simulate the UAS flight; Mission Services to simulate the actual UAS mission; Awareness Services to simulate the airspace integration, and Payload Services to simulate sensors.

eDEP is a low-cost, lightweight, web-enabled ATC simulator platform, offering an environment for rapid prototyping applications. eDEP includes the core platform functions for airspace management, flight plan preparation, flight management, trajectory prediction, coordination services and flight path monitoring, and provides an EATMP compliant controller working position (CWP), and a graphical pilot working position (PWP); etc.

Operational simulations will be conducted by employing traffic available from Eurocontrol and the most realistic UAS models available to us, including a NASA's Reaper and Global Hack platforms. These simulations will be conducted by interacting with the X-Plane simulation environment. Completion of the USAL eDEP X-Plane integration is currently well underway supported by Eurocontrol.

UAS ATC integration will be implemented initially through ADS-B. Both the USAL architecture and the eDEP simulator will interchange ADS-B messages. Messages interchanged by eDEP and USAL follow the Asterix formalism within category 021. Message 021/110, trajectory intent will be crucial to evaluate separation conflicts (Figure 11 depicts some initial results), contingency/lost link scenarios, and is currently being implemented. USAL generated telemetry and the intentions that will translated into the corresponding ADS-B messages, therefore capturing the dynamic behavior of the UAS in a realistic way. Overall, the UAS will behave as other vehicles inside eDEP and in this environment separation conflicts could be evaluated. From the ATC point of it messages could be relayed to the UAS requiring updates in its route.

VI. CONCLUSIONS AND FUTURE WORK

This paper has reviewed open issues that still limit the integration of UAS in non-segregated airspace. These issues relate to the fact that UAS operate as mission-oriented vehicles rather than point to point transportation, and the necessity to trade-off between automated and autonomous operations.

In order to address these factors, an UAS oriented simulation environment is being developed. The system supports mission-oriented UAS operations combined with an ATC simulation environment. The system supports embedded contingency reactions so that the pilot can supervise semi-automatic

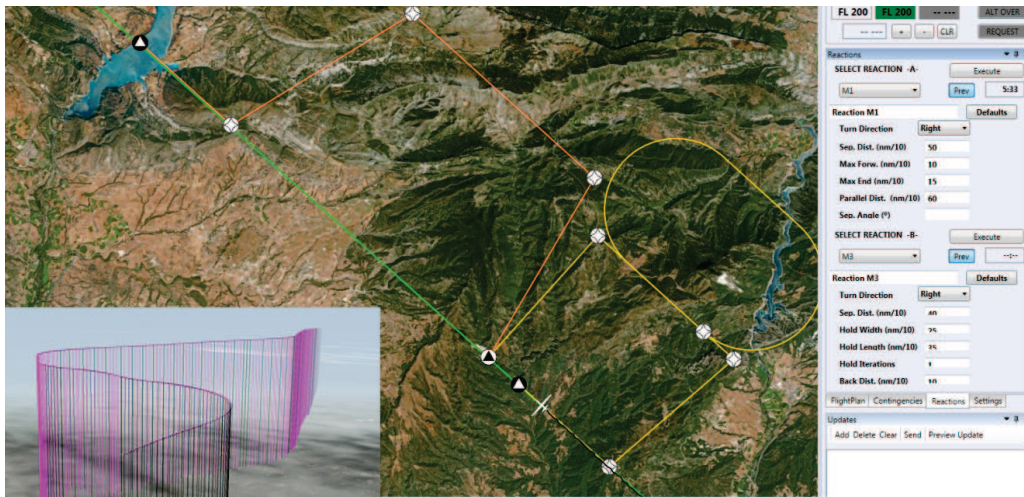


Fig. 10. HMI interface for the UAS pilot to select between separation maneuvers (trajectory example show in the left corner).

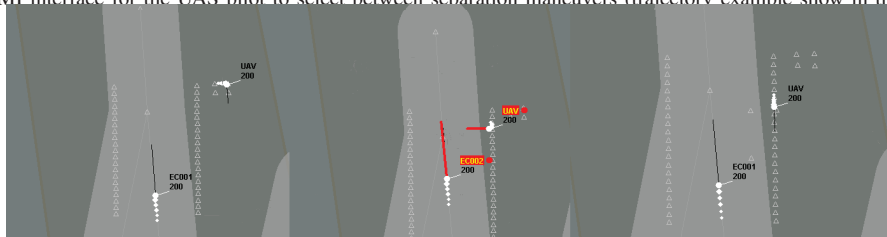


Fig. 11. Preliminary examples of the eDEP simulator integrated with the USAL UAS real-time simulator.

reactions, or the UAS can automatically react as pre-planned in case the air-ground link is lost. Current work addresses the analysis of the automatic reaction to both tactical and strategic conflicts, and how the UAS mission-oriented flight plan can be retaken after conflicts are resolved.

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