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Depart and Approach Procedures for UAS in a VFR Environment

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ABSTRACT

This paper assesses the depart and approach operations of Unmanned Aircraft Systems (UAS) in one of the most challenging scenarios: when flying under Visual Flight Rules (VFR). Inspired by some existing procedures for (manned) general aviation, some automatic and predefined procedures for UAS are proposed. Hence, standardized paths to specific waypoints close to the airport are defined for depart operations, just before starting the navigation phase. Conversely, and for the approach maneuvers, it is foreseen a first integration into a holding pattern near the landing runway (ideally above it) followed by a standard VFR airfield traffic pattern. This paper discusses the advantages of these operations which aim at minimizing possible conflicts with other existing aircraft while reducing the Pilot-in-Command workload. Finally, some preliminary simulations are shown where these procedures have been successfully tested with simulated surrounding traffic.

Categories and Subject Descriptors

J.2 [**Physical Sciences and Engineering**]: *Aerospace.*

General Terms

Performance, Reliability, Experimentation.

Keywords

UAS, landing take-off operations, automation.

1. INTRODUCTION

This paper deals with airfield operations of Unmanned Aircraft Systems (UAS), imagining a civil scenario where manned aircraft will coexist with Unmanned Aircrafts. Nowadays, UAS are mainly designed for military missions and very few civil applications have been developed so far. One of the principal reasons for the absence of civil UAS is the lack of a regulation basis concerning their certification, airworthiness and operations. Nowadays, the few existing civil UAS use special airfields away from populated areas and closed to other traffic (see for instance [2,3]). However, if extensive and commercial UAS applications might be a reality in the future, airfields for UAS operations should be chosen prioritizing as much as possible the mission

requirements. This means that in most of the cases UAS operations will have to coexist with other manned operations in the same airfield.

From an end-user point of view, the operation of a UAS is similar to the operation of a manned aircraft in IFR (Instrumental Flight Rules) conditions [1]. In general, the UAS operator will not use external visual references in order to aviate and navigate the UAS, since it is expected that UAS will be equipped with autopilots and flight planning capabilities. However, even if a UAS may be fully capable to fly under IFR rules, an extra functionality is needed if the UAS operations are performed in an airport with no IFR procedures published. In fact, it is quite probable that initial UAS operations in civil airspace will be conducted in small airports instead of in busy ones. Hence, it is also quite probable that in such airports no IFR operations will be published. Moreover, in these airports the majority of traffic will be general aviation aircraft, which in general are less equipped as commercial airliners with respect to sensors and automated systems. Therefore, in order to minimize the risk of mid-air collisions, it is needed to add an extra safety layer by introducing procedures that are predictable and well known by all the users [4].

In this work, among all separation and collision avoidance mechanisms, we focus only on the procedural layer by assessing UAS depart and approach procedures in one of the most challenging environments: airfields with no IFR procedures published. Thus, some specific procedures are proposed in order to safely operate UAS, while minimizing at the same time the interference with other traffic. Section 3 presents a set of proposed departure procedures for UAS evolving in VFR environments, while Section 4 presents approach operations. Contingency reactions are outlined in Section 5. Finally, Section 6 shows some preliminary flight simulations implemented in a specific UAS architecture.

2. UAS OPERATIONS IN VFR ENVIRONMENT

VFR operations are based on visual cues that the pilot takes from outside the cockpit, representing a big challenge when performed by UAS. Several research efforts are devoted to develop sense and avoid (S&A) systems aiming at fulfill the future safety requirements for such UAS operations (see for instance [14-20]). On the other hand, new self-separation applications are also foreseen, by using for example Automatic Dependent Surveillance (ADS) equipment, data-link communications and information sharing networks, among others [21]. Besides specific S&A and separation systems, the use of standardized and predictable

procedures for the UAS would be a complementary safety layer, which would eventually decrease the complexity of these systems and their certification process (see Figure 1).

These procedures are described in this section and are conceived for a wide range of UAS, regardless of their actual S&A and separation systems. In fact, they aim at minimizing the interference with surrounding traffic and also the Pilot in Command (PiC) workload, which will be connected with the UAS by using some kind of data-link communications. As mentioned earlier, the mid-air collision risk is reduced if procedures are clearly defined, and their use is even more important around airports because a greater risk of mid-air collision exist [18]. In addition, the procedures may facilitate the coordination with eventual Air Traffic Control (ATC) or in the non-controlled case, with the rest of pilots operating in the same area.

Figure 1. Separation and collision avoidance mechanisms.

Planning operational stages

All kinds of aircraft operations are preceded by some sort of pre-flight planning or preparation stage: from simple and short briefings of light aircraft when performing local flights, to the complex planning and dispatching processes present in big airlines. UAS operations will be no exception and will indeed follow some kind of pre-flight planning flow too [22]. With respect to airfield operations, we have identified three clear operational stages which are somehow strategic, tactical and real-time levels in the operation of the UAS:

Airfield analysis stage: Well before actual operations, the airfield of operations for a particular UAS will be studied. In this stage some default procedures and waypoints will be generated automatically according to the location of the airfield, the runway length and orientation and the average UAS performances. Then, these default settings will be refined by considering the specific particularities of the airfield, surrounding scenario, and the characteristics of the UAS. Thence, aspects such as terrain, populated areas or restricted zones, existing procedures for other aircraft types, the presence of air traffic services (ATS), the type of the UAS S&A equipment, its level of automation, its reaction in case of contingencies, among others; will be

considered to finally place the location of certain waypoints defining depart or approach procedures, or even add or remove some of them.

Dispatch stage: This stage is performed some hours before the actual operation of the UAS. Hence, more information will be available on weather conditions, ATS, actual sensors on the UAS and final UAS architecture, estimated traffic conditions around the airfield, UAS performances and limitations, etc. Therefore, the initial procedures and waypoints defined in the previous stage will be fine-tuned according to all these considerations and uploaded to the UAS flight services.

Flight stage: Finally, it is also expected that during actual operations, waypoints and procedures can be always updated by the PiC by uploading new parameters in real time. This would allow reacting to unexpected changes such as weather or traffic conditions.

In this paper, we show a set of generic procedures and associated waypoints that will be automatically generated at the airfield analysis stage. They are conceived aiming at providing a set of well-defined and predictable trajectories minimizing conflicts with other aircraft. Yet, they are flexible enough to be modified during the dispatch process or even in real-time, should particular conditions mandate.

3. DEPART OPERATIONS

It is clear that a manual take-off is always possible, especially if the PiC is present in the departing airfield and has visual contact with the aircraft. In this case, the UAS would fly up to a point and/or height in where the navigation phase can be initiated and the auto-pilot system engaged. Yet, we propose an automatic take-off phase to execute this process easier, more predictable and therefore, safer. Thus, the take-off phase will automatically fly the aircraft from the departing runway to an End of Departure Waypoint (EDWP). These waypoints are located close enough to the airport in order to avoid complex navigation paths for the UAS, but far enough to reduce as much as possible, conflicts with surrounding traffic. Once at the EDWP, the UAS will engage to navigation mode.

In general, the exit points that are depicted in some Visual Approach Charts (VAC) could not be used as EDWPs, since they are usually placed too far from the runway. In the case of flying in an airport where these kinds of points are published, the UAS will fly from the EDWP to the published exit point in the same way that the rest of the flight plan would be executed.

End of Departure Waypoints

Given an airport and a departing runway, five default EDWPs will be systematically computed. The location of these points relies on the characteristics of the traffic pattern for that particular runway. In the general case, two standard traffic patterns (clockwise and counterclockwise) will be considered and the five EDWPs will be allocated as shown in Figure 2. Point EDWP-A is defined 500 ft AAL and along the extended runway centerline. Point EDWP-B is defined along a line

starting at EDWP-A, and forming 45° to the left of the extended runway centerline. Symmetrically, point EDWP-B is at the right of EDWP-A. On the other hand, point EDWP-C is defined at the end of the left downwind leg for the considered runway while point EDWP-C is defined symmetrically at the end of the right downwind leg. The end of the downwind is that point where a line from the landing threshold forms 45° with the extended runway centerline.

Once the five EDWPs are defined, five different areas can be associated to them, as shown in Figure 2. The first navigation waypoint will fall in one of these areas and this will determine which of the EDWPs will be used for the departure. For example, if the first navigation waypoint turns to be inside Area-B then the UAS will perform an initial climb up to EDWP-A, followed by a right turn direct to EDWP-B where the take-off procedure will be terminated. From that point, a direct navigation to the first waypoint will be performed. The different limiting lines of 45° with the extended runway centerline have been chosen aiming at reducing the amount of the turn heading change that follows the EDWP (i.e. just when the aircraft flies directly to the first navigation point).
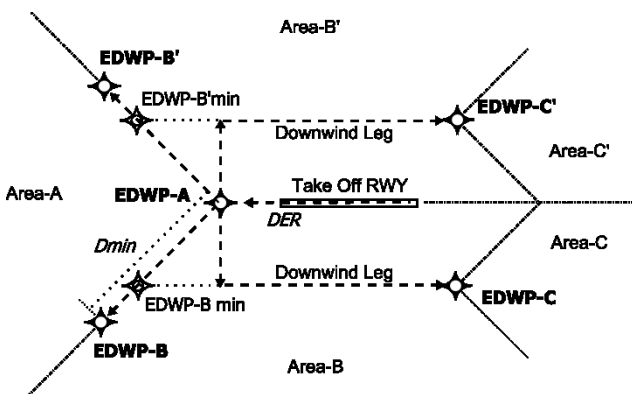

Figure 2. End of Departure Waypoints (EDWP) and associated departure areas.

4. APPROACH OPERATIONS

Following the same philosophy as with the departures, we propose some standardized procedures that may be performed by the UAS in the approach phases to a given airport. These procedures are inspired in what is flown currently by manned aircraft operating in VFR and in non-controlled airfields (see Figure 3). We think that these procedures will allow improving the predictability of UAS trajectories, so they might be also used in case of flying to an airport even with ATC services, but with no IFR procedures published.

Arrival to a predefined holding pattern

The proposed approach procedure will start in a holding pattern located near (or over) the landing runway. The flight planning system will guide the UAS to this holding point by using normal navigation waypoints while taking into account all possible restrictions that may prevail in the airport (entry points, minimum/maximum altitudes, etc.). The minimum arrival altitude will be at least 500 ft

above the highest of the airfield traffic patterns in order to avoid conflicts with aircraft already there. By default, the holding will be performed just over the runway, as it is considered the location which less potential interferences with arriving or already approaching traffic. The UAS will remain in this holding pattern up to the moment it is considered appropriate to integrate the downwind leg of the traffic pattern.
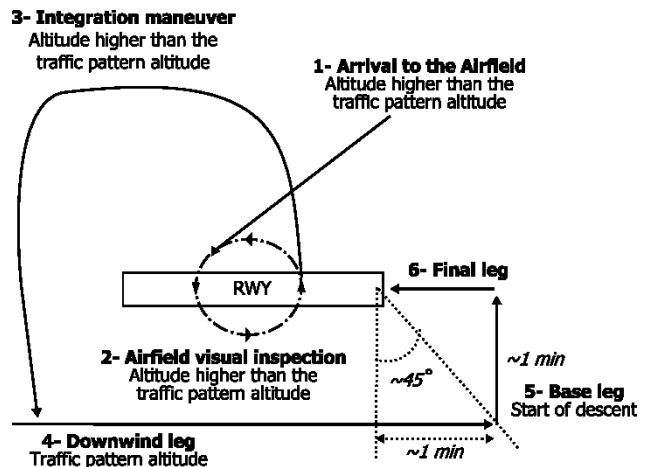

Figure 3. Standardized procedure for the arrival and approach operations in non-controlled VFR airfields.

In order to ensure omni-directional arrivals, five waypoints will define the holding pattern and depending on the arrival direction, the UAS will integrate the holding pattern by flying directly to one of the four external waypoints. These waypoints will be automatically computed by defining the coordinates of the center waypoint, along with the holding aircraft speed. Aircraft minimum turn distances will be considered in order to compute a minimum separation among these waypoints (see Figure 4).

A source of potential conflicts may be with those aircraft aborting the landing in final. In general, it is the responsibility of the aircraft performing the go-around to avoid conflicts [8]. Yet, all the aircraft in the vicinity of the airfield will know that the UAS is holding at the vertical of the runway facilitating in this way, its visual identification.

Integration to the airfield traffic pattern

Once in the holding, the PiC will decide the best moment to integrate to a left (counterclockwise) or right (clockwise) traffic pattern. These decisions could be based on ATC clearances (in a controlled airfield) or on pilot-to-pilot communications (in the non-controlled case).

Depending on the landing runway and the direction of the traffic pattern turns, one of the external waypoints of the holding will be designated as a Holding Exit Waypoint (HEWP). Only at this waypoint, the aircraft can quit the holding pattern and fly directly to a predefined Integration Waypoint (IWP), which is located on the extended runway centerline. An Initial Downwind Waypoint (IDWP) is also defined to guide the UAS to the start of the downwind leg.
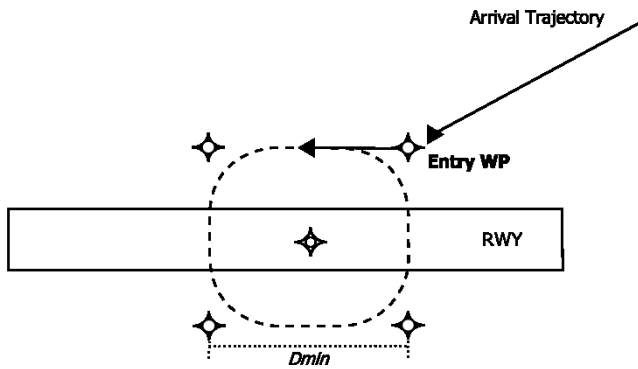
Figure 4. Arrival holding.

Figure 5 shows the location of these three predefined waypoints. Both IWP and IDWP ensure a smooth transition from the holding to the traffic pattern in such a way that the aircraft integrates the downwind leg at the correct altitude (usually 500 ft below the holding). Moreover, and aiming to avoid conflicts with departing traffic, the aircraft will start the descent once the IWP is overflown.

Future UAS are likely to be equipped with a 4D trajectory prediction tool [13]. Therefore, the UAS pilot will have a good knowledge of the required times to fly from one waypoint to another. This will allow him/her to better deal with ATC clearances or coordination tasks with other pilots. Moreover, having a Traffic Information System (giving the position of the surrounding aircraft and displaying them in the same screen) would definitely help the UAS pilot to perform this integration.
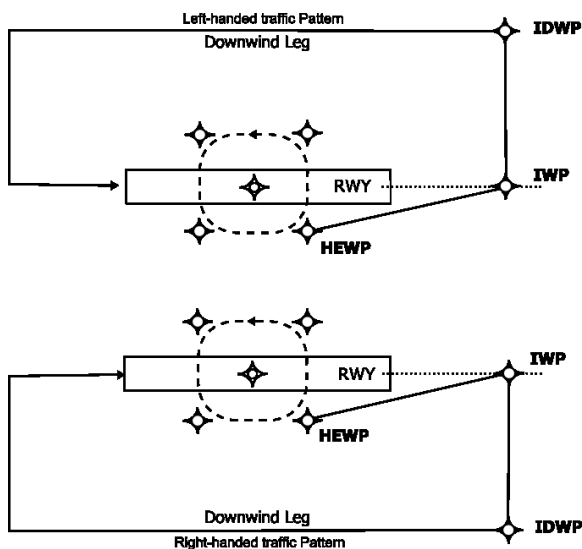

Figure 5. Integration to the airfield traffic pattern.

Approach phase: flying the airfield traffic pattern

The airfield traffic pattern will be flown like any other manned or unmanned flight evolving under VFR: by following sequentially a downwind leg, at a specified constant altitude; a base leg, where descent will be initiated; and a final leg aligned with the runway centerline. Moreover, if the used airport publishes some particularities regarding the traffic pattern (non-standard altitudes, prescribed legs, etc.) these will be taken into account by the UAS. Conversely, if nothing is published

a standard traffic pattern will be used.

Besides the traffic pattern parameters, the UAS will incorporate two functionalities aiming at increase the distance to the preceding aircraft for separation purposes. Thus, we propose to extend the length of the downwind leg as shown in Figure 6 if the PiC considers it necessary. Again, the 4D trajectory prediction tool will assist him/her to choose the amount of time that this leg should be extended. For longer delays, it will be also possible to perform a holding at the end of the downwind leg, as depicted in Figure 7. These two maneuvers will allow to adjust the separation with the preceding aircraft for the base and final legs, but also to give way to other aircraft (perhaps with higher right-of-way priority) that may join directly the final leg, or even perform the opposite traffic pattern. Furthermore, it is also foreseen to start the holding procedure at any moment during the downwind and not only at the end of the leg. This will allow the UAS to react in case of an unexpected potential loss of separation with the preceding aircraft or with other aircraft with higher right-of-way priority integrating directly ahead in the downwind or base legs.

Landing maneuver

The landing maneuver is formed by a single leg where the angle of descent should automatically be computed in function of the last waypoint of the base leg and the touchdown fix. If the PiC, motivated for more or less automated tools and indicators provided by the UAS, considers that landing is not safe enough a missed approach procedure will be commanded. In this abort phase, the aircraft will maintain runway heading and climb up to the traffic pattern altitude. In this way, potential conflicts with other aircraft holding above the runway would be minimized. Once at this altitude and after over-flying the DER (whatever comes later), three different options appear:

- Re-join the traffic pattern, and thus continue at constant altitude towards the IWP and proceed to a normal traffic pattern integration;
- Deviate to an alternate airfield, and therefore fly to the desired EDWP; or
- Integrate the arrival holding.

Following the same principle used for the downwind leg, the end of the missed approach maneuver can also be extended (by continue flying straight on runway heading), delaying the execution of the following phase. This will allow to establish appropriate separation with surrounding traffic and/or to provide with enough flight distance to gain the required altitude to integrate the arrival holding (500 ft above the highest aircraft).
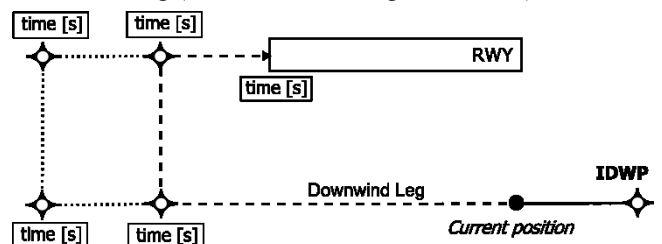

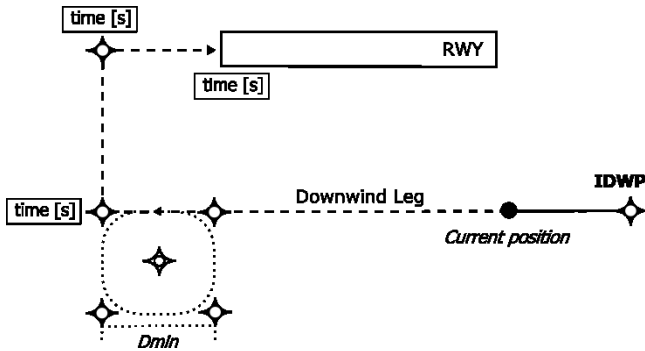**Figure 6. Dynamic adjustments of downwind leg: leg extension.**

Figure 7. Dynamic adjustments of downwind leg: holding.

5. CONTINGENCY MANAGEMENT IN AIRFIELD OPERATIONS

A thorough analysis of contingency situations and reactions are out of the scope of this work, since they are completely dependent on the UAS type, architecture, on-board systems, redundancies, etc. However, due to the relevance of this issue, some general discussion is given next, focusing on the type of contingencies that may occur during airfield operations and their possible reactions. In general, contingencies can be classified in three categories, in function of their severity: catastrophic, hazardous and minor contingencies. Minor contingencies are related to payload malfunction and therefore are omitted in this discussion.

Catastrophic Contingencies

The most important and restrictive category is the catastrophic contingency, which applies for all those situations where the UAS flight is still controllable but an immediate landing is required. In the majority of situations, this would lead to a forced landing due to the impossibility to safely reach an airport. For example, situations such as losing the power-plant, running out of fuel/batteries, experiencing a severe fire, etc. would fall in this category. In such a situation, immediate flight termination becomes the priority and must be performed safely regarding potential collisions with people and goods on ground. Some UAS are equipped with parachute systems or can perform spiral maneuvers to reduce the energy of potential ground impacts. Both actions are designed to eventually terminate the flight while reducing the hazard when crashing into ground. Some other aircraft may not be equipped with such a flight termination system and would simply glide to a crash safe zone.

Providing that this paper focuses in procedures and not specific UAS technologies or implementations, we propose the definition of a set of Flight Termination Zones (FTZ) nearby the airfields. These FTZ will be analyzed beforehand and their location defined during the airfield analysis and dispatching stages. After the FTZ assessment has been completed, the whole nominal trajectories will be divided in different segments and a FTZ will be assigned to each of them. Thus, should a catastrophic failure occur, the UAS will immediately head to the associated FTZ to implement there the

termination maneuver. It should be noted that these segments do not necessarily correspond to nominal legs (such as downwind or base legs) since they depend on the FTZ location and UAS performances. Moreover, in function on the risk that a ground impact represents, which mainly depends on the UAS size and population density [2,4], the number and dimension of the available FTZ will be different for each case. Consequently, this will affect the final placement of the different waypoints (such as the EDWP, for example) and eventually, it could happen that some UAS will not be able to operate in a particular scenario because after a catastrophic contingency it cannot be guaranteed that in any moment, a FTZ can be reached.

Hazardous Contingencies

All those situations that reduce aircraft airworthiness, but still allow controlled flight, are considered hazardous contingencies. In these cases, the main priority is to land as soon as possible and closely monitor the status and trajectory of the aircraft in order to prevent a catastrophic contingency in a later stage. It is clear that a proper and quick contingency detection and reaction can save the UAS platform by performing an emergency landing at the airfield. Therefore, if the aircraft is already executing an approach procedure, the UAS will continue towards a landing, because delaying the operations may simply aggravate the situation. In case of a departure, the transition to the navigation phase will not be performed and the UAS will join the airfield traffic pattern, or the arrival hold, and then transition to the approach mode. However, if the risk of performing an emergency landing is deemed too high, the hazardous contingency can be re-classified as a catastrophic contingency and command a flight termination in the appropriate FTZ as defined above. This decision will depend again on the UAS equipment, the type of contingency, the specific airfield scenario and also the presence of other traffic nearby the airfield. These reactions could have been pre-programed in the UAS logic, or uploaded from the ground control station in real time.

A very particular hazardous contingency is the case of failure of the data-link communications channel relaying the UAS with the ground control station. In such a situation, the UAS becomes completely autonomous and again, depending on the particularities of the UAS (and especially on the capabilities of the airborne S&A system), the reactions in front such a contingency may be different. A lost link situation is somehow similar to a radio communication failure in manned aviation. In that case, if the airfield is not controlled safety is ensured by see-and-avoid and right-of-way rules. Conversely, if the airfield is controlled, we expect that the ATC would be aware of the situation and he/she will prioritize the UAS above other traffic and take opportune actions to ensure separations. In the case of the UAS, it is up to the regulator to decide whether this emergency is to be considered catastrophic or if an emergency landing is deemed appropriate. In fact, it seems reasonable that different considerations may exist, depending on the UAS equipment (and notably on the capabilities of the S&A system in autonomous flight); the type of airfield;

the airspace class; the weather conditions; etc. Thus, the behavior of the UAS in such an emergency will be conveniently programmed and known before-hand.

In both cases the proposed solution is to abort the procedure in execution, for an emergency landing integrate the arrival holding pattern at a safe altitude for a predetermined time (allowing for a potential data-link recovery) while transmitting special emergency messages over the VHF communications channel and setting the transponder (if equipped) into a special distress code. For take-off procedures, abort the transition to the navigating phase and also integrate the arrival holding pattern corresponding to that runway. Then, after a given timeout it will perform the predefined landing pattern procedure, assuming that all necessary emergency clearances have been managed by the PiC. If a flight termination is preferred, a similar holding pattern would be executed over the predefined FTZ and if command and control communications are not reestablished after a given timeout, a flight termination procedure would be initiated. Note, however, that if an emergency landing procedure is pre-planned as a reaction to a lost-link situation, the UAS will perform a highly predictable operation, which cannot be changed into a flight termination unless some alternative communication mechanism exists.

6. EVALUATION OF THE PROPOSED CONOPS

The proposed concept of operation has been implemented within a UAS specific system architecture called USAL (UAS Service Abstraction Layer). This architecture has been introduced as a flexible, reusable and distributed architecture to support the development of UAS civil operations. The reader is referred to [24,25] for a more detailed description.

USAL Flight Services

The absence of UAS civil (and commercial) applications has driven the development of UAS highly dependent on the type of mission to be accomplished and on the flight scenario expected for that mission. At present, there is an increasing amount of different autopilot manufacturers providing solutions for UAS (see for instance the survey done in [26]). Thus, very specific and non-flexible systems exist nowadays to control the desired flight profile, the sensor activation/configuration, the data storage, etc. The goal of the USAL architecture is twofold. On one side, USAL promotes the development of advanced concepts of operation by implementing

specific functionalities as integral part of the architecture. Relevant examples are the definition of enhanced flight plans [27,28] including contingency management, autopilot management, a mission control engine, support for payload management and data storage, etc. On the other hand, USAL provides flexibility for the development of additional systems required to implement the actual UAS mission, while reducing the development effort when creating a new UAS system. The USAL is designed as a set of *services* and their interrelations running on top of a communication mechanism, as a basic starting point for further development by users. Available USAL services have been classified into the following categories:

- **Flight Services**, which are responsible for basic UAS flight operations: autopilot, flight plan management, basic monitoring, contingency management, etc.
- **Awareness Services**, which are responsible for the safe operation of the UAS related to terrain avoidance and integration with other airspace users.
- **Mission Services**, being responsible for carrying out the actual UAS mission.
- **Payload Services**, specialized in interfacing with the input/output capabilities provided by the payload on board the UAS.

Both the flight and awareness services are directly related to the objectives of this work. Figure 8 depicts the fundamental components in both sets of services and the major relationships among them. The *Virtual Autopilot System* (VAS) manages the interaction with the selected autopilot and abstracts its peculiarities providing a uniform view [25]. The VAS offers a number of information flows to be exploited by the USAL, but at the same time retains a number of critical flight aspects like those related to manual flight and automated take-off/landing operations. Alongside the VAS, we have developed a *Flight Plan Manager* (FPMa) that implements much richer flight plan capabilities on top of the available capabilities offered by the actual autopilot [27]. The FPMa offers an almost unlimited number of waypoints, waypoint grouping, structured flight plan phases with built-in emergency alternatives, mission oriented legs with high-level semantics like repetitions, parameterized scans, and in particular the set of properties/parameters needed to perform takeoff and landing operations following the proposed concept of operation.
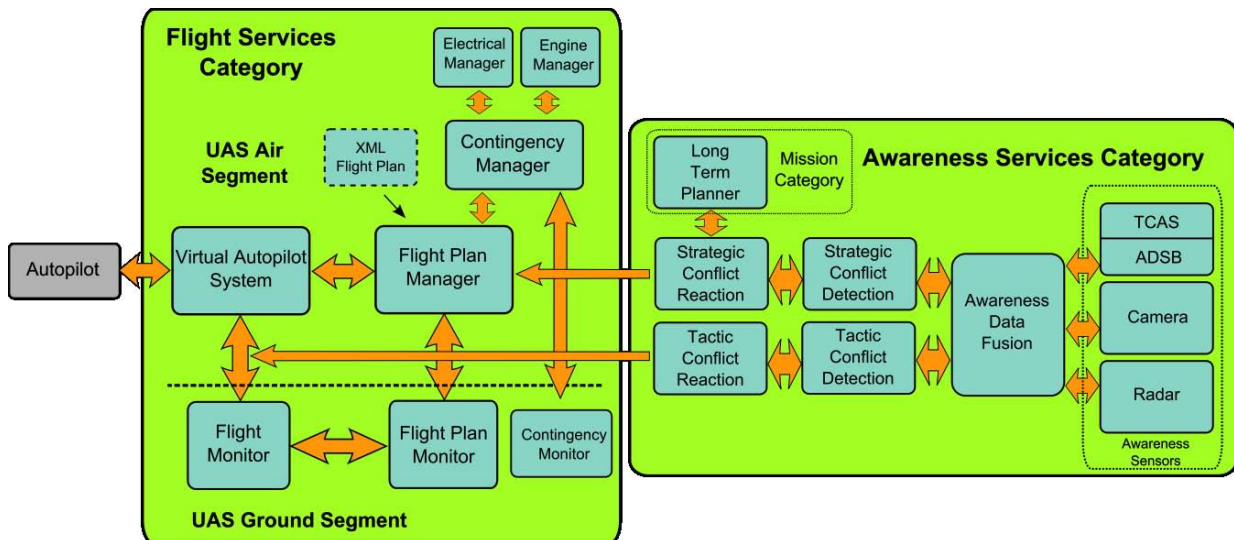
Figure 8. Overview of the fight and awareness services within the UAS Service Abstraction Layer (USAL).

Within the USAL architecture all the PiC Human-Machine-Interfaces (HMI) has been divided in two coordinated interfaces: a classical pilot-like interface and a flight-plan oriented interface. Generally speaking, current UAS autopilots offer manual and/or assisted piloting plus basic waypoint navigation support. The design of the USAL HMI interfaces maintains such manual piloting and waypoint navigation capabilities through the VAS, and provides them to the ground through the FMo service; *e.g.* manual piloting, basic flight monitoring, contingency management, navigation support including heading-based and waypoint-based, and take-off and landing support.

The Flight Plan Monitor (FPMo) is the main interface system that should help the PiC to exploit all the automation and dynamic reconfiguration that the USAL architecture and the Flight Plan Manager can offer. As previously mentioned, the FPMa executes a mission-oriented flight plan designed to implement high-level operation structures and to allow dynamic flight updates decided by the on-board mission systems of by the PiC through the offered HMI interfaces. When the UAS develops a complex mission using the USAL, the flight plan itself will contain all the required landing and take-off parameters necessary to implement the proposed concept of operation. At each stage of the flight, the FPM will notify the VAS and the FMo which should be the actual usage of those parameters. This flexibility is necessary because the actual landing site may change according to the actual mission development or due to the existence of potential in-flight emergencies. This scheme opens the door to implement complex operational schemes in which the FPMo supports the selection process of the most convenient parameters, to be later on sent to the VAS/FMo for their implementation by the PiC.

Flight services in USAL also incorporate a service that it is in charge of managing potential contingency situations. This component is called Contingency Manager (CM) and is responsible for collecting status information related to multiple sources as: autopilot, engine,

electrical, fuel, communications, etc; identify potential contingency situations; and determine the most appropriate reaction from a pre-planned set of reactions [29].

Experimental Simulation Environment

A simulation environment was setup to test the proposed operational concepts while using the modular UAS architecture presented above. Figure 9 shows the different components created around the main USAL flight services. Only the relevant flight services within the USAL architecture are shown in the figure: the VAS and the FPMa and their equivalent HMI interfaces. In the architecture proposed above the auto take-off will be performed by the VAS and once at the EDWP, the FPMa takes care of the navigation that follows. On the other hand, once the UAS has integrated the arrival holding pattern, the control of the aircraft will transition from the FPMa to the VAS before starting the approach procedure.

In order to provide a realistic real-time simulation scenario, the dynamics of a UAS platform was simulated using the Flight Gear Flight Simulator software, and therefore a VAS service has been implemented to interface with its build-in autopilot. This flight simulator was also used to produce a synthetic pilot view that was used in the flight monitor HMI pilot display. Airfield depart and approach operations were simulated in an hypothetical scenario with the presence of surrounding traffic. In these preliminary simulations the other aircraft were generated by an independent computer and followed specific pre-programmed flight trajectories.

The flight intentions for these emulated traffics were not known before hand by the PiC of the UAS, which had to deal with them according to the procedures and tools presented in previous section. The remaining components of this simulation environment support the multi-vehicle scenario environment and a Google Earth tracking tool to store and reproduce the trajectories of all involved aircraft.

Experimental Results

A number of simulations were performed in order to validate the proposed concept of operation. All specific maneuvers were fully automated and initial HMI interfaces offered to the PiC. Various scenarios were tested, from the UAS operating standalone within nominal parameters, to scenarios with a limited number of conflicting traffic so that the deconflicting operations have been commanded from the PiC in order to guarantee separation.

Figure 10 shows a screen-shot during a take-off in where EDWP-C was selected by the PiC. As seen in the figure, with this procedure the altitude of the UAS when overflying the downwind leg is higher than the airfield traffic pattern altitude, reducing in this way, possible conflicts with other traffic. Moreover, the fact that the UAS is overlaying the downwind leg until EDWP-C is reached, improves the situational awareness of the other users. An arrival procedure is shown in Figure 11 where it can be seen how the UAS integrates to the arrival holding defined over the runway while other traffic integrate the downwind leg of the traffic pattern. When the PiC judges it is safe to continue with the approach, the UAS leaves the holding and integrates to the downwind leg after the preceding aircraft. Finally, Figure 12 shows a case where the PiC decides to extend the downwind leg in order to increase the safety distance with the preceding traffic.
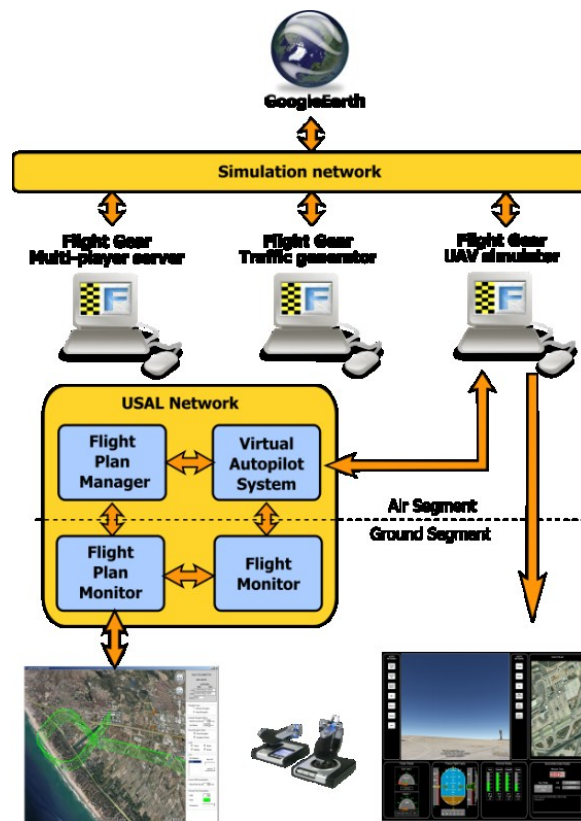

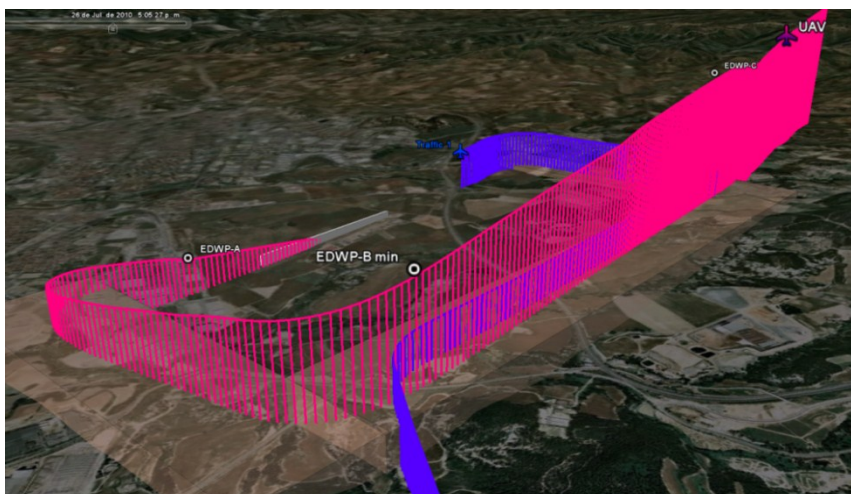Figure 9. Overview of the simulation environment.

Figure 10. Example screen-shot for the simulation of take-off operations.

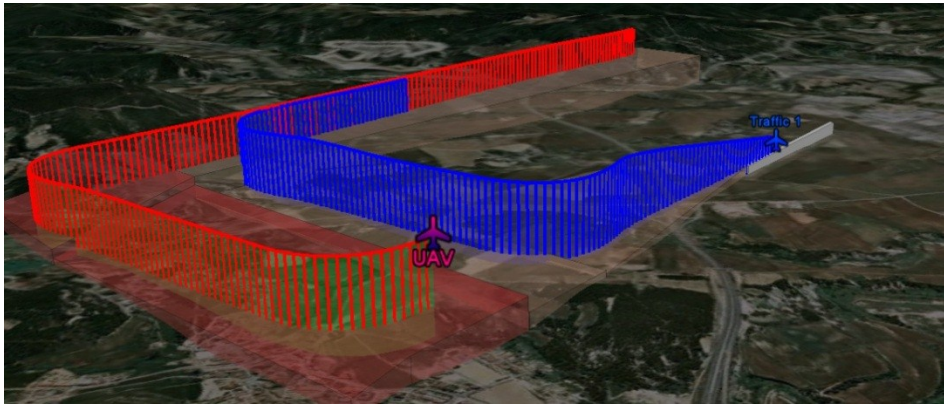**Figure 11. Example screen-shot for the simulation of arrival operations**.

Figure 12. Example screen-shot for the simulation of extended downwind operations

7. CONCLUSIONS

In this paper we have discussed about the integration of civil UAS operations in depart and approach operations. Manned flights under VFR rely on the pilot's ability to see and avoid terrain and other surrounding traffic. Even if VFR environments exist from the very beginning of aviation, and therefore they have been proved safe, they present a big challenge for the integration of UAS operations due to their lack of predictability, precision and repeatability. On the other hand, the high levels of automation in UAS permit to easily execute flights under IFR with the possibility to achieve high degrees of transparency with the ATC services and the other airspace users. Not all the airports offer IFR procedures, however. Thence, this paper proposes some standardized operations for UAS evolving in such VFR environments.

The proposed procedures do not significantly differ from current manned VFR operations in non-controlled airfields. However, manned operations do not always follow systematically these default paths. This is mainly due to the high flexibility inherent in all VFR flights, and to the possibility to override some legs in presence of ATS or where the pilot considers it is a safe decision. Conversely, we believe that if the UAS is always executing systematically the same set of procedures, the situational awareness will notably increase and in short, we will be adding a significant procedural safe layer on top of all the separation and collision avoidance mechanisms. Moreover, they are conceived in such a way that the UAS will interfere as less as possible with other aircraft, while providing high levels of predictability in the trajectories and decreasing the workload of the UAS flight crew. We believe that these procedures would be useful in all VFR operations, either in controlled or in non-controlled airfields. They are also generic enough to serve as baseline procedures, which can always be modified and adapted to specific scenarios and according to UAS particular equipment.

Moreover, we have considered that the UAS has with similar performances than the other aircraft flying in the same airport. It is clear that for UAS flying significantly slower than the other aircraft separate airfield traffic patterns may be considered (such as done nowadays in airfields with small Ultra-Light Motorized (ULM) vehicles or gliders). Finally, it is worthwhile mentioning that the example simulations given in this paper are preliminary results for the proof of these concepts. Work is underway in setting up a new simulation environment with several human pilots on flight simulators sharing the same scenario, along with the UAS. Therefore, the proposed procedures will be tested against different situations, ranging from nominal operations to different emergency situations, along with unexpected behaviors from other traffic. Finally, and in a near future, some test flights with a real UAS platform are also foreseen.

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