An Assessment for UAS depart and approach operations

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Unmanned Aerial Systems (UAS) have great potential to be used in a wide variety of civil applications such as environmental applications, emergency situations, surveillance tasks and more. The development of Flight Control Systems (FCS) coupled with the availability of other Commercial Off-The Shelf (COTS) components is enabling the introduction of UAS into the civil market. The sophistication of existing FCS is also making these systems accessible to end users with little aeronautics expertise. However, much work remains to be done to deliver systems that can be properly integrated in standard aeronautical procedures used by manned aviation.

In previous research advances have been proposed in the flight plan capabilities by offering semantically much richer constructs than those present in most current UAS autopilots.[1] The introduced flight plan is organized as a set of stages, each one corresponding to a different flight phase. Each stage contains a structured collection of legs inspired by current practices in Area Navigation (RNAV[2,3]). However, the most critical parts of any flight, the depart and approach operations in a integrated airspace remain mostly unexplored.

This paper introduces an assessment of both operations for UAS operating in VFR and IFR modes. Problems and potential solutions are proposed, as well as an automating strategy that should greatly reduce pilot workload. Although the final objective is a full autonomous operation, the pilot is always kept in the control loop and therefore HMI aspects are also considered.

I. Introduction

Nowadays, in civil aviation, a set of procedures and standardized practices are followed in order to operate safely, efficiently and regularly all kind of aircraft. As it is well known, civil air traffic can be divided in two main groups: those aircraft evolving under Visual Flight Rules (VFR) and those which are under Instrumental Flight Rules (IFR). In addition, other classifications exist in civil aviation like for example the aircraft category (A,B,C,D or E) in function of the aircraft speed at threshold[4] and even more basic divisions such as the ultra light models (ULM), the very light aircraft (VLA), the helicopters etc. These classifications play a very important role in how most of the aircraft procedures may be conducted, specially air navigation and separation procedures.

Most Unmanned Aerial Systems (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 mission. UAS developers face the development of specific systems to control their desired flight-profile, sensor activation/configuration along the flight, data storage and eventually its transmission to the ground control. All this elements may delay, increase the risk and cost in the implementation of a new UAS application. Should realistic missions be

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developed, additional support must be created to offer flexible and adaptable platforms for any application that is susceptible to use them.

This paper addresses one of the issues that will arise if extensive civil UAS application became a reality in a near future, imagining a scenario where manned aircraft will coexist with unmanned vehicles. In particular, the integration of UAS in the depart, arrival and approach phases is assessed, taking into account all possible situations ranging from high or low performance UAS into busy and controlled airspaces or remote and uncontrolled aerodromes.

In Section II of this paper it is discussed how departs, arrival and approach procedures are carried out, at present, by manned aircraft. In Section III our proposal for the UAS integration in departure, arrival and approach phases is presented. HMI aspects of the ground systems that should support a high level of automating for our proposed operations are discussed in Section IV. In Section V an example of procedures for UAS for departure and arrival at a given airport is done. Finally the paper ends with the Conclusion and Further work of Section VI.

II. Current depart, arrival and approach operations

As it was mentioned previously there exist two kinds of flight rules in civil aviation: VFR (Visual Flight Rules) and IFR (Instrumental Flight Rules). VFR navigation is based on visual references which the pilot picks from the outside, such as rivers, mountains, roads etc. This kind of navigation is strictly constrained to the existing meteorology with some minimum conditions measured in terms of visibility and minimum separation from clouds. As a consequence, the use of VFR is usually restricted to private or leisure aviation. On the other hand, an aircraft flying under IFR rules uses several navigation instruments which provide the pilot with information for following its trajectory or navigation route with no need for external visual references. The route to be followed can not be any trajectory, but one which has been previously studied by the competent authorities in air traffic, and conveniently published to let it be known by the users of the air space. Particularly, these trajectories are called procedures (for airport departure, arrival or approach manoeuvres) or airways (for the en-route phase). The design of procedures and airways guarantees the clearance to obstacles (mountains, buildings...) by means of a secure flight altitude, as well as the minimum separation between aircraft using different procedures or airways in the same zone and, finally, it helps managing and directing the air traffic flow in a better way. VFR or IFR operations are highly dependent on the kind of airspace or airport being used.

II.A. IFR operations

All aircraft evolving in IFR conditions must follow a specific procedure, which have been previously designed and approved by the competent authority. Therefore, an airport accepting IFR flights will have one or several depart/approach procedures already published. Instrumental flight procedures are usually divided in three different types: Standard Instrumental Departures (SID), Standard Terminal Arrival Routes (STAR) and Instrumental Approach Charts (IAC). Different procedures might be published in function of the aircraft category and radionavigation system being used.

Even if Air Traffic Control (ATC) services are not present in the airport (not controlled airport), there must exist some IFR procedures published if IFR operations have to be carried out. In some cases, omni directional departures and/or arrivals are published. These procedures do not specify a particular route to follow for the departing or approaching aircraft but indicate the minimum altitudes for one or several sectors around the airport in order to satisfy a minimum obstacle clearance altitude. These omni directional procedures may also apply for controlled airports but with a relative small volume of traffic and, therefore, giving the operation aircraft the maximum flexibility for choosing their departing or arrival routes.[5]

In non controlled airports, it is the responsibility of the pilot in command to ensure the minimum separation with the other traffic. All pilots in the area may coordinate among them and respect the published procedures. In this context, the pilot in command reports his/her positions and intentions at each significant point of the IFR procedure.

IFR procedures in non controlled airports are not permitted in all countries and are subject to different regulations. For example, in France, the instrument approach procedure is only permitted if there exists at the airport a station designated to provide QNH or an automatic data information system. In this case, the approach is restricted to a circling to approach procedure (i.e. an instrumental procedure ending in a visual maneuvering phase) and straight-in approaches are prohibited. In addition, for night operations, an operator agent should be present at the aerodrome being able to trigger the safety plan of aerodrome if an emergency occurs.[5]

II.B. VFR operations

For high density Terminal Manoeuvring Areas (TMA) VFR flights may have important restrictions like for example VFR sectors, corridors or routes as well as some limitations in minimum and/or maximum altitudes. Concerning VFR operations in dense airports, these may publish Visual Approach Charts (VAC) detailing, for example the preferred side for the airport traffic pattern circuit, eventual exit or entry points etc. For example, in Figure 1 the VAC from Eelde airport for runways 05/23 is presented. In general, these kind of charts identify one or more traffic patterns, entry or exit points and, eventually possible routes to follow.

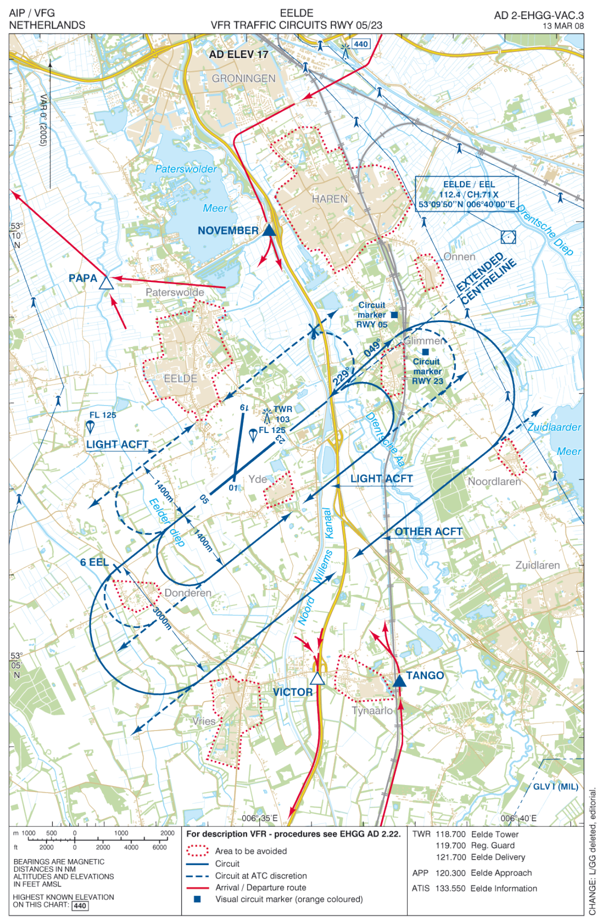


Figure 1. VAC chart from runways 05/23 from Eelde aiport (EHGG).[6]

A completely different situation exists for VFR operations in non-controlled aerodromes. In these cases there may not exist any VFR specific procedure published and a default procedure is generally applied. It is the captain's duty to fly his/her aircraft within its maneuvering limits according to circumstances so as not to bother other aerodrome traffic or traffic in the vicinity.

The arrival phase is maybe the most challenging one. In this case, the pilot in command must evaluate the prevailing conditions of the aerodrome before joining the traffic pattern by overflying the intended landing runway in circles in order to see the physical status of the runway, possible other traffic operating nearby and the wind conditions if a wind-sock is operative (see Figure 2). This should be done at a height greater than the highest of the aerodrome circuits (usually 500 ft above) minimizing, in this way, possible conflicts with existing aircraft already in the traffic pattern.[7]

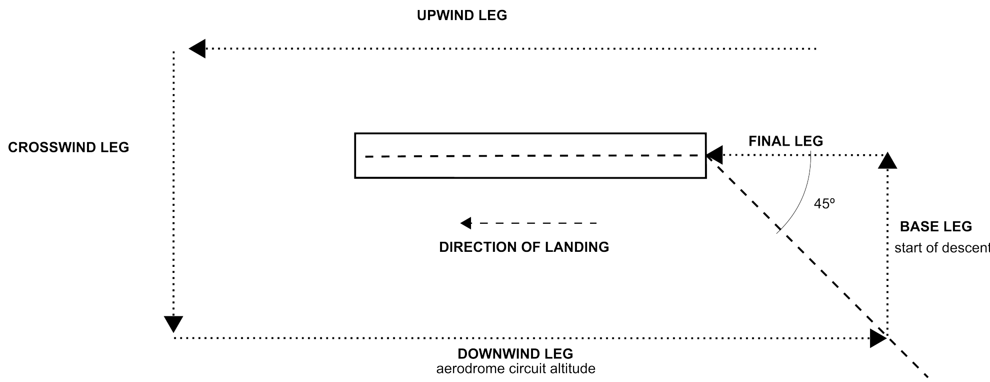


Figure 2. General VFR integration and approach to non-controlled aerodromes.

After this evaluation, the aircraft starts an integration to the beginning of the downwind leg while attaining the published altitude for the traffic pattern. This joining maneuver is done maintaining the hold altitude until passing through the extended runway centerline so as to not bother possible departure traffic. It is at this point where the descent begins. As stated above, the target is to arrive at the begin of the downwind leg at the correct height, speed and heading.

Once the integration is finished, an standard traffic pattern is flown with downwind, base and final legs with the possibility to dynamically adjust them in function of the other traffic while assuring safe separations. As a general rule, aerodrome circuit dimensions are not strictly defined but the base leg and the end of the downwind leg take usually a minute of flight. On the other hand, if not specified otherwise, the downwind leg is flown at 1000ft AAL (Above Aerodrome Level) and a left hand turn is used. On the other hand, when going around (in a missed approach maneuver), the pilot in command should not make any maneuvers which could bother other circuit traffic.

It is possible to join directly the traffic pattern at the downwind leg, base leg or even final leg at aerodrome circuit height ensuring visual separation with aircraft already in the aerodrome traffic if the pilot in command estimates that this maneuver is safe and is not bothering other aircraft already in the circuit.

The captain does not have to examine the aerodrome on arrival if he is aware of the runway in use by listening to the messages transmitted on the auto information frequency by aircraft already in the aerodrome traffic and if he already knows the wind direction and velocity and what signals are displayed on the signaling area and taxiway. This standard procedure can be slightly changed for noise abatement reasons, obstacle clearance or air traffic management purposes. The changes might include avoid overflying certain noise sensitive areas, join the aerodrome circuit at further distances than in the default case and/or fly the aerodrome circuit at higher altitudes than the default case.

On a non controlled aerodrome an aircraft in the aerodrome traffic which is aware of an inbound IFR flight must, unless previously agreed between captains, fly in such a way so as not to interfere with the approach and landing of the IFR flight. This disposition only applies if the IFR flight is making a final instrument approach for a direct landing on the runway in use or when the final approach is followed by a visual maneuvering with prescribed track.

In controlled airports any aircraft must be given clearance before going on to taxiing on the ramp, going on to the runway, taking off, joining aerodrome traffic and landing. It is possible that the air traffic controller can clear the pilot in command to fly directly to any segment of the landing pattern.

Finally, for take-off and depart operations the aircraft should arrive 500 ft above the runway and then turn direct to navigation. In the case when the destination point is just in the opposite direction, the usual maneuver is to join the traffic pattern, continue climbing and leave the circuit pattern at the end of the downwind leg.

III. UAS operations in arrival and approach phases

As has been previously remarked, UAS use is expected to grow, so their integration in different airports with different traffic is expected. The nominal use of UAS systems will be like IFR systems, they will not use external references in order to perform the navigation. However, their use in aerodromes without defined IFR procedures needs to be possible, especially if their use will probably start in small non-controlled airports instead of in busy ones. Four different scenarios for UAS arrivals and approaches have been identified in this work:

- controlled airports with IFR procedures published
- non-controlled airports with IFR procedures published
- controlled airports without IFR procedures published
- non-controlled airports without IFR procedures published

III.A. Airports with IFR procedures

In controlled airports where IFR procedures exist, different STARs are used and published in function of the aircraft category. Therefore, the UAS will follow the procedures that fits with its performances. The main advantage of this solution is that its behavior will be the same as manned traffic and thus transparent to the ATC (Air Traffic Control). With the future introduction of DataLink between the ATCO (Air Traffic Control Officer) and the aircraft,[8] the UAS can easily become fully autonomous. In the actual concept of operations, with voice communications, the pilot in command will interact with the ATCO, that will not have to distinguish between manned and unmanned traffic, and transmits the orders to the UAS. The first problem that outcomes is that UAS with significant smaller performances than the A category will fly long and non-optimal procedures. In this case, some specific procedures for aircraft with less performances will have to be assessed. Another issue that must be taken into account is the delay in communication between the UAS and the pilot in command. Depending on the technology used and on the position of the ground station with respect the vehicle the delay can be greater than the acceptable one. In this case, the ground station that controls the UAS has to be close enough to the airport to deal with ATC clearances and orders in a response time equal to a manned aircraft.

In the case of an UAS operating in a non-controlled airport that has published instrumental procedures, the UAS will be able to develop the trajectory published like in the previous scenario. However, the coordination with other aircraft becomes an issue. If ADS (Automatic Dependent Surveillance) becomes available, the UAS will be able to have an autonomous system to detect and deal with other traffic. Otherwise, the authors propose a solution similar to the applied to IFR aircraft operating in non-controlled aerodromes at night, where an operator agent should be at the aerodrome. In the UAS case, this operator will be able to deal with the traffic and avoid any conflict. Moreover, IFR traffic, like the UAS one, will have priority over VFR traffic and thus conflicts will be minimized. If necessary a procedure like the one described in the case of airports with non IFR procedures can be used.

III.B. Airport without IFR procedures

Obviously the most challenging situation for a UAS is the operation in an airport where only VFR flights are permitted. As it was commented in section II, VFR operations are only based with visual cues that can be seen from the cockpit by the pilot in command. For unmanned flight, one possible solution for VFR operations would be to install a set of cameras in the aircraft and transmit all the video signals to the ground control station, where the UAS pilot in command would *remotely fly* in visual conditions. However, this approach is not considered in this paper because in the great majority of UAS implementations this solution would not be feasible. Thus, another solution is proposed based in specific and predictible procedures for the UAS either for depart or arrival/approach operations. These procedures are thought aiming at minimizing the interference with surrounding traffic. Moreover, they may facilitate coordination with eventual ATC or, in the non controled case, with the rest of pilots operating in the same area.

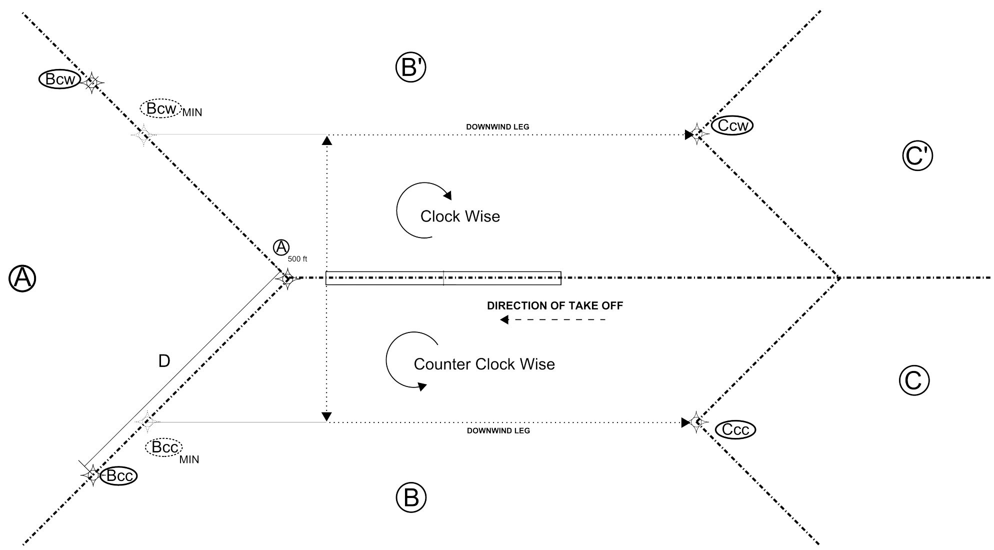


Figure 3. Departure 5 points.

III.B.1. Depart operations

It is clear that a manual take-off is always possible. In this case, the pilot in command will fly the UAS to an height or point where the navigation phase will start. However, the authors propose an automatic take-off phase to do this process easier, more predictable and safer.

The goal of the auto take-off phase is to fly from the runway to an End of Departure Way-Point (EDWP). The EDWP, are way-points that are close to the airport, in order to do not require a difficult navigation process but far enough to do not bother the possible traffic on the airport. At he EDWP the UAS will start the navigation phase commanded by the Flight Plan Manager System (FPMS).

The entry and exists points that are usually described on the VAC charts can not be used as EDWPs because they are too far from the aerodrome and a navigation is needed to reach them. That is the reason why the authors suggest that previously at the use of an airfield, the system will compute five different EDWPs for each runway. These diagrams are defined in function of the traffic patterns and built in base to it. Some operational facts need to be take into account in order to define the limits of position of the EDWPs. The authors proposal is to generate two standard traffic patterns (one clockwise and one counterclockwise) for each runway. And then apply eventual restrictions to them. The flight dispatcher will modify the pre-computed points if necessary. For instance, it could be possible that some computed EDWPs are not valid and need to be cancelled due to obstacles, restricted areas or preferred senses of operations, or that they need to be slightly moved. This work should be done once for each runway of each airport. After that a diagram like the one showed in Figure 3 will be created providing the FPMS enough departure way-points to cover all possible destinations.

In Figure 3 can be observed that five EDWPs exists (A, Bcw, Bcc, Ccw and Ccc) and that four areas are created (A, B, B', C and C'). In function of in which area is the first navigation waypoint one EDWP or another will be selected. For example, if the first navigation waypoint is located in the C' area, then the selected EDWP will be Ccw.

The way-point A is computed as the point where the UAS reaches 500 ft AGL. If this altitude is reached before the end of the runway then the WPA is translated to the runway threshold.

This EDWP should be selected if the flight plan starts in the area A, which is the area limited by 45° from the axe of the runway.

From the way-point A the UAS will be allowed to go directly to the way-points Bcw and to Bcc. This points should be placed at least at a distance of $1.5 * D_{minturn}$ from the WPA and the line defined by Bcw and WPA and by Bcc and WPA should have 45° with respect the axe of the runway. This distance is needed to ensure that the aircraft arrive to the point in a stable manner. If locating the points at $1.5 * D_{minturn}$ from the WPA they are within the traffic pattern then they must be located at least in the intersection between the downwind legs and the defined line of 45° (points Bcw_{min} and Bcc_{min} in the Figure 3).

Finally Ccw and Ccc are located at the intersection of the downwind and base legs of the traffic pattern.

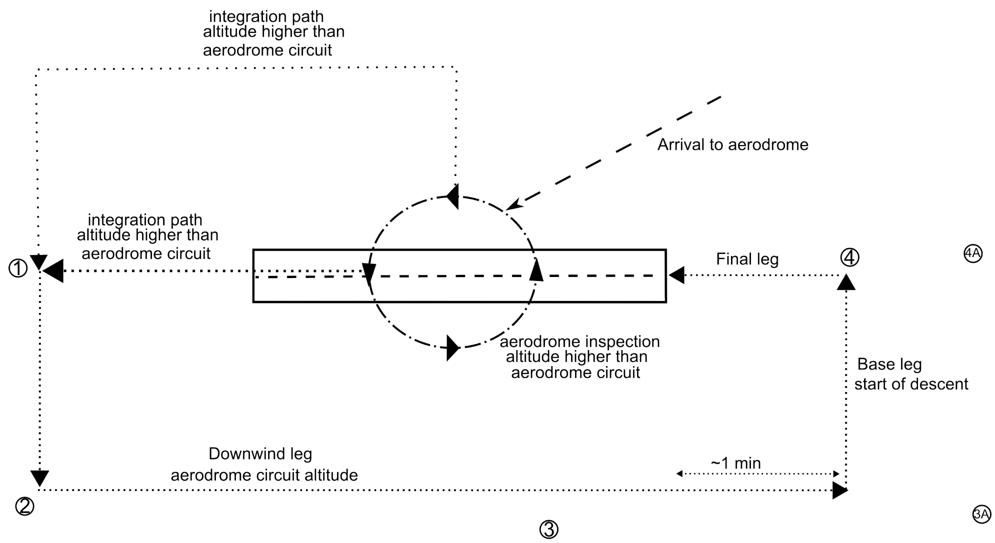


Figure 4. UAS approach and circuit pattern proposal.

This points define the areas C and C' with lines that have 45° with respect the downwind legs. If these EDWPs are selected the UAS will fly the landing pattern following the appropriate downwind leg to them.

The limits of 45° have been selected in order to avoid excessive turns.

The UAS should gain altitude during the whole procedure of departure until arriving 1500 ft AAL, in addition they should maintain V_{app} until arrive to 250 ft over the traffic pattern level in order to bother as less as possible the other traffic.

It is possible that during the take-off phase something suggest than an abort and safe landing is needed. In this case, it should not be necessary to go to the navigation phase. If the abort phase is executed while the take-off is taking place, the UAS will join the traffic pattern and then change to the land mode.

The integration on the downwind leg can be extended in order to avoid the bother of other traffic and a emergency downwind at 500ft AGL should be possible to be commanded to the UAS if necessary.

III.B.2. Arrival and approach operations

If the UAS should operate in a controlled airport where non IFR procedures have been published, if the ATCO demands, it is possible to directly integrate the traffic pattern at any of its segments. However, the authors propose a procedure based on the VFR procedures in non-controlled airports, see Figure 4.

Taking into account all possible restrictions such as entry and exits points, altitudes, etc., the UAS will overfly the airfield at a height greater than the highest of the aerodrome circuits. By default, the hold will be done at a point over the aerodrome's vertical. At this point, the aircraft will be able to wait at a safety altitude before joining the aerodrome traffic pattern. Even if a go-around is done by any aircraft in the aerodrome, the UAS will be safe at the vertical of the field because all the aircraft will know its presence and because it is responsibility of the aircraft doing the go-around procedure to do not make any manoeuvre which could bother other traffic.[7]

The pilot in command will be able to inspect the aerodrome and contact by radio with other possible traffic. With this information the pilot will have the capability to choose which is the sense of landing, the wind direction etc.

In order to have an omni directional arrival, it is proposed the use of a five waypoints holding pattern (four in a square and center one). Those points can be automatically computed by setting the coordinates of the center and the holding speed (see Figure 5). The idea is to have a circumference holding pattern where the pilot in command chooses the entry point, the sense of the hold (clockwise or counterclockwise) and the height.

Once in the holding, the pilot in command should select the circuit pattern or the ATC will command the integration in one defined sense. The pilot in command has to choose the Exit WP from the holding, the Integration WP and the Initial downwind WP (see Figure 6). Thanks to the 4D trajectories, the UAS will be able to performs the calculation of how much time is needed to make the upwind and crosswind length

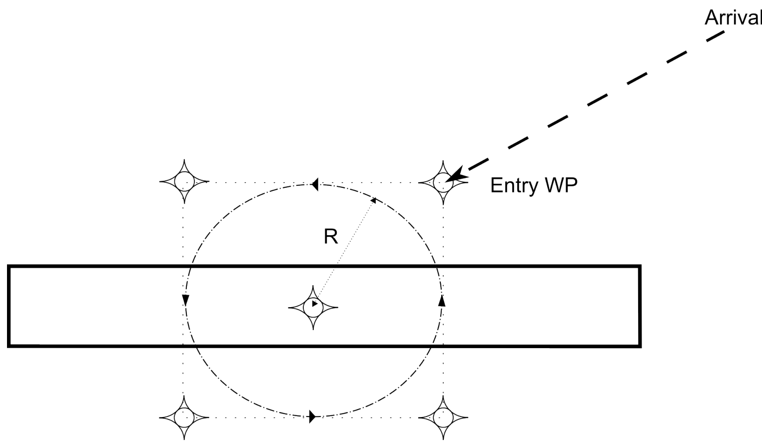


Figure 5. Holding.

in order to do the integration in the landing circuit. This information is useful for the pilot in command to be able to deal with ATC clearances and restrictions. The pilot in command will know if the commands the UAS to do the integration how much time it will take (see Figure 7).

Once cleared by the ATCO to join the traffic, the UAS will do the procedure like any other VFR flight. It will fly the upwind and crosswind length and integrate the downwind leg at the height of the circuit. This integration maneuver is very important to assure that the UAS arrives to the downwind leg at the correct height, heading and speed. It is important to avoid integrations while descending.[9]

This integration maneuver ends at the beginning of the downwind leg at the aerodrome circuit altitude. Therefore, it is preferred to link the holding pattern and the aerodrome circuit at the end of the upwind leg in order to assure a stable arrival of the UAS to the downwind leg. To avoid bothering departure traffic, the aircraft must not start descending until it arrives to the Integration WP (which is placed over the extended axes of the runway), see Figure 7.

When the UAS has join the traffic pattern at the beginning of the downwind leg the auto land phase should start.

If there is a published VAC that specifies an preferred traffic pattern this should be used. Otherwise, the pilot in command will use the standard pattern in a left or right turn.

The downwind leg is parallel to the runway and one minute flight at V_{app} away from it. It finish where a line forming a 45° angle with respect the axe of the runway from the touching point intersects with the downwind leg.

On demand, it will be able to make adjustments on the length of the downwind leg by the adjustment of the landing-decision length, in order to ensure the separation from other traffic. It is suggested to extend the landing-decision length in thirty seconds blocks, however, the pilot in command can abort the extension at any time and command the UAS to continuous with the base leg. It will be also possible to make a holding if necessary (see Figure 8).

After the downwind leg is finished, the UAS will fly the base leg has any other aircraft. Usually the base leg is perpendicular to the downwind leg and a descend starts.

Finally, the landing maneuver is formed by a single leg which angle of descent should automatically be computed by setting the last way-point of the base leg and the touchdown fix. The auto pilot should compute the difference between the Desired Touch-Down Fix (DTDF) and the real one (RTDF). If the deviation obtained is greater than a predefined threshold, the missing approach procedure should start by passing to the abort phase. It is clear that the same abort procedure should be used with respect any lateral deviation, speeds variations out of a valid range, or rates of descent out of valid margins.

In case of an abort of the landing, the UAS should fly until re-joining the traffic pattern or until arriving to an EDWP of the runway. The pilot in command should have the capability of command an abort at any time during the approach or landing.

Following the criterion used in the downwind leg, in case of re-joining the traffic pattern, the pilot in command can command an extension of the missed approach leg if necessary to deal with other traffic in the circuit. On the other hand, if the pilot in command desires to go back to navigation, the UAS should

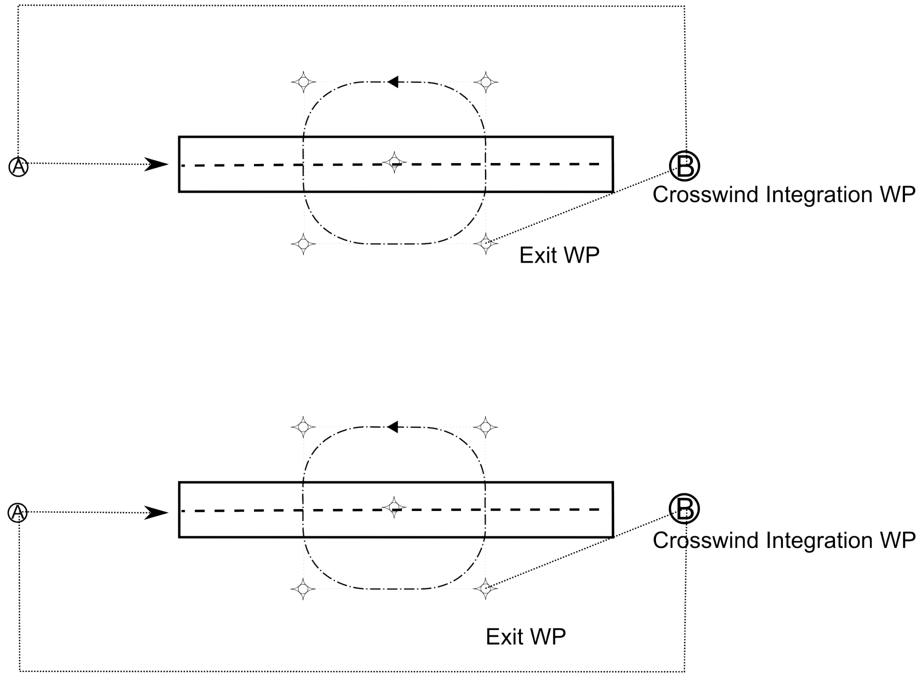


Figure 6. Choose of integration point.

fly to an EDWP of the runway (by default the A EDW should be used).

Finally, if the UAS should land on an airfield without air traffic control and without IFR procedures the last concept is also suggested to be used. First, an evaluation of the situation is done by doing a holding over the aerodrome in a stack philosophy. Once the pilot in command consider that it is possible to joint the traffic, it will demand the UAS to do so. The pilot in command can use predictions computed by the UAS of how much time the aircraft will take to do the integration, in order to take the decision of when is the best moment to starts the manoeuvre. Like in the previous case, the UAS is able to adjust the length of the downwind length or make a hold to ensure its separation form other traffic.

In all the cases, it could be possible to publish different circuits for UAS that have performances much more limited than general aviation aircraft, in IAC or in VAC charts, like nowadays is done for ULM or gliders. For the UAS it should not be a problem to do an left or a right hand circuit. This will not be incompatible with the main integration process described before but can help to segregate slow traffic when necessary.

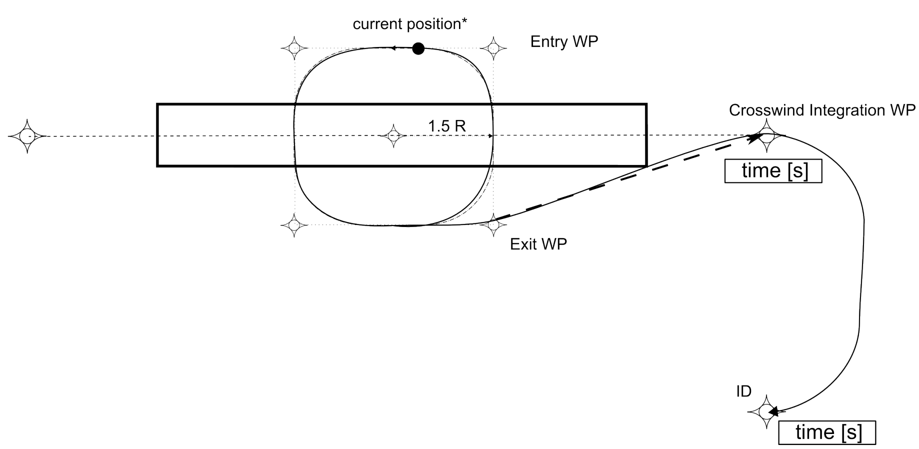
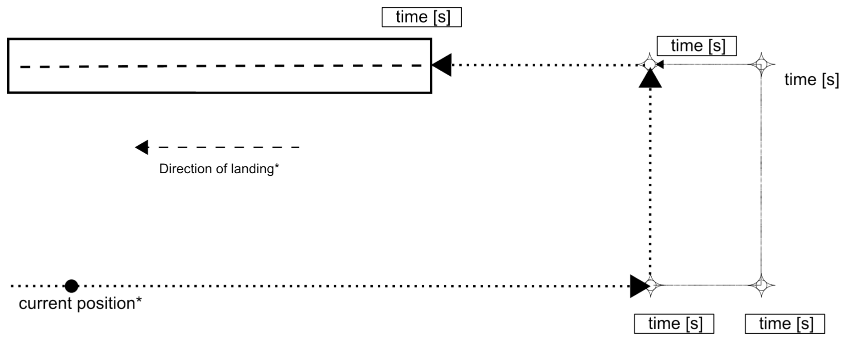
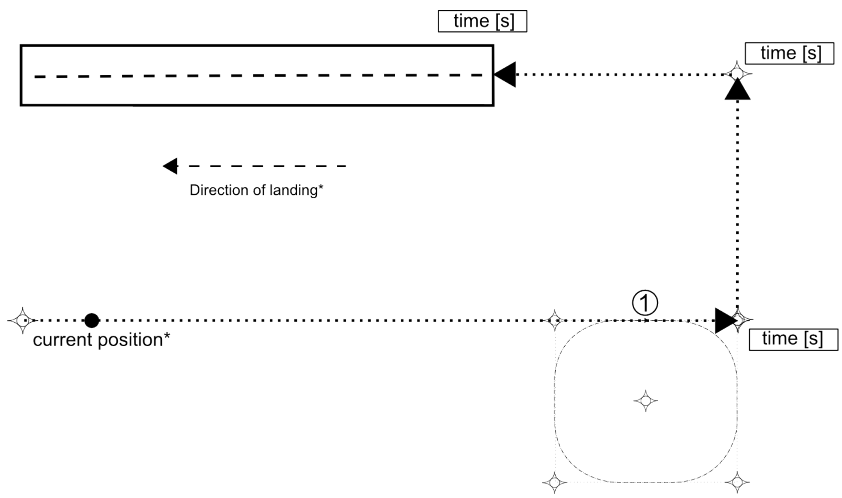


Figure 7. Integration times.



(a) Extension of downwind leg



(b) Holding on downwind leg

Figure 8. Adjustments of downwind leg to adapt to traffic.

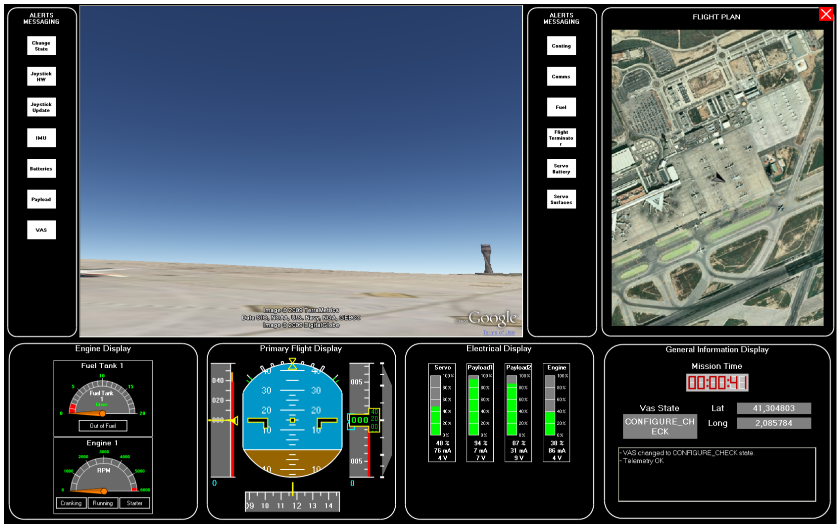


Figure 9. Example of Main Pilot Screen developed for this research.

IV. Human Machine Interface Aspects

The reliable operation of departure and approach operations for UAS requires minimizing the Pilot in Command workload, but at the same time maintain a high level of situational awareness. In order to achieve this objective we have designed an specific Human Machine Interface (HMI) that should complement traditional piloting and navigation displays usually employed in the ground control stations. This section describes the main design principles being employed.

IV.A. The Pilot Interface

The Pilot in Command interface should be highly intuitive and exclusively present in the most relevant information for each phase of the UAS operation. This information should be presented in such a way that just looking at the interface, the PiC could know if all the parameters are within the limits and actuate if necessary.

Radio equipment is also required so as PiC could communicate with the other traffic or the ATC in addition of a first person view with which see other possible traffic and the state of the aerodrome.

The PiC station being developed is called the *Flight Monitor Service*, and it is split in two screens: the Main Pilot Screen and the Auxiliary Multifunction Screen. Of both elements, the Main Pilot Screen contains the classical piloting resources, *i.e.* artificial horizon and most useful gauges, but also including a direction of flight view provided by on-board cameras or by synthetic generated views.

The Auxiliary Multifunction Screen is a reconfigurable tactile screen that will change its contents according to the phase of the flight. In the rest of the section we will establish the main guidelines that drive the design of this auxiliary screen. Figure 9 shows an example of Main Pilot Screen developed for this research that works tightly coupled way with the Auxiliary Multifunction Screen proposed in this paper.

IV.B. Auxiliary Multifunction Screen

As mentioned above, the Auxiliary Multifunction Screen is a secondary tactile screen where schematic information is shown in an intuitive way.

This multifunction screen will be split into three main parts (see Figure 10): the *Differential Display* (DD), which will present "differential information; the *Main Display* (MD) where we will find the more relevant information in each procedure, and the *Interaction Display* (ID), which is the part of the screen where the PiC will have the tools to interact with the UAS. Two secondary parts are also suggested: a parameter summary box and a console which would act as a phraseology reminder in controlled scenarios.

In the case of change to manual operation, the interface will operate as a support device to the PiC.

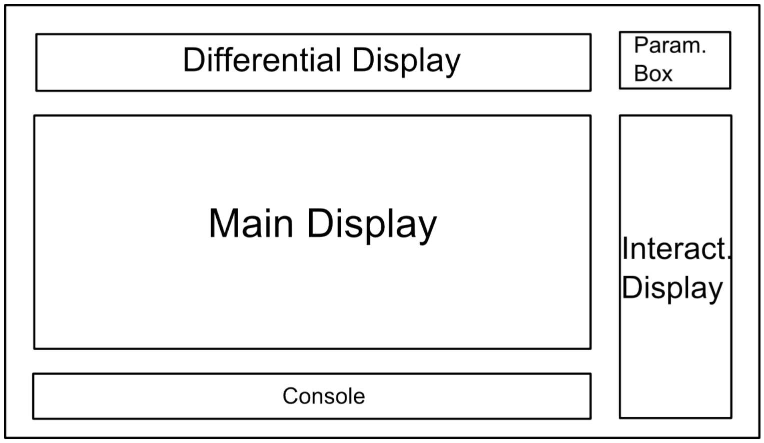


Figure 10. Auxiliary Multifunction Screen.

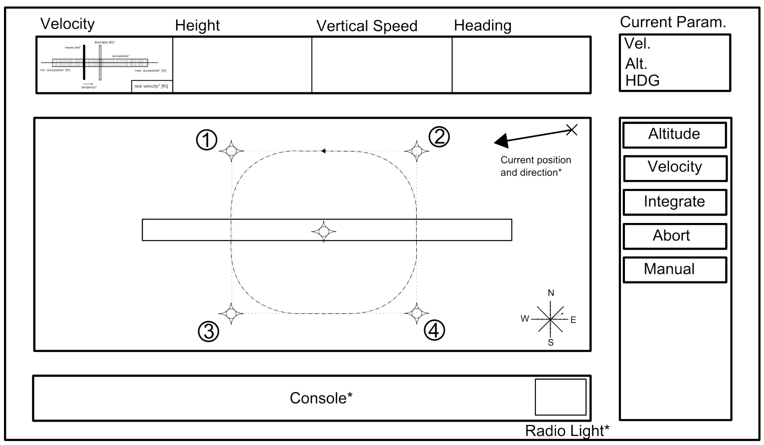


Figure 11. Auxiliary Multifunction Screen: Hold Pattern View.

IV.B.1. Main Display

For each procedure, the most important view of the situation is shown in this display. For example, in the “land pattern phase the most important view is the “plant of the operation, while in the last phase of an “auto land operation a cross section view gives more information. Figure 11 shows an schematic view of the selected information during the hold pattern, while Figure 12 show an equivalent view used during the traffic pattern.

IV.B.2. Differential Display

All the parts in which this display is split would present the desirable value, the current value and a margin of acceptable values for different parameters. The information needed for the construction of these diagrams is at aerodromes parameters database or is directly related to UAS performances.

The construction of a differential diagrams, like for example for the UAS velocity, will be formed by a margin of acceptable velocities, a desirable one (which could be tuned by the PiC), the real (or measured) with its tendency direction and module. All the elements are only descriptive, no one of them would appear in the workstation, and Magnitudes into square brackets are suggested to appear in number.

IV.B.3. Interaction display

The main idea of the interaction display is to decrease the workload of the PiC. In order to achieve that objective, we have designed a display such that the minimum interaction is required. The main buttons (and its operation) that will appear in this display are briefly commented below:

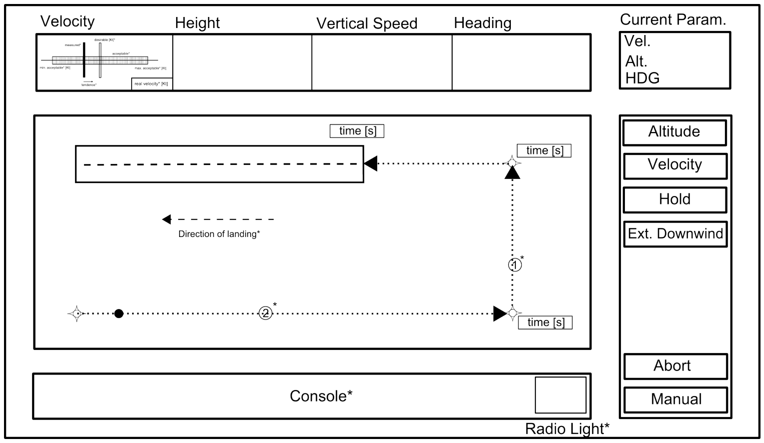


Figure 12. Auxiliary Multifunction Screen: Traffic Pattern View.

Selection button This button should be applied to magnitudes as altitude, velocity, or time. In the two first, once the Ok button has been pushed, the screen comes back to the previous appearance. The changes applies to the desired values, it is AP duty to take into account the performances of the UAS so as to achieve the desired value (see Figure 13).

In the case of the Extended Downwind, to distinguish between “selected time or “time being selected, before pushing the “Intro button the numbers should tilt.

Change state button It is important to note that a semantic distinction have been done between “cancel and “abort. The semantics of cancel is to leave the present procedure and return to the previous one, whereas abort has connotations of change of state.

We suggest putting always Abort and Manual buttons in the same place for ergonomic reasons. This will help the PiC to quickly actuate in view of eventual contingencies.

IV.B.4. Secondary displays

Our proposal is to provide some extra information which could help the PiC to remind parameters or procedures. In order to achieve that objective, we suggest the Parameter Box, the Console and the Radio Indicator.

Parameter Box Within the Parameter Box, fundamental magnitudes for a safe flight should be displayed. These parameters could be: current velocity, height and heading/bearing.

Console and Radio Indicator These two indicators are thought for aiding the PiC in the radio communications. The radio indicator turns on when someone is talking on the selected frequency (for the radio communications a radio interface is required). And main function of the console is to remind the PiC the phraseology in the different cases. A button should be provided in order to skip the phrases. It could also be used as console or reminder in other cases.

V. Example of depart and arrival procedures at an airport without IFR procedures

The arrival procedure for UAS operating at airports without IFR procedures that has been described in Section III is presented for the airport of Sabadell (LELL). The procedure can be seen in Figure 14. The initial holding pattern is shown in orange, in yellow is presented the nominal land pattern and finally in green can be seen the optional holding during the downwind phase and the extension of the downwind to deal with traffic.

For the same airport in Figure 15 is presented the departure procedure. The runway is presented in blue. In this image the take-off and landing will be conducted to the left side of the image. In yellow is displayed

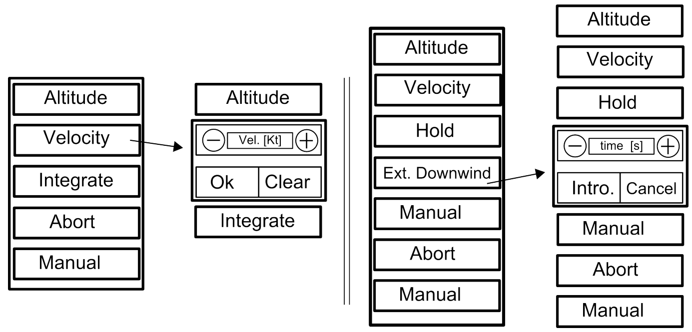


Figure 13. Auxiliary Multifunction Screen: Traffic Pattern View.

Figure 14. Arrival procedure to LELL.

the land pattern, the different areas and EDWP are shown for this airport. The UAS should be able to take-off and fly to one of the EDWPs safely and automatically. From them the navigation will start.

VI. Conclusions and further work

In this paper, a full analysis of the different scenarios where UAS will need to perform departures, arrivals and approaches has been done. As it has been presented, four different cases arises.

As previously said, the UAS will fly like an IFR flight, therefore, the procedures that exists for IFR aircraft can be used for UAS without major changes. In the controlled case with IFR procedures, the UAS will be transparent to the ATC who will deal with it like with any other aircraft. Only in the case where the aircraft has very limited capabilities new procedures might be needed; or even restrictions to their use might apply, like nowadays appends with UML or gliders in major airports.

The pilot in command and not the ATCO will have the responsibility to command the UAS. This means that the ATCO needs to clear and order to the pilot who will command the UAS. Therefore, a communication between the pilot in command and the ATCO should exist. Depending of the used technology the solution will be different but a delay analysis will be necessary in all cases to ensure that the response time of the vehicle is similar to the one reached by manned aircrafts.

Due to the fact that UAS are similar to IFR flight, in a controlled airspace, it should not produce any problem to deal with them. As a consequence, the most challenging operation will be in airfields without IFR procedures, non-controlled and with VFR traffic operating in them. Moreover, it is expected that in the upcoming years, the UAS starts to operate in this kind of fields instead on in busy airfields where IFR traffic operates.

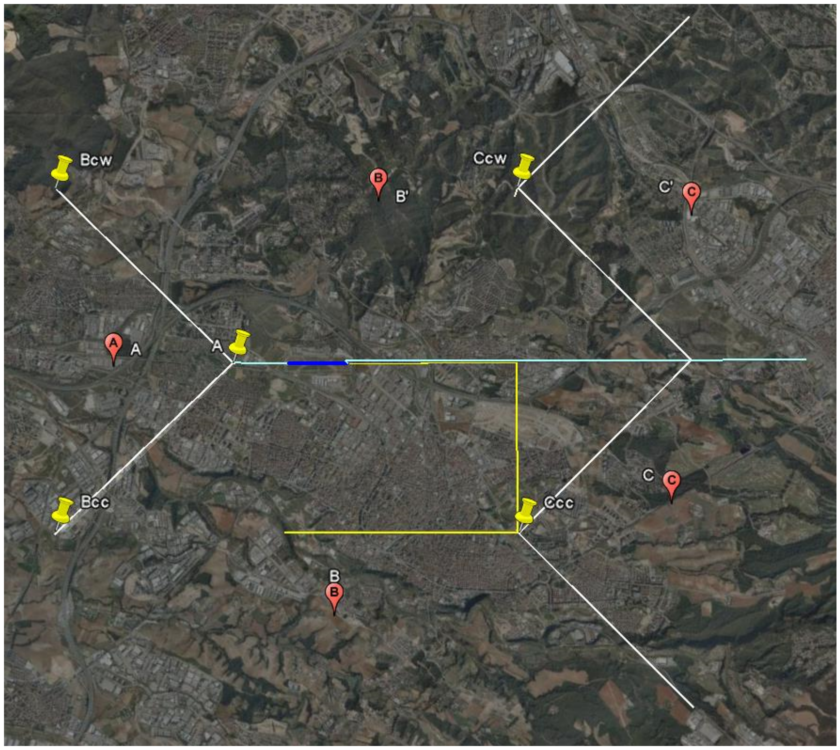


Figure 15. Departure procedure to LELL.

In this case, for arrivals, the authors have propose the use of a pattern similar to the used on VFR on general aviation. This will allow the UAS to fly the most transparent as possible to other traffic in a predictable and safe manner. The authors suggest to use this generic proceeding when there not exists IFR procedures at an airfield even if it is controlled. This will give more confidence to the ATCO, who will know what are the UAS intentions and procedures.

Finally if there are not IFR procedures to take-off, it is proposed to use the diagram shown in Figure 3. Using one of the EDWPs the departure will be much more controlled and automatic. This will reduce the pilot in command workload and will increase the safety and the predictability. The UAS will take-off in a similar manner as general aviation. Moreover, the computation and validation of the EDWPs will be done during the dispatching phase minimizing the workload once in the field if a change on runway or on the first navigation way-point is done.

Further work should investigate how this procedures are integrated in an specific architecture of an UAS. Simulations of the procedures should be done. And finally it should be done a deep study of the interfaces the pilot in command needs to operate the UAS in an easy and safe manner for departure and approach.

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