UAS Air Traffic Insertion Starts Now (Real-time simulation of UAS in ATC)

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Abstract

Civil Unmanned Aircraft Systems (UAS) are presently deployed in segregated airspace; passage though controlled airspace is taking place only through segregated corridors. With the increased use and the growing size of Unmanned Aircraft (UA), the need for insertion in non-segregated airspace increases, with first steps being taken in environments with air traffic control services in normal density traffic situations (en-route and not too busy TMA's). Already, civil UAS are flying in segregated airspace to carry out maritime surveillance missions and their insertion in ATC can be expected to be requested soon.

The European Commission (EC), European Space Agency (ESA), and the European Defence Agency (EDA) have established a European Framework Cooperation (EFC) in which UAS air traffic insertion is identified as major topic to be addressed.

We will describe the results of two experiments with real-time, man-in-the-loop air traffic control simulations to support UAS air traffic insertion.

1 Introduction

Several studies investigate UAS air traffic insertion, mostly addressing Detect And Avoid (DAA), safety of the operations (related to the aircraft, other airspace users, and population on the ground), architectures for data link communication, and definition of standards for certification. However, little effort is currently dedicated to performing actual flight trials and preparatory simulations for actually achieving the ultimate goal: air traffic insertion.

The major work so far in air traffic insertion is the European Civil UAV Roadmap defined by the European Commission funded UAVNet consortium [1] . A further roadmap was defined by a consortium called Air4All [2] The document defines six consecutive steps until full integration is achieved in step 6, where civil type certified UAS fly Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) across national borders routinely in controlled and uncontrolled airspace (airspace classes A, B, C, D, E, F, and G).

In this paper, we present the set up and results of simulations for UAS in order to prepare for full flights in the near future. Actual flights cannot be carried out before the full set of routine and emergency procedures has been evaluated in a simulated environment.

In order to evaluate and validate routes, procedures, and emergency situations, we have set up simulations in a real-time man-in-the-loop Air Traffic Control (ATC) environment, including UAS, which were piloted from a realistic Remote Pilot Station (RPS). In two projects, USICO (Unmanned Aerial Vehicle Safety Issues for Civil Operations, in 2007) and SINUE (Satellites enabling the integration in Non-segregated airspace of UAS in Europe, simulations have been organized, where real air traffic controllers participated to experiments for the introduction of UAS in non-segregated airspace.

For the USICO, a dense traffic sample of the Frankfurt Flight Information Region (FIR) was chosen. For SINUE, we have chosen to set up a radar simulation facility which has been configured for running the scenarios around the Canary Islands in Spain. For this, the Spanish airspace was set up and a representative traffic sample with flights from and to Gran Canarias was implemented.

2 Background – earlier work

2.1 Air4All

In June 2008, the Air4All [2] consortium, comprising of European aviation defense companies and major UAS industry partners, presented a roadmap and implementation plan defining the way to the routine use of UAS within European airspace.

On the understanding that all challenges will not practically be completely solved in one step, the route to insertion of UAS was divided into a number of increasingly challenging steps based around the different classes of airspace and the relative difficulty of operating in them.

Step 1: Fly experimental UAS within national borders in segregated airspace (regular, at short timescale) – Unpopulated range

Step 1a: Fly experimental UAS within national borders in segregated airspace (regular, at short timescale) - overflown sparse population

Step 2: Fly an experimental UAS as IFR traffic within national borders in controlled, non segregated airspace (airspace classes A, B and C)

Step 3: Fly a national type certified state UAS as IFR traffic within national borders, routinely in controlled airspace (airspace classes A, B and C)

Step 4: Fly a civil type certified UAS as IFR traffic within national borders, routinely in controlled airspace (airspace classes A, B and C)

Step 5: Fly a civil or state UAS as IFR traffic across national borders, routinely in controlled airspace (airspace classes A, B and C)

Step 5a: Fly a civil or state UAS as IFR traffic across national borders; routinely in controlled airspace (airspace classes A, B, C, D and E)

Step 6: Fly a state UAS as IFR and VFR traffic across national borders, routinely in controlled and uncontrolled airspace (airspace classes A, B, C, D, E, F and G)

Step 6a: Fly a civil type certified UAS as IFR and VFR traffic across national borders, routinely in controlled and uncontrolled airspace (airspace classes A, B, C, D, E, F and G). Summarized Air4All identifies steps from

- experimental UA to type certified aircraft
- state aircraft vs. civil use of UAS
- national airspace use vs. cross border operations

as depicted in figure 1.

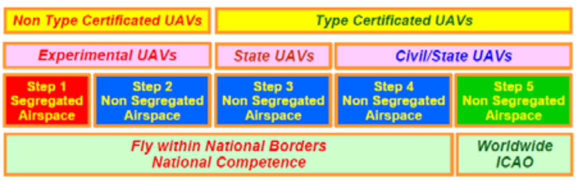


Figure 1 Air4All steps

The Air4All consortium notices that step 1 has already partly been achieved and in progress and the focus for research must therefore be laid at step 2. According to Air4All, step 2 has a number of immature challenges but is considered achievable in a reasonably short timeframe. Step 2 consists of a number of issues, linked to technical challenges and is deemed feasible to be implemented for demonstration by the end of 2011.

2.2 E4U

A representative group of European research establishments has set up a prioritization of actions to identify the major challenges that need to be considered for air traffic insertion of UAS.

The E4U study describes the topics:

- UAS Air Traffic Insertion
- Single European Sky
- UAS Missions
- Platform and payload
- Radio Bandwidth Allocation
- Ground Control Station
- Propulsion systems

The study is ongoing until the end of 2011; early results show that, as expected, DAA and security are important topics to solve in the near future. Furthermore, LOS/BLOS infrastructures and safe recovery systems are identified as important elements for research. In BLOS operations, automated take-off and landing are required.

2.3 Working groups

Standardisation committees EUROCAE WG-73 and RTCA SC-203 are identifying necessary elements of the architecture of communication systems that will support the operation of UAS in non-segregated airspace. Their role is not to endorse or promote a particular architecture, and consequently there is no consensus on what the architecture should look like.

The European Commission (EC), European Space Agency (ESA), and the European Defence Agency (EDA) have established a European Framework Cooperation (EFC) in which UAS air traffic insertion is identified as major topic to be addressed.

3 Introducing UAS flight in non-segregated airspace

Both Air4All and E4U studies identify the flight of an experimental UAS within national borders in controlled, non-segregated airspace as first steps in UAS air traffic insertion. We assume that the current state-of-the-art in UAS insertion is that the aircraft already fly in segregated airspace without major difficulties. Although not all issues are solved completely, we will consider in this paper the next step: fly an experimental UAS in IFR traffic. Topics that need to be addressed for this are.

Separation. The UA will now fly in airspace together with other aircraft. It is expected that increased separation criteria and dedicated ATC is necessary to separate the UA from other aircraft flying in the same sector.

Collision Avoidance. To avoid other traffic, the simplest step is to fly IFR under control of ATC, where ATC will provide separation between aircraft. Airspace considered will be low density class C en-route airspace and quiet Terminal Maneuvering Areas (TMA). The UAS flight will need to be monitored more closely by ATC, but can also be followed e.g. with a chase aircraft or a ground monitoring system. Collision avoidance also concerns obstacle avoidance and the avoidance of controlled flight into terrain.

Secure and sustainable communications for command and control. Security and integrity of the datalink is assumed to be available. The UA is expected to react ‘immediately’ to the instructions of ATC. The experimental flight must be performed at a geographical location where satellite coverage can be ensured.

Radio Bandwidth allocation. This challenge is only relevant to the real experimental flight and not for initial simulations. It must ensure that national authorities provides allowance; the World Radio Conference 2012 (WRC 2012) will decide on allocation of frequencies for UAS.

ATC Interface. The challenge concerning the ATC interface covers the following items:

- Ensure suitable data exchange with ATC
- Ensure continuous ATC interface with sufficient integrity

- Ensure ATC conformal operator interface
- ATC interface for pre-flight information needs definition

A dedicated architecture needs to be set up for communication between ATC and the UA in those situations where a satellite system is used as main communication means.

Dependable emergency recovery. A procedure must be defined and implemented in the UA to ensure safe recovery in emergency cases. An emergency route and procedures for flying towards and at the route need to be set up, just as well as a "home"-area, where the aircraft will eventually fly to in case of emergencies.

Emergency recovery is a major issue for ensuring the safety of flight.

Health monitoring / Fault detection. This challenge concerns the ability of the UA to detect faults which affect the ability to continue safe flight and to avoid collisions. This feature is scripted in the simulation, so that we assure that possible faults are evaluated in our experiments.

UAS pilot / commander training. The UAS pilot must be able to control the vehicle in normal and in degraded operating states. When the UA or communication with the UA is in a degraded state, the pilot must be able to asses the ability to safely fly and land the aircraft.

Furthermore, the UAS pilot must be able to use standard radio communication procedures in communicating with ATC and must have the capability to react 'immediately' to the instructions of ATC.

Demonstration preparation. All studies identify the need for early demonstration and a thorough preparation of demonstration flights. We propose to carry out simulations in a realistic ATC environment in order to explain and train air traffic controllers in handing the aircraft.

4 Research question

To bring air traffic insertion of UAS further, we start with simulating the environments in which the aircraft will fly. It will be possible to set up the necessary architecture in a network of simulators, for the air traffic control station, the RPS, and the satellite communication link. In a real-time simulation environment, air traffic controllers will be able to experience without risk, the aircraft in operation in their sector and experience themselves the aircraft's characteristics, the use of emergency routes and procedures, communication with a remote pilot, and the interaction with other traffic. Our research question was to

1) Identify a suitable architecture for BLOS operations with UAS.

2) Examine the effects on ATC of UAS in their airspace.

5 The architecture set up

In most scenarios, the aircraft will fly en-route their missions in a remote area and will therefore be flying Beyond Line of Sight (BLOS). Communication between the pilot and the aircraft will have to take place through satellite communication. Just as well, communication between the ATC centre and the RPS will be relayed over satellite. Therefore, the architecture proposed must at least enable the Command and Control (C2) link between the UAS pilot and the UA and the ATC link between the UAS pilot and the ATC center, see the functional decomposition in figure 2 (from [2]) below.

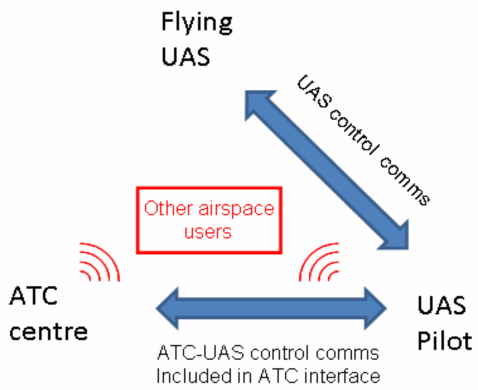


Figure 2 Functional set up

In the simulation experiment, the architecture as depicted in figure 3 was chosen.

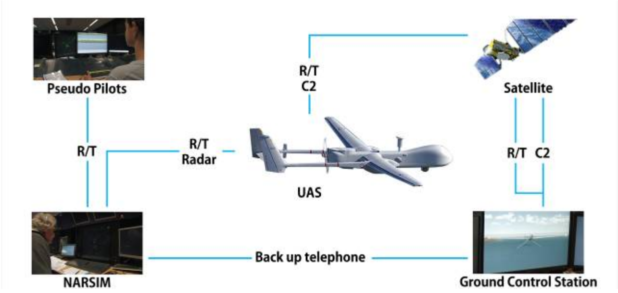


Figure 3 Functional set up

In the center of figure 3, the UA is flying a mission in controlled airspace. The UAS pilot has no line of sight with the aircraft, so command and control will be relayed over satellite. This already is a standard operating procedure for UAS that fly BLOS operations.

Specific attention has been paid to VHF R/T communication between ATC and the UAS pilot. In our set up, the aircraft will receive all R/T on the frequency and relays this signal on a dedicated channel to the satellite. This set up requires significant bandwidth hence operating costs, but our calculations do show that bandwidth does not form a limitation here. A back up for R/T communication is available through a standard telephone line.

A pseudo pilot had to control the other traffic in the simulation. In a typical simulation, depending on the intensity of the required actions, pseudo pilots are capable of dealing with 10 to 20 aircraft at the same time.

6 Emergency Situations/Procedures

The mission of the European Aviation Safety Agency (EASA) is to promote and maintain the highest common standards of safety and environmental protection for civil aviation in Europe and worldwide. EASA performed a study for an impact analysis on safety of communication for unmanned aircraft systems [5].

From this study, through a functional hazard analysis, the following list of relevant emergency situations needs to be covered during experimental simulations and flights:

- Loss of voice communications between UAV/S pilot and ATC
- Interruptions to voice communications between UAV pilot and ATC
- Intelligibility and latency of voice communications between UAV pilot and ATC
- Loss of command and control link between UAV and GCS
- Interruption of command and control link between UAV and ATC (due to system reliability or satcom coverage)
- Loss of surveillance information feed to ATC
- Interruption of surveillance information feed to ATC (due to system reliability or radar coverage)
- Loss of surveillance information to other airspace users
- Interruption of surveillance information to other airspace users (due to system reliability or coverage)

With the exception of the “loss of surveillance information”, all events were considered in the experiments to cover all emergency situations emerging from the use of UAS. As the C2 and ATC signals are relayed through different channels on board the aircraft, the “loss off”- emergency situations can occur for either one of them or for the both simultaneously.

For the design of emergency procedures, three aspects need to be considered: a home area, an emergency route, cleared from the other airspace routes, and a procedure to fly from the current location (where the emergency occurs) to the emergency route.

6.1 Home area

The home area is a base, where the UA will fly to when an emergency occurs. The aircraft will land there or perform a maneuver which will destroy the aircraft without risk of casualties. For each flight and for each experiment, the home area needs to be defined, depending on the local situation. For the two experiments mentioned in this paper, USICO [4] and SINUE [3], two distinct procedures were defined.

In the SINUE set up, a home area above sea was defined, where the aircraft would fly a circular pattern and be climbing in order to try to re-establish communication with a land based station that would be within line of sight. In USICO, an emergency airport was identified.

6.2 Emergency route

An emergency route must be designed that is fully separated from other air traffic routes, so that the UA can follow a path separated from all other traffic. For every flight with a UAS, the route must be carefully evaluated in order to check whether it is easily and safely reachable from the mission area.

Figure 4 shows the route used in the Spanish experiments, where one route was sufficient for all experiments performed. This route was designed in cooperation with air traffic controllers and was designed such that several entry points were defined towards which the aircraft would fly in case of an emergency. The points were chosen so that the aircraft would never fly over inhabited areas in case of an emergency and was vertically separated from other crossing air routes. The figure below shows the emergency route in red. The home-area is located at the bottom in the middle of the figure.

One special situation is when the aircraft is on final approach. In this case, the UA would fly the standard missed approach procedure to avoid it flying through other aircraft on approach, see the “hook”–pattern on the bottom of the picture.

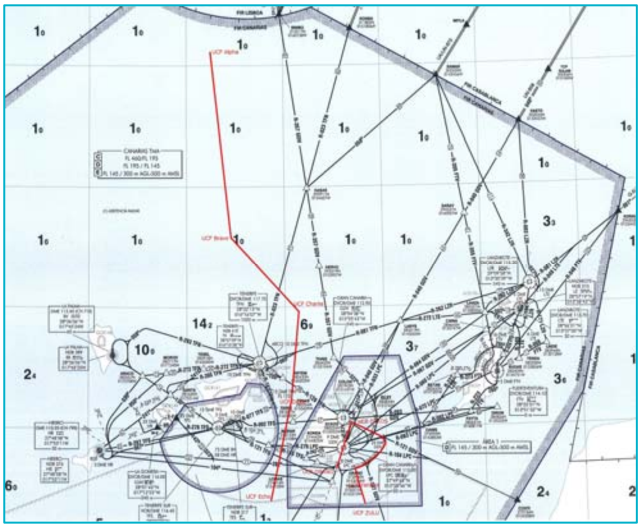


Figure 4 Design of emergency routes

For USICO, the simulated airspace is the TMA Frankfurt controlled by Frankfurt Arrival and the western sector controlled by Langen Radar. Controller working positions of the ATC center (Frankfurt Arrival and Langen Radar) are provided by the employed ATMOS. The simulated traffic in these two sectors is piloted by the pseudo pilots. The traffic in the northern and southern sector is navigating fully autonomously, i.e. it is so called dummy traffic. See figure below. For the emergency, the airport of Hahn was planned as alternate.

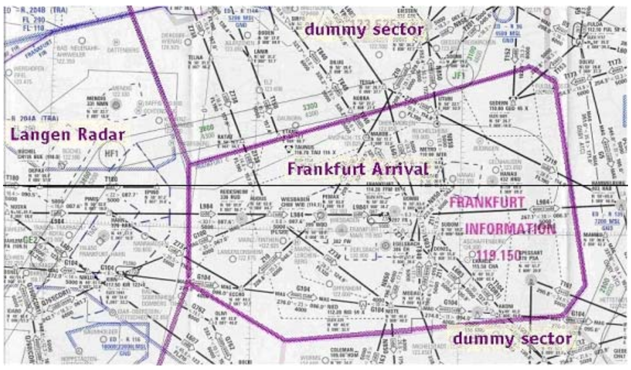


Figure 5 USICO TMA Frankfurt

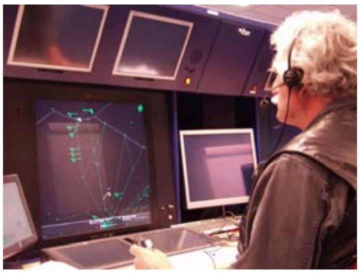
6.3 Towards the emergency route

To reach the emergency route, the UAS follows a standard procedure which is known to the controller and the remote pilot. The procedure chosen in the SINUE study follows the procedure that has to be followed by other aircraft as well: the UA will abort its flight path by turning towards the closest way point on the emergency route and maintain its current altitude for two minutes. After the two minutes the aircraft would climb or descent towards the altitude of the closest way point on the emergency route.

7 Experiments

In the simulations we carried out experiments in air traffic control simulation facilities, where real air traffic controllers participated to carry out the simulation and to evaluate the proposed concept and procedures.

We used an air traffic control simulator, which resembles the airspace where the aircraft is flying as much as possible.



Experienced air traffic controller and pseudo pilots were running the experiments, who were briefed at the beginning of the day and were given the possibility for training.

Through questionnaires directly after each run and at the end of a simulation day a directed list of questions was handled. Just as well, at the end of the day, a discussion session was held with all participants of the simulations.

8 Results

The goal of the two studies was to examine the effects on ATC of UAS in their airspace. From the simulations, questionnaires, and debriefings, we obtain results for the sessions that were held.

Separation and collision avoidance. In the simulations, we did not use different separation criteria than those currently in use. The aim was to see if current separation can be maintained, even though there is no pilot on board the aircraft. We instructed controllers to use current separation criteria for the UAS, which they were able to maintain. In initial practical trials with real aircraft, for safety, the separation between a UA and a piloted aircraft will be increased in actual air traffic insertion experiments. The exact separation will need to be decided by the regulatory authority.

Communication. Communication delay because of the satellite connection will not be an issue when high quality bands are used. For SINUE we have chosen to perform the mission around the Canary Islands, where coverage of the Hispasat satellite system can be ensured. The satellite gives a delay in voice communication of around two seconds. In the scenario (no dense traffic), this was rated acceptable by the air traffic controllers.

ATC interface. We investigated the interface with ATC with respect to these aspects. New special squawk codes are proposed:

7600: comm loss
7660: datalink loss, proceed as planned
7661: datalink loss, return home
7662: datalink loss, fly to emergency field
7700: emergency

Although controllers have indicated that they do not particularly require specific terminology or symbols for UAS guidance. Either they do not feel comfortable with more information, or they expect that more information will not help them in solving the issues at hand.

Dependable emergency recovery

In the simulation, we have defined a “home”-zone, to which the aircraft will fly following a standard route which is separated from other airspace routes. The procedure for flying towards the standard route follows common practice.

Controllers in all cases indicated they felt comfortable with the procedures defined, even where the emergency situation would occur at the “most inconvenient moment”. In our case an UA was flying without control trough an arrival stream and in another situation straight towards two low flying IFR aircraft. As long as emergency situations are defined similar to those of manned aircraft, controllers are well trained for emergency situations.

Situational awareness. It is important for all parties to have a good overview of the traffic situation and to have the same mental picture of a traffic situation. This implies that there is a need for a good situational awareness for air traffic controllers, UA pilots, and pilots of other traffic.

The air traffic controller will need to know that he is dealing with an unmanned airccraft in an instance. Already at any existing ATCo's (Air Traffic Controller) display, the aircraft type is indicated in the aircraft label. The aircraft types need to be known to controllers. Other options to give more recognition to the UAS can be:

- A special convention for the use of callsigns can be arranged for UAS.
- A dedicated UAS symbol can be used to depict the aircraft.
- The UA label at the ATCo's display can be made more explicit, e.g. by use of a special colour.

The unmanned aircraft must be easily visible by eye for controllers in the control tower, which implies that the colour coding of the aircraft bodies and liveries must be carefully designed.

During the introduction phase of UAS into air traffic control, other pilots will need to be aware of the flying objects around them. Air traffic control must play a role in this, through informing pilots that an unmanned aircraft is flying ahead of them. This can be quite easily accommodated through informing other traffic over the R/T that a special aircraft is flying in their vicinity. This is already common practice, e.g. with hot air balloons and glider traffic.

Just like for air traffic controllers in the tower, the aircraft must be easily visually recognizable for other pilots.

Emergency procedures. In the experiments, all emergency situations as identified by EASA were tested.

We observed that controllers were not always fully aware of the aircraft's behavior at the moment that it was flying towards the emergency route. This was partly due to the fact that they used it for the first time.

From the discussions with controllers, it is suggested to define and discuss the emergency routes in advance of any simulation or real flight trial, based on the planned flight of the UA. The altitude of the points on the route must be defined such that the aircraft will make as little as possible a vertical movement on its way towards the route. Just as well, the route must also be defined as high as possible, to increase the possibility for re-establishing communication, either through satellite or via direct line-of-sight.

The emergency route can be displayed at the controller's display, either at all times or only at request of the controller.

Back up phone. One specific back up element was introduced in the SINUE experiment. The air traffic controller was able to contact the UAS pilot directly by phone. This possibility is especially interesting in case of R/T failure between ATCo and UAS.

The procedure to initiate a phone call was implemented as follows. In case of a communication failure involving the UA, the UAS pilot initiates a phone call between him and the ATCo. The controller has to "answer the phone". The connection was a fixed phone connection that is open as long as the connection was active. Voice on the telephone was relayed over the headset of the ATCo. The ATCo used his microphone to talk and did not have the use the Press To Talk (PTT) button. This mean the UAS pilot was able hear all communications from the ATCo to the other pilots and that all other traffic was able to hear the instructions from the ATCo to the UAS pilot. The UAS pilot and the pilots of the other traffic were not able to hear each other.

In any future concept, it needs to be identified in what particular situations the telephone connection should be activated. Possibly, all communication between the pilot and the ATCo can be performed over telephone, removing the necessity for R/T installations on board the UA.

Workload. One important issue is workload. We measured workload with some of the USICO experiments After adequate training of controllers during the warm-up runs the controllers felt that the simulation set-up represented quite well a real working environment of ATC controllers. Hence there is evidence that the obtained results are representative for a real ATC/ATM environment.

The trials started with the baseline of the normal traffic. Later on, 2 UAVs have been added into the airspace. It could be shown, that the workload increased, which was due to the "new" behavior of the type of aircraft. Figure 6 shows an example of the results of NASA TLX workload determination of the controllers for those different trials

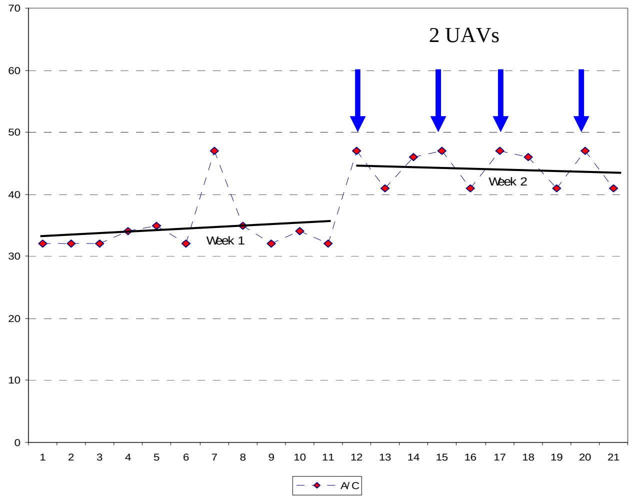


Figure 6 NASA TLX workload vs. trials without (left) and with UAVs (rigth) included in airspace [6]

Recommendations

We asked the controllers whether they would assign a different priority to unmanned aircraft over manned traffic. Interestingly, they considered UA traffic lower priority than commercial traffic and would treat it as small VFR traffic. This needs to be taken into consideration with assigning routes and sequences to the UA.

From the results of the simulations, the following recommendations are given:

- When operating over satellite, keep the RPS on the party line. The UA pilot and the pilots of other traffic must be able to hear each other and hear the instructions given to each of them.
- Dedicated R/T must be developed or existing R/T must be adapted to inform other pilots of the UA in their vicinity.
- The UA does not require new symbology on the ATCo's display, but the ATCo must be able to see in a glance that the aircraft on his display is unmanned. A simple indication by using a dedicated type of call sign will do.
- The ATCo does not require more information on emergency transponder codes.
- ATCo's need good training of emergency situations.
- Benefit can be taken from the fact that communication with the UA pilot can be established over a high quality land line.

9 Conclusions

We have set up a real-time man-in-the-loop simulation environment, where real air traffic controllers, a pilot at a UAS RPS, and a real pilot (for other traffic) participated to evaluate the concept. Several representative scenarios were evaluated, including emergency situations.

We have shown that integration of UAS in controlled airspace is a feasible concept; air traffic controllers indicated that control of the UAS did not differ significantly from control of other, manned, aircraft. We have also demonstrated that UAS emergency procedures can be designed equivalent to those of manned aircraft, such that the air traffic controller will understand them and is able to predict the behaviour of the UAS in several loss-of-satellite-communication situations.

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