"FILE AND FLY" – PROCEDURES AND TECHNIQUES FOR INTEGRATION OF UAVS IN CONTROLLED AIRSPACE

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Abstract

The mission spectrum of future UAVs will require their integration into civil airspace. Up to now neither technologies nor procedures to enable UAV operations in civil controlled airspace have been established. In this paper standard and emergency procedures for UAV guidance are presented based on the idea that in civil controlled airspace a UAV should behave like a manned aircraft from ATC's point of view. Special emphasis is given on the emergency case of datalink loss. Further on, a generic system architecture for a UAV system is presented which enables the validation of the proposed procedures.
Results of the ongoing national German WASLA-HALE project are presented which includes ATC simulation trials as well as flight trials with DLR`s research aircraft acting as an UAV.

1. Introduction

The fulfillment of existing and future surveillance requirements can only be guaranteed by a strong connection between ground-, air-, sea- and space-based systems. One component in this surveillance scenario will surely be a high-flying, air-based system with long endurance (HALE – High Altitude Long Endurance). It can be assumed that such a surveillance system will be based on an Unmanned Aerial Vehicle (UAV).

Assuming that a HALE-UAV will be based on its own territory, flight to mission area will require participation in common airtraffic. Currently operated systems can only be flown in restricted airspace and are not certified for operation in civil airspace.

In order to achieve the flight level required for the surveillance mission (approximately 50-65kft), several zones of controlled airspace have to be passed before the mission area is finally reached. Figure 1 shows a typical HALE mission profile with respect to the passed zones of airspace. The numbers 1 through 8 denote the following flight/mission phases:

1. Mission preparation
2. Taxi
3. Climb
4. Cruise flight
5. Flight in mission area
6. Return flight to base
7. Approach
8. Landing

Every flight phase may happen in civil airspace and besides phase 5 they do not differ from those of a normal flight of a civil manned aircraft.

Therefore, a major requirement for UAVs will be that from ATC's point of view they behave and perform like manned aircraft. Consequently, a UAV system must be capable [4] of

1. having standard (voice) communication with ATC,
2. following ATC commands immediately,
3. performing emergency procedures.

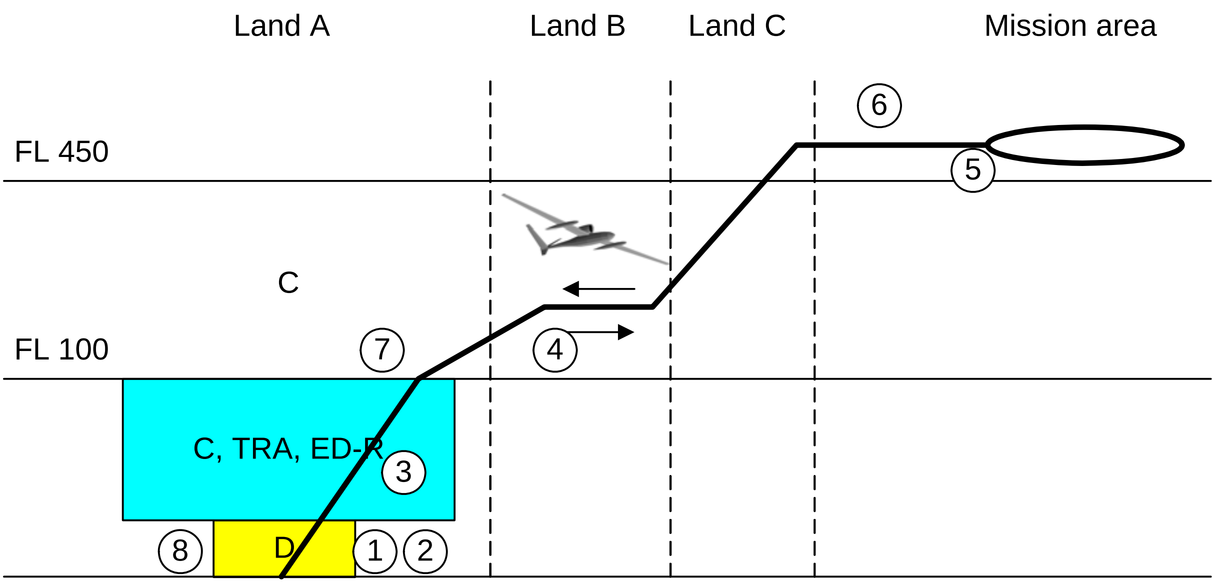

Fig. 1 Scheme of a HALE mission

In addition, it has to be considered that a HALE mission should always be carried out using IFR due to required all weather capabilities and due to the technical constraints of remote guidance (e.g. limited datalink capacity).

1.1 The WASLA-HALE Project

In 2000 the national German UAV demonstration project WASLA-HALE (Weitreichendes Abbildendes Signalerfassendes Luftgestütztes Aufklärungssystem – High Altitude Long Endurance) started. The project consists of 3 phases and is sponsored by the German Ministry of Defense. The project is carried out by a consortium of DLR, DFS, ESG, EADS and WTD61. The main objective of the project is to develop procedures and techniques for the integration of UAVs into civil controlled airspace and to validate them in simulation and flight trials. After a short definition phase, the main activities of the second phase (2001 – 2004) comprised procedure development (with focus on emergency procedures), their validation in ATC simulations, and the development and flight testing of a UAV evaluation platform based on DLR’s research aircraft ATTAS. The third phase has started recently with a focus on “See and Avoid” aspects. This contribution will report on the results of the second phase. Sections 2 and 3 are focusing on standard and emergency procedures for UAV operations in controlled airspace with special emphasis on the problem of datalink loss including results of ATC simulations. In section 4 basic concepts of a UAV system (airborne and ground components) are described which allow the validation for the procedures for UAV integration in civil controlled airspace.

2. Principles of Procedures for UAV Guidance in Controlled Airspace

The general idea that in controlled airspace a UAV should behave as a manned aircraft has some major advantages. As long as the complete UAV system consisting of the UAV itself, the ground control station and the datalink maintains the same level of safety as a manned aircraft there’s no need to design special new procedures for UAV for standard operations like radar vectoring, communication, etc.

In such a scenario the datalink between the ground control station and the UAV has to fulfill two tasks:

1. Transmit all information from and to the UAV necessary for UAV guidance and control

Table 1. Example of a chain of action to implement an emergency procedure for datalink loss

Step	Action Ground Control Station	Action UAV	Action ATC	Remarks
1		Two minutes after datalink loss has been detected, transponder code 7700 is sent. Simultaneously, a program is activated to navigate according to the actual flight plan		If radar vectoring is in use the UAV will navigate directly to the nearest significant way point of the actual flight plan.
2			Ensures that the expect flight path is free	
3	Dependent on the flight phase (see above) a new flight plan is generated	Dependent on the flight phase (see above) a new flight plan is generated		UAV starts the activation of the new flight plan 30 minutes after the datalink loss has been detected, assuming that all necessary coordination already have been carried out by ATC and the ground control station
	UAV operator informs ATC about the future plans of the UAV via telephone			
4			Ensures that the expect flight path is free	
5		UAV navigates according to the new flight plan to the approach fix, performs a 10 minute holding and starts to land		

2. Enable communication between ATC and the UAV operator. Here, the UAV itself serves as a relay station, so that the air traffic controller has the illusion he’s talking to a pilot of a manned aircraft.

As long as the datalink is working properly even emergencies can be handled in the same manner for UAVs as for manned aircraft. Only a few UAV related enhancements may be necessary. E.g. the UAV operator has always the possibility to communicate with ATC via telephone so information can be exchanged even if standard VHF voice communication is no longer possible.

One emergency case that is very special for UAVs is the datalink loss between UAV and ground control station. Up to now there exists no emergency procedure which covers this case of a fully autonomous unmanned vehicle in controlled airspace. Of course, the actual performance of the UAV in such a case depends on the onboard capabilities to react in a proper way to this emergency.

The basic concept to handle such an emergency is based on the standard “Lost Com” emergency procedure: The UAV should behave exactly in the same manner as a manned aircraft that lost its capability to communicate with ATC which means that basically the UAV will follow its flight plan. But having in mind that UAV missions can be quite long, one design criterion for the datalink loss emergency procedure could be to reduce the amount of time the UAV is within controlled airspace. Depending on the flight phase one of the following three alternatives is proposed be used:

1. Proceed as planned, if the UAV is on the return flight and remaining flight time is less than 60 minutes or
2. Return home, if UAV has just started and remaining time to home base is less than 60 minutes or
3. Fly to alternate airport otherwise.

Following this concept three different variants for the datalink loss emergency procedures have been developed:

1. Adaptation of the Lost Com emergency procedure without considering possible telephone communication between ATC and the UAV operator.
2. The same approach as in 1 but the UAV is reducing the remaining flight time by approaching the next alternate airport (see above). The UAV operator will inform ATC about the expected UAV maneuver.
3. The third variant corresponds to proposal 2 but the controller will be informed about possible alternates when the UAV enters the sector so that in case of datalink loss no telephone communication between ATC and the UAV operator is required.

As an example the chain of actions to implement the emergency procedure number 2 for datalink loss is described in the table 1:

3. ATC Simulations

The general objective of the ATC simulation runs at the DFS facilities in Langen was to validate whether or not UAV could be treated form ATC's perspective like standard IFR traffic. Special emphasis was given on the previously defined emergency procedures. Fig. 2 shows a typical profile which has been used during the simulations.

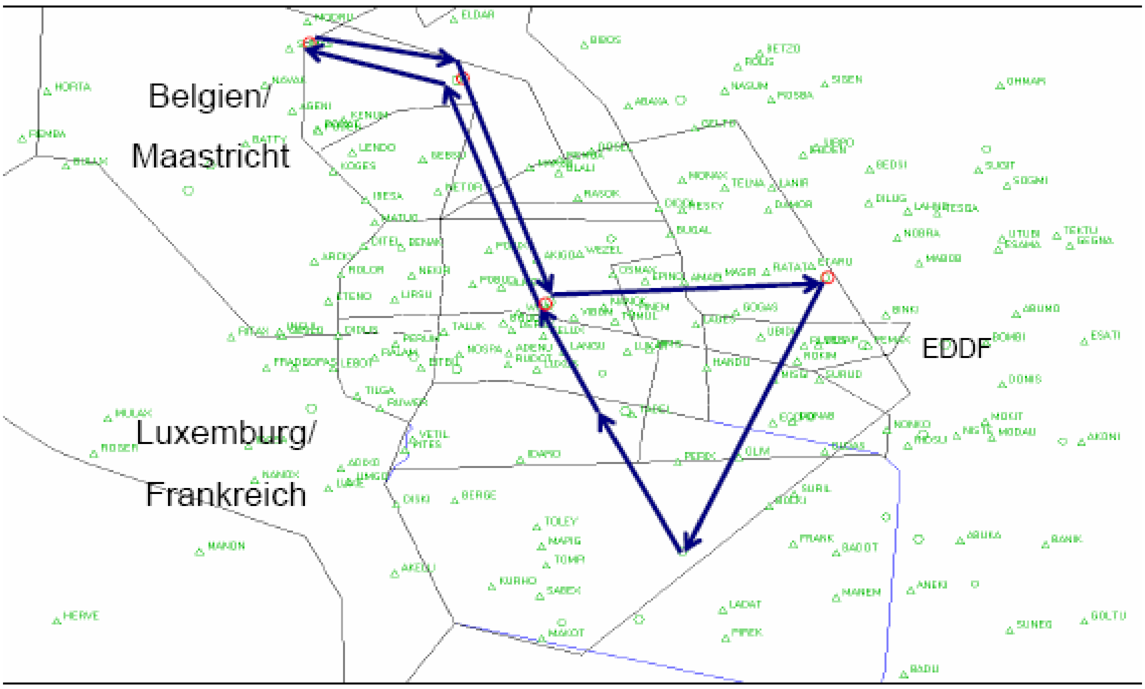

Fig. 2 Typical example of a UAV flight path used in the ATC simulation

The following emergency procedures have been investigated during the trials:

- Engine failure
- R/T Failure
- Datalink Loss

Furthermore, procedures like avoiding a bad weather area and TCAS (Traffic Alert and Collision Avoidance System) events have been simulated.

A 2 week simulation campaign has been conducted with 4 experienced controllers from DFS. During this period, 18 simulation runs with a total simulation time of about 9 hours have conducted. After each run questionnaires have been answered by the controllers and workload assessment using NASA TLX have been performed.

The results of the trials can be summarized as follows:

1. **UAV operations in controlled airspace under IFR without emergencies:** There are no additional requirements on controllers for UAV operations under normal conditions. UAVs can be handled like standard IFR traffic.
2. **UAV operation in emergencies that can be compared to those of manned aircraft:** Emergencies during an UAV operation like R/T failure, engine failure, TCAS events can be handled according to the emergency procedures of standard IFR traffic, provided that the UAV performance is comparable to standard aircraft performances.
3. **Datalink Loss**: This emergency is the most challenging one from the ATC perspective. All three different procedures as described in section 2 have been tested or discussed with controllers. Currently, the first proposal can be regarded as the safest one since it follows the standard Lost Com procedure. But this might lead to a long period in which the UAV will still fly within the controlled airspace which will introduce higher workload for that long period. The second proposal for datalink loss shortens this time period by using an alternate for landing. But this requires a direct communication between the controller and the UAV operator which might be difficult to realize, depending on where the UAV-operator is located. In the third proposal, the respective alternate airport is communicated to controller when the UAV enters the sector. Thus the predictability of the UAV trajectory in case of datalink failure is ensured. On the other hand, since such an emergency should be a rather rare event, this additional information will in most cases not be used by ATC and thus may lead to situations where this information will not be registered anymore.

In addition, controllers would prefer that a UAV specific squawk for the datalink loss is introduced. A datalink failure does not correspond exactly to the Loss Com case (Squawk 7600) neither to the Emergency Squawk 7700 because the UAV is still in a stabilized situation due to the autonomous airborne systems. An additional UAV specific squawk for datalink loss would give as well the possibility to indicate further deterioration of the UAV in case of e.g. an engine failure.

4. UAV system design

In order to be able to fly both standard procedures and emergency procedures in controlled airspace an adequate situation dependent work share between the UAV and its ground control station has to be established. This may reach from full ground control authority up to full onboard autonomy. Full ground control authority means that all UAV movements are initiated and controlled by the UAV operator. The autonomy given to the UAV will result from the datalink latencies, e.g. in order to avoid PIOs, A/C stabilization will be performed automatically. Full onboard autonomy requires only minor (or even no) activities from the UAV operator, the ground tasks are mainly planning and monitoring oriented. Especially in case of datalink loss the capability of full onboard autonomy is of major advantage for the integration of UAVs into the controlled airspace (see section 2).

The problem of situation or task dependent work share in aviation between man and machine has already been addressed in the field of pilot assistance. The basic idea behind a pilot assistance system is that of an “electronic co-pilot” [1]. In order to assist aircrews performing the guidance loop consisting of situation assessment, plan generation according to the present state and the given mission order, decision which plan to follow, execution of the plan, and finally monitoring if the flight is following the active flight plan, a concept for an ”electronic co-pilot”, a so-called Intelligent Pilot Assistant (IPA) has been developed. As depicted in Figure 3 this IPA performs exactly the same loop of tasks as the pilot besides the task of decision making. In commercial aviation and many military applications this step still is within the responsibility of the aircrew. Nevertheless the concept can provide complete autonomous operation modes, as they might be required for future single piloted cockpits or UAVs as addressed in this paper.

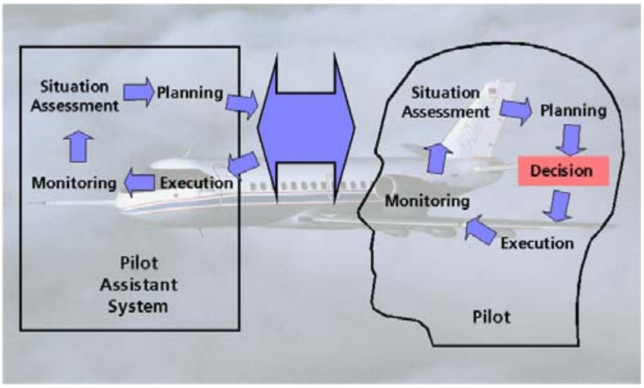

Fig. 3 Concept of an Intelligent Pilot Assistance System

A generic architecture for intelligent pilot assistance has been developed and validated by DLR's Institute of Flight Guidance in cooperation with the University of the Armed Forces in Munich and the ESG-GmbH [2][3][6]. Within this architecture assistant functions are implemented as modules grouped around a core system consisting of a central data pool and a module manager, see Figure 4. This data pool contains all relevant data available on board. Therefore every module connected to the data pool is able to access any necessary data via the module manager.

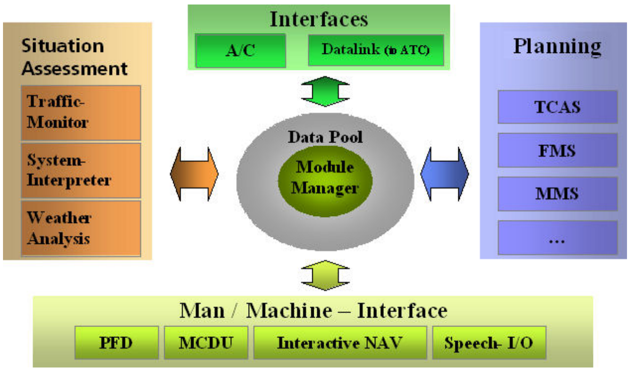

Fig. 4 Generic architecture of an Intelligent Pilot Assistance System

Sophisticated data handling methods are implemented in this architecture to allow modules to be notified whenever relevant data have changed. This architecture allows sequences of actions performed by the system to be modeled entirely by specifying which input data are required for certain functions. Changes in these data will then trigger the corresponding functions. This mechanism is used to achieve the situation assessment and automatic response to critical situations.

The architecture is very flexible and easily extendible. Because of its generic character it easily can be used as core for any kind of assistance system. Predefined templates allow a rapid design of new modules and functions. In addition already existing systems like the Traffic Alert and Collision Avoidance System (TCAS), Ground Proximity Warning System (GPWS) are integrated as well.

Obviously, this concept can be transferred easily to the design of a UAV system. The onboard system must have the same capabilities except that a HMI is not necessary and decision making capabilities (for full autonomous operations) as well as datalink interfaces for communication with the ground control station have to be added. Thus, a high integrity system chain covering all systems involved in aircraft control like

- Mission Management System (MMS)
- Flight Management System (FMS)
- Automatic Flight Control System (AFCS)

can be established.

For architecture of the ground part of the UAV, again a similar architecture has been developed (or derived from the IPA architecture). Of course, a HMI for the UAV operator is needed which can be used to guide or control directly (full ground control authority) the UAV and for communication with ATC using the UAV as a relay station. Furthermore, onboard tools like MMS and FMS are integrated in the ground system, too. These systems can be used to assist the UAV operator in guiding and controlling the UAV as described in detail in [5].

Especially in the case of datalink loss these systems are important because they are identical to the respective onboard systems. So these systems can be used to forecast the behavior of the autonomously operating UAV in case of datalink loss. Consequently, ATC can still be informed about the future flight path of the UAV in that special emergency case.

Fig. 5 DLR's Advanced Technologies Testing Aircraft System ATTAS

These systems (ground and onboard) have been flight tested in phase II of the WASLA-HALE project. In total 36 flights with altogether about 50 flight hours have been performed using DLR's Advanced Technologies Testing Aircraft System 'ATTAS' as shown in Figure 5.

The UAV Flight Demonstration Program covered among others the following items:

- Demonstration of standard procedures in restricted airspace (TRA)
- Flight according to pre-planned IFR flight plans
- In-flight re-planning of IFR flight plansDemonstration of emergency procedures in restricted airspace (TRA)
- Demonstration of standard procedures in civil controlled airspace
- Demonstration of emergency procedures in civil controlled airspace

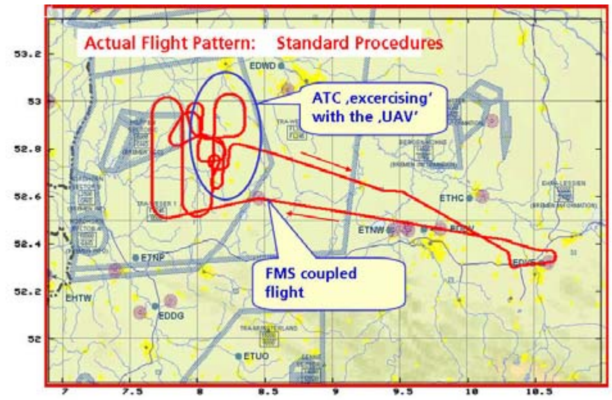

Fig. 6 Flight trial results of standard IFR procedures

Figure 6 shows as an example of the flight trials the flight path of the UAV (the ATTAS operated by the UAV ground station located in Braunschweig) performed in a reserved airspace (TRA). Both, standard FMS operations and ATC giving radar vectors have been performed successfully. Figure 7 shows the results of a flight trial in which emergency procedures have been successfully tested: Firstly, a bad weather area has been avoided an secondly, after a datalink failure the UAV diverted correctly to the alternate airport (here Hopsen).

The flight campaigns have shown very promising results. They give strong evidence that the presented procedures and technologies are adequate means for the integration of UAVs into controlled airspace.

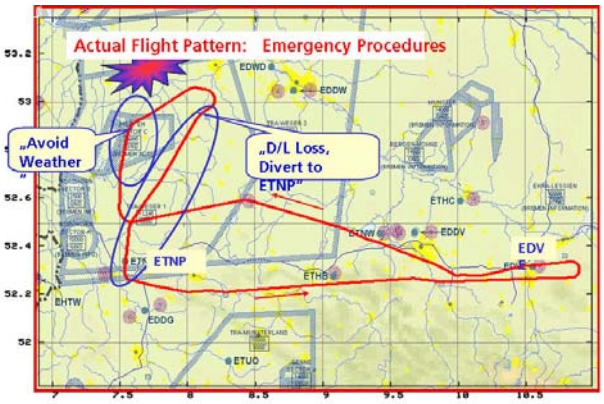

Fig. 7 Flight trial results of emergency procedures

5. Conclusion

Future military as well as civil applications probably will require operations of remotely guided UAVs in civil controlled airspace. Up to now neither procedures and nor technologies for integration of UAVs in common airspace have been established. The idea of a UAV behaving like a manned aircraft from ATC's point of view offers a very elegant solution to this problem. Except the emergency case of datalink loss only few enhancements to existing emergency procedures for manned aircraft have to be established. Comprehensive ATC simulations gave strong evidence that UAV integration into controlled airspace should be possible.

The problem of datalink loss has been addressed in this paper. Emergency procedures have been proposed and tested in ATC simulations which allow a safe operation of autonomously operating UAV in controlled airspace. Such procedures require onboard systems which are able to generate and execute situation dependent emergency flight plans autonomously. In addition system architectures for both the onboard and the ground system have been presented. Using the same control and planning tools like MMS, FMS and AFCS in the ground system as in the onboard system, the UAV's behavior and future flight path can be forecasted by the ground control station and transmitted to ATC. The procedures and technologies presented in this paper are currently being tested and validated in an ongoing German UAV demonstration program. First results of the flight trials have shown promising results that based on the presented concepts a safe integration of UAV operations into controlled airspace seems to be feasible.

However, one important point when operating in civil airspace should not be neglected. Currently, the "See/Sense and Avoid" principle is valid as a safety net for all aircraft operations in any airspace. Consequently, UAVs have to have this capability. Among others "See/Sense & avoid" is currently investigated in the third phase of the WASLA-HALE program. First results of flight trials will be available in mid 2007.

6. References

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