PRACTICAL EXAMPLES OF PROCEDURE DEVELOPMENT FOR UNMANNED FLIGHT IN CONTROLLED AIRSPACE

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Abstract

Uninhabited aerial vehicles (UAV) experience an increased attention for various military and civil applications. Especially these civil applications as well as training requirements for the military UAV require these vehicles to operate in controlled airspace. As UAVs exhibit a considerably different system architecture compared to conventional manned aircraft, the design, validation, verification, and certification of these systems is a key focus of current research and development activities.

Aspects of miniaturization of flight system hardware, increased navigation system requirements, secure and reliable data link, etc. need to flight demonstrated in order to reduce the development risk of future UAV airframes. The DLR Advanced Technologies Test Aircraft System (ATTAS) is a highly suitable tool to host these flight systems and expose them to a real flight environment.

The present paper describes an integrated UAV technologies demonstration approach using this aircraft.

One key element of UAV technologies is unmanned flight in controlled airspace. Currently, no commonly practiced and accepted procedures exist for certification and acceptance of UAV in controlled airspace. All UAV operations up to now have been performed in restricted areas (TRA temporary restricted areas) without or low population density, over oceans, in a time limited fashion, or during military battle field operations.

The present paper therefore also includes a part on UAV flight test demonstration in controlled airspace using ATTAS. Necessary activities include definition of operational requirements, development of standard and emergency procedures. Main focus is always on the interaction with air traffic control (ATC) while addressing issues like mission planning (flight plan), flight guidance and control, communications, secure separation to other aircraft, autonomous landing, and data link. The flight test demonstration approach for emergency procedures due to loss of data link, loss of communication with ATC, system failures and external disturbances will be covered as well.

1 Introduction

Uninhabited aerial vehicles (UAV) experience an increased attention for various military and civil applications. Especially these civil applications as well as training requirements for the military UAV require these vehicles to operate in controlled airspace. Currently, no commonly practiced and accepted procedures exist for certification and acceptance of UAV in controlled airspace. All UAV operations up to now have been performed in restricted areas (TRA temporary restricted areas) without or low population density, over oceans, in a time limited fashion, or during military battle field operations.

The present paper describes a flight test demonstration approach how the existing

German category I and II certification standards can be extended to also cover category III UAV like Global Hawk. Necessary activities include definition of operational requirements, development of standard and emergency procedures. Main focus is always on the inter-action with air traffic control (ATC) while addressing issues like mission planning (flight plan), flight guidance and control, communications, secure separation to other aircraft, autonomous landing, and data link. The flight test demonstration approach for emergency procedures due to loss of data link, loss of communication with ATC, system failures and external disturbances will be covered as well.
The importance of system safety is discussed and possible modifications of manned aircraft regulations - for example JAR / FAR 25 – are introduced. One resulting point is a pragmatic definition of a safety factor for flight critical subsystems that may cause catastrophic events on malfunction.

Introduction

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

Figure 1: Certification of Unmanned Systems

Presumed that a HALE-UAV will be based on own territory, flight to target area will require participation in controlled airspace traffic. Currently operated systems, see
Figure 1, can only be flown in restricted airspace and cannot be certified for operation in controlled airspace.
Certification rules for UAV are currently not available. Readily available FAA and JAA regulations can only be applied partly, since not only the aircraft itself but the entire UAV system including ground control units and datalink has to be certified. Additionally, modifications and amendments already existing regulations regarding pilot have to be considered carefully.
Prior to the establishment of such certification rules (Figure 2), the proof of techniques and procedures for the participation of UAV in controlled air traffic is required.

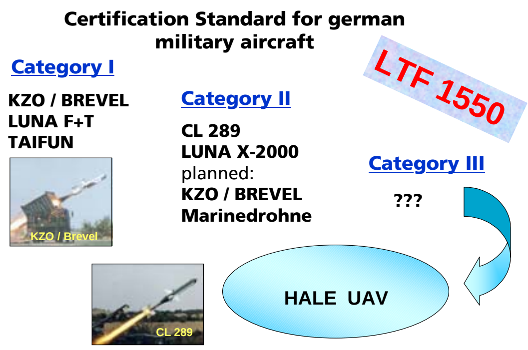

Figure 2: Certification Standard for German Military UAV

The following tasks have to be performed to overcome this situation:
Identification of UAV specific technologies and peculiarities and their impact on ATC.
Definition of criteria, guidelines and procedures for UAV certification together with national and international authorities.
Demonstration and validation of procedures and techniques for safe ground-based guidance of an UAV.

To achieve these three tasks, a UAV demonstration program has been set up by the

German Federal Office of Defense Technology and Procurement (BWB) in which

DLR,
EADS Military Aircraft,
ESG GmbH,
WTD 61, and
DFS Deutsche Flugsicherung

together demonstrate techniques and procedures for a UAV in controlled airspace on DLR's Advanced Technologies Testing Aircraft System (ATTAS).

2. Applicable Regulations

Routinely operation of an UAV in civil airspace will not be accepted before successfully having proven a sufficient reliability. The probability of an UAV-induced catastrophic event must not be greater than it is allowed for manned aircraft of the same category. At that time no certification regulations for UAV in civil airspace exist. Numeric values for failure probabilities of manned aircraft could be transferred into the unmanned scenario in doing some general considerations.

Regulations of Joint Aviation Authorities or Federal Aviation Administration are valid for most civil aircraft certifications. For UAV systems in considered payload category of around 1000 kg regulations based on JAR/FAR 23 and maybe 25 could be applied. Crew- and passenger-related sections are excluded.

3. Reliability Requirements

A general reliability requirement for UAV can not be defined. For example, FAA requires failure probabilities of at the most 10-9 for large commercial planes, not exceeding 10-6 for small aircraft with single piston engine and a weight below 6.000 lbs. These numbers represent the probability of a catastrophic failure a primary aircraft system experiences which leads to an uncontrollable aircraft.

If this fatal failure occurs on board of a large passenger aircraft all inmates and all in direct surrounding flying aircraft as well as people and objects on the ground are at risk. This leads to the catastrophic event if the crash can not be averted. The required probability of this event has been generally numbered with "not exceeding 10-9". With the considered category of aircraft the probability of a critical failure equals that of the catastrophic event because due to the existence of several people on board.

Executing unmanned flight, the probability of a catastrophic event depends on the population density of the area being overflown as well as some UAV specific parameters. An important parameter is the so called "lethal area" which can be described as the area around the point of impact where people experience severe injuries.

$$p_f = p_{Av} \cdot \left(A_{la} \cdot d_p\right)$$

Figure 3 shows an example for the probability of a crash-inducing failure which depends on the parameters population density and lethal area. Here, the probability of the catastrophic event has been chosen to 10-9. For details see Rackur, 2002.

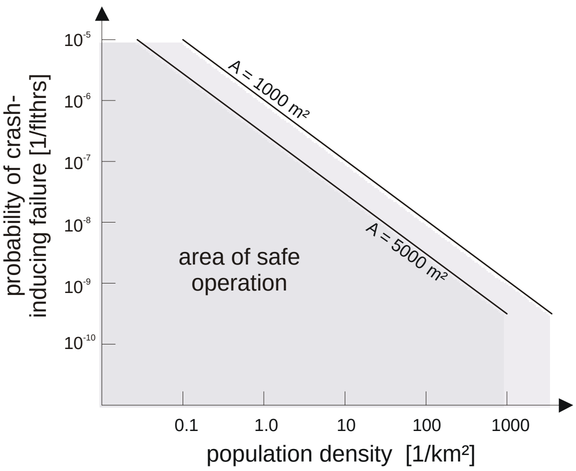

Figure 3: Possible Certification Requirements

4. Mandatory Auxiliary Systems

The reliability of UAV can be increased by implementation of a flight termination system (FTS). Critical and crash-inducing failures have to be detected precisely to carry out a flight termination if necessary. It is clear that in this case no damage to people or objects can be accepted, whether through collision with manned aircraft or crash on the ground.

In conjunction with the failure detection the FTS is an important system for safety. Furthermore it is required to avoid collisions with other aircraft during the mission or to prevent flights within adverse weather conditions. For this purpose see-and-avoid, respectively sense-and-avoid systems are being used. These enable the aircraft to recognize possible dangers and to react in a necessary way. In general, the flight control system would have a structure as shown in Figure 4.

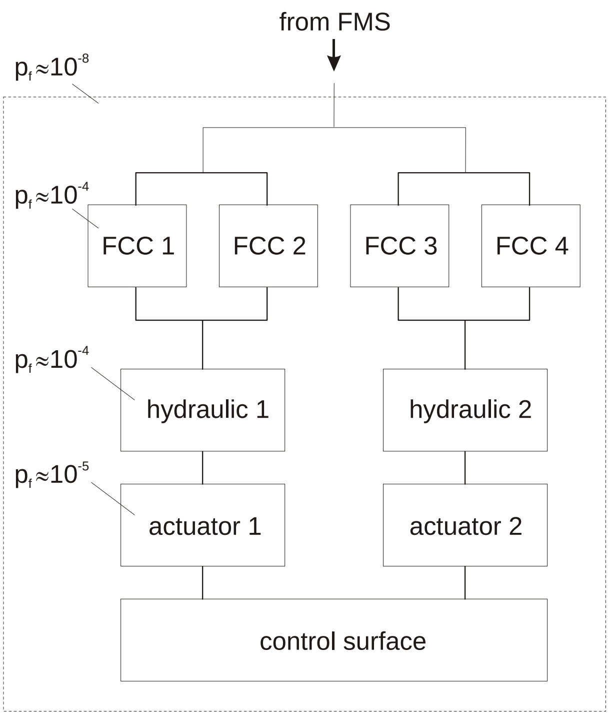

Figure 4: Flight Control Structure

5. Demonstrator

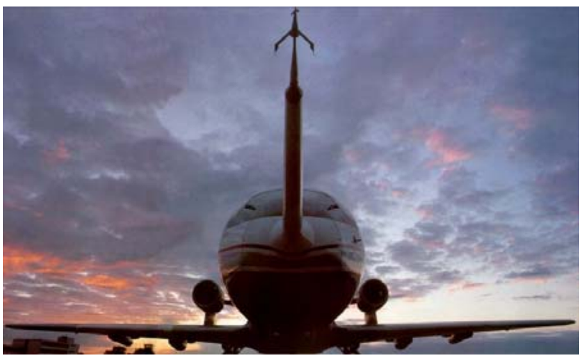
Figure 5: ATTAS

The UAV demonstration is performed on DLR's Advanced Technologies Testing Aircraft System ATTAS (Hahn, 1996). ATTAS (Figure 5) is an experimental full fly by wire aircraft with different kinds of safety features. Some features of the highly modified basic VFW-614 are shown in Figure 6.

ATTAS has been designed as an In-flight Simulator with an experimental pilot at the left and a safety pilot at the right seat. The aircraft can be controlled by a conventional wheel and column with artificial force or an experimental sidestick. All control surfaces can be manipulated by the Fly-by-Wire system so that the behavior of ATTAS simulates the attitude and accelerations of a different aircraft at the position of the experimental pilot.

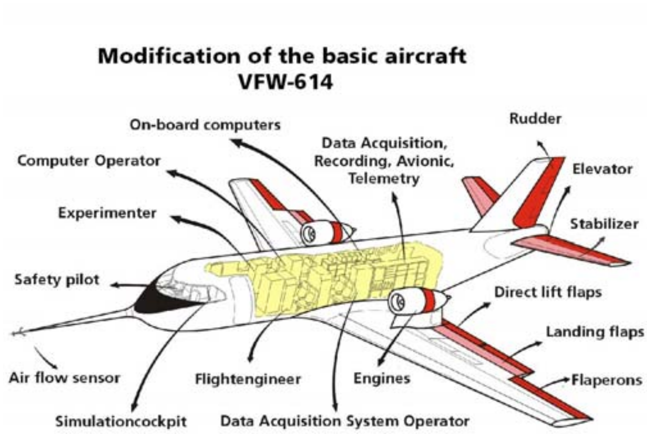

Figure 6: ATTAS Systems

For direct lift application the aft part of the landing flap is separated into 6 parts which could be activated independently very fast. The onboard data acquisition system records nearly 2000 parameters. For the UAV demonstration the flight engineer's station is equipped with interfaces to the experimental FMS and MMS.

6. Mission

Figure shows the segments of a typical HALE mission. The peculiarities of all these phases need to be considered for an overall UAV demonstration. Different types of airspace restrictions and regulations for example close to the ground during climb and descent compared to very high altitudes yield different standard and emergency procedures.

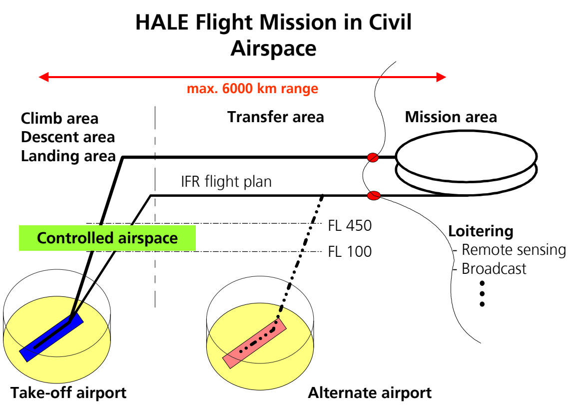

Figure 7: Typical HALE Mission Profile

Even if the take off and landing will be performed from a military airfield, by passing FL 100 to 450 the UAV has to pass civil controlled airspace. Various standard and emergency procedures can be identified for UAV. Standard procedures include but are not limited to:

- mission planning
- establishing communication
- taxi
- take-off
- auto-piloted flight along trajectory or via way points
- change of flight plan / mission replanning
- communication with ATC
- hand-over to a second ground control station
- autonomous flight segments
- approach and landing

A few examples for emergency procedures include but are not limited to:

- loss of uplink
- loss of voice link
- loss of propulsion
- system degradation due to malfunction
- dangerous encounter with other air vehicle
- encounter of severe weather
- aborted take-off

A good example of the difficulty to assess the full impact of UAV technologies on its performance, reliability, and last but not least its characteristic behavior in the ATC environment in normal and abnormal operation is given by the datalink technologies (Figure 8). During different portions of the mission, different types of datalink play flight safety critical roles. Various causes for a possible loss of these datalinks have to be considered. They subsequently yield different impact and strategies on how top cope with such a situation.

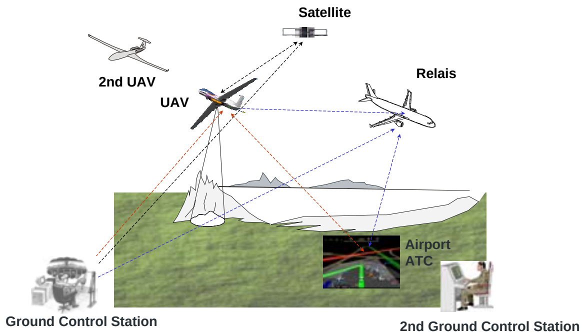

Figure 8: Datalink Scenario

7. Experimental System

In order to achieve the planned demonstration, an appropriate environment regarding ground and airborne components has to be set up. Figure 9 shows the architecture of the demonstrated experimental UAV system.

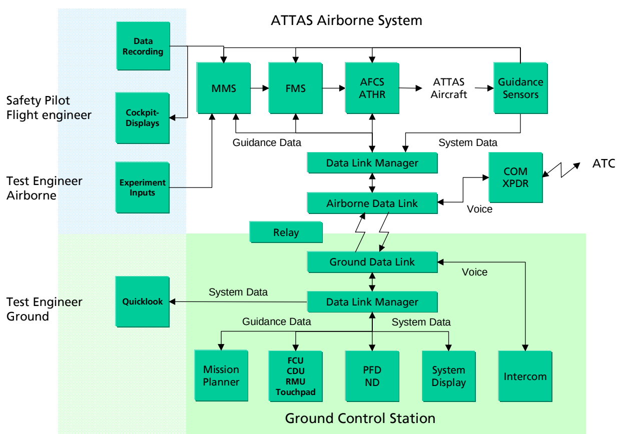

Figure 9: ATTAS Experimental UAV System

Basic elements of the onboard system are:
Advanced Flight Control System, AFCS

Mission Management System, MMS
Advanced Flight Management System, AFMS

The functionality of the mission management system onboard and the mission planning system of the ground control station is identical, so that in case of loss of datalink a logical process with a 4D-simulation is started in the ground control station with the same initial information as onboard at the beginning of the loss of datalink to simulate the autonomous reaction of the UAV.
Additional to the essential UAV-parts on ground and onboard some components are added for the safety pilots to monitor the experimental system and the actual status of the experiment. Figure 10 shows the links (control/guidance, sensor data and voice).

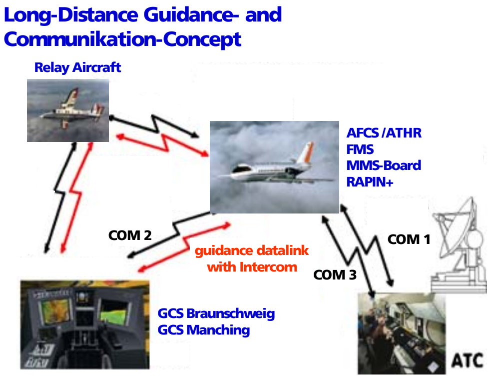

Figure 10: Communication Concept

All communications from ground control station to air traffic control and back are going via the UAV. Therefore the UAV could be treated by air traffic control comparable to a conventional manned civil aircraft. Because the ATTAS system has an experimental status with safety-pilots on board, the datalink and all ground and onboard system exists only simplex. In case of an actual failure which put a risk on the basic aircraft the test pilots could take over the manual control of ATTAS within a timeframe of 200 ms.

8. Flight Tests

The flight test is performed in three steps:

1. Functional test and standard procedures in temporary reserved areas (TRA)
2. Standard and emergency procedures in TRA
3. Complete missions to a different airfield in controlled civil airspace

Figure 11 shows the typical flight test pattern from Braunschweig airport, a surveillance track in the TRA and back. During these tests the ground control station is located 150 km away from the TRA at Braunschweig airport.

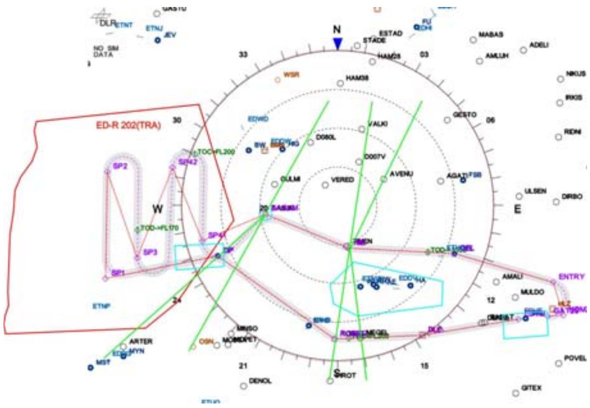

Figure 11: Flight Test Pattern

The first milestone was reached at the end of November 2002. Several flight tests were performed to show the functionality of the of the experimental UAV guidance system in following standard commands from air traffic control.

The standard program of an experimental flight was:

- Flight according to pre-planned IFR flight plan
- In-flight re-planning of IFR flight plans
- Following ATC commands

To behave like a civil manned aircraft, the pseudo-UAV ATTAS was guided from the ground control station by typical autopilot commands like:

- heading change/hold
- altitude change/hold
- airspeed change/hold

First flight test were performed showing the behavior of the onboard UAV system in standard procedures and also in case of control datalink loss and the reconnection of the datalink after a certain period of time. The onboard mission management system reacts as required. Figure 12 shows the track of a typical flight test with maneuvers reacting on ACT commands.

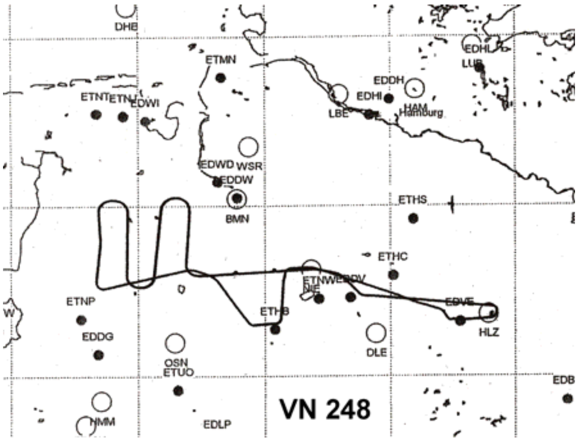

Figure 12: Actual Flight Test Track

During theses first tests ATC was satisfied with the reaction of ATTAS flying as a pseudo-UAV. Reaction time on ATC commands was comparable to normal manned aircraft.

9. Summary

As UAV include various new and uncommon technologies compared to manned aircraft, a set of accepted standard and emergency procedures need to assure proper UAV operation in controlled civil airspace. A development and demonstration program has started with DLR's In-Flight Simulator ATTAS. The functionality of the experimental UAV-system has successfully been shown during first flight tests. The communication with ATC and the guidance of the UAV was achieved by the Ground Control Station operator. Different kinds of standard and emergency procedure including landings on an alternate airfield are addressed. In cooperation with the German air safety organization procedures are tested to come up with a proposal for procedures to integrate UAV into controlled civil airspace.

10. Acknowledgement

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References

AeroVations Associates: *Suggested flight approval process for Unmanned Air Vehicles*, AeroVations Associates, 24 September 2001

BWB. *LFT 1550-001 Sonderbestimmungen bei der Prüfung und Zulassung unbemannter LfZ der Bundeswehr*, WTD 61. L/ML, September 2002

DeFlorio, F.: *Airworthiness for UAV's, A discussion paper*, EURO-UVS

Hahn, K.-U.: *VFW 614/ATTAS Test Aircraft*, Issue 1, DLR-6.2-WD002, German Aerospace Centre, Germany, October 1996

Haddon, D., Whittaker C.: *Aircraft airworthiness certification standards for civil UAVs*. Civil Aviation Authority, 17th Bristol UAV Conference

JAA: *JAR23 Normal, Utility, Aerobatic and Commuter Aeroplanes*. JAA, 11.03.1994

JAA: *JAR25 Large Aeroplanes*. JAA, 01.05.1994

Rackur, C.: *Systemkonzept eines HALE UAV für zivile Zulassung*. DGLR Jahrestagung, Stuttgart, Germany, 2002