UAV VTOL RESEARCH TESTBED 'SHARC'

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OVERVIEW

EADS Innovation Works Germany is working on the design of a VTOL UAV for evaluation and demonstration in the context of their research activities. The main activities in the focus are sensor evaluation, the development of onboard image processing as well as the advance of autonomous functionalities. The system is designed for flexible use with respect to the onboard basic system functionality as well as its ability to integrate multiple payload components. This paper shall give an overview on the motivation for the decision to create the test-vehicle, its design criteria and the envisaged tasks. It shall also describe briefly the system architecture and the basic functionality.

1. DESIGN MOTIVATION

One of the challenges of today's industrial research is to close the gap between the research institutes and the business providing parts of the company. For the practical work this means the identification of promising technologies and the evaluation for the potential applications in an aerospace environment. Today's commercial projects very rarely offer the opportunity to evaluate and test multiple technologies in order to come to a feasible solution. This task, in many cases, can be delegated to industrial research departments in order to identify future key technologies. This can also be considered as a risk reduction activity from a commercial point of view.

In an emerging UAV segment of the aerospace market, multiple technological aspects come to mind, when developing new products. Apart from the classical disciplines of structural- and propulsion engineering of course the avionic segment plays a major role there. The aspects of Flight Guidance, Air vehicle navigation and flight control are an important field of activity, facing new challenges due to the missing pilot on board. This puts requirements to the system that require functions that utilize automation and autonomy. The ability to operate with certain automatisms or even autonomy requires knowledge of the relevant conditions in the surrounding environment, in other words: situational awareness. One factor in the chain to achieve situational awareness in UAV's is the onboard sensors for the data gathering. Together with the information channel via the data links, required information is made available to the onboard system and its decision strategies. Depending on the degree of autonomy, more or less advanced functions are implemented to make use of the gathered sensor data. This can vary from the simple sensing with transmission to the Ground Control Station up to the processing of sensed data onboard with information extraction and decision making.

The latter in the case of Mission UAV's is mainly related to the discipline of image processing. Here, the full image processing chain needs to be addressed. For the industrial research this means to address the challenges not only in a laboratory but also in the relevant environment, which in this case of course is the airborne application.

The advantages of an experimental vehicle in this context are the flexibility and the ability to perform configuration changes without following the full design and certification process of a commercial product.

The main tasks for testing and evaluating are located in the following areas:

- Sensor Integration and Evaluation
- Image Data gathering
- Sensor Fusion & Redundancy Concepts
- Flight Guidance & Flight Control Concepts
- Autonomous Functionalities

When evaluating the opportunities to test in the real environment, the question for a suitable test bed comes up and before making a choice, it is necessary to have a look at the boundary conditions that exist. In our case, the requirement is to have an accessible vehicle that is affordable in its direct operation cost. Day to day evaluation and test campaigns in research very seldom follow a schedule that can be planned months or years ahead. For the sensor platform applications it is desirable to have a stable sensor carrier that, nevertheless, can perform agile manoeuvres. As it is the goal of modifying the system and the change in configuration with respect to the navigation and mission sensor suite is desirable to have an open configuration. The impact of the sensor suite on the basic air vehicle avionics is significant and the level of integration reaches deep into basic functionality. This is valid as well for modifications and adaptations in the flight control and guidance system. Therefore, it is highly desirable to be able to modify the system within the research organisation, independent from external suppliers. For the modification, a deep insight knowledge of the system is necessary, only to be gathered by designing the system in-house and together with partners. For the Flight Control System, EADS Innovation Works has teamed with the chair of Flight Dynamics of RWTH Aachen.

In order to be able to test and evaluate hardware and technologies that is relevant and applicable to larger scale air vehicles it seemed appropriate to focus on vehicles with a payload capacity higher than the standard hobby-size air vehicles. The same is valid for the capacity of payload volume. The development of demonstration components or prototypes does not necessarily lead in a first step to highly integrated systems. Flexibility with respect to volume and mass is mandatory.

Especially in the field of image processing, where some of the challenges are only unveiled when having to face the task of bringing a system into an operational environment this flexibility will pay off. A major problem in this field is the real time capability of the algorithms on the target hardware integrated into the platform. This means that a high degree of flexibility is required to integrate processing hardware into the vehicle. Also, the operational environment for the sensor systems itself are not negligible. Vibration, lack of accuracy of the navigation systems and position tolerances in the mounting are boundary conditions to overcome and to cover in a robust design of the payload systems. Multiple approaches can be evaluated here, not requiring a highly advanced product approach. The range can include anything from prototype demonstrator setups until certified computing hardware. The same is valid for the sensor hardware. Also here, the full range if technology readiness is possible.

With respect to the applications, especially with image processing techniques, the focus is widespread. The currents areas of activity are in the fields of image based navigation, automatic target detection and recognition and image enhancement.

The selection for the strategy to follow was made on the above mentioned criteria.

2. SYSTEM CONFIGURATION

The requirements for the system were derived from analysis made by considering useful and technically feasible system configurations for the test & demonstration operations. One of the results was that it was desirable to integrate optical sensor systems on turrets that are in a weight class of approximately 15kg. When considering the necessary additional components like sensor control unit, data link and in the case for onboard image processing also the processing hardware, it becomes obvious that for comfortable test operation a payload capacity of 35-40 kg should be available.

In addition, the flight behaviour aimed at, with respect to stability, was that of a stable platform to represent a suitable platform for sensor operations. This requirement asked for a platform with a reasonable operational weight and wing / rotor loading.

On the flight operation side it was favourable to operate the aircraft in multiple locations, independent from airfields. This voted out a fixed wing platform due to the fact that an enormous effort would have been spent on launch and recovery systems for off-field operations. In addition, it is the aim to create a sensor platform with the utmost flexibility which means to be able to vary speed down to a hovering flight condition.

These demands in the end asked for a rotary wing platform.

With respect to the operator command station it was decided to aim for an environment that offers not only minimum control functionality but a working space suitable for work with the research payload and extended ground work in the field.

3. AIR VEHICLE

In the end, a system was chosen that incorporates a helicopter in coaxial rotor configuration with a maximum take off weight (MTOW) of 200kg. The helicopter is depicted in FIG 1.

FIG 1: UAV System SHARC

The rotor system has a diameter of 3,20m and consists of two 3-blade rotors. It features two V-shape fins for directional stability in forward flight.

The helicopter is powered by a 37kW combustion engine, located in the aft section. The engine is air cooled and equipped with a redundant ignition system and electrical starter. The landing gear is using four disk-shape landing pads that ease lateral movement during touchdown in order to reduce the risk of flip-over in gusty or windy conditions.

The system is designed modular in order to maintain a high degree of flexibility throughout its operation. It can be divided in multiple sections:

- The centre-section, in which the main rotor components, the gearbox and the fuel tanks are located
- The engine compartment aft of the centre section, including the engine control actuators
- The forward avionic section, consisting of the basic avionic systems
- The forward and the aft payload compartment.

The centre section houses the main gear box for the rotor drive, the oil pump for the gearbox cooling and the fuel tanks. The fuel tank system consists of three separate composite tanks, with an overall capacity of 45l. Should there be a requirement for extended payload volume, close to the centre of gravity the upper fuel tanks can be exchanged with payload. This reduces the fuel capacity by approximately 50%. In a test configuration this would lead to an endurance of 1.5 to 2 hours. The electric actuators for the rotor control are also located in that section in order to keep mechanical links at a minimum length. An integrated INS/GPS navigation solution and the Power distribution box complete this section.

The engine compartment holds a two-stroke 37kW combustion with two cylinders in row configuration. It transfers the power via a centrifugal clutch to the main gear box. The engine is equipped with a dual ignition system and an attached electrical generator. To be able to start the engine autarkic, a starter is included in the propulsion system. As the engine is included completely into the structure, a mentionable effort had to be taken in order not to run into thermal problems in full power-high temperature conditions. In this compartment, also the fuel-valves are located. These valves are used to support a flight termination system in case of command & control failures or deviations.

The forward basic avionic section houses the Flight Control Computer, Barometric- and Laser-Altimeter and the Data Links as well as the batteries for the main power supply. In addition, an I/O-Controller is integrated to handle a part of the sensor interfaces within in the system architecture. The basic avionics section is condensed in order to reserve large volumes for a flexible installation of potential payload. The Laser Altimeter is installed with an angle of 15° in order to handle best the attitude for slow forward flight.

In front of the basic avionic components for the green system is the space for scientific payload.

4. AVIONICS

The avionics system can be divided into two sub-systems that have the following tasks:

- Enable basic flight operation
- Enable functionality for sensor integration and implementation of advanced modes

The segmentation was done due to a reduced effort necessary for testing and validation when having an unchanged segment of the system responsible for the safety critical flight tasks.

The basic avionic system consists of a flight control computer (FCC) that is hosting the majority of the system functions. It represents the interfacing unit with the inertial measurement unit, the primary data link and the electrical system as well as to the propulsion- and fuel system. In addition, the Weight-on-wheel sensors are interfacing with the FCC.

Interfacing with the sensors for altitude sensing and the secondary data link, as well with the DGPS unit is performed via an Input-/output controller (IOC) that is interfacing with the FCC via CAN-Bus following the CANaerospace standard [2]. The IOC offers growth potential with respect to connectivity of additional sensing or actuation units. The pre-processing of incoming data into the IOC helps to reduce bus-load on the CAN bus and reduces workload for the FCC.

The main operation system software is managed by state machines guiding through all relevant system conditions. Segmentations in the state machine design have been incorporated in line with the sub-system boundary definitions (e.g. propulsion system, electrical system, flight control…). The communication of the state machine substructure is hierarchical in order to set hard rules for future extension of the system. This will guarantee the mutual exclusivity in the setting of system states where necessary and increases the transparency in the design.

In the Operation mode management, the procedures for mode changes are standardized, independent of the trigger of such changes in the state. The reason for this is the exchangeability of action triggers for future design levels. If an action today is triggered via the human operator it will serve as an equal input into the system as an autonomous decision of the vehicle for the same action in a future design step.

Currently the user operates the UAV with a set of high level commands and, if in the appropriate system state, with commands that are directly fed into the flight control system like attitude commands, velocity or speed commands. The non high level commands are limited to the basic flight operation in the flight control sub-system.

For the reasons of flight safety, means have been integrated to ensure termination of flight in case of loss of control over the aircraft. They consist of an isolated system that is capable of deactivating the propulsion system by switching off both ignition circles as well as the fuel cut-off to the engine. The signal for termination is transmitted via an independent data link and is processed via independent hardware. The transmitter on ground is also separated from the operational ground processing units and the data links.

5. GROUND CONTROL STATION

The aim of the Ground Control Station is to be an integrated solution to command and control the basic flight operations of the air vehicle as well as the payload functionality. The Ground Control Station was designed using the structure as given by STANAG 4586 having in mind the future operation of multiple UAV's from one Ground Control Station. It consists of two industry computers, each connected two one flatscreen-display and one touchscreen-display. The systems are connected via a local network and can be used either as redundant systems or with complementary functionality. The system is mounted on a Mercedes Sprinter mini-truck. The computers are rack-mounted together with the transmitter section of the Flight Termination System. The system can be powered externally or via internal batteries from an emergency power supply.

The ground control station software provides visibility of the relevant system states and relevant situational awareness with respect to the flight status. Information is structured hierarchically and functionally in order not to overload the operator with unpractical information. In the practical application this means that if e.g. the overall sensor status in a subsystem states an operational status it is not necessary to provide information on the functionality of a single sensor additionally on a top level status page. This will become important, and then displayed, if the requirements for an overall operational sensor system are not met anymore. Then the operator might want to know which sensor specifically failed and provoked the failure display. This particular information will then be displayed.

6. INTERFACE TO MISSION SYSTEM AND PAYLOAD

In order to be able to react to external test and evaluation mission demands an interface exists, enabling the communication between the Mission Avionics and the Basic Air vehicle Flight Control Computer (Green System) via a Mission Bus. The advantage of the segmentation is a reduced test and validation workload when integrating additional equipment. The philosophy is that all information on the Basic Avionic part of the system shall be made available to the Mission segment for processing and interpretation within the relevant function. The data stream into the other direction, from the Mission Computer to the Flight Control Computer, is somewhat more restricted, as the flight critical systems might be influenced by incoming information in case of a too global data handling.

If written in a hierarchical way, the Green System Avionics control the following interfaces:

- Flight Control Actuation
- Flight Control Sensors
- Flight Critical Data Links
- Interfaces to the vehicle management (propulsion system, electrical system…)
- The interface to the mission system
- Power management.

The Mission system controls its interfaces to:

- "Mission" sensors, e.g. payload to be tested
- Mission data links (i.e. data links additional to the flight critical links
- Additional payload components, not being part of the basic avionics.

The segmentation can be seen in the following FIG 2. In a practical example e.g. a mission flight trajectory generated in the mission computer will pass the interface to the green system flight control computer, is checked for compatibility within the system and then processed in the flight control system. This 'non-integrated' approach puts a minimum of restriction to the range of interfacing functions. As long as the mission computer – flight control computer interface is being managed, there is no risk in operating the air vehicle with respect to incompatibility issues. Safety analysis efforts when integrating new functionality is reduced to formal interface analysis and potential violations.

In order to follow that approach, to restrict vehicle critical interaction to the green system avionics, also the power management (power supply) for the mission system is managed in the Green System part.

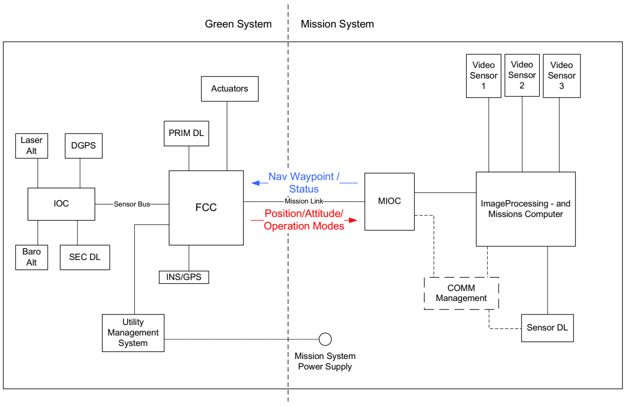

FIG 2: Green System / Mission System Interfacing

For the Mission system, power supply with 12V and 28V is available. With respect to the energy capacity, depending on the demand of the payloads, batteries can be added.

The selected approach and the design philosophy satisfy research demands and leave enough room for flexible operation. The growth potential is enormous, due to the openness of the configuration.

7. STATUS AND WAY AHEAD

The status at the time of the creation of this paper is the completion of ground test and the entry into the flight test phase. First flight was successfully performed in June 2007 performing testing of the operation system management. Currently the system is running through an engineering flight test campaign, testing the full range of system functionalities necessary for basic flight operations and gathering experience. Data is gathered for validation and improvement of the system model. For system monitoring and control, the ground control station is used. In the following months it is expected to mature the systems and gather confidence in the design by practical experience.

8. ACKNOWLEDGMENTS

As mentioned in the design motivation, EADS Innovation Works has teamed with the chair of Flight Dynamics at RWTH Aachen for the design of the Flight Control System of the UAV.

9. REFERENCES

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