AVIATION
2010
14(1): 24–32

DESIGN AND EQUIPMENT OF VUT 001 MARABU UNMANNED AERIAL VEHICLE FOR OPERATION IN NON-SEGREGATED AIRSPACE

Miroslav Šplíchal, Jidřich Finda

Institute of Aerospace Engineering of Brno University of Technology, Technicka 2, 616 69 Brno, Czech Republic
E-mail: splichal.m@fme.vutbr.cz

Received 21 April 2009, accepted 22 February 2010

Miroslav ŠPLÍCHAL, PhD
Date and place of birth: 1979 in Brno, Czech Republic.
Education: Brno University of Technology, Aerospace Institute.
Research interests: aviation safety management, unmanned aerial vehicle.
Publication: 11 articles, 3 research reports.

Jindřich FINDA, PhD
Date and place of birth: 1980 in Znojmo, Czech Republic.
Education: Brno University of Technology, Aerospace Institute.
Research interests: aviation maintenance, aircraft design.
Publication: 9 articles, 12 research reports.

Abstract. The paper describes the design process and the summary of expected requirements for unmanned aerial vehicle operation in non-segregated airspace and on-board equipment of the VUT 001 Marabu airplane for experimental operation as a civil unmanned aerial vehicle (CUAV).
The VUT 001 Marabu airplane is being developed at the Institute of Aerospace Engineering of Brno University of Technology as a platform for testing of variety CUAV equipment. The testing of CUAV equipment in real conditions is currently impossible, because there does not exist any regulatory requirement for this particular airplane category. The Institute of Aerospace Engineering proposed UAV-equipment-testing methodology based on a piloted version of the future UAV aircraft. The pilot has priority in control during flight, which eliminates potential accidents after system failures. Our goal is to ensure technological progress in this area and to develop technology before applicable regulations are introduced.
The demonstration of the potential capabilities of the UAV VUT 001 Marabu can motivate other involved institutions and producers to quicken progress in this field.

Keywords: design, UAV, non-segregated airspace.

ISSN1648-7788 print / ISSN 1822-4180 online
http://www.aviation.vgtu.lt
DOI: 10.3846/aviation.2010.04

1. Introduction

For the successful utilisation of unmanned aerial vehicles (UAV) in civil airspace, it is necessary to solve problems related to full UAV integration in the airspace structure. Civil UAVs have to be able share the airspace with other users without safety impact. Today, segregated airspace is used for the operation of UAVs. This means that there are many limitations on the full utilization of the advantages of UAVs. The non-existence of clearly defined requirements and rules for the airworthiness and operation of UAVs is a barrier against the future evolution of UAV applications in Europe. There are many organisations and interest groups dealing with these problems, but many questions are still open or they are only partially solved. The evolution of UAVs is aimed mainly at the small and simple UAVs usually with max. take-off weight up to 150 kg or non-military UAVs.

The Institute of Aerospace Engineering (IAE) of Brno University of Technology wants to contribute to the solution of this problem with its VUT 001 Marabu grant project. We want to help create interest between potential users and national authorities to solve this barrier. The VUT 001 Marabu project combines a piloted experimental aircraft and UAV airborne equipment for joint testing in real conditions. The size of the airplane offers suitable capacity for the tested payload. The pilot onboard the experimental airplane ensures safety and enables flights in compliance with current legislation. Our goal is step-by-step evolution from fully piloted aircraft to unmanned aircraft with attention on safety.

2. Utilisation of UAVs in non-segregated airspace

Non-segregated airspace can be controlled, i.e. airspace where air traffic service (ATC) is responsible for safe separation between aircraft or uncontrolled airspace where pilots are responsible for safe separation between aircraft. In this airspace, ATC provides only an advisory role.

One of UAV characteristics is variability in flight performance from RC model characteristics to small business jet characteristics. UAVs have to follow ATC commands and procedures with the same efficiency and safety as piloted aircraft for the successful integration of UAVs into the controlled airspace. Form this point of view; large airplane is more suitable as a platform for UAVs. Similarly, flight characteristics allow using the existing ATS procedures without the necessity of developing new procedures. UAVs that require special procedures, such as mini and micro UAVs, cannot operate in non-segregated airspace even in the short-term future. Large scale is an advantage for visual contact with a UAV by other airspace users. The present popularity of mini and micro UAVs is result of their availability and low price of suitable onboard equipment (Splichal 2007).

Advantages of large size UAVs in non-segregated airspace:

Economy:

The UAV solution should be acceptable in terms of price and able to integrate different components for an intended mission. The sum of all expenses for a UAV solution has to be lower than the expense for conventional piloted aircraft. High costs reduce the competitive advantage, except for dangerous life missions. UAV equipment should preferably be existing technologies before special technologies are developed for one UAV type. The initial use of UAVs can be expected in areas as:

- national security (monitoring areas of interest, traffic, infrastructures etc.),
- environment monitoring,
- communications (signal retranslation, monitoring, radio equipment verification).

This area can be better covered by large UAVs. They have greater endurance and payload capacity. The disadvantages are high costs for acquisition and maintenance.

Safety:

An autonomous flight control system inherently removes human operator intervention from vehicle functionality. The capability of an aircraft of considerable mass, travelling at high velocity, to cause damage to people or property is substantial. It is critical that the flight control system should include several flight modes. Special attention had to be given to UAV behaviour in the air when contact with the ground station is lost. Small UAV can be hard to detect, both by radar and visually. Large UAVs can have back-up systems thanks to their higher payload capacity. There is also the possibility to use the same certified equipment used for piloted aircraft. These are benefits for safety.

Capability:

UAV for the civil sector must be able to navigate long and short distances with the ability to adapt to wind conditions and to altitude constraints. This involves the ability to fly direct paths between waypoints, and to accommodate for weather conditions to minimize cross track errors. The Command and control package must be adaptable to allow for integration with a variety of fixed wing platforms. Furthermore, competition requires that the vehicles should be able to automatically take off and land. This allows the operator’s workload to be decreased. Large airplanes are suitable for these requirements.

Reliability and maintainability:

This is directly related to system safety. UAVs have to be able to operate in changing conditions a have to minimize risks of losing of the aerial platform or onboard instruments. Bigger dimensions can make airframe more robust and easily maintainable. The power unit can be the same as the power unit for piloted aircraft. This makes the UAV more reliable.

2.1. Description of Czech Republic airspace

The Czech Republic has a small area (only 78.866 km^2). The country is located in central Europe and both commercial airplanes and sport planes intensively use the airspace. According to ANS, in 2008 was a record peak with 1759 IFR flights per day (until December, 5^{th} 2008). The amount of VFR-rule flights is not included. Over 1200 airplanes with MTOW higher than 450 kg and 4400 ultra-light airplanes, including paragliders, are registered in the Czech Republic.

Czech Republic airspace has the following airspace classes in accordance with ICAO airspace classes:

- C class airspace, above FL 120 to FL 195 VFR flights are prohibited;
- D class airspace, typically for CTR civil and military airports;
- E class airspace, from 300m AGL to FL 95. Over FL 60, transponder is required;
- G class airspace, from GND to 300 AGL, only for VFR flights.

Segregated spaces such as terminated restricted area, terminated segregated area, and prohibited area are part of the airspace. Czech army and air force usually use these airspaces. The total area of segregated space represents approximate 35 % of lower airspace.

The situation in Czech Republic airspace indicates very limited space for UAV operations in non-segregated airspace. UAVs in non-segregated airspace will be operated only under IFR conditions and only in controlled airspace because of safety reasons. Under altitude 1850 (FL60) is unknown VFR traffic without precision radar surveillance. In an ideal situation, all flights will be made under IFR conditions. Take-off and landing under IFR conditions require an airport with controlled traffic. The Czech Republic has only four aerodromes that satisfy this requirement.

The Czech Republic presently has no legislation for UAV operations in non-segregated airspace. Current legislation allows operation of UAVs by civil aviation law, but only under special approval issued by the national civil aviation authority. The main user of UAVs in the Czech Republic is the army. In the civil segment, several small UAVs are operated. A similar situation exists in other European countries.

Today situation in Czech Republic theoretically allows use C or D class of airspace for UAV operation under IFR conditions. The use of publicised routes is necessary in C class airspace. Routes above FL 100 have max IAS M=1 and are designed for commercial airliners. In E class airspace, IFR flight is theoretically possible, but under FL 95 unknown traffic like sailplanes, paragliders, etc. is possible. Only one route, mainly for training flights, is publicised in lower airspace. It is necessary to have freedom in airspace to use the full potential of UAVs. In the future, it is necessary to also use lower flight levels for some UAV missions. Sharing lower altitudes with other unknown traffic needs UAVs with special capability. Development of such UAVs and special technologies in the nonexistent legislative environment is risky for private subjects but an opportunity for university research.

3. Description and design process of VUT 001 MARABU project

The design process of every new aircraft prototype has not only a technical level (technical parameters, data, computer models, and design documentation), but also important human factors, (design team cooperation and consonance). This part of the paper is dedicated to a description of the VUT 001 Marabu design process and its impact on the knowledge and activities of the Institute of Aerospace Engineering (IAE).

3.1. Project history

The Institute of Aerospace Engineering has participated in Czech aircraft industry projects in different fields of aircraft design (design of aircraft, strength, aerodynamics and reliability analyses and statics, and dynamics tests of aircraft structures). It was typically practical realization based on specific requirements.

In 2005, Prof Pištek brought together part – the VUT 001 Marabu. The Czech Ministry of Industry and Trade also supported the entire project under the grant FI-IM3/041 ("*Design and realization of VUT 001 Marabu aircraft for UAV applications in the civil sphere*"). A list of partners involved in the grant project and description of their activities is in table.

Table shows the novel concept for the development of the experimental airplane – a mixture of industrial partners and academia under the lead of the university partner (academia). The VUT 001 Marabu should provide an experimental platform for testing UAV equipment and step-by-step integration of UAV systems.

The VUT 001 Marabu project is the first aircraft fully designed and also produced by the IAE. This means primary design, detailed design work and analyses, the CAA approval process, and manufacturing. This had a great effect on design organization. Connect of young specialist teams and typical industrial rules were created. This type of organization is not typical for universities. Although many of the institute workers have significant scientific experience and extensive experience cooperating with industry, complete aircraft design is new experience for them. Prof Pištek, leader of many Czech industrial projects, has an important role in project management. Engineers and postgraduate students can work on small tasks of project design and manufacturing.

3.2. VUT 001 Marabu description

The basic requirements for the VUT 001 Marabu project were: that the airplane needs to have an empty space in the fuselage nose part for sensors, acceptable operational endurance, and MTOW up to 600 kg. The structure should enable simple integration of systems for UAVs (Pištek 2009).

Table. Partners involved in the VUT 001 Marabu project

Partner	Role in the consortium	Activities in the project
Institute of Aerospace Engineering / Brno University of Technology (IAE)	Coordinator	Design of experimental aircraft, participation on fuselage production, final airplane assembly, holder of "Permit to Fly", test flights
Prvni brnenska strojirna Velka Bites (PBS)	Partner	Production of TJ100M jet engine, further development and optimization of small jet engines for UAVs, experiments with the jet engine
Jihlavan – Airplanes (JA)	Partner	Production of airplane metal structures (wing, horizontal tail unit), control system for flaps and trim.
Plast Service (PS)	Partner	Production of airplane composite structures (fuselage)

The abovementioned requirements led to the development of an airplane with a rear-mounted propeller powered by a piston engine supplemented by a small experimental jet engine. The technological platform selected for realization included the combination of the composite fuselage and all-metal wing. The design of the aircraft from scratch enabled optimisation of the airframe for a wide variety of missions. CS-VLA regulation is applied to the design of the VUT 001 Marabu (EASA… 2003).

The basic concept uses a rear-mounted propeller to enable the integration of sensors in the nose (such configuration is not typical in the given aircraft class). In the design of systems, attention is given to functions important for future integration of UAV systems into the airplane. The VUT 001 MARABU is an experimental test-bed for wide variety of UAV systems and related equipment. Within the size of the aircraft (max. take-off weight of 600 kg), the move towards the concept of a more electric aircraft is done as far as practically possible. This should offer a significant advantage for the integration of UAV systems into VUT 001 aircraft compared to existing conventional aircraft.

Structure, geometric and performance characteristics

The aircraft has a combined structure composed of glass fibre composite fuselage, metal wing, and horizontal tail unit (Fig 1). The major reason for the combined structure is the reduction in developmental risks and the reduction in development time for the airframe. The metal wing structure and horizontal tail unit were taken from the successful aircraft Rapid200 (developed also at the IAE). Only the fuselage, made of composite materials, is completely new.

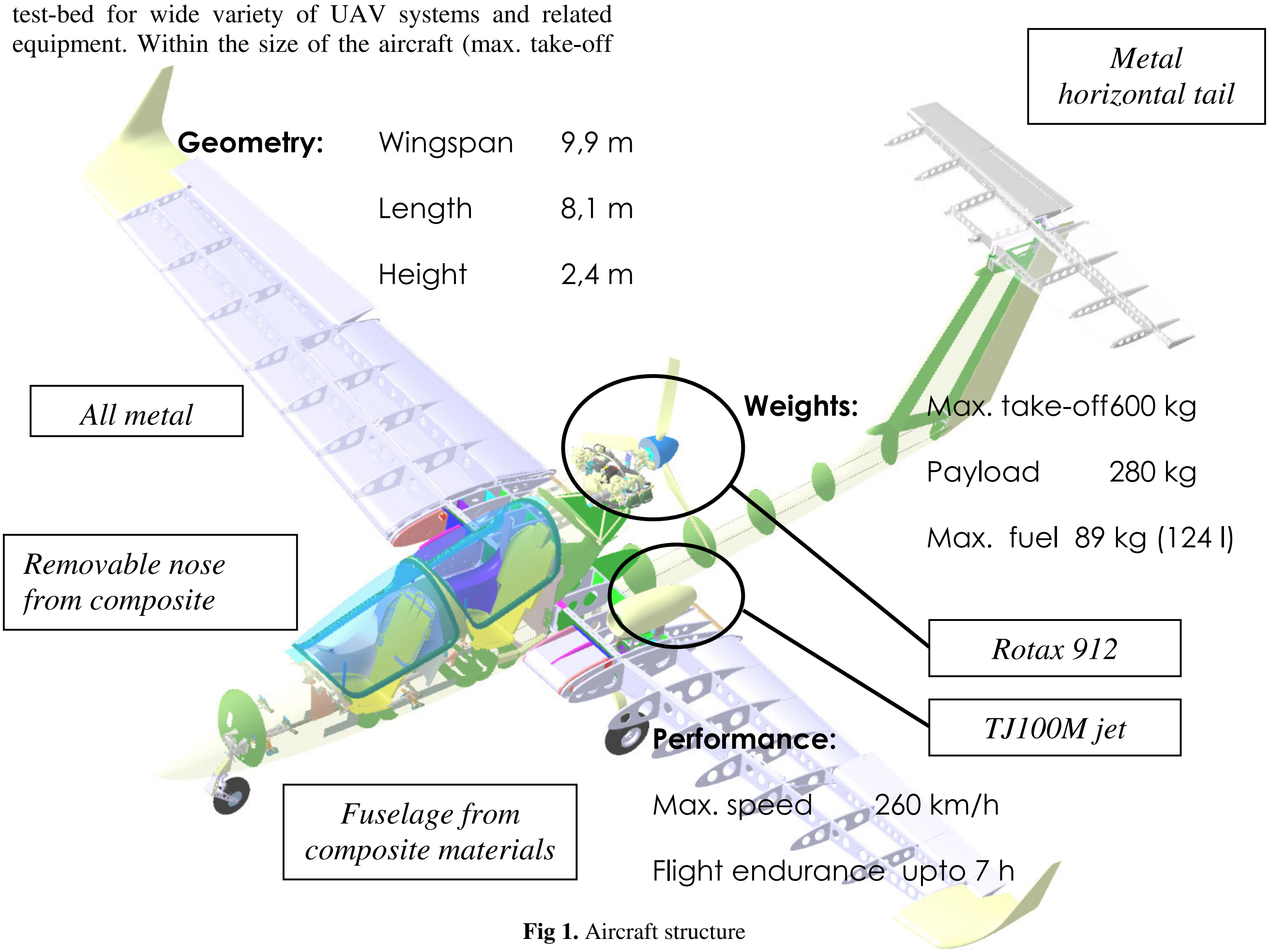

Fig 1. Aircraft structure

The aircraft has significantly larger fuel tanks than conventional aircraft in the same category. Besides two classic fuel tanks in the wing centre section (taken from the original Rapid200), two additional fuel tanks are installed in the leading edge of the outer wing. A total of 124 liters (89 kg) of fuel gives the airplane ability to perform up to **7 hours of continuous flight** (in configuration with only the piston engine). This enables the simulation of typical UAV missions.
The current prototype with a jet engine reduces the fuel available for the piston engine to the two outer fuel tanks. Fuel tanks in the wing centre section are reserved for JET A-1 fuel (for TJ100M engine).

Primary design

VUT 001 Marabu project went through the process of finding an optimal concept. Constraints related to partners, the grant goal, technological requirements, organization, and time limits had to be taken into account. Basic views of the aircraft were created (AUTOCAD software was used). The 3D-model was created with Catia 5V14 software. This model was modified and developed (Fig 2).

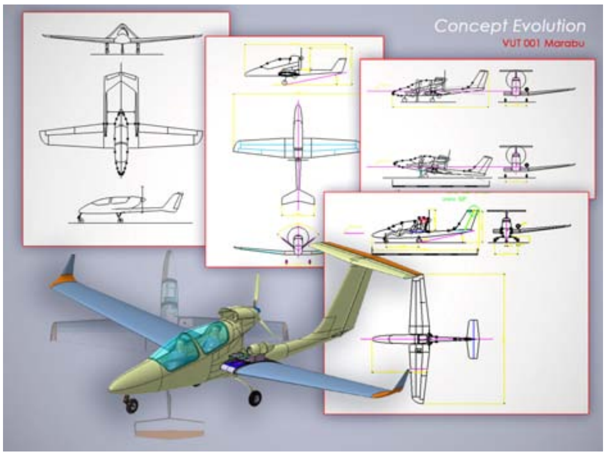

Fig 2. Evolution of VUT 001 Marabu concept

Aerodynamics analysis, flight performance and characteristic , c.g. position and load

The chosen aircraft concept and the conceptual design of the structural elements were analysed. Aerodynamic optimisation of the shape of the fuselage was performed using ***Fluent 6.3, Ansys Icem CFD,*** *and* ***Tecplot 10*** software (Fig 3). Flight performance, characteristics and c.g. position analyses were solved analytically and by using ***AAA*** software. The exact positioning of wings, empennage, engine, pilots, equipment and fuel was defined in this step. The main parts load of the aircraft airframe, gear, control system, and engine bed was computed. CS-VLA requirements were applied and ***GLAUERT*** software was used for the calculation of wing lift distribution.

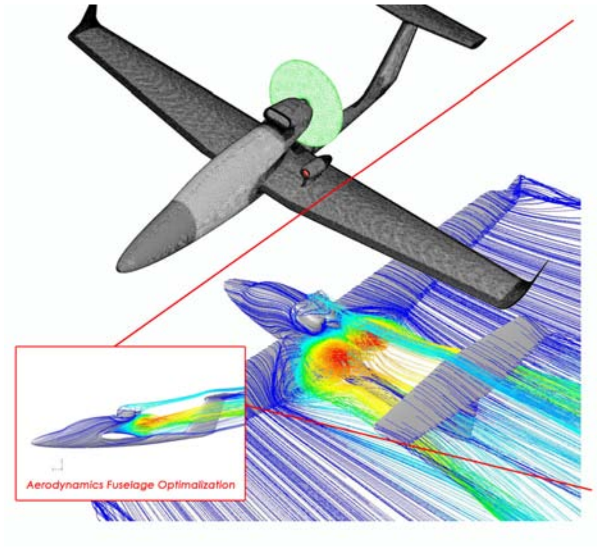

Fig 3. Optimisation of VUT 001 Marabu fuselage shape

Design process, kinematics, and strength analysis

Solving aircraft design problems is always an iterative process. The optimal solution of design, strength, and technological requirements is searched for. Design work is influenced by the need for cooperation and the time schedule. ***Catia 5V14*** software was used as the basic instrument for design. ***Patran/Nastran*** and analytical calculations was used for strength analysis (Fig 4). ***Mathcad*** was used for control system kinematics and load.

3.3. Manufacturing

Basic structural components are manufactured with the cooperation of all partners. The interior parts of the fuselage and general assembly are done in the working room of the Institute of Aerospace Engineering. Direct feedback from the manufacturing process helps to improve knowledge on detailed optimal procedures in the area of composite structures (Fig 5).

4. Proposed development of VUT 001 Marabu airplane

As mentioned above, a piloted airplane is a good platform for development and testing of airborne equipment for UAVs in today's legislative situation. It will enable an easier transition from piloted aircraft to full UAV operated in non-segregated airspace, especially in the development of sense-and-avoid technology. The pilot onboard can ensure safety and take corrective action when failures of technology occur. Our airplane can test equipment in real conditions and search for weaknesses. The development of the VUT 001 is planned in several phases.

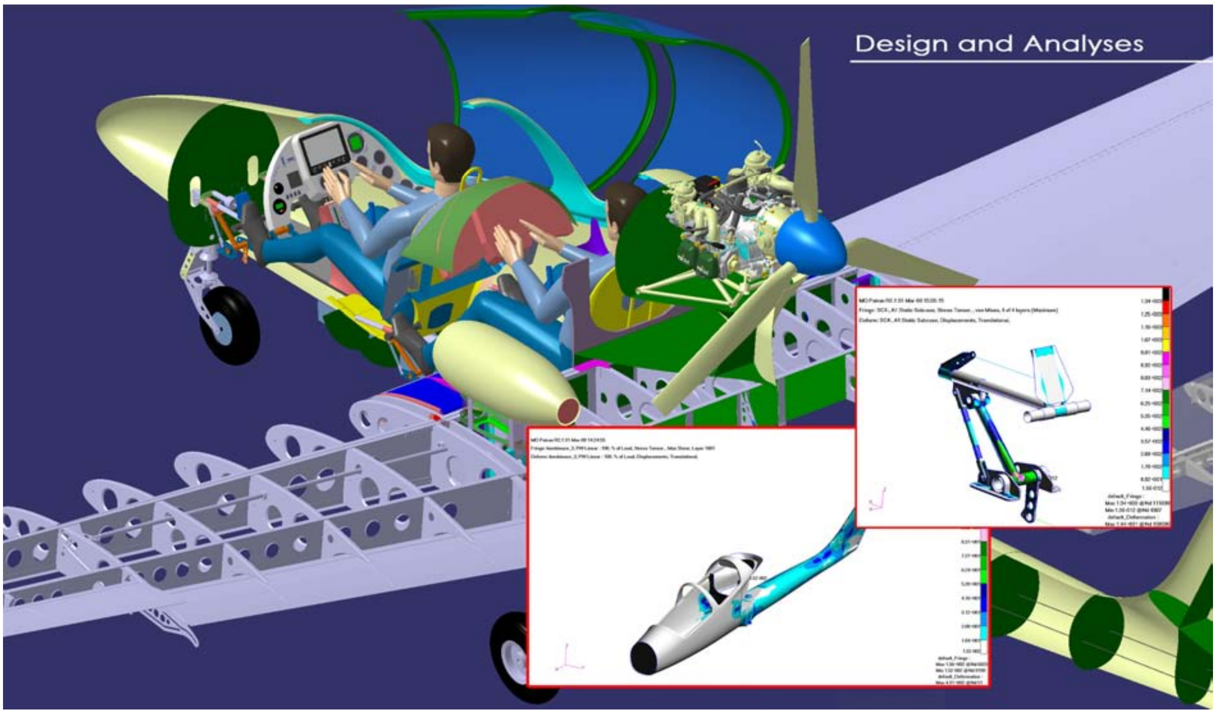

Fig 4. VUT 001 Marabu design and analyses

Fig 5. VUT 001 Marabu manufacture

***First phase*:** development of the piloted airplane, and testing of flight characteristics in whole flight envelope. The Brno University of Technology and particularly the IAE (in cooperation with other institutes) developed *Flight Data Acquisition System* to support in-flight measurements for various projects (Popela *et al.* 2008). Particular attention in the application of the system is given to UAVs, enabling the automation of the measurement process and simplifying the integration of the measurement system into the aircraft.

Another goal of this phase is the selecting suitable sensor, equipment and testing its onboard integration. The development of new equipment is usually very expensive and time consuming. We intend to use existing equipment for conventional airplanes and existing equipment for UAVs.

Second phase**:** development of "sense-and-avoid" technology. In this phase, the pilot is still onboard. The pilot has full priority in control of the airplane. This demand can be fulfilled only by classical mechanical control. The pilot has to be able to override all autopilot actions. This is a complication for aircraft control. Such an autopilot needs special strong actuators with a clutch. For the VUT 001 Marabu, we plan a solution which integrates the pilot into the chain of control. We use standard servos for autopilots used in small airplanes. This solution does not guarantee control of the airplane in all phases of flight, and therefore the pilot will assist in accordance with instructions displayed on the multifunction flight instrument.

Third phase**:** focus on development of the control system for autonomous flight without the pilot onboard. The control system will be designed as on other large UAVs with actuators directly connected to control surfaces. The ground station for control will simultaneously be designed. This phase solve human factor related issue. Operator UAV has to have correct situational awareness. This need develop suitable data presentation on ground station.

4.1. VUT 001 Marabu Equipment study

There are rules defined by the ICAO for avoidance in non-segregated and uncontrolled airspace (see Annex 2). In the Czech Republic, the equivalent regulation is L2. The rules for VFR traffic are set up on the principle of "see and avoid". In the UAV category the term *sense and avoid* is used. Requirements for this UAV capability were first defined in the British regulation CAP 722. A UAV must be able to satisfy this specification concerning separation and collision avoidance capabilities:

- Detect and avoid traffic (air and ground operations) via Rules of the Air;
- Detect and avoid all airborne objects, including gliders, hang-gliders, paragliders, microlights, balloons, parachutists, etc;
- Avoid hazardous weather;
- Detect and avoid terrain and other obstacles;
- Perform equivalent functions, such as maintaining separation, spacing and sequencing that would be done visually in a manned aircraft.

These specifications require having on board equipment for reliable detection of other traffic in a minimum range of 5 km. This is the minimum visibility range for VRF fights. The pilot has about 30-90 seconds to detect and avoid an obstacle. The pilot can detect the obstacle by sight. For a UAV, we can use various types of technology for detection such as:

- radar data analysis,
- picture analysis from optical sensors.

Support for these primary detection methods can be:

- infrared spectrum analysis,
- transponder response monitoring,
- air radio broadcasting, and vector and signal intensity monitoring.

For operations in controlled airspace the same equipment is required as for piloted IFR flight. In the Czech Republic, RNP 5 is required for operating outside ATS routes within FIR Praha above FL 95. Under FL 95 RNPs are not defined, but for operation outside of ATS routes high navigation accuracy is expected. Basic equipment for IFR flights is one VOR receiver, ADF, DME, and one ILS receiver. Other additional equipment can be required depending on the ATS route.

Suitable technologies that cover these requirements are on the market today. High-resolution cameras with analysing software are commonly used in transport. Low power radar is also commercially available for small UAVs. It is possible to use the same radio navigation instruments as are used for piloted aircraft. Many instruments for piloted aircraft have the capability to communicate with others by data interface such as a serial link, USB port. It is easy integrate these instruments in a system. A possible scheme for the onboard equipment of the VUT 001 Marabu is in figure 6.

The anti-collision block presents an interesting element. Different sensors that detect surrounding traffic and calculate avoidance manoeuvres are concentrated in this block. A stereo camera is the major sensor. Detection and tracking algorithms characterise global scene motion, sense objects moving with respect to the scene, and classify the objects as threats or non-threats. The big problem is false detections. The radar can contribute to eliminating them.

Onboard equipment communicates through an optical network. This provides higher data transfer capacity and is resistant to electrometrical interference. Two autopilots are a common solution for large civil aircraft. To improve reliability every autopilot has its own sensors and actuators. The VUT 001 Marabu can use standard aviation equipment such as VOR receiver, inertial navigation, and aeronautical sensors. Most avionic equipment has data output which uses standard communication protocol. It is relatively easy to integrate such avionics in a system. The advantage of this approach is saving money and time for the development of special equipment.

Datalink is a critical component in every UAV. For safe operation, it is necessary to have a reliable connection. Many solutions are currently on the market for UAV datalink, but there are still no clearly defined frequencies for UAV operation. Another problem is satellite Datalink; civil UAV can use only commercial satellites. It is necessary to solve the problem with data security and reliability. We will test a variety of Datalink connections in the VUT 001 Marabu project. Data transfer by satellite connection is expensive; in the initial phases of the project UHF frequencies will therefore be used.

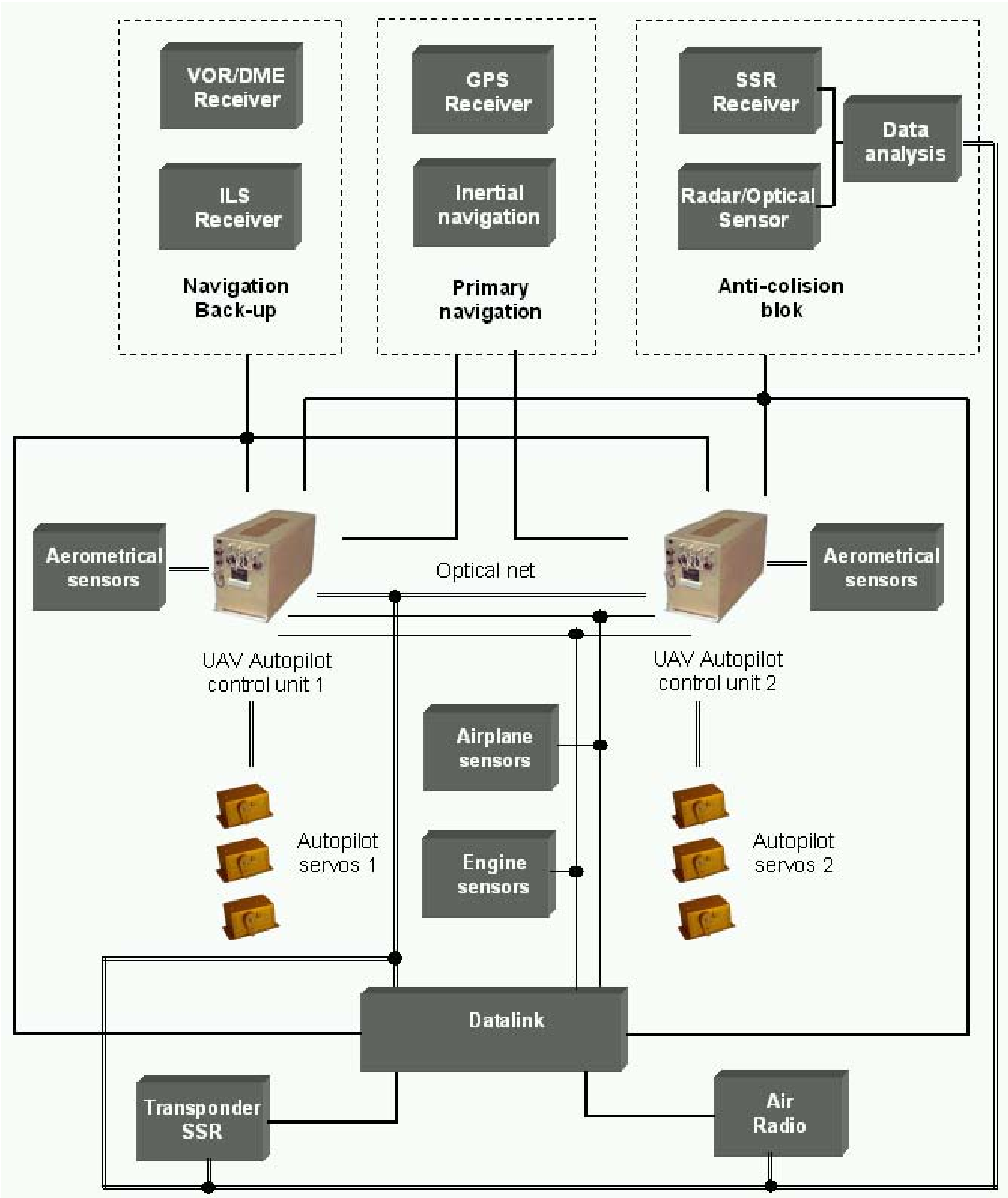

Fig 6. Design of onboard equipment for operation in non-segregated airspace

5. Conclusion

For future massive use of UAVs, it is necessary to achieve the same level in the use of airspace as for manned aircraft. UAVs need the capability to share non-segregated and uncontrolled airspace with other users including gliders, hang-gliders, paragliders, microloghts, balloons, and parachutists.

Brno University of Technology (BUT) and the IAE will support the development of new technology with our VUT 001 Marabu airplane.

The VUT 001 Marabu is the first project fully realized (including production) at the Institute of Aerospace Engineering. Its concept and design meet all current requirements, and it provides space for future enhancements. Now, the basic design of the prototype is finished, and the design of systems and equipment is still in progress.

Acknowledgment

The activities presented were partially supported by the Ministry of Industry and Trade of the Czech Republic (in the frame of the grant project FI-IM3/041).

References

EASA Advance-Notice of Proposed Amendment: Policy for unmanned aerial vehicle certification. 2005. no. 16.

EASA CS-VLA: Certification Specifications for Very Light Aeroplanes, European Aviation. 2003. Safety Agency, 18/RM.

Pištek, A. 2009. Design philosophy and realization of an experimental aircraft supporting UAV application in civil sector (VUT 001 Marabu), in *International Symposium "Light Weight Unmanned Aerial Vehicle Systems and Subsystems"*. March 11-13, 2009.

Popela, R.; Drahansky, M. 2008. Flight data acquisition system, *Czech Aerospace Proceedings* 2. ISSN 1211-877X.

Splichal, M. 2007. *Statisticky rozbor bezpilotnich prostredku* [Statistical analysis of unmanned aerial systems]: Internal report LU09-2007-001, AS.

BEPILOČIO ORLAIVIO VUT 001 MARABU PROJEKTAVIMAS IR JO APARATŪROS EKSPLOATAVIMAS NEKONTROLIUOJAMOJE ORO ERDVĖJE

M. Šplíchal, J. Finda

S a n t r a u k a

Šiame darbe aprašomas projektavimo procesas ir pateikiama santrauka apie numatomus reikalavimus, skirtus bepiločių orlaivių (BO) eksploatavimui nekontroliuojamoje oro erdvėje bei VUT 001 Marabu orlaivio borto aparatūros, pritaikytos civiliniam bepiločiam orlaiviui, eksperimentiniam panaudojimui.
VUT 001 Marabu orlaivis yra tobulinamas Brno technologijos universiteto Aeronautikos inžinerijos institute (Čekijos Respublika) kaip testavimo platforma, skirta įvairios CBO aparatūros tobulinimui. Tačiau šiuo metu CBO aparatūros testavimas realiomis sąlygomis yra neįmanomas, kadangi vis dar nėra šiai orlaivių kategorijai pritaikytų kontrolės reikalavimų. Aeronautikos inžinerijos institutas yra pasiūlęs BO testavimo aparatūros metodologiją, pritaikytą būsimo BO pilotuojamai versijai. Sugedus sistemai, pilotas turi pirmenybę skrydžio valdymui, o tai sumažina galimo incidento tikimybę. Tyrimo tikslas yra užtikrinti šios srities technologijų progresą ir plėtojimą, kol dar nėra įvestos atitinkamos nuostatos.
Bepiločio orlaivio VUT 001 Marabu galimų pajėgumų pristatymas gali motyvuoti institucijas ir gamintojus pagreitinti progresą šioje srityje.

Reikšminiai žodžiai: projektavimas, bepilotis orlaivis, nekontroliuojama oro erdvė.