Modular design of Unmanned Aerial Vehicle (UAV)

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Abstrakt

Příspěvek pojednává o návrhu, výrobě a zkoušení nové modulárně řešené platformy bezpilotních prostředků (UAV) s maximální vzletovou hmotností 7kg vyvíjené na Ústavu letadlové techniky ČVUT v Praze. Během řešení projektu vznikly dvě varianty provedení platformy - materiálově smíšená konstrukce a čistě celokompozitní verze. Platforma je po dokončení využívána jako létající laboratoř umožňující díky modulární konstrukci s přesně stanovenými spojovací uzly snadnou koordinaci vývojových prací a poskytuje studentům dostatek prostoru pro jejich tvůrčí práci a profesní rozvoj. Modulární řešení zároveň zajišťuje projektu dostatečnou odolnost proti chybám, které vzniknou během jeho realizace. Zapojení do projektu umožňuje studentům z různých fakult ČVUT získání znalostí a zkušeností v oblasti navrhování, stavby, provozu a monitorování letových parametrů bezpilotních prostředků.

Keywords

Unmanned Aerial Vehicle, UAV, composites

1. Introduction

This paper describes the results of projects SGS "Modular design of Unmanned Aerial Vehicle (UAV)" (SGS12/059/OHK2/1T/12) and "All-composite unmanned aerial vehicle (UAV)" (SGS13/068/OHK2/1T/12).

The aim of projects was to design, manufacture and test a flying modular platform for unmanned aerial vehicle (UAV) with take-off weight up to 7 kg. The overall concept was firstly tested on the first prototype of mixed construction (composites, wood, aluminum) and subsequently the second prototype was made in all-composite glass-fiber (GFRP) design.

2. Preliminary Design

Basic requirements for UAV and its structural design have been defined in the preliminary design stage. The maximum takeoff weight MTOW=7kg has been selected with regards to "Supplement X" of Aviation standard "L2 - Rules of the Air" and the minimal payload has been determined about 1.5kg. The mid wing configuration with a span L=3m has been selected. Brushless motor with folding pusher propeller was selected as the propulsion unit.

Pusher propeller configuration was chosen because of mounting measuring and recording electronics measuring in the forward fuselage. Self-detachable take-off dolly has been chosen instead of classic undercarriage.

The modular design with well-defined connecting nodes allows easy coordination of project and provides to project researchers and students make UAV design changes in the future.

Modular solution of the project ensures sufficient resistance against errors, which will arise during its implementation.

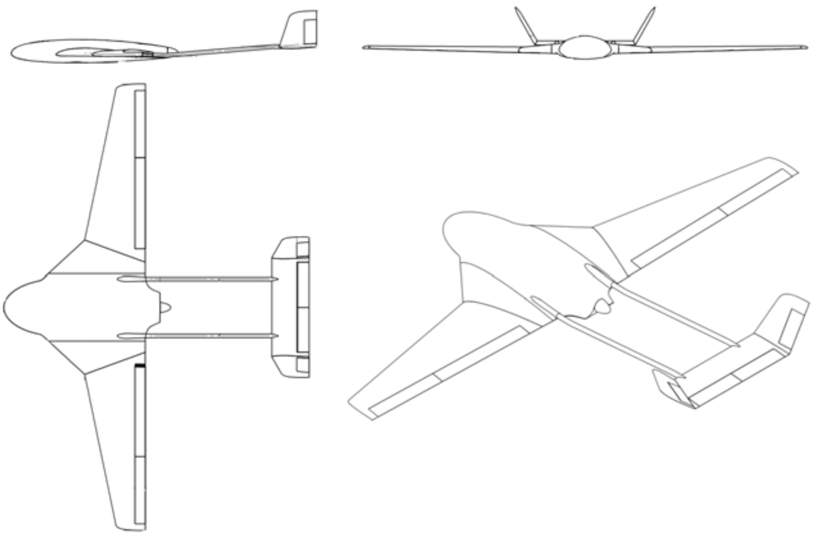

Fig. 1. *UAV Conceptual design*

2.1 Aerodynamic

The wing has SD 7037 (Selig/Donovan 7037 low Reynolds number airfoil) airfoil and it is equipped with plain flaps at trailing edge. The flap increases lift and drag coefficients and decrease landing length. The 2D CFD airfoils analyze was done for airfoil with and without plain flap.

Tab 1. *– Airfoil parameters*

	Airfoil SD 7037	**Airfoil SD 7037 with plain flap**
Maximal relative thickness **t´ [%]**	9,2% at 26.1% of depth	9,2% at 26.1% of depth
Maximal relative camber **c´ [%]**	2,5% at 44.7% of depth	2,5% ve 44.7% of depth
Maximal Lift coefficient **C_Y [-]**	1,469 at α = 14°	1,772 at α = 10°
Minimal Drag coefficient **C_X [-]**	0,0157 at α = 00°	0,041 at α = -04°

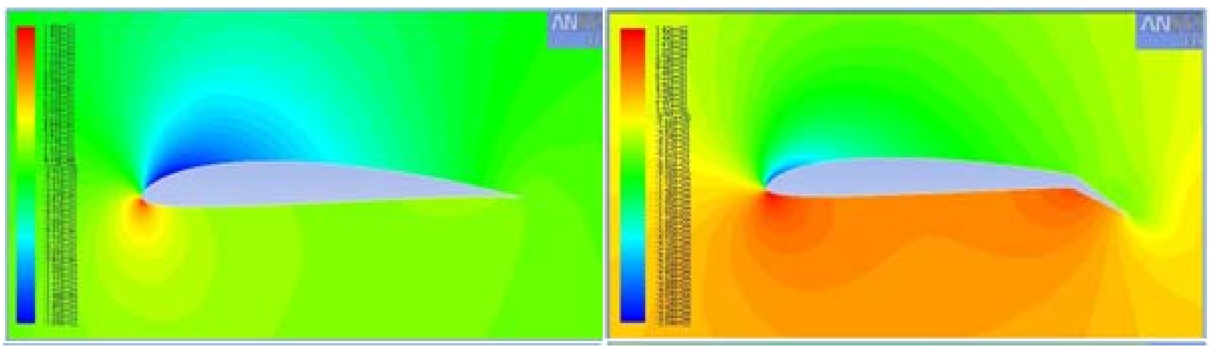

Fig. 2. Pressure distribution - airfoil (left) and airfoil with flap (right)

Based on airfoil CFD analyze results, the wing geometry characteristics were determined (Fig. 3.). Designed wing was then subjected to 3D CFD analysis. Calculated aerodynamic characteristics in the form of aerodynamic polars for airfoil and wing are shown in Fig. 4.

CFD analyzes were performed using ANSYS Fluent 14 program.

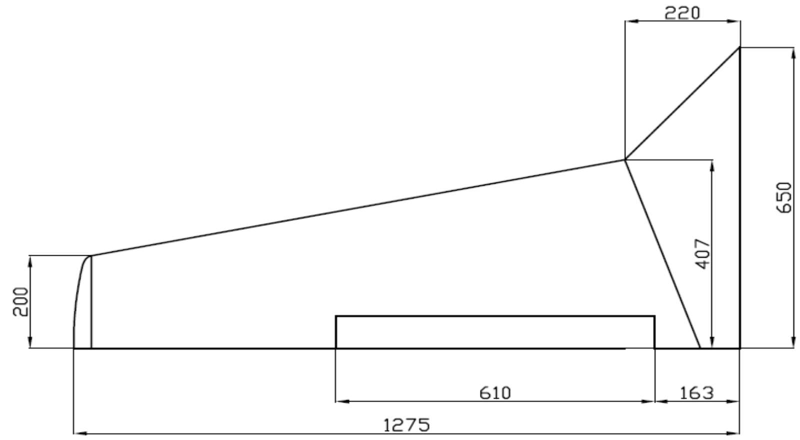

Fig. 3. Wing geometrical characteristics

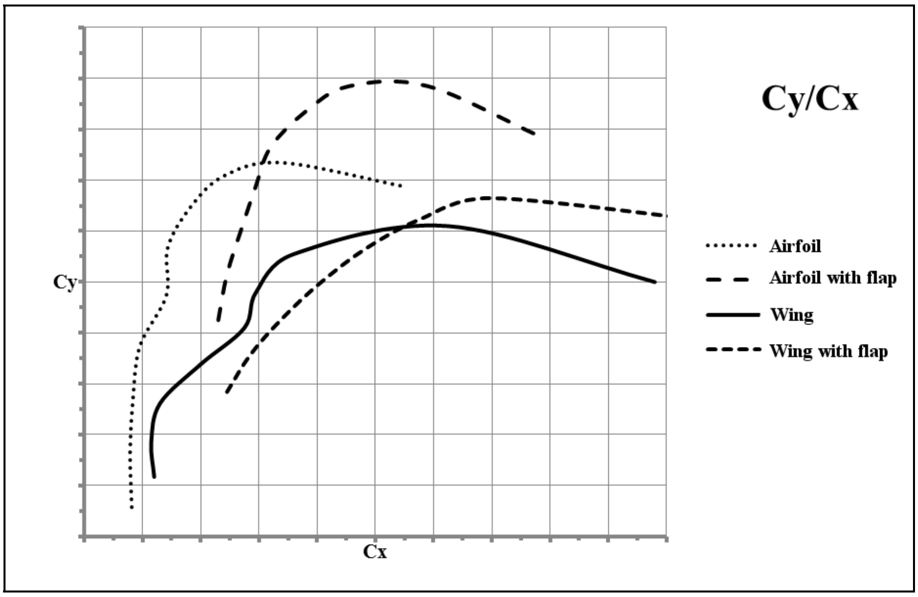

Fig. 4. Aerodynamic polar

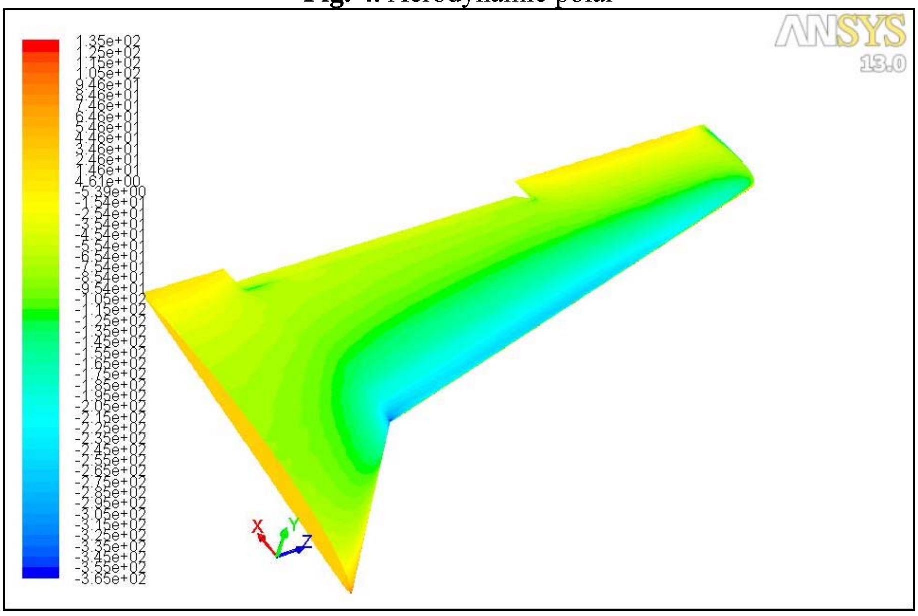

Fig. 5. Upper side wing pressure distribution

3. Structural design

As noted above, two variants of the UAV were developed during project solution. The first prototype had a mixed design of balsa, plywood, aluminum and composite. This mixed design was chosen because of ease of modifiability and reparability. After verification of the design concept, all-composite (GFRP) wings, tail planes and rear fuselage was used for second prototype. This new design allowed an increase payload of about 400g and quality improvement of the aerodynamic surfaces. Last but not least all composite design will allow improving the quality and repeatability of production.

4.1 Fuselage

The airplane fuselage was designed as aerodynamic lifting part. Forward fuselage was made from glass-epoxy sandwich (PVC foam) composites skins, reinforced by system of bulkheads and stringers (enable local force distribution). Rear fuselage consisted of two beams. This beams ware made from aluminum-alloy in the first prototype. Second prototype has beams made from combination of glass and carbon epoxy composite. Forward fuselage was same for both prototypes.

3.2 Wings

The wing was design as semi-monocoque construction. It has double tapered aerodynamic shape. Depth of the wing at the root is 650mm and at the wing end is 200 mm. The wing did not twisted or geometrically, or aerodynamically and is equipped with a plain flap. Ailerons and flaps deflection was provided by electrical servo controlled by pulse width modulation (PWM).

The first prototype had a system made out mostly of balsa wood and plywood. The wing system was consisted of skin, 17 ribs, main spar and 5 auxiliary spars. Flange of main spar was reinforced by carbon roving.

The second prototype has a support system consisting of a sandwich skin (GFRP-PVC foam-GFRP), 2 ribs, one main and one rear spar. Web of main spar were made sandwich box, the flange was made of carbon roving.

3.3 Tail plane

The tail planes were made up of two vertical tails and one horizontal tail, which are divided into a fixed part and movable control surfaces.

The tail planes were design as semi-monocoque construction. Control surfaces deflection was provided by electrical servo controlled by pulse width modulation (PWM). The elevator was divided into two parts which have independent control. The design of the tail plane of each prototype was principally identical to the structure design of the wing variations.

3.4 Take-off and landing device

The aircraft is not equipped with conventional landing gear. The take-off was used self-detachable take-off dolly. Landing was performed on the lower surface of the fuselage.

3.5 Propulsion unit

Propulsion unit consisted of brushless motor (AXI 5320/18) with a maximum output of 1.5 kW connected with pusher four-blade folding propeller (diameter 330mm, pitch 165mm).

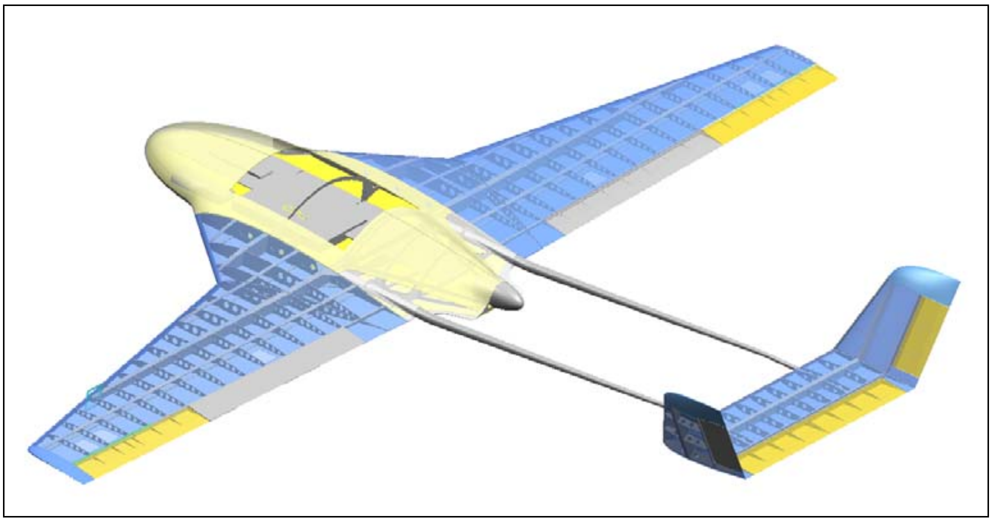

Fig. 6. *UAV design- first prototype*

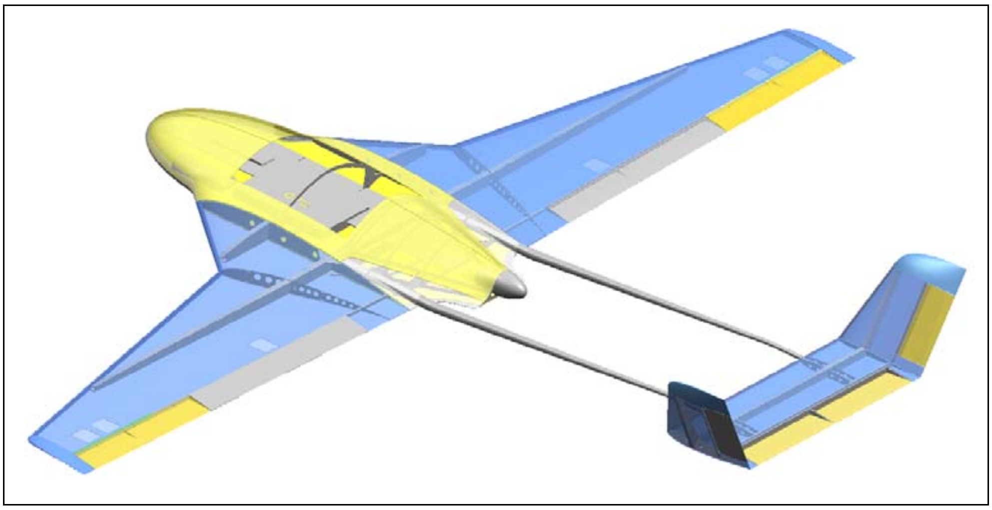

Fig. 7. *UAV design- second prototype*

3.6 Control and measurement systems

To control the airplane is used RC kit operating at a frequency of 2.4 GHz. To transfer video and telemetry data is used frequency of 5.8 GHz. The airplane during the flight records the location (GPS position), speed and altitude (pitot-static system), multiple operating parameters of power unit (power, speed, temperature).

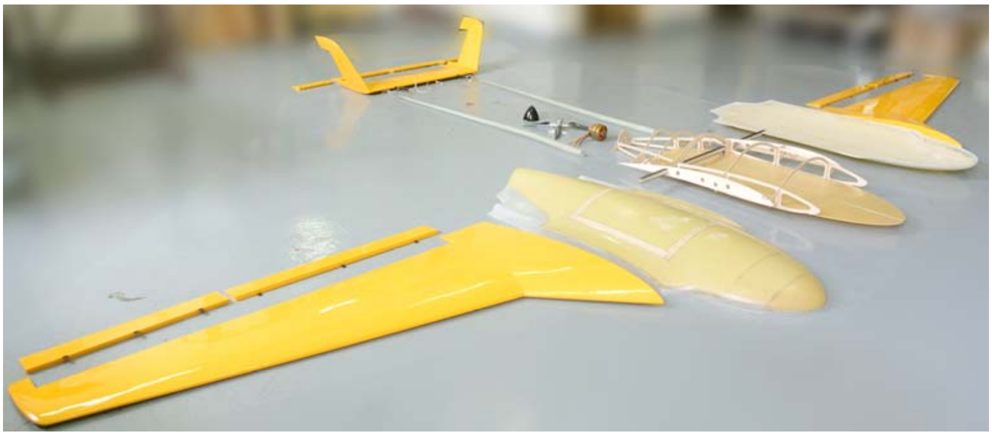

Fig. 8. UAV before final assembly

4. Manufacturing

Production of wings and tail planes of the first prototype was performed by traditional modeling techniques - bonding balsa wood and plywood ribs and spars. Subsequently, the system was bonded together with balsa wood skins.

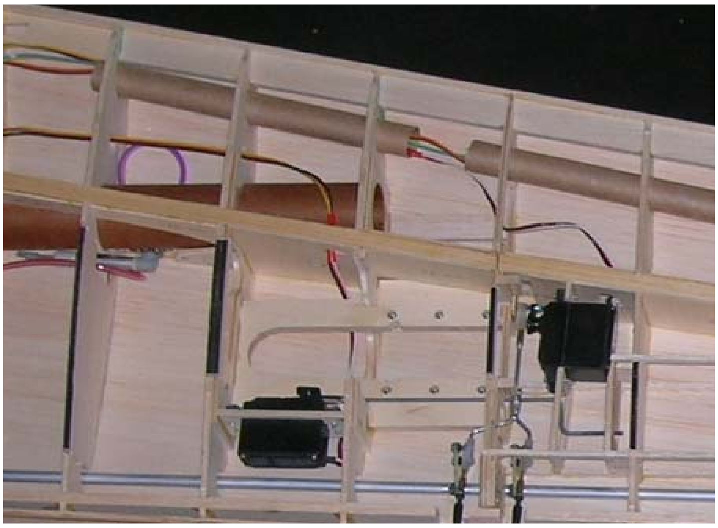

Fig. 9. Example of balsa-wood design

Composite parts were made by hand lay-up lamination, followed by curing in vacuum. Laminating of skins (wing, tail plane, fuselage) was carried out into negative molds. The molds were produced directly by CNC milling (wing, tail planes) or by lamination of the master model (front fuselage). The ribs and spars were CNC milled from composite panels (self-made).

Fig. 10. Wing skin manufacturing

5. Test flights

During the project solution was carried out several test flights of both prototypes to verify the performance and flight characteristics of the UAV. Structural strength and overall conception was also tested during these test flights. The UAV was fully controlled by operator from ground during test flights. After completion of the development of autonomous systems (FEE CTU in Prague) and resolving legislative and administrative problems are planned autonomous flights without operator intervention.

Fig. 11. Test flights - before take off

Fig. 12. Test flights

6. Conclusion

Two flight prototypes of UAV modular platforms was designed, manufactured and tested during projects solution. The second prototype represents final design of all-composite UAV modular platform. Maximum takeoff weight is 7 kg, payload is approximately 1,9 kg and flight endurance about 40 minutes with 5Ah accumulator (22V).

This platform is used as flying laboratory. The modular design with well-defined connecting nodes allows easy coordination of future project, provides to students with enough space for their creative work and professional development. Modular solution of the project ensures sufficient resistance against errors, which will arise during its implementation.

Realization of the project allow to students from different faculties of CTU gaining knowledge and experiences in design, construction, operation and monitoring of flight parameters of UAVs.

List of symbols

L	Wing span	(m)
MTOW	Maximal take-off weight	(kg)
t´	Maximal relative airfoil thickness	(%)
c´	Maximal relative airfoil camber	(%)
C_Y	Lift coefficient	(-)
C_X	Drag coefficient	(-)

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