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ANALYSIS AND CONCEPTUAL DESIGN OF MICRO CLASS UAV FOR AERODESIGN INTERNATIONAL COMPETITION

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Abstract

Aero Design is an annual student competition held by Society of Automotive Engineers in which the goal is to design and build a flying UAV capable of lifting the highest payload while observing lowest payload weight and fitting in a specified carrying case. To achieve that task teams have to choose between conflicting objectives that are lowest empty weight and highest lifting capacity. The rules state that design to enter the competition must be a fixed wing aircraft fitting in a box with inside dimensions of 24x18x8 inches. The payload bay has to be a rectangular block measuring 5x2x2 inches. There also is a limit of 55 pounds total weight with payload. The aircraft must take of either by hand launch or be propelled using a rubber tubing, than do a 360-degree circuit of the flying field and finally land within 200 feet landing zone. The article presents requirements analysis, weather research, design research, considered about launch method, wing layout and aircraft layout study (napkin sketches).

Keywords: *UAV, unmanned aerial vehicles, drones, analysis, aircraft design*

1. Introduction

Aero Design is an annual student competition held by Society of Automotive Engineers in which the goal is to design and build a flying R/C model capable of lifting the highest payload while observing lowest payload weight and fitting in a specified carrying case. To achieve that task teams have to choose between conflicting objectives that are lowest empty weight and highest lifting capacity. The rules state that design to enter the competition must be a fixed wing aircraft fitting in a box with inside dimensions of 24x18x8 inches. The payload bay has to be a rectangular block measuring 5x2x2 inches. There also is a limit of 55 pounds total weight with payload. The aircraft must take of either by hand launch or be propelled using a rubber tubing, than do a 360-degree circuit of the flying field and finally land within 200 feet landing zone.

2. Flight score analysis

Micro Class Flight Score is given by the following Equations.

$$Final\ flight\ Score = \sum_{1}^{n} R_n, \qquad R_n = (2 - EW) x PF_n + (P_n x \sum_{1}^{n} P_n), \tag{1}$$

$$P_n = Payload\ (lbs.), \qquad PF_n = Payload\ Fraction = \frac{n}{(P_N + EW)}. \tag{2}$$

Empty Weight and Payload Fraction have substantially lessened influence on the flight score. Reliability on the other hand has a major increase in overall score though it is not direct. The main factor when considering final flight score is the consistent ability to carry as much weight as possible. The considered object is presented in Fig. 1.

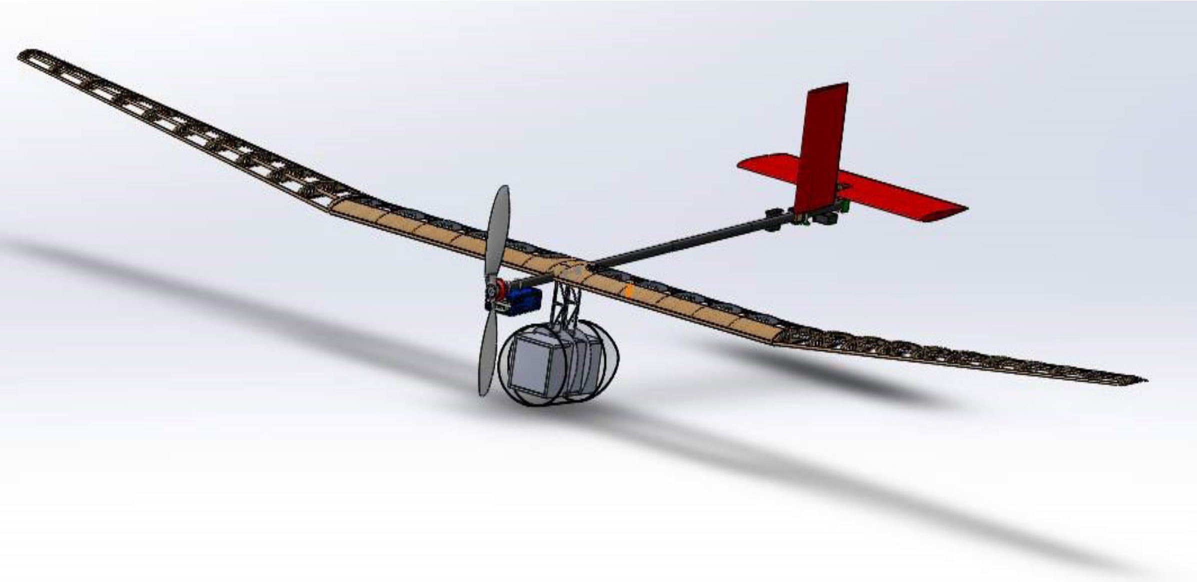

Fig. 1. The project of unmanned aerial vehicle

3. Requirements analysis

After throughout analysis of rules and scoring system we formulated our own requirement list for our aircraft. That allowed us to form this systems specification Tab. 1.

4. Design research

We preselected several designs that we saw fit up to this task [1]. They were as follows: Conventional layout, canard, Bi-plane and the BWB – Blended Wing Body fairly new design developed in recent years by Boeing as the transport plane of the future [Tab. 2].

The subjective winner is the conventional design, which in perfect conditions may not be the most effective, but in the real world it is just what we need: rugged, simple, and fast to design and build. Since we have an ambitious plan of flight, testing time needed to build the aircraft is a factor that we cannot underestimate.

Tab. 1. The aircraft design requirements analysis table

System requirements and specifications		Functional requirements	Components and interaction	
Weight and dimensions	– carrying case measuring 24 x 18 x 8 in. – payload dimensions: 5x2x2 in. – Lowest empty weight possible – max 370 g – transmitter of: 7.7x7.7x5 in. fits into the box	platform subsystem: – structural components – size, weight , and configuration of aircraft	– mechanical	– glass fibre flat plates – carbon fibre tubing – epoxy resin – cyanoacrylate – balsa wood – extruded polystyrene foam

Operation	– carrying as much cargo as possible – doing a 360° circuit of the flying field in max 2 min – take-off by hand, landing in 200 ft. – lowest take-off speed possible	cargo subsystem: – holding the payload as homogenous plates – landing gear with minimal drag	– mechanical – mechanical	– hardware joints – ball bearings – servos
Communication	– spectrum dx7 transmitter with a 4 ch receiver	communication subsystem: – R/C transmitter	– electrical	– orange 4 ch micro receiver
Cost	no more than 500$	components cost needs to stay within budget		– off the shelf composite materials
		power subsystem	– electrical	Li-Po batteries

Tab. 2. The aircraft types

Category	***Weight [%]***	***Conventional***	***Canard***	***BWB***	***Theoretical***
Ease of construction	20	8	7	7	10
Empty Weight	40	9	8	3	10
Stability and control	20	9	7	2	10
Design sequence	10	9	6	1	10
Historical data	10	10	7	1	10
TOTAL	100	8.9	7.3	3.2	10

5. Aircraft layout study – napkin sketches

The aim of this study was to perform analysis three types of layouts were considered during the design process [Fig. 2-4].

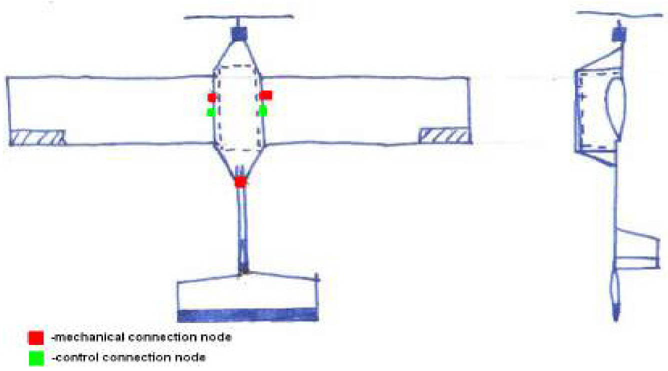

Fig. 2. The conventional design of unmanned aerial vehicle

Conventional design:

- simple,
- we have experience,
- easy to build,
- no excessive connections.

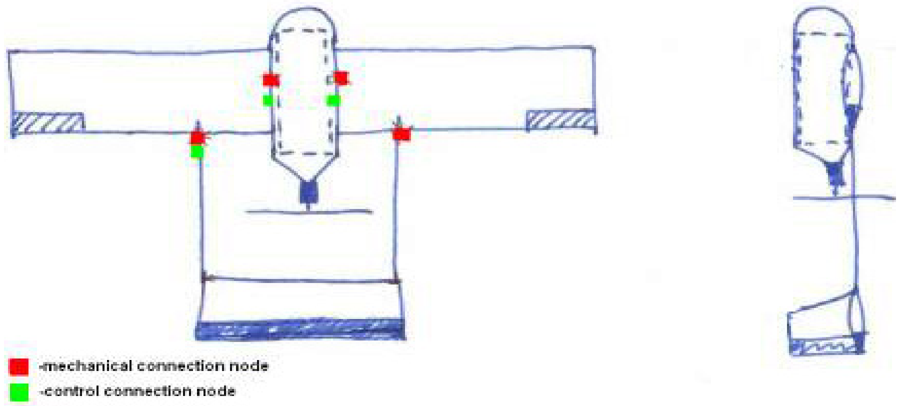

Fig. 3. The pusher design of unmanned aerial vehicle

Pusher:

- tail surfaces directly in prop wash,
- more structurally complex,
- heavier than conventional,
- hand launch is risky.

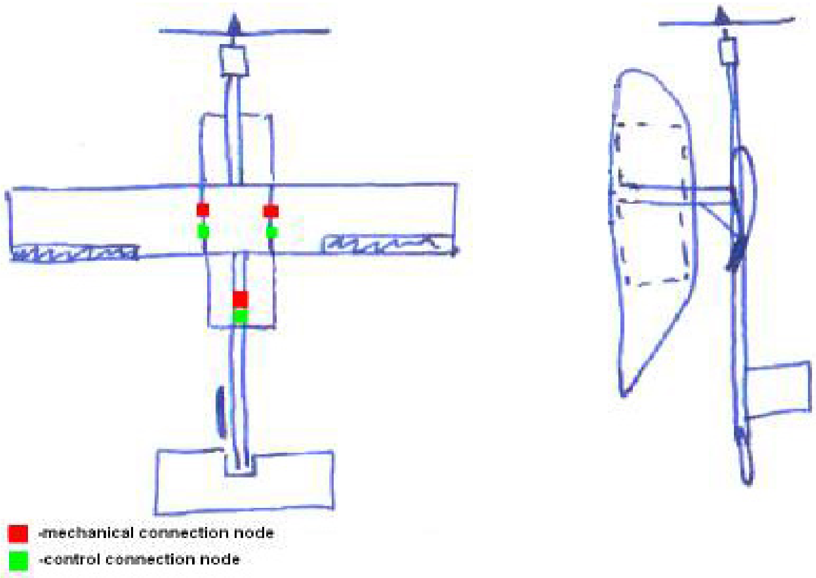

Fig. 4. The "central pod" design of unmanned aerial vehicle

„Central pod" aircraft:

- payload in an external pod,
- very simple to build,
- very low landing gear weight,
- extra stability,
- great modularity.

6. Payload bay

Payload bay [Fig. 5] was separated slightly from the fuselage. This allowed us to design a very robust landing structure and lower the CG location [2]. This also allowed us to design the payload bay in a fashion that will not generate much drag and allows nice hand launches.

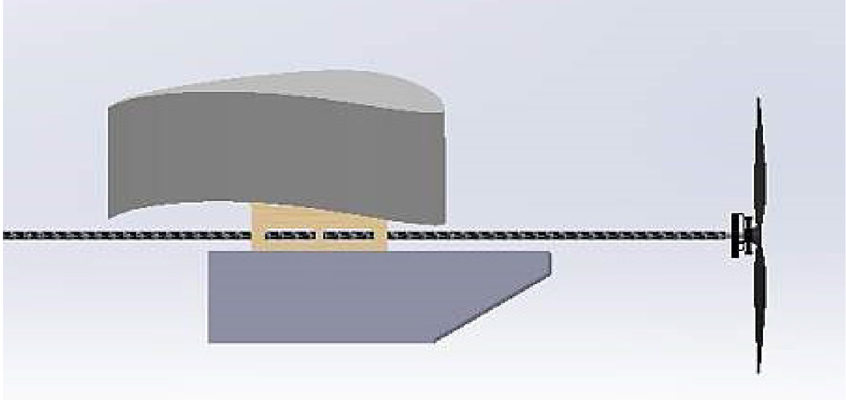

Fig. 5. The fuselage design

7. Technology demonstrator

A prototype technology demonstrator was built to confirm our assumptions about airfoils performance.

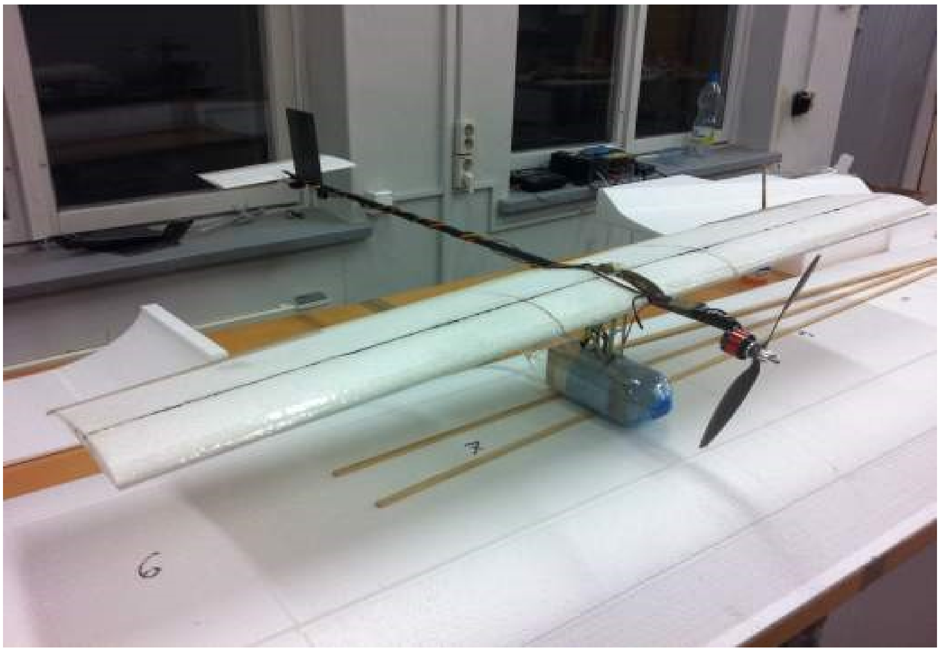

Fig. 6. The prototype unmanned aerial vehicle

Flight tests were successful. Hand launch was not an issue. Hand launch speed was measured to be around 10-11 m/s. Weight build-up of the final aircraft was done in Solidworks software [3] and [4].

Tab. 3. The prototype weight build-up

Element	*Weight [lbs]*
Wings	0.12
Battery	0.05
Tail	0.02
Engine and drive	0.14
Fuselage	0.10
TOTAL	0.43

Drag analysis was computed using 3-D panel method in XFLR5 [Fig. 7].

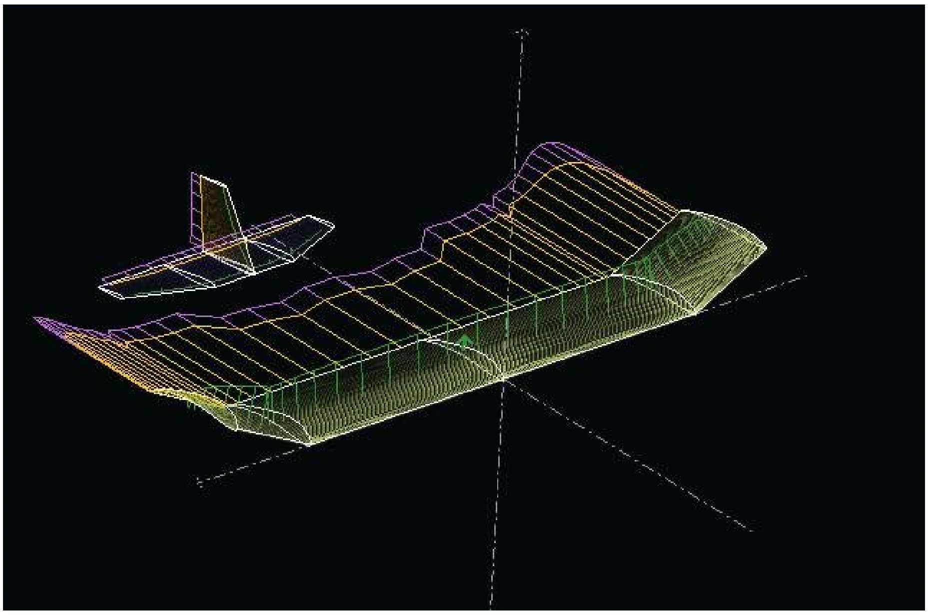

Fig. 7. The aerodynamic XFLR5 model

Static lateral stability helps to stabilize the lateral or rolling effect when one wing gets lower than the wing on the opposite side of the airplane. Four main design factors make an airplane laterally stable, e.g. dihedral, keel effect, sweepback and weight distribution. The most common procedure for producing lateral stability is to build the wings with a dihedral angle (δ) varying from one to three degrees. The basis of rolling stability is, of course, the lateral balance of forces produced by the airplane's wings. Imbalance in lift results in a tendency for the airplane to roll about its longitudinal axis. In our project, we have used dihedral angle 3° [5].

There are no ailerons on the wings to save weight on the servos. Flight stability is also improved by high wing location, which also helps to obtain a stabilization moment. In a sideslip, the wing into the wind is operating with an effective decrease in sweepback, while the wing out of the wind is operating with an effective increase in sweepback. The swept wing is responsive only to the wind component that is perpendicular to the wing's leading edge. Consequently, if the wing is operating at a positive lift coefficient, the wing into the wind has an increase in lift, and the wing out of the wind has a decrease in lift. In this manner, the sweptback wing would contribute a positive dihedral effect and the swept forward wing would contribute a negative dihedral effect.

Longitudinal stability is the quality that makes an airplane stable about its lateral axis. It involves the pitching motion as the airplane's nose moves up and down during flight.

Longitudinal unstable airplane has a tendency to dive or climb progressively into a very steep dive or climb, or even a stall. Thus, an airplane with longitudinal instability makes flight difficult and sometimes dangerous. Static longitudinal stability or instability of the airplane is dependent upon four factors:

1. Location of the wing with respect to the centre of gravity;
2. Location of the horizontal tail surfaces with respect to the centre of gravity;
3. The area or size of the tail surfaces
4. The total moment of the wing

In stability analysis, a body is free to rotate only around its centre of gravity. To obtain static longitudinal stability, the relation of the wing and tail moments must be defined according to the following rule.

Propeller is an important part of airplane to provide the necessary thrust for powered flight. Fixed-pitch and ground-adjustable propellers are designed for best efficiency at one rotation and forward speed. They are designed for a given airplane and engine combination. Choosing a propeller that provides the maximum efficiency for either take off, climb, cruise, or high-speed flight will result in decreasing efficiency of both the propeller and the engine when these conditions change. Since the efficiency of any machine is the ratio of the useful power output to the actual power input, propeller efficiency is the ratio of thrust horsepower to brake horsepower.

Thus, propeller efficiency varies from 50 to 87 percent, depending on how much the propeller "slips". Propeller slip is the difference between the geometric pitch of the propeller and its effective pitch. Geometric pitch is the theoretical distance, which propeller should advance in one revolution; effective pitch is the distance, it actually advanced. Thus, geometric or theoretical pitch is based on no slippage, but actual or effective pitch includes propeller slippage in the air. Performance of propeller is affected by several factors: diameter relative to rotate per minute and blade area relative to power absorption and pitch.

7. Discussion

The aim of this study was to perform analysis and conceptual design of Micro Class UAV for Aerodesign International Competition. Payload prediction was based upon achievable take-off velocities at hand launch. Launch speed from the drag analysis was 10 m/s. Analytical model was made and put into an excel spreadsheet. Maximum predicted payload was estimated to be 5.5 pounds.

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