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AERODYNAMIC AND MECHANICAL 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. The most important aspect in aircraft design is choosing suitable aerodynamic and mechanical configurations for example: aircraft and wing layout, airfoil with the correct Reynolds (in this case low) number, airframe, and landing gear construction. The article presents airfoil selection, trade studies, tail aerodynamic design, tail sizing, drag analysis, calculations of stability, stress analysis, propulsion selection and manufacturing of UAV prototype.

In particular, the comparison of different aircraft designs, effect of taper ratio on lift distribution, the design of wings, lift vs. angle of attack curves and. angle of attack curves, the aircraft tail surfaces, fuselage design are presented in the article. The aim of this study was to perform analysis of aerodynamic and mechanical of Micro Class UAV for Aerodesign International Competition. All projects will be doing in a prototype technology demonstrator was built to confirm our assumptions about airfoil's performance. Flight tests were successful. Analytical model was made and put into an excel spreadsheet. Maximum predicted payload was estimated to be 5.5 pounds.

Keywords: *unmanned aerial vehicles, drones, Aero Design, 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 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).

2. Design research

Three types of construction:

Canard for instance seemed like a good alternative for the standard layout. There are some serious disadvantages to this type of designs. Since the front control surface should stall before the main wing, the aircraft cannot operate at highest angles of attack and therefore cannot achieve Clmax.

Another issue is tail heaviness (since the wing and engine are in the back) that forces to move cargo bay forward of the main wing which adds substantially to structural weight of the fuselage. There is one advantage: all high lift airfoils have high negative pitching moment coefficients, in conventional designs the trim forces are negative which reduces the effectiveness of the main wing that problem in canard aircraft does not exist, though that is substituted by the wing – canard interference, which also reduces the effectiveness of the main wing. All that combined with limited historical data made us realize that that was not what we were looking for.

Blended Wing Body is yet another attempt to raise the old flying wing concept back into the air. It is complicated to design, but done right it has much to give in return. For instance building a BWB, we could utilize a fairly wider wingspan, since there is no tail. Unfortunately, biggest advantages of this type of construction are in the same time its biggest flaws. The integration for instance makes it very hard to design the airplane in a way that even the slightest change in weight distribution would not make it unstable. Those stability issues forces us not to use the best high lift airfoils but self-stable ones instead. Another way around that is using very steep wing sweep. Both methods cancel the advantages of higher wingspan. And last but not least is the payload bay dimensions that makes it pretty hard to fit into BWB heaving no dedicated fuselage by definition.

Than we have the old but reliable conventional design [2]. It is fairly easy to achieve static and dynamic stability in this type of design. However, the main advantage is its simplicity and ease of manufacturing. In addition, there is plenty of historical proof of this design being the most reliable in high lift tasks. Conventional aircraft gives us an opportunity to choose the airfoil as freely as possible especially from the low Reynolds high lift airfoils that are designed solely for these kinds of tasks. Not many profiles are capable of giving a high lift coefficient at relatively low speed and still have gentle stall characteristics and acceptable pitching moment. The comparison of different aircraft designs in Tab. 1.

Tab. 1. The comparison of different aircraft designs

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

3. Wing planform design

Because of the Re number concerns minimum wing chord was arbitrarily set at 7.87 in. That should secure Re of at least 150,000 in all flight regimes. Such aspect ratio should provide L/D ratio of more than 10. It was adopted mostly avoid low Re at the wingtips. Taper of 0 gives was adopted not to compromise Re number at the wingtips. Fig. 1 presents the effect of taper ratio in lift distribution [4].

To improve spiral stability and prevent duck roll dihedral angle of 30 degrees was applied at the wingtips and no geometric twist was applied. Incidence angle was set to 0 degrees. Fig. 2 presents the design of wings.

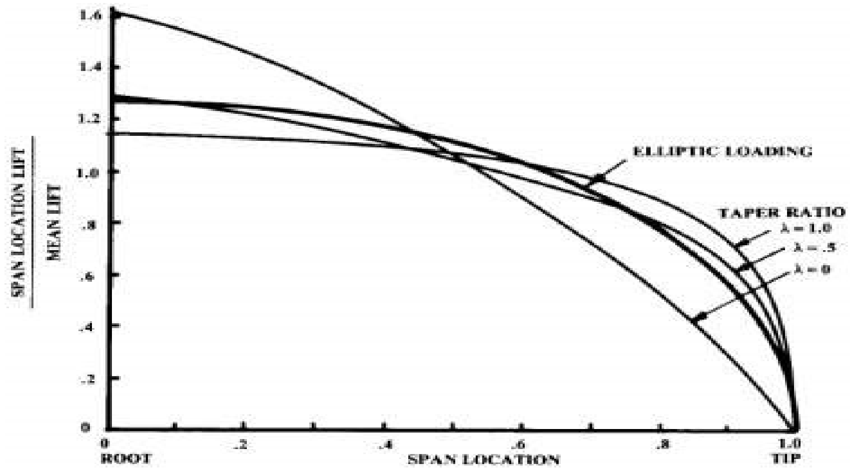

Fig. 1. The effect of taper ratio on lift distribution

Fig. 2. The design of wings

4. Airfoil selection

The most important aspect in aircraft design is choosing suitable airfoil for the correct Reynolds (in this case low) number [1]. For take-off conditions, it is essential to achieve the maximum lift coefficient (Clmax), which directly influences to the lift force value. To produce such high lift coefficients, we require very high negative pressure distribution on the upper surface of the airfoil. To select the airfoil correctly we should first estimate Re at which it would operate.

To decide which airfoil met the criteria the best we analysed performance of several low Reynolds number ones: Clark Y, MH 18, NACA-6412, Selig 1223, Eppler 423 and Li 71 using XFLR5. The results of Eppler 423 and Selig 1223 were the most appropriate so we continued and expanded CFD analysis in Fluent Software. Fig. 3 presents the lift vs. angle of attack curves.

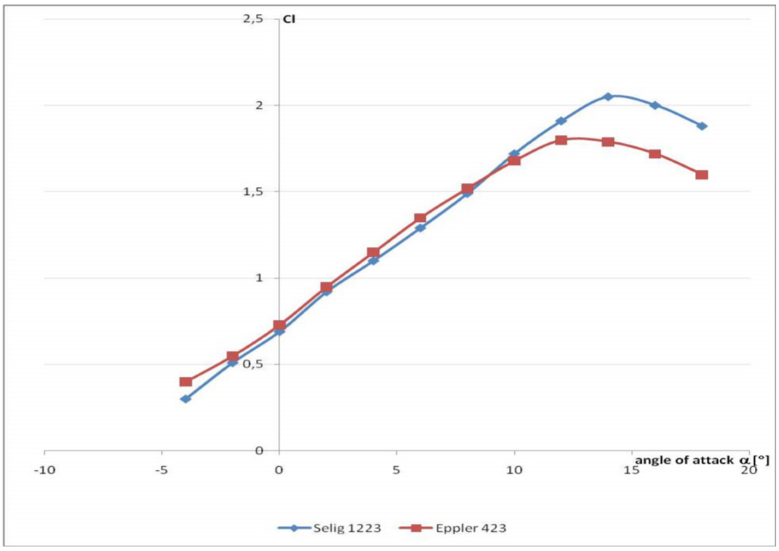

Fig. 3. The lift vs. angle of attack curves

Selig 1223 was chosen for it higher lift coefficient at Re 150,000 it has a difficult to manufacture trailing edge but the increase of the empty weight will be insignificant versus the amount of lift gained [2].

For further investigate, this airfoil performance in this transitional Re region we sought airfoil data gathered from aerodynamic tunnels. This was done to reduce the risk of laminar separation on the airfoil. Laminar separation can drastically decrease performance of the airfoil, causing stall at very low angles of attack. Data was found [3] in M. Selig's 'Summary of low speed airfoil data' vol. 1. [Fig. 4].

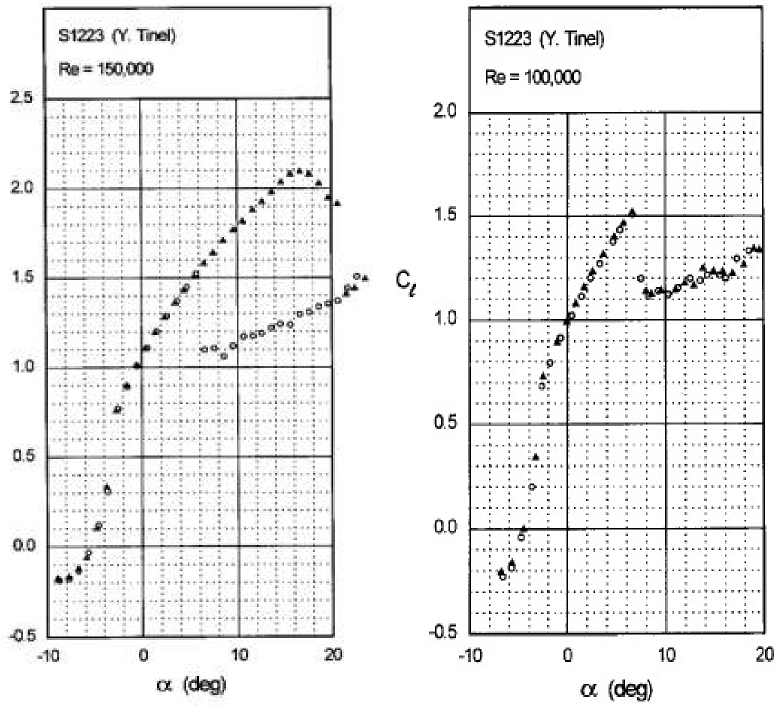

Fig. 4. The lift vs. angle of attack curves

As we can see, Selig has a nice characteristic until it reaches stall when the laminar separation occurs – that phenomenon causes a hysteresis loop to occur. We are not concerned about that since at Re 150,000 this occurs right after stall, which can only occur during take-off and will effect in a failed attempt. During flight significantly higher speed are expected so hysteresis would fade.

Establishing useful Re number gave us the opportunity to establish design speed of our aircraft. From our research of weather conditions, we established a certain coefficient that combined with a chord of 7.87 in. gave us take-off design speed of 11.2 m/s

5. Tail

The tail surfaces were arranged in a conventional layout. Control surfaces were designed to be at 50% of the root chord to allow good low speed handling. Deviation of control surfaces by ±20° is sufficient to control the flight. Vertical fin shape does not have significant influence on drag. The proposals aircraft tail surfaces in Fig. 5.

6. Payload bay

Payload bay was separated slightly from the fuselage. This allowed us to design a very robust landing structure and lower the CG location. This also allowed us to design the payload bay in a fashion that will not generate much drag and allows nice hand launches. The Fig. 6 presents fuselage design with payload bay.

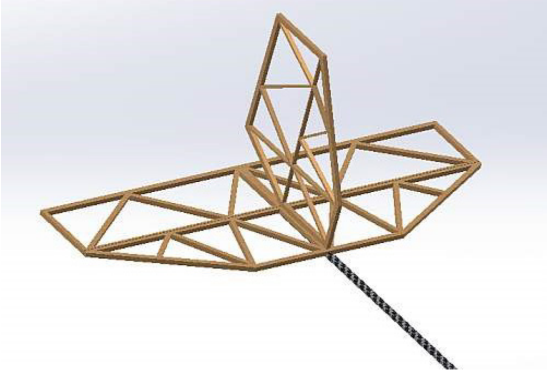

Fig. 5. The aircraft tail surfaces

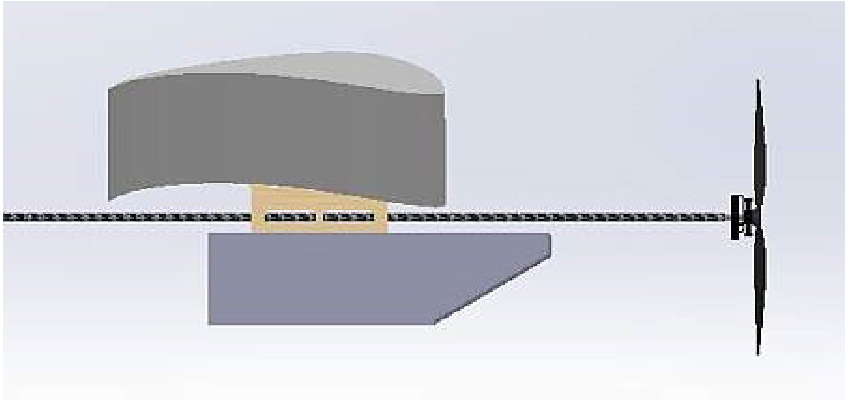

Fig. 6. The fuselage design

7. Discussion

The aim of this study was to perform analysis of aerodynamic and mechanical of Micro Class UAV for Aerodesign International Competition. All projects will be doing in a prototype technology demonstrator was built to confirm our assumptions about airfoil's performance. Flight tests were successful. Hand launch was not an issue. Hand launch speed was measured to be around 10-11 m/s. Analytical model was made and put into an excel spreadsheet. Maximum predicted payload was estimated to be 5.5 pounds.

References

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