A COMPUTATIONAL STUDY ON THE DESIGN OF AIRFOILS FOR A FIXED WING MAV AND THE AERODYNAMIC CHARACTERISTIC OF THE VEHICLE

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Keywords: *X-foil, Fluent, MAV, Airfoil*

Abstract

A MAV(Micro Aerial Vehicle) is defined as under 100g, 15cm unmanned vehicle and it is operated in the range of low Reynolds number. The Low Reynolds number flow has 4 general aspects:1)laminar flow, 2)flow separation, 3)separation bubble and 4)reattachment caused by turbulent flow. The separation bubble reduces lift, increases drag, and changes the pitching moment characteristics. It is important to obtain the longitudinal stability since the separation bubble has influenced on the pitching moment characteristics. Hence, several airfoils have been developed by modifications and combinations of existing airfoil geometries. This study is focused on improvement of 2D and 3D aerodynamic characteristics for those modified airfoils.

1 Introduction

A MAV(Micro Aerial Vehicle) is defined as under 100g, 15cm unmanned vehicle as proposed by DARPA in 1990 and it is operated in the range of low Reynolds number.(1)

The surface flow of a fixed wing MAV is in the range of low Reynolds number which is 80,000 to 150,000 due to limited physical shape. The Low Reynolds number flow has 4 general aspects such as laminar, transition, laminar separation bubble and reattachment caused by turbulent flow. Since the separation bubble reduces lift and increases drag and changes the pitching moment characteristics it is important to secure aerodynamics characteristics of airfoils in designing aerodynamics of MAV.

Also, high viscous effect of MAV operated in low Reynolds number flow and complicate 3 dimensional flow patterns based on low aspect ratio rapidly decrease the maximum lift to drag ratio and cause unfavorable aerodynamics characteristics.(6)

2 Analysis method

2.1 Shape of Airfoil

S5010 airfoil can obtain relatively high lift coefficient and lift to drag ratio (6) but can't overcome a matter of longitudinal static stability of MAV due to low Cm.

R-series airfoil, which is from NACA series airfoil with different size and position of camber, has better Cm characteristics compared to S5010 but relatively low lift coefficient. We designed S5010-R2 airfoil with combination of the top of S5010 and the bottom of R-series (thickness 10%, camber 2%, camber position 20%) to utilize advantages of the two airfoils and analyzed its aerodynamics characteristics.

Since both airfoils use the shape of leading edge of NACA series, distribution of radius curvature of the leading edge, which is very important in low Reynolds number flow, is consecutive and smooth. In addition, we made S5010-4d, a variant shape of airfoil, In previous study which we conducted, static margin over 0.05 is required to secure stable longitudinal static stability for a fixed wing MAV and airfoil which has pitching moment over +0.06 should be developed for the case of zero lift. Inverse method, in fact, is impossible and even partial inverse method is very difficult due to characteristics of low Reynolds number flow.

Hence, we have developed an airfoil which has excellent moment characteristics based on the analysis of variable characteristics by design factors to change moment characteristics of existing airfoils.

We smoothly bent upward the trailing edge of S5010 airfoil which is used for existing MAV, attempted to change the design of the bottom to enhance excellent features of the top and confirmed aerodynamics characteristics through X-foil Analysis.

In this study, we would like to confirm 3D aerodynamics characteristics when the new airfoil is applied to a fixed wing MAV through computational fluid dynamics.

We used X-foil, an airfoil analysis program (2), and Fluent 12.0, a commercial program, was used to interpret, compare, and analyze aerodynamics characteristics of MAV with each airfoil. by 4° Reflex angle on trailing edge with overlap of tangent ogive curve between 70% chord position and camber line based on the camber shape of existing S5010 airfoil.

The new variant airfoil shows similar effects to the case elevon moves upward by 10 degree for longitudinal static stability in preceding designs for a fixed wing MAV. The shapes of airfoils used in this study are in Fig.1.

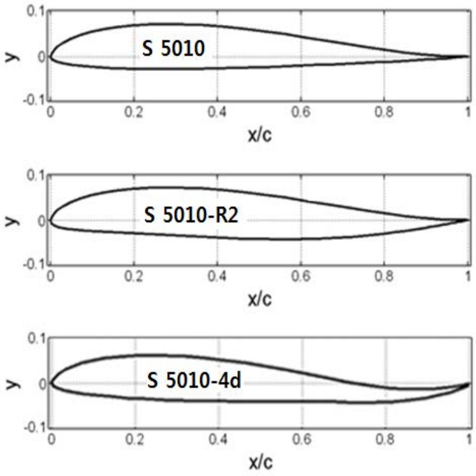

Fig. 1. Airfoil geometry

2.2 Shape of MAV

Since it is small, most of MAV is a tractor type which has low aspect ratio which causes reduction of stability of longitudinal and lateral motion. Its shape has a sweptback angle because it is needed to move an aerodynamic center backward to secure stability of longitudinal motion. The sweptback angle delays separation of flow and enhances lateral static stability too. Fig 2 is a ground plan and a side view of MAV which was designed in this study. The sweptback angle is added from $150mm$ central chord line to $100mm$ wing tip and 6° of dihedral angle is applied. Fig 3 is a grid system, for 3D computational fluid dynamics, which consists of 400 thousands unstructured grids with one plane of symmetry by Gambit 2.4, a commercial program. Fluent 12.0, a commercial program which was a numerical analysis tool to analyze 3D viscous flow field of MAV with high angle of attack(AOA) flying in range of low Reynolds number flow, was used to analyze 3D wings. In addition, Navier-Stokes equation, and K-omega turbulent model to analyze low Reynolds number flow and diffusion of shear flow were used in this study.

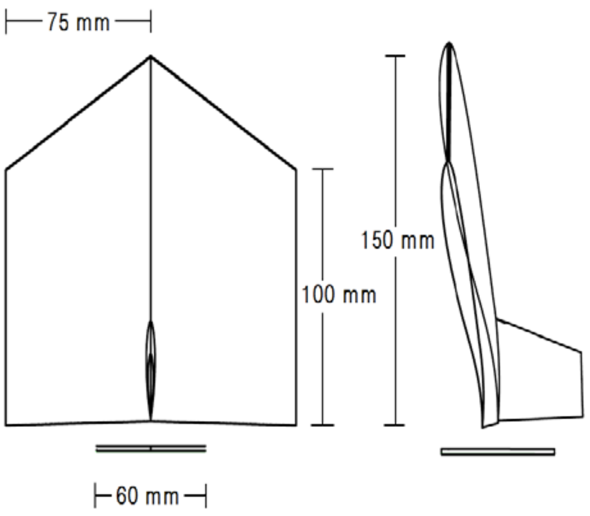

Fig. 2. MAV configuration

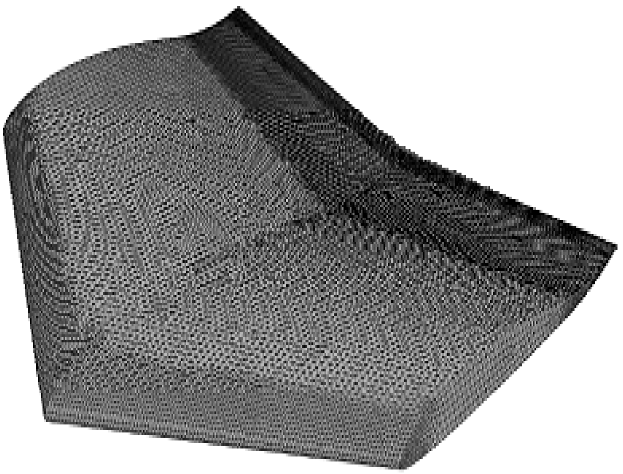

Fig. 3. MAV configuration and unstructured mesh grid

2.3 Conditions for analysis

Reynolds number of MAV during smooth fly is about 83000 and it is required to fix a transition point of a leading edge for stable collecting in X-foil analysis of low Reynolds number flow. Hence, enforced transition was applied to 10% chord of both the top and bottom of an airfoil. Mach to apply was 0.03.

160 panels were distributed on the surface of an airfoil and concentrated on the leading and trailing edges. Same conditions were given to both Fluent 12.0 and X-foil and 30000 numerical grids were used.

3 Results and Analysis

3.1 Aerodynamic characteristics of an airfoil

Aerodynamic characteristics of an airfoil which was designed by X-foil and Fluent 12.0 was analyzed and compared to existing S5010 airfoil. Mach was 0.03 and Reynolds number was 83,000 for free stream conditions at sea level and standard atmosphere.

AOA between -4 and 20 degree was interpreted and X-foil was interpreted by 0.5 degree and Fluent 12.0 was by 1 degree. As you can see in aerodynamics characteristics of fig 4 and 5, maximum lift coefficient of designed airfoils were decreased by 0.1 to 0.4 compared to S5010 but their moment characteristics were enhanced in entire AOA as shown in fig. 6 and 7.

Fluent 12.0 estimated flow separation later by about 3 degree compared to X-foil and it was reflected to moment characteristics. We consider results of X-foil which can estimate separation bubbles more accurately is credible.

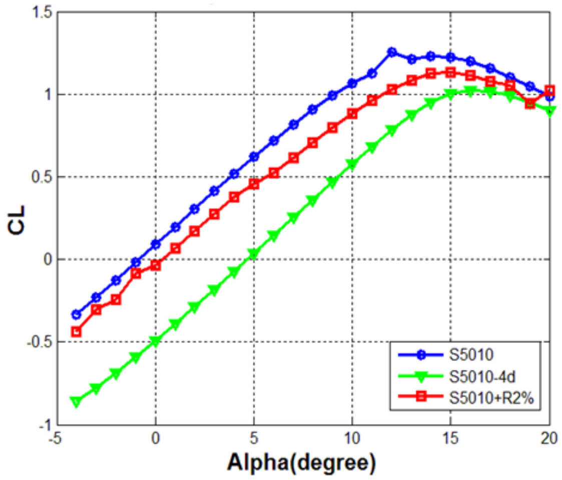

Fig. 4. Lift Coefficient - Fluent 12.0

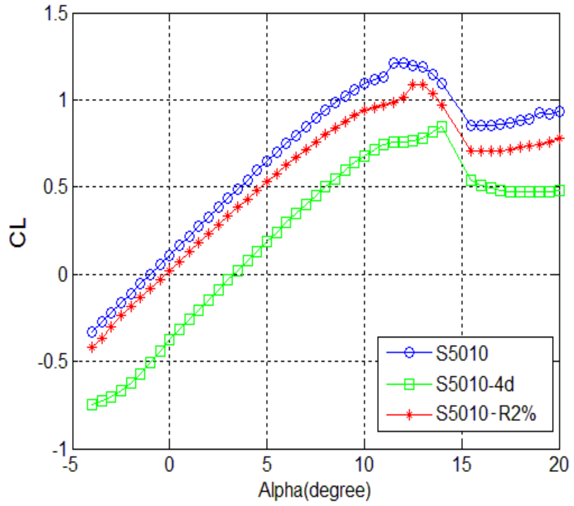

Fig. 5. Lift Coefficient – Xfoil

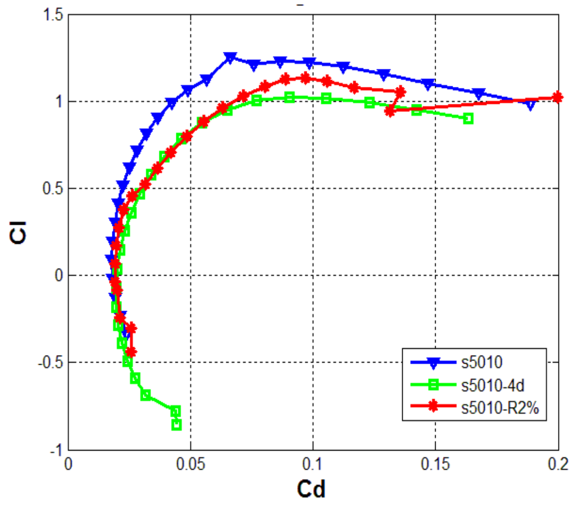

Fig. 8. Drag Polar - Fluent 12.0

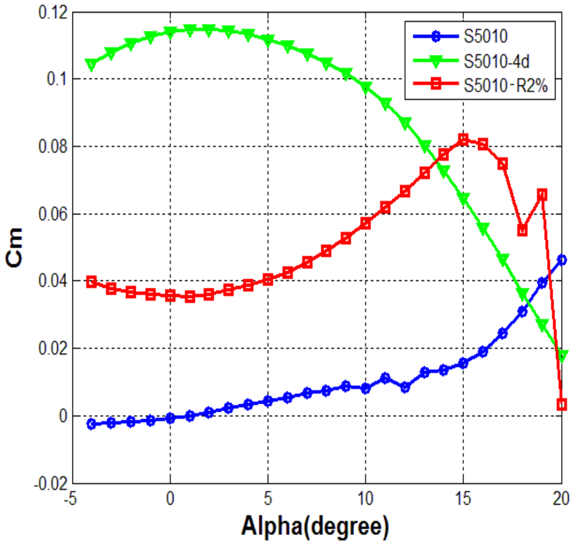

Fig. 6. Moment Coefficient - Fluent 12.0

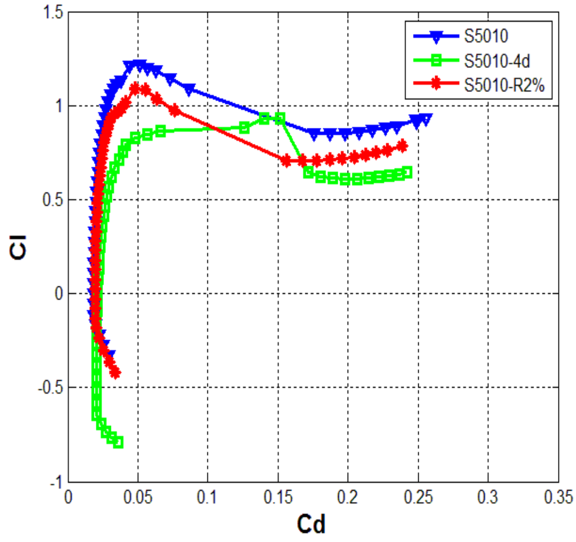

Fig. 9. Drag Polar - Xfoil

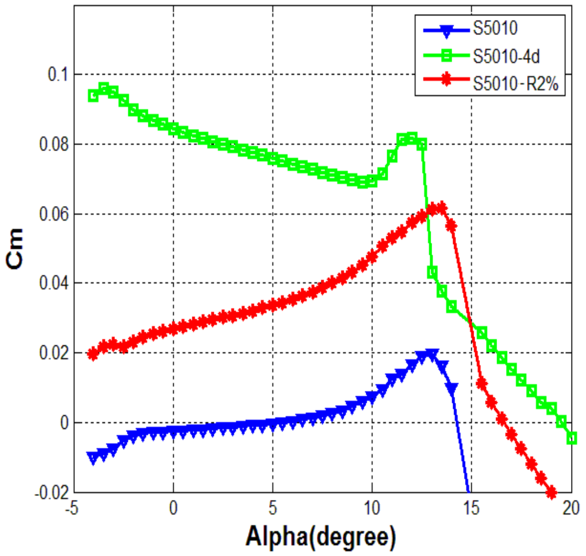

Fig. 7. Moment Coefficient - Xfoil

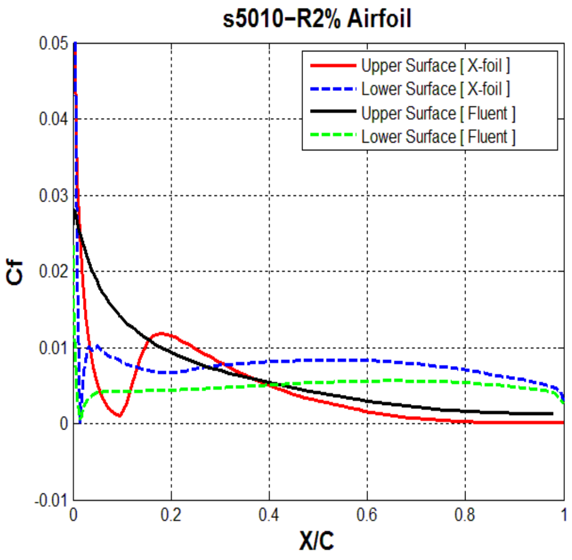

Fig. 10. Skin friction at AoA 10

As you see in Drag Polar(Fig. 8,9), Fluent 12.0 estimates less lift to drag ratio for all airfoils compared to X-foil.

Fig. 10 shows that a fluent reaches close to separation at the top of a leading edge but cannot follow the flow which transits by turbulent flow.

3.2 3-D aerodynamic characteristics of MAV

X-foil, which is designed by integral boundary layer equation for airfoils and turbulent transition model, is more suitable for analysis of low speed airfoil aerodynamics characteristics but considering integral boundary layer relational expression for low Reynolds number flow is less credible, it is not confirmed. 3D Drag Polar, moment characteristics, and lift to drag ratio of MAV are described in fig. 11 through 13. Maximum lift to drag ratio is about 2.5. We consider it shows features of a flying object with low aspect ratio but drag is excessively calculated.

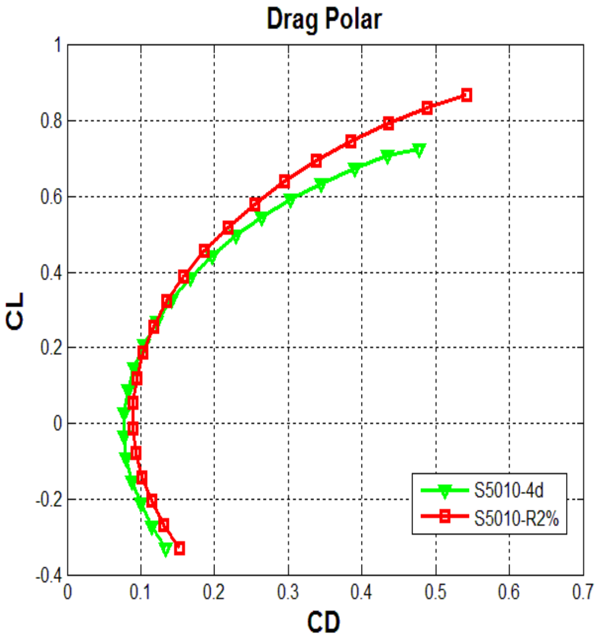

Fig. 11. MAV Drag Polar

Lift to drag ratio of flying objects with developed airfoils was over 4 in our previous studied.

S5010-R2 airfoil was estimated to have a negative slope for moment characteristics but it was confirmed that it had sufficient longitudinal static stability by results of power and non-power flying test. There may be a problem in calculating a moment coefficient and we are examining it.

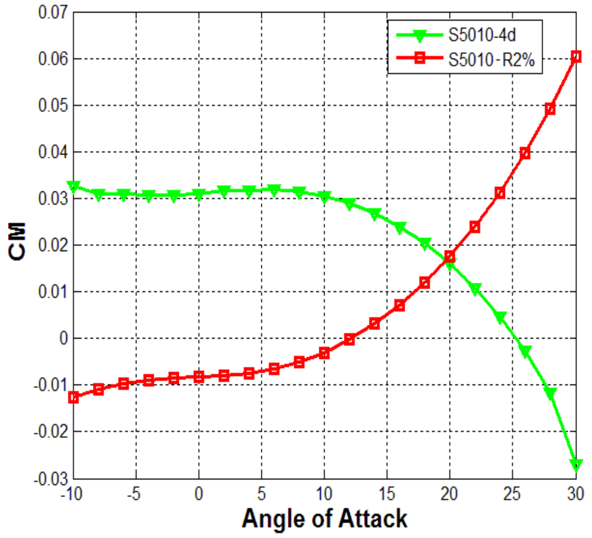

Fig. 12. MAV Moment Coefficient

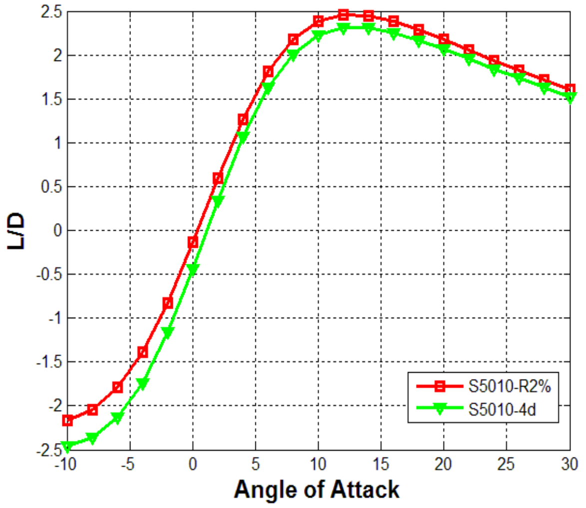

Fig. 13. MAV Lift to Drag Ratio

4 Conclusion and Future work

This study conducted 2D aerodynamics characteristics analysis of airfoil which was designed to have big pitching moment value to secure longitudinal static stability of MAV and 3D aerodynamics analysis based on it.

We confirmed that low Reynolds number flow causes low lift to drag ratio and Fluent 12.0 estimates excessive drag for both 2D airfoil and a shape of 3D flying object

Also, it was confirmed that moment characteristics of 2D airfoil was similarly reflected to aerodynamics characteristics of 3D flying object applied by it. This shows an aspect of a problem which computational fluid dynamics of low Reynolds number flow, which has prominent attenuation effect of vortex by turbulent model and artificial viscosity, has. In the future, we are planning to modify errors in estimating moment coefficient and more quantitatively analysis the accuracy matter of X-foil and Fluent 12.0 for low Reynolds number flow by wind tunnel test.

5 Acknowledgement

This study was supported by the New and Renewable Energy Program of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government Ministry of knowledge Economy.

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