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Design and Analysis of Multi-Section Variable Camber Wing

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Abstract: The "variable camber wing" introduced in this thesis is to provide an effective and a simple way of changing the shape of the wing. The wing rib is divided into 4 sections that can rotate relative to one another providing discrete but smooth change in camber. The multi-section configuration is chosen so it is convenient to vary the shape of the wing because it is composed of movable parts just like a human fingers and limbs.The theoretical estimation of lift and drag of the wing is calculated and analysis is done using Xfoil program at the baseline configuration and at the cambered configuration and the results were compared. The lift-to-drag ratio value at the baseline configuration is less than in cambered configuration. Comparing to the baseline rigid wing and the variable camber wing, the variable cambered wing obtained high lift-to-drag ratio at different angle of attack and Reynolds number. The experiment results were obtained through virtual wind tunnel software (DESIGNFOIL, XFOIL) and the results were also compared.

Keywords: Angle of attack, Airfoil, Cambered wing, Drag, Designfoil, Reynolds number, Xfoil.

I. INTRODUCTION

A small percentage reduction in the fuel consumption of an airplane can lead to major savings in aircraft operational costs. Since the amount of fuel stored in the aircraft is limited, lower fuel consumption means greater range or endurance in flight. There has been a great deal of research focused on achieving this goal. One promising concept is the use of a variable camber wing. This wing can change its configuration and provide variations in lift and drag that satisfy different flight conditions so fuel can be consumed efficiently. Variable camber wing concepts have been explored and developed extensively since the beginning of flight. The most significant variable camber devices currently used in most transport aircrafts are high-lift devices such as leading-edge slats and trailing-edge flaps. Those devices have demonstrated very promising results in reducing fuel consumption. Throughout this thesis, a wing with high-lift devices [3] will be referred to as a conventional variable camber wing.Research on the development of variable camber wings using smart materials such as Shape Memory Alloys and piezoelectric materials has become one of the most significant sources of interest in aerospace engineering.

II. MULTI-SECTION VARIABLE CAMBER WING

The model was a 12-inch span and 12-inch chord NACA0012 [1]-based airfoil with 4 wing ribs. Each rib was divided into 6 sections with circular cuts at both ends except for the leading and trailing edge sections, which had a circular cut at only one end. Each rib section except for the second section had a ¼-inch diameter hole for inserting the ¼-inch sub-spars; the second section from the leading edge had 5/8-inch diameter hole for a 5/8-inch diameter main spar and another ¼-inch hole for inserting a ¼-inch stainless tube for rigidity of this section. Due to space limitations, the main spar was not located at the quarter-chord, but instead at the 1/6-chord location. The ribs were made of aluminum and the spars were made of stainless steel tubes.

Each rib section and the corresponding spar were secured together by setscrews, which allowed for convenient adjustment. Custom-made aluminum links were used to connect the rib sections together and allowed them to rotate freely. Each rib section could rotate up to 10 degrees around its own spar without providing significant discontinuity in the wing surfaces.

III. CAD MODEL OF VARIABLE CAMBER WING

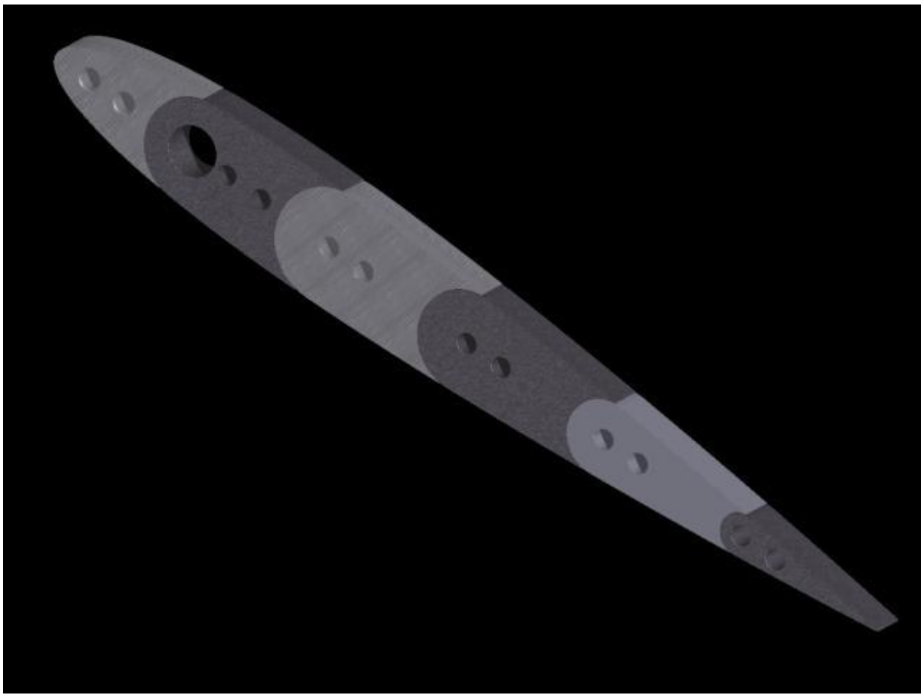

FIG.1 NACA 0012 six sectioned Airfoil

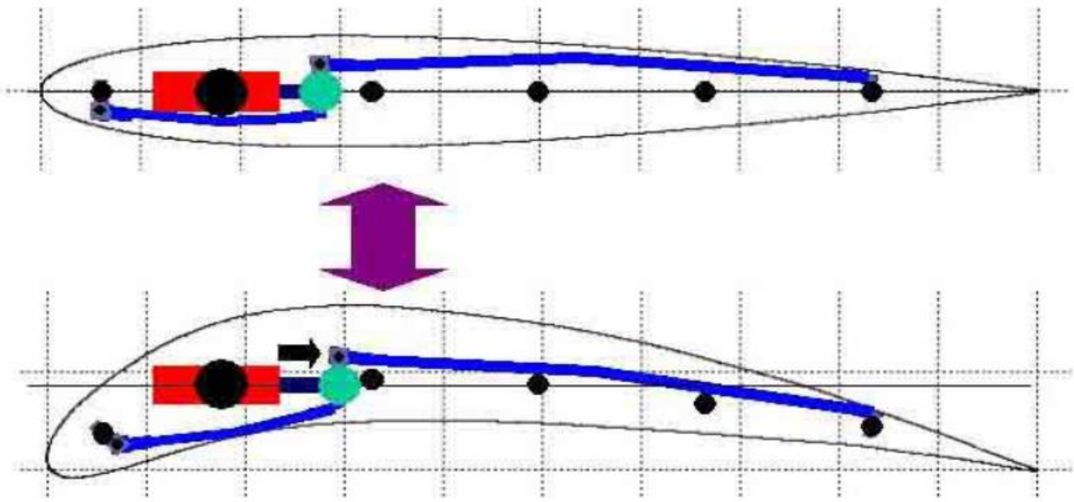

Fig.2 Actuation Scheme

IV. AERODYNAMIC ANALYSIS

The focus of this study was to explore the possibility of using a multi-section variable camber wing concept to enhance the range and endurance [2] of unmanned aerial vehicles. Therefore, the low speed (less than Mach 0.6) aerodynamics was investigated. The influence of variable camber wing on the ability of unmanned aerial vehicle is to fly greater range and endurance. The methodology adopted in this study has a Reynolds number of -3e6 [5], Mach no 0.6 respectively.

In the model of variable camber wing, it can be changed various NACA airfoils by deflecting the front portion of the wing downward. The maximum camber of NACA 0012 is placed 30% of the wing. So the pivot point is taken from the 30% of its total chord. Deflection is done at the portion which is ahead of pivot point to obtain various shapes of NACA airfoils. Maximum thickness airfoil is fixed at the same point of 30% of chord.

The aerodynamic analysis is obtained in DESIGNFOIL and Xfoil [4] software, the aerodynamic parameters are varied significantly due to the effect of changing camber. Whenever increasing the camber of an airfoil the aerodynamic propertied increases linearly. The results are obtained by using commercial software Xfoil. Mach number, angle of attack and Reynolds number are fixed for all NACA airfoils.

V. RESULT

The following tables shows the result of tested aerodynamic parameters in virtual wind tunnel under various conditions.

TABLE.1 ANGLE DEFLECTION REQUIRED FOR VARYING CAMBER.

SL.NO	NACA AIRFOILS	REQUIRED ANGLE DEFLECTION IN DEGREE
1	0012	0
2	1312	3
3	2312	6
4	3312	8
5	4312	10
6	5312	13
7	6312	16
8	7312	20
9	8312	22
10	9312	24

The first section of the model is deflected up to 20° the deflection angle required for getting various NACA airfoils are shown in the above table.1. The comparative aerodynamic parameters of various NACA airfoils are shown below.

TABLE.2 COMPARITIVE RESULT OF VARIOUS AERODYNAMIC PROPERTY FOR VARIOUS NACA AIRFOILS

NACA AIRFOILS	LIFT COEFFICIENT	DRAG COEFFICIENT	LIFT/DRAG	MOMENT COFFICIENT
0012	0	0.0051	0	0
1312	0.1113	0.00521	21.37	-0.0218
2312	0.2229	0.0056	39.81	-0.0436
3312	0.3347	0.00652	51.229	-0.0651
4312	0.4428	0.00698	63.4	-0.0861
5312	0.5494	0.00734	74.88	-0.1069
6312	0.6547	0.00768	85.23	-0.1274
7312	0.7590	0.00802	94.6	-0.1476
8312	0.8608	0.00844	102.04	-0.1674
9312	0.9613	0.00866	108.44	-0.1868

VI. CONCLUSION

A multi-section variable camber wing, using four rib sections with pneumatic actuators and a simple linkage system embedded inside the wing, was designed as another means to vary the shape of a wing. This variable camber wing did not involve complicated actuation components or a control system, but effectively provided satisfactory changes in wing camber. A change in camber of 10% before applying the wing skin, and 8% after applying wing skin, were obtained from this wing concept.Three wing models, one variable camber wing and two rigid wings, of 12-in chord and 12-in span were built for wind tunnel testing. The size of the wing model was determined from the test result of other wing models previously in the same wind tunnel. The aluminum wing rib sections manufactured by CNC machine, the chain links, and the stainless steel tubes were the primary structures of the variable camber wind tunnel model.

The variable camber wing was covered by the combination of latex sheet and insignia cloth which provided very satisfactory flexibility, strength and stiffness. The latex sheet showed low magnitude but high frequency vibration during testing causing the flow to attach to the wing and delay separation. This was an unexpected phenomenon which benefited the test results. Two rigid wings for the baseline and cambered configurations of the variable camber wing were built using foam core and composite wing skin for comparison of wind tunnel test results.The research was mostly experimental, based on wind tunnel test results. The experiment results were obtained through virtual wind tunnel software (DESIGNFOIL) and the results were also compared. The measured aerodynamic coefficients were used to determine the advantage of variable camber wing over that of a rigid wing. The wind tunnel results were also used to compare with the calculated values obtained from the Xfoil software. The static test was performed at airspeeds of 50 ft/s, 75 ft/s, and 100 ft/s or at the chord Reynolds numbers of 322000, 479000, and 636000 respectively, in the same atmosphere conditions for all three wings. The wind tunnel results showed significant advantages of the variable camber over the rigid wing in camber configuration, such as higher stall angle and higher lift-to-drag ratio. However, due to high drag generated by the wing skin of the variable camber wing during baseline configuration, the lift-to-drag ratio of the variable camber wing was lower than the baseline rigid wing.

The comparison of wing performance between the rigid wings and the variable camber wing was not quite accurate since the flexibility of the wing skin caused the vibration injecting the energy into the flow. Additionally, the wing skin of the variable camber wing acted as a pseudo-boundary layer trip keeping the flow attach to the wing.

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