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# Fluid-Structure Interaction Analysis of UAV

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## ABSTRACT:

This thesis investigates the effects of camber change on the mission adaptive wing of a structurally designed unmanned aerial vehicle (UAV). The commercial computational fluid dynamics (CFD) software ANSYS/FLUENT is employed for the aerodynamic analyses. Several cambered airfoils are compared in terms of their aerodynamic coefficients and the effects of the camber change formed in specific sections of the wing on the span wise pressure distribution are investigated. The mission adaptive wing is modeled structurally to observe the effect of span wise-pressure distribution on the wing structure. For the structural design and analysis of the UAV under this study, commercial software MSC/NASTRAN are used. The structural static and dynamic analyses of the unmanned aerial vehicle are also performed under specified flight conditions. The results of these analyses show that the designed structure is safe within the flight envelope.

## Keywords:

Cambered Airfoil, Mission Adaptive Wing, Structural Design of a UAV.

## 1.INTRODUCTION:

Cruise efficiency is one of the most important concepts for the design of an air vehicle. Aerial vehicles must be designed for their own decided mission profiles. This phenomenon is a deficiency for most of costly aerial vehicles.The main scope of project is to develop a wing which is capable of providing different maneuvers with increasing or decreasing of wing planform area for a specific mission segment. There are lots of researches about performing these kinds of wings called 'morphing wing'. Increasing or decreasing plan-form area, introducing high lift devices and changing camber are most common ways to morph a wing.

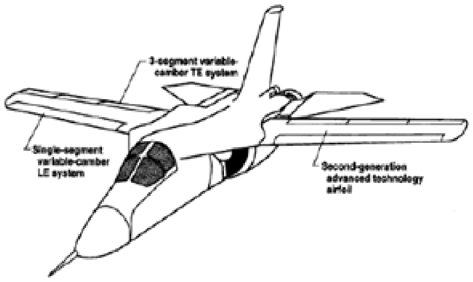
In this study, morphing is introduced by sectional camber change which can also generate twist. This kind of wing enables an unmanned aerial vehicle have a mission adaptive property. The structural design and analysis of this unmanned aerial vehicle having mission adaptive wing is also performed in the scope of this study.

## 2.LITERATURE SURVEY

Capability of changing the planform of the wing during flight can be referred to "Morphing". This capability may result in economical fuel consumption, increase in mission adaptability and performance. Fixed wing aircraft are designed for considering the flight envelope and the mission profiles. The efficiency of these aircraft can be observed only within their mission profiles. For instance, fixed wing aircraft which are designed for high altitude level flight is not suitable for a dog fight. The aim of a morphing wing is adaptation of the wing within of the entire missionprofile. Understanding how birds fly is an inspiration for the researches that has beencarried out [1]. Birds can morph their wing shape to enhance flight performance and  maneuverability in different flight conditions.

### Morphing Research Programs:

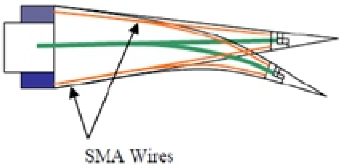
In the early 1980s, a "mission adaptive wing" (MAW) [4], which is shown in Figure 2.2.1 , was used on F-111 aircraft to replace its supercritical wing. This was a part of the Advanced Fighter Technology Integration (AFTI) program which was started by the NASA and the US Air Force.



MAW Modifications to F-111 (From NASA TM-4606)

## Smart Wing program:

In 1995, DARPA (Defense Advanced Research Projects Agency) initiated the Smart Wing program [5] which had the scope of combining the benefits of variable camber of MAW and variable wing twist of Active Aeroelastic Wing (AAW). The main objective of this program was improving the aerodynamic and aeroelastic performance of military aircraft by developing smart technologies and showing the novel actuation systems which would yield the performance increasing shape control.




Novel actuation systems

## DARPA's Morphing Aircraft structures program:

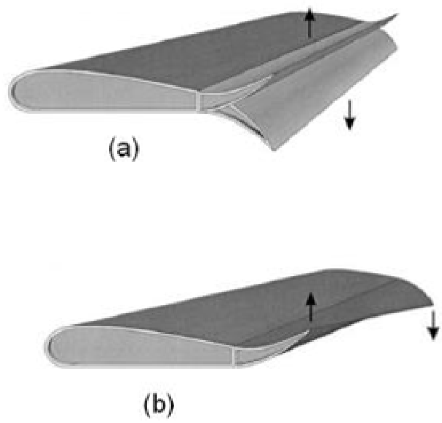
Continuing research, which was established by DARPA, aims to create shapechanging, multi-mission aircraft using smart materials. In this project, DARPA investigates aspects like 200% change in aspect ratio, 50% change in wing area, 50% change in wing twist, and a 20-degree change in wing sweep. "Sliding skins", and "folding wings", concepts may constitute examples of morphing of a plane from a fast, attack configuration to a slower long distance shape.

Fig: Sliding Skins Concept

Fig:Folding Wing Concept

## 3. 2D AERODYNAMIC MODELING AND ANALYSIS OF MISSION ADAPTIVE WING:

There is a basic inconsistency in the design of aerial vehicle wing considering aerodynamic aspects. For instance, wing requires high wing loading and less camber during level flight, on the contrary; higher camber values are required during takeoff and landing. This concept results in requirement of a larger wing area ,Flap and aileron are the most commonly used structures enabling the increase in camber of airfoil.There are many new approaches about variable cambered wings. These are in the form of "chordwise camber change" and "spanwise camber change" as shown in Figure.




This enables having different or opposite directional lift in each wing so different control surfaces, like ailerons can be simulated by the help of this approach. Aerial vehicle wings require airfoil sections with different cambers during flight in order to sustain cruise efficiency. In this section, NACA4412 airfoil is selected as the main airfoil to be altered by using specified techniques in means of having different camber values. Then 2D aerodynamic analyses are performed with these varied cambered airfoils to examine the changes in aerodynamic coefficients.

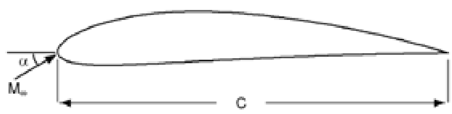



Fig:NACA4412 Airfoil and Analysis Parameters.

## Generating Initial Mesh and Boundary Zones.

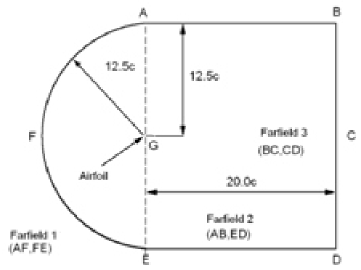



Fig: Boundary Condition Zones for the Analysis.

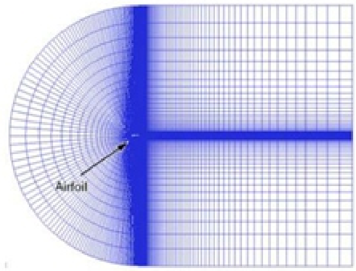



Fig:NACA 4412 Airfoil and the Solution Domain

## Parameters for Camber Change:

For 4-digit NACA series airfoils, mean camber line and the vertical distances from the line to the upper and lower surfaces are defined by means of dimensionless distance 'x' in the fallowing equations .

$$y_{camber} = \frac{m}{p^2}[2px - x^2]$$

$$y_{camber} = \frac{m}{(1-p)^2}[(1-2p) + 2px - x^2]$$

$$\pm y = \frac{t}{0.2}(0.2969\sqrt{x} - 0.126x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4)$$

In the above equations 'm' variable is for the maximum camber ratio and 'p' variable is for the chordwise position of maximum camber and 't' is for the ratio of maximum thickness to chord. For NACA4412 profile m, p, and t are 0.04, 0.4 and 0.12 respectively.

Mean camber line coordinates of airfoil defined in Equations

$$\Delta_y camber = \lambda s^2(3L^2 - s) \quad 0 \le s \le L$$

$$\Delta_y camber = \lambda L^2(3L^2 - s) \quad L \le s \le 1$$

## Cambered Airfoils

In this part, the airfoil section models are generated by using the aforementioned method. The airfoils generated will be named according to deflection parameters. From now on 'Δte' represents the displacement of trailing edge point in terms of chord length like 'Δte= -0.04c' means downward deflection of the trailing edge point with an amount of 4% of chord length, and 'dp' shows where the deflection takes place on chord. 'dp=0.60c' means airfoil deflection starts at 60% of chord length measured from leading edge. In the analysis performed, 191 cambered airfoils are studied as a research domain. The cambered airfoils are presented as points regarding the deflection parameters in the research domain in Figure 3.6.1. Cambered airfoils wheredp=0.60c set as constant and changes in Δte is presented in Figure 3.6.2 and Δte= -0.06c set as constant where changes in dp is presented in Figure 3.6.3 as illustrations.

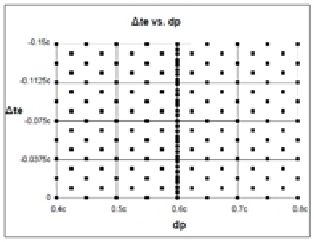



Fig: Cambered NACA4412 Airfoils Research Domain.

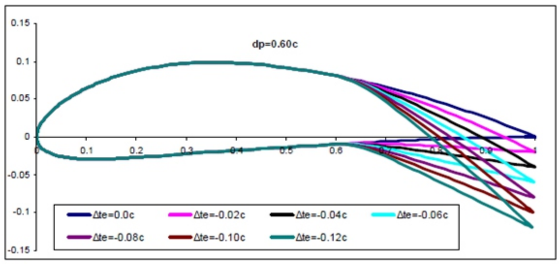



Fig: Cambered NACA4412 Airfoils Constant dp.

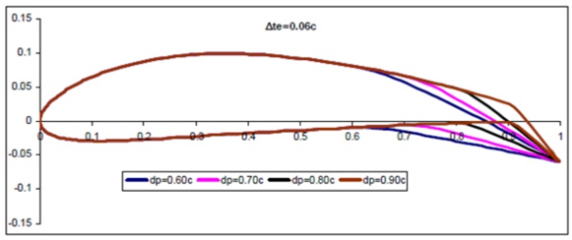



Fig: Cambered NACA4412 Airfoils Constant Δte.

| Δte | 0.0c | -0.02c | -0.04c | -0.06c | -0.08c | -0.10c | -0.12c |
|---|---|---|---|---|---|---|---|
| Cl | 0.4502 | 0.6904 | 0.9193 | 1.1344 | 1.3050 | 1.5574 | 1.6922 |
| Cl [10] | 0.4000 | 0.6652 | 0.920 | 1.1696 | 1.4244 | 1.6688 | 1.9184 |
| Cd | 0.0111 | 0.0124 | 0.0142 | 0.0169 | 0.0210 | 0.0578 | 0.0714 |
| Cm | 0.2133 | 0.0124 | 0.3941 | 0.4813 | 0.5520 | 0.6798 | 0.7426 |
| Cl/Cd | 40.7201 | 55.6774 | 64.7394 | 67.1243 | 62.1429 | 26.9446 | 23.7009 |

Table: Aerodynamic Coefficients for Cambered Airfoils (dp=0.6)

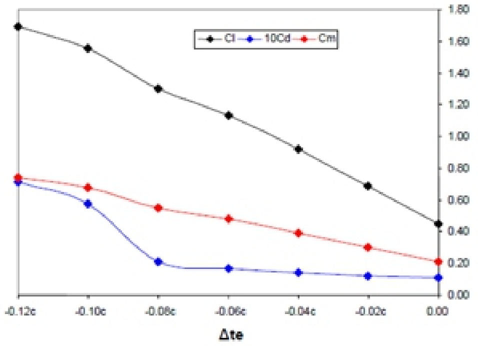



Fig: Aerodynamic Coefficients forCambered Airfoils (Cl , 10Cd, Cm)

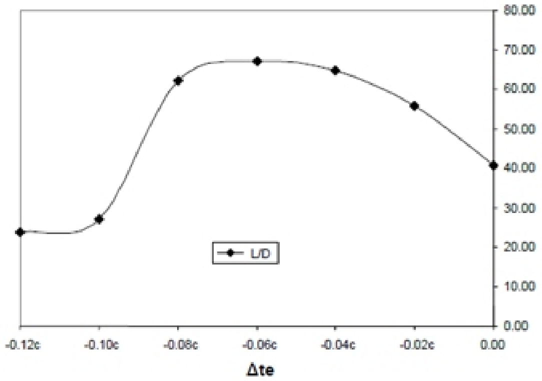



Fig:L/D for cambered aifoils

## 3D AERODYNAMIC MODELING AND ANALYSIS OF MISSION ADAPTIVE WING

In this chapter, 3D CFD analysis is performed considering the 2D CFD analysis results. The camber change position of the wing is fixed at dp=0.6c,In this section of the study, the methodology for the 3D mesh generation is presented. Computer Aided Design (CAD) model for the wing to be analyzed is needed to be imported before the generation of the mesh. 3D CAD model of the wing is created by using MSC®/PATRAN and imported to ANSYS®/GAMBIT in STEP format. The CAD model of the wing having NACA4412 profile (Δte=0.0c) is presented. In this model, chord and span is 0.5 [m] and 1.5 [m] respectively.

Fig: CAD Model of the Wing

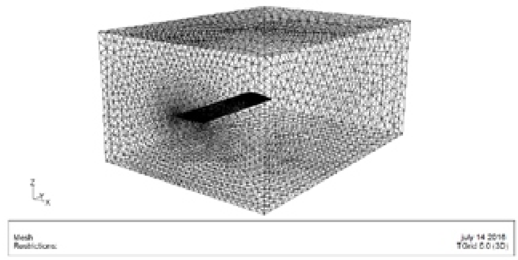
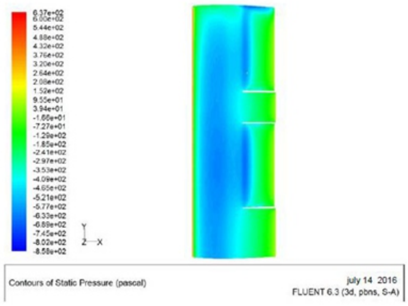


Fig: mesh and Inner Solution Domain (Isometric View)

## 3D CFD Analysis results:




Upper Surface Static Pressure Contours [Pa] (with Control Surfaces)

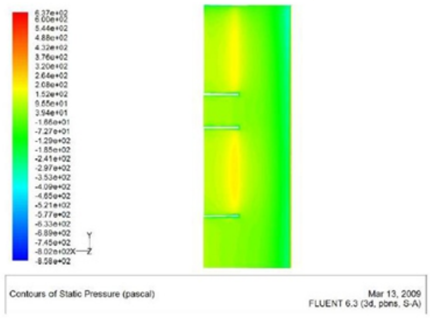



Fig:Lower Surface Static Pressure Contours [Pa] (with Control Surfaces)

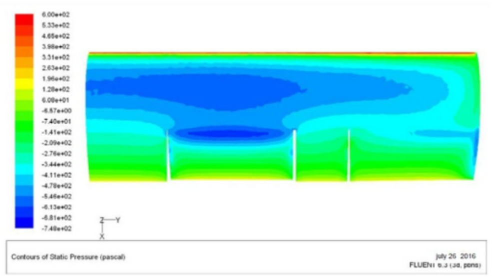



Fig:Pressure on the Upper Surface of the Wing with Twisted Outer Control Surface [Pa]

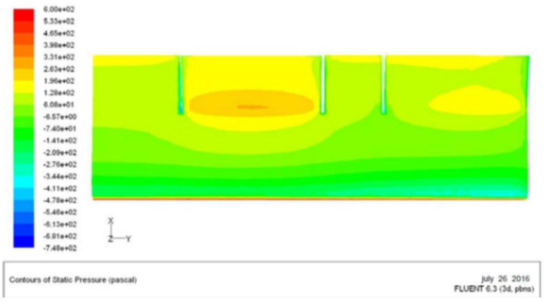
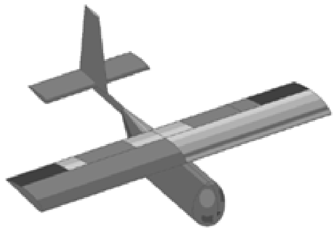
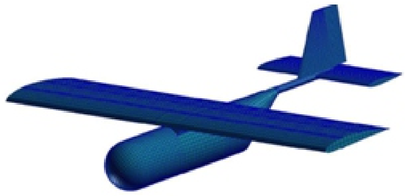



Fig:Pressure on the Lower Surface of the Wing with Twisted Outer Control Surface [Pa]

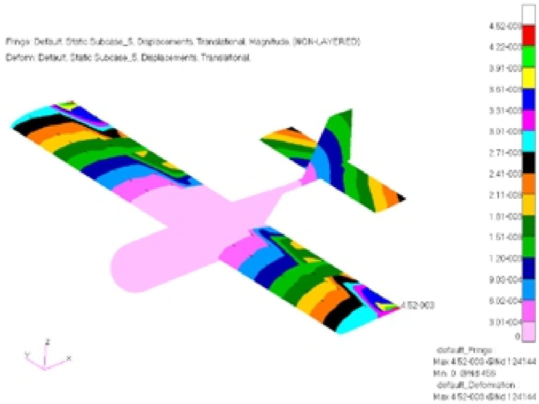
## 4. STRUCTURAL MODELING AND ANALYSIS OfMISSION ADAPTIVE WING



3D model of uav



Meshing of uav



Displacement Result of the UAV [m]

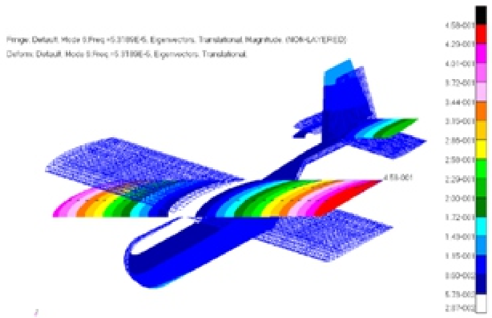


Fig:Deformation of uav during Roll.

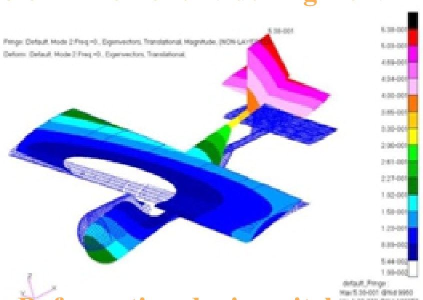


Fig:Deformation during pitch

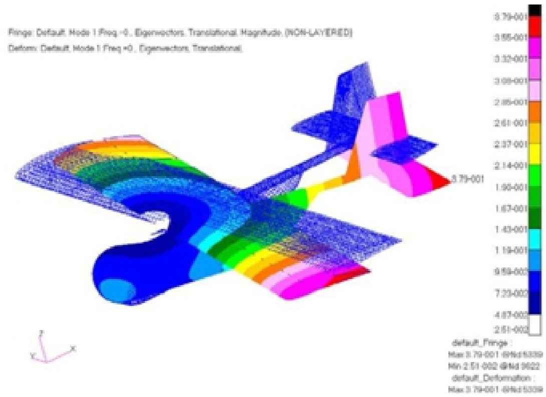


Fig:Deformation of uav during Yaw.

## CONCLUSION:

After examining various cambered airfoils, some of them are selected considering the established camber change methodology and are then used in 3D CFD analyses in order to investigate the aerodynamic effects on the wing surfaces. The analyses performed show that the change in aerodynamic coefficients in an effective way can be achieved by performing the introduced camber change methodology.The results show that the designed UAV is structurally intact. Having validated the integrity of all parts of the UAV,The aeroelastic performance of the generated structural model of the ing is then checked within the flight envelope of the UAV. Additionally, the wing is tested structurally under the pressure load which is generated by a specific sectional camber change.

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