DESIGN AND ANALYSES OF AN UNMANNED AERIAL VEHICLE HYBRID TRAILING EDGE CONTROL SURFACE HAVING CAMBER AND DECAMBER CAPABILITIES

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ABSTRACT

This paper presents the design and analyses of an unmanned aerial vehicle hybrid trailing edge control surface having camber and decamber capabilities. Initially, a brief introductory information were given about morphing concepts. Then, the structural design and analyses in in-vacuo condition are presented. The aerodynamic loadings were calculated at the morphed configurations, and these loads were transferred to the structural mesh in order to assess the design capability under the aerodynamic loading. It is shown that the developed trailing edge control surface can successfully perform camber and decamber both in in-vacuo condition and under aerodynamic loading.

INTRODUCTION

The conventional hinged mechanism, the smart-material-made actuators and the compliant mechanism are the three methods in the design of a camber variable wing [Shili et al., 2008]. Although the conventional control surfaces has the main advantages such as easy integration, simple actuation system, there are major drawbacks which cannot be ignored. Due to existing discontinuties produced by conventional control surfaces, the aerodynamic efficiency decreases significantly which is a result of airflow separation and drag increase [Barbarino et al., 2010]. The unconventional control surfaces such as the compliant mechanism provides a smooth shape change along the wing, which increases the aerodynamic efficiency compared to its conventional counterparts.

In this study, the aerodynamic and structural design and analyses of a trailing edge control surface of a fully morphing unmanned aerial vehicle wing is conducted. The trailing edge control surface is developed in Middle East Technical University, Department of Aerospace Engineering within the scope of Seventh Framework Programme of European Comission Project CHANGE (Combined morpHing Assessment software usiNG flight Envelope data and mission based morphing prototype wing development). TEKEVER (Portugal), University Beira Interior (Portugal), Middle East Technical University (Turkey), Technical University of Delft (Netherlands), DLR (Germany), INVENT (Germany), Swansea University (Wales), Cranfield University (England) and Aircraft Research Association (England) are the nine partners of CHANGE Project. [CHANGE Project, 2012].

The main aim of the project is to combine the several morphing mechanisms into a single wing, including, telescopic wing change, leading and trailing edge camber changes, and twist change, shown in Figure 1.

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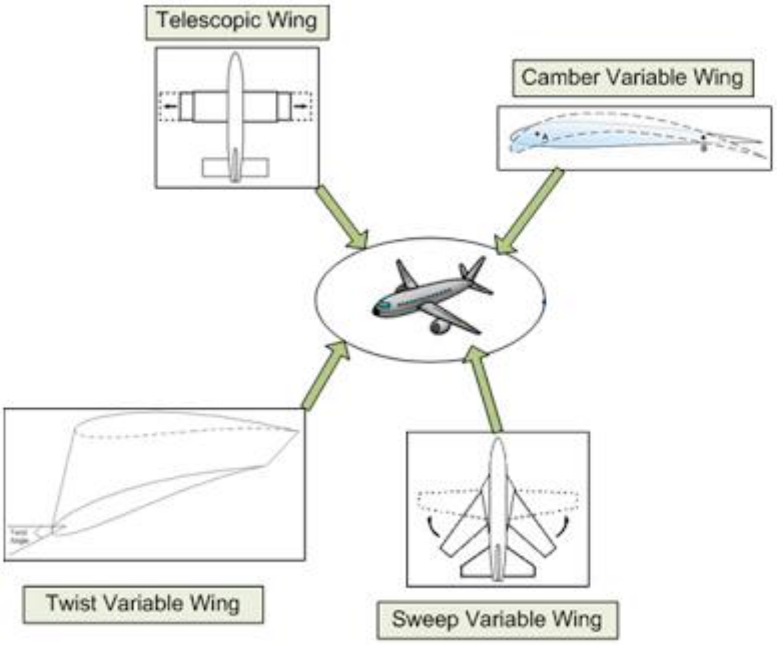

Figure 1: *Intended Morphing Capabilities of the CHANGE Wing [CHANGE Project, 2012]*

The CHANGE Project intends to optimize the aerodynamic performance of each flight phase by changing the wing profile and doing this in terms of unconventional ways. The approach, called as fully morphing, envisions that the fuel consumption as well as the aerodynamic noise will be decreased and also less emission of harmful gasses to the atmosphere will be achieved [Bolonkin and Gilyard, 1999; Kintscher et al., 2011; Friswell, 2009; Özgen et al., 2010].

The responsibilities of Middle East Technical University in the project are to indigenously design the hybrid trailing edge control surface of the aerial vehicle [Arslan et al., 2014A-B], [Tunçöz, 2015], to perform the ground vibration tests of the wing, to contribute to wind tunnel tests of the wing and to flight tests.

STRUCTURAL DESIGN AND ANALYSES IN IN-VACUO CONDITION

The control surface was designed in an unconventional manner such that the existing gaps and possible seams in conventional control surfaces were eliminated. Hence, a hybrid approach was considered during the design of the control surface via CATIA V5-6R2012 package program by using four different materials, namely, aluminum, composite, foam and a very flexible material which can easily extend called as compliant material. The solid model of the control surface is shown in Figure 2.

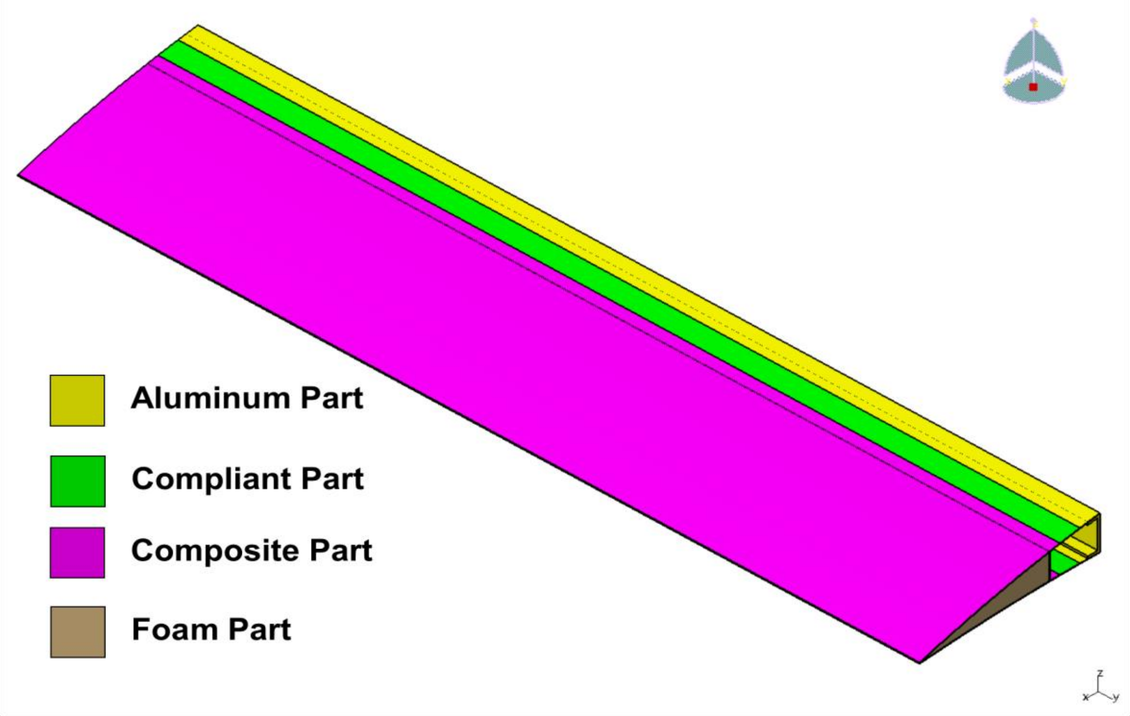

Figure 2: *The Designed Hybrid Trailing Edge Control Surface*

The main purpose of the design is to morph the control surface into several target profiles. The baseline profile of the control surface is NACA6510. It is required that control surface can morph into NACA8510 which results in camber increase, and to NACA3510 and NACA2510 which results in camber decrease (decamber) profiles. These profiles are shown in Figure 3 along with the baseline profile.

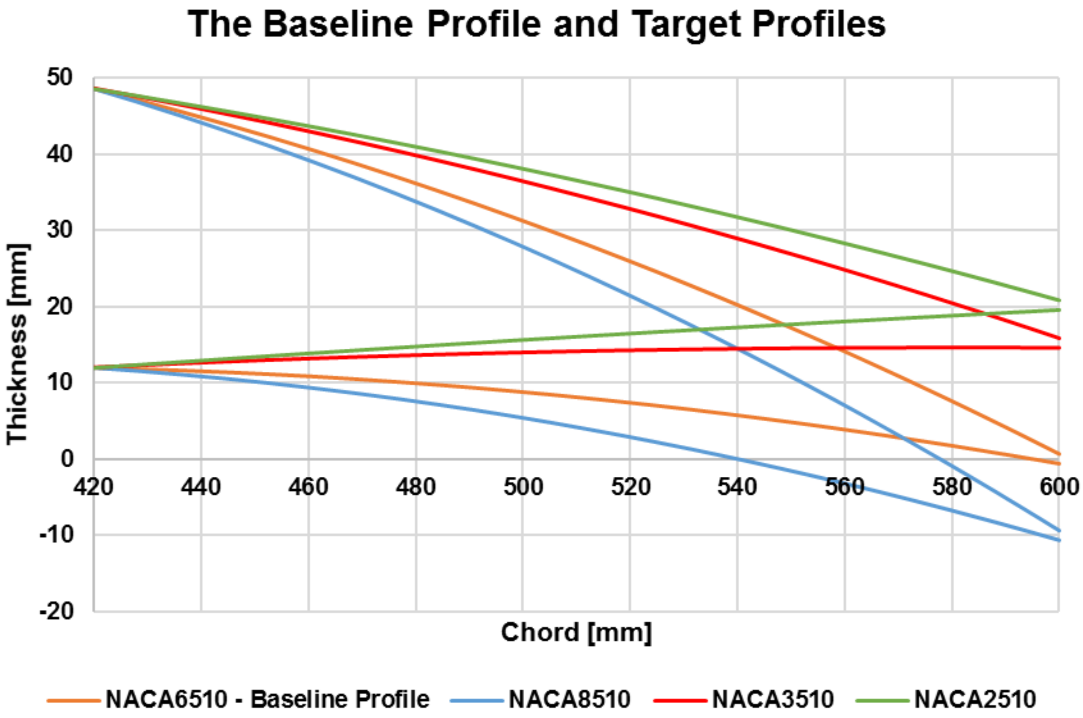

Figure 3: *The Baseline and Target Profiles of the Designed Trailing Edge Control Surface*

The camber and decamber change of the control surface was achieved by using the servo actuators which were placed within the control surface. The structural analyses were done by using ANSYS Workbench v14.0 package program and the optimum location and number of servo actuators were determined. Various trade-off studies were conducted for the determination of the effects of different materials and the mesh sizing. As a first step, the structural analyses were conducted in in-vacuo condition. Since the compliant material can displace in great amount, non-linear solution methods of the package programs were used in all structural analyses.

A silicone based material was used for the compliant material. The material properties were determined by uniaxial tension test of the specimen, which is shown in **Figure 4**.

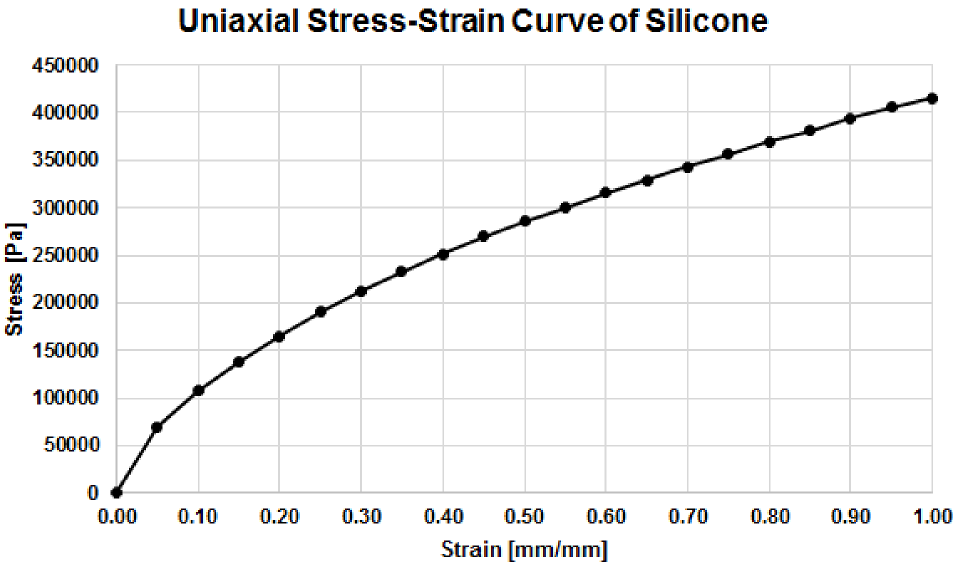

Figure 4: *Uniaxial Stress-Strain Curve of Silicone*

The material properties of the aluminum is given in **Table 1**, composite is given in

Table 2 and foam is given in **Table 3**.

Table 1: *The Material Properties of Aluminum (ANSYS, 2011)*

Density, ρ [kg/m3]	Young's Modulus, E [GPa]	Poisson's Ratio, v [-]
2770	71	0.33

Table 2: *The Material Properties of Glass-Fibre Prepreg EHG250-68-37 Composite (Invent GmbH, 2015)*

Density, ρ [kg/m^3]	Young's Modulus, E11 [GPa]	Young's Modulus, E22 [GPa]	Poisson's Ratio, v12 [-]
2770	71	23.8	0.33
Shear Modulus, G12 [GPa]	Shear Modulus, G13 [GPa]	Shear Modulus, G23 [GPa]	Ply Thickness [mm]
4.7	3.6	2.6	0.25

Table 3: *The Material Properties of Rohacell 51 RIMA Foam (Rohacell, 2015)*

Density, ρ [kg/m3]	Young's Modulus, E [MPa]	Poisson's Ratio, v [-]
52	75	0.49

The side view of the generated finite element mesh of the control surface is given in **Figure 5**.

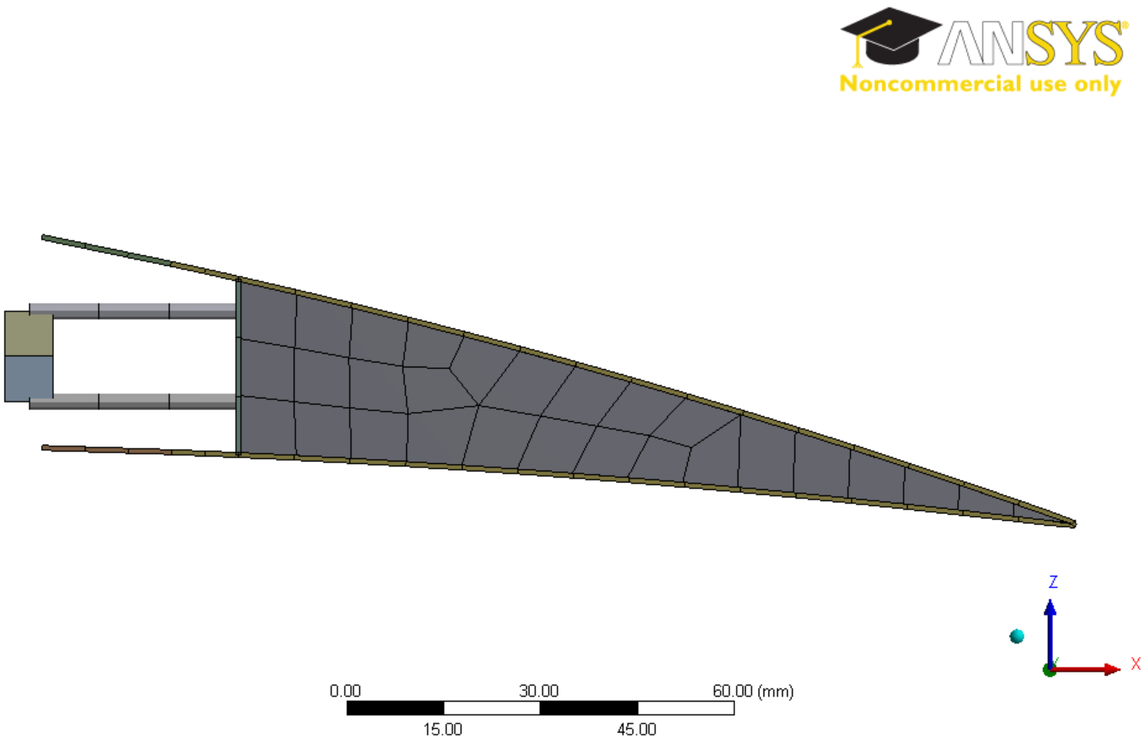

Figure 5: *The Side View of the Generated Finite Element Mesh of the Control Surface*

The applied boundary conditions to the system is given in **Figure 6**. In the model, aluminium part was not modelled since this part provided a rigid-like support. Therefore, the fixed boundary condition was applied to the edges of the compliant part, which is shown as A and B. The standart earth gravity was also taken into consideration in order to include the weight effects. The effects of actuation forces coming from the servo actuators were modelled as rotational boundary conditions and shown as D, E, F, G and H.

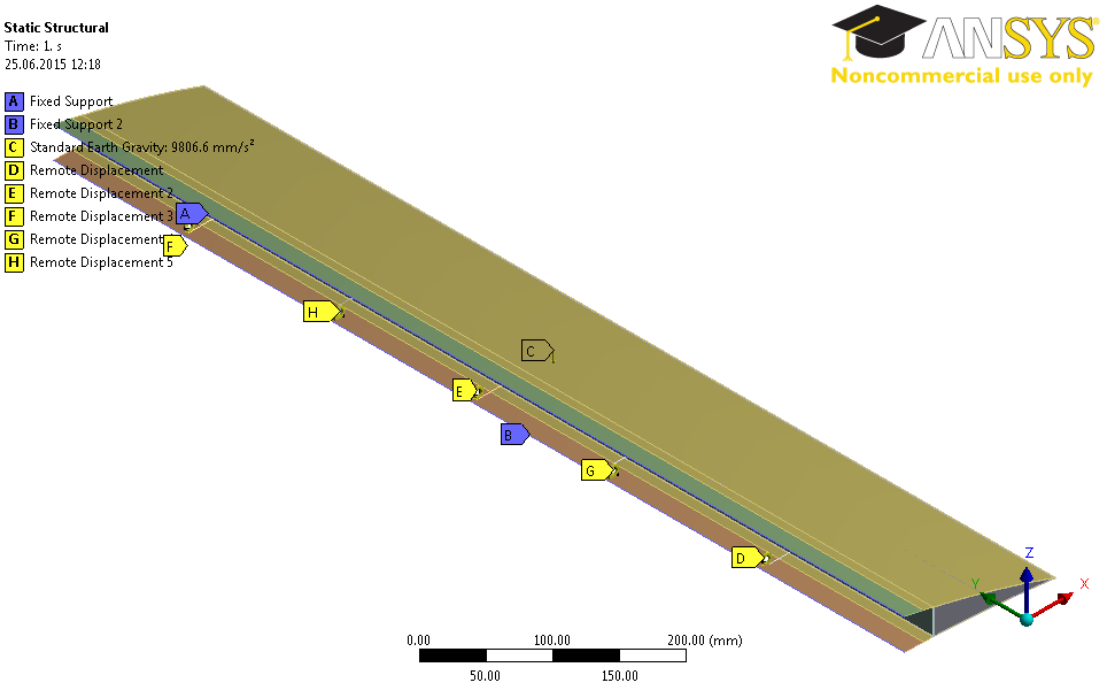

Figure 6: *The Applied Boundary Conditions to the Model*

The obtained transverse displacement results for camber and decamber morphings are presented in Figure 7, Figure 8 and Figure 9.

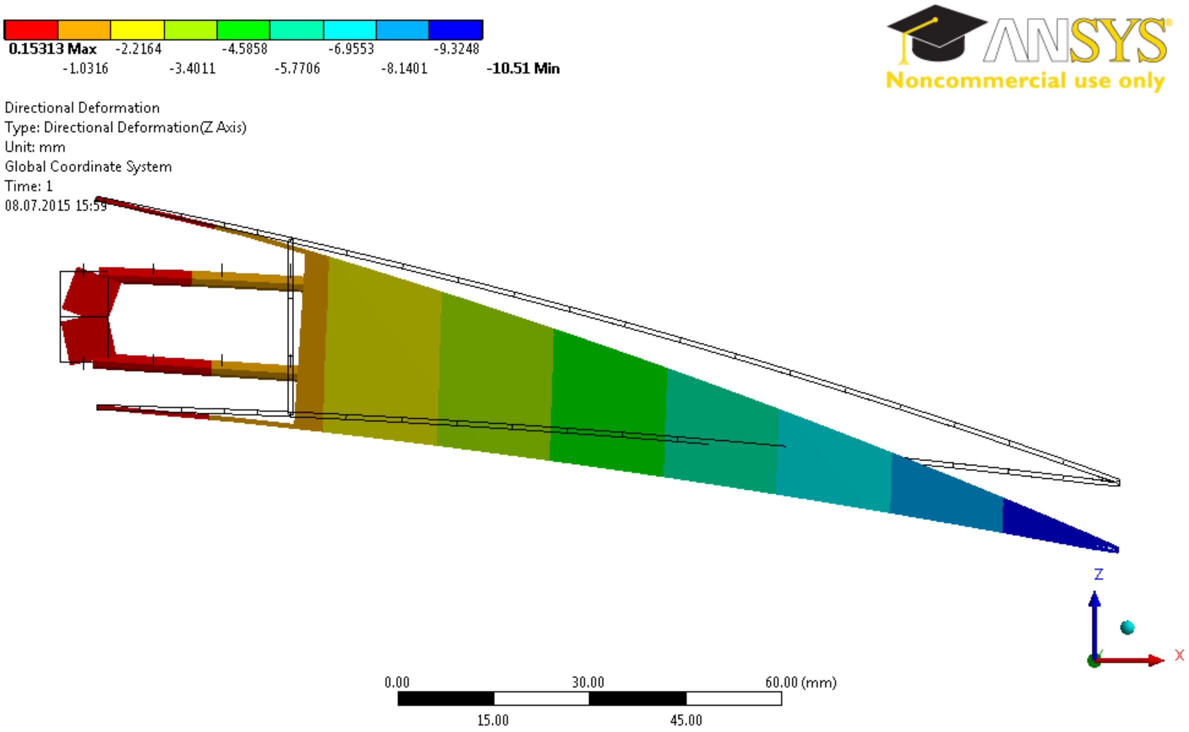

Figure 7: *Transverse Displacement Contours of the Control Surface for NACA8510 Morphing*

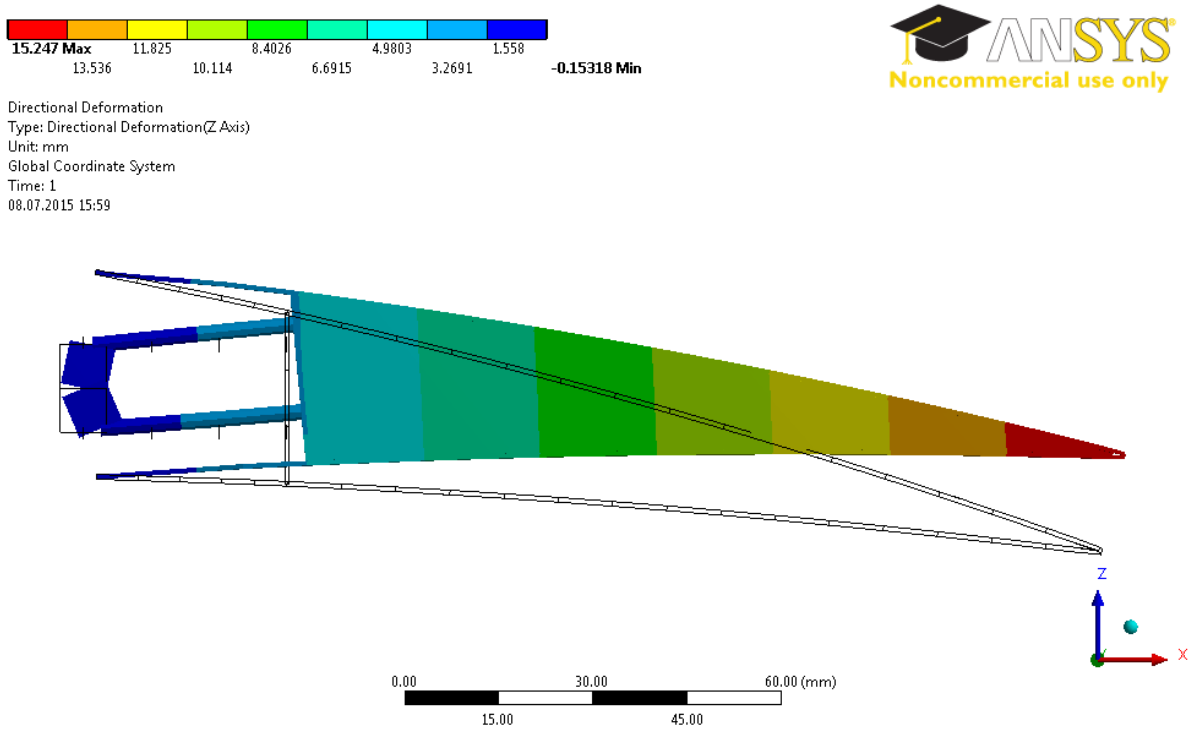

Figure 8: *Transverse Displacement Contours of the Control Surface for NACA3510 Morphing*

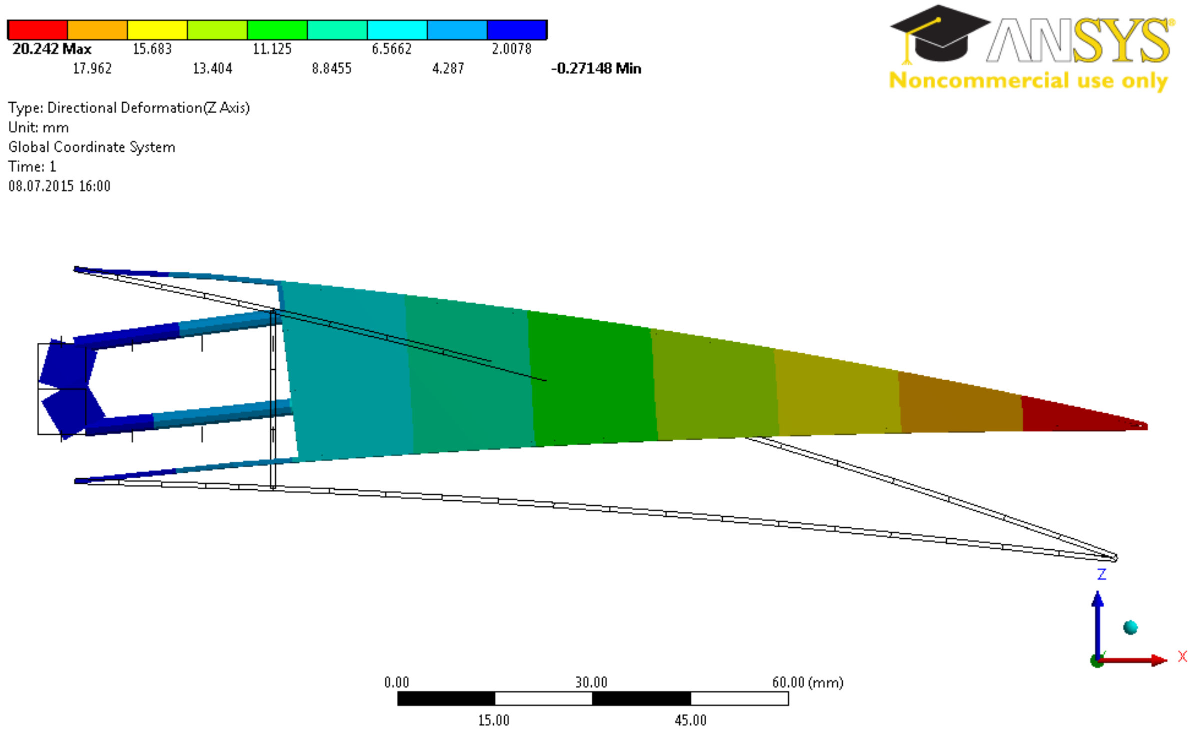

Figure 9: *Transverse Displacement Contours of the Control Surface for NACA2510 Morphing*

AERODYNAMIC ANALYSES

The aerodynamic loading was calculated by using 1g aerodynamic loads and the morphed profiles in different flight conditions of the Unmanned Aerial Vehicle to which the developed control surface will be attached to. The incompressible RANS and Spalart-Allmaras turbulence model was used. In order to create the aerodynamic mesh Pointwise® V17.2R2 package program was used and to solve the aerodynamic flows SU2 V3.2.3 open-source software was utilized. The generated aerodynamic mesh is given in Figure 10 and the flow parameters which were used during the solution are presented in Table 4.

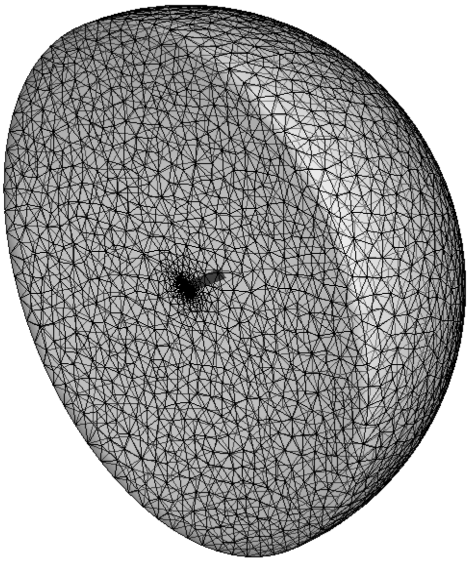

Figure 10. *The Generated Aerodynamic Mesh*

Table 4. The Flow Parameters used in Aerodynamic Analyses

	NACA8510 Configuration	NACA3510 Configuration	NACA2510 Configuration
Flight Speed – [m/s]	13.244	21.152	30.556
Angle of Attack – [deg]	6.373	1.713	1.056
Reynolds Number	524536	857990	1210135
Density – [kg/m^3]	1.189	1.225	1.189
Mach Number	0.039	0.063	0.090
Altitude – [ft]	1000	0	1000

STRUCTURAL ANALYSES UNDER AERODYNAMIC LOADING

After calculation of the 1g aerodynamic loads, they were transferred to the structural mesh and the analyses were conducted under given loads. Obtained transverse displacement contours are given in Figure 11, Figure 12 and Figure 13.

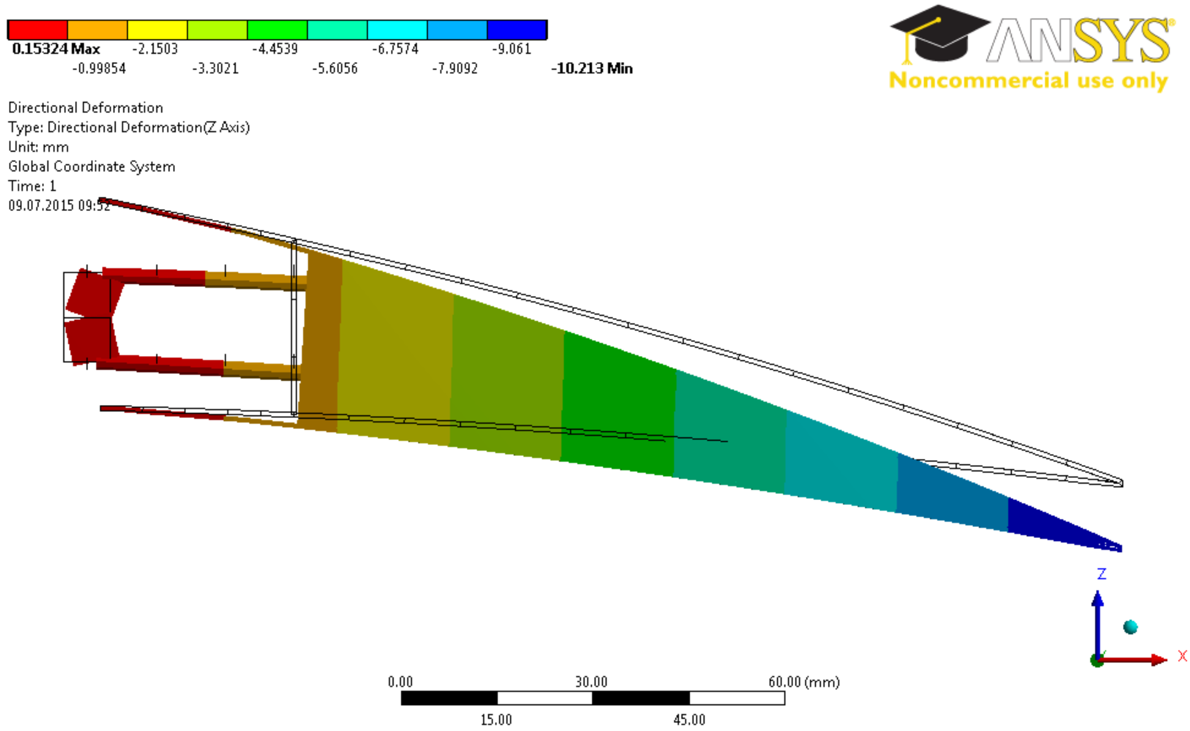

Figure 11. *Transverse Displacement Contours of the Control Surface for NACA8510 Morphing under Aerodynamic Loading*

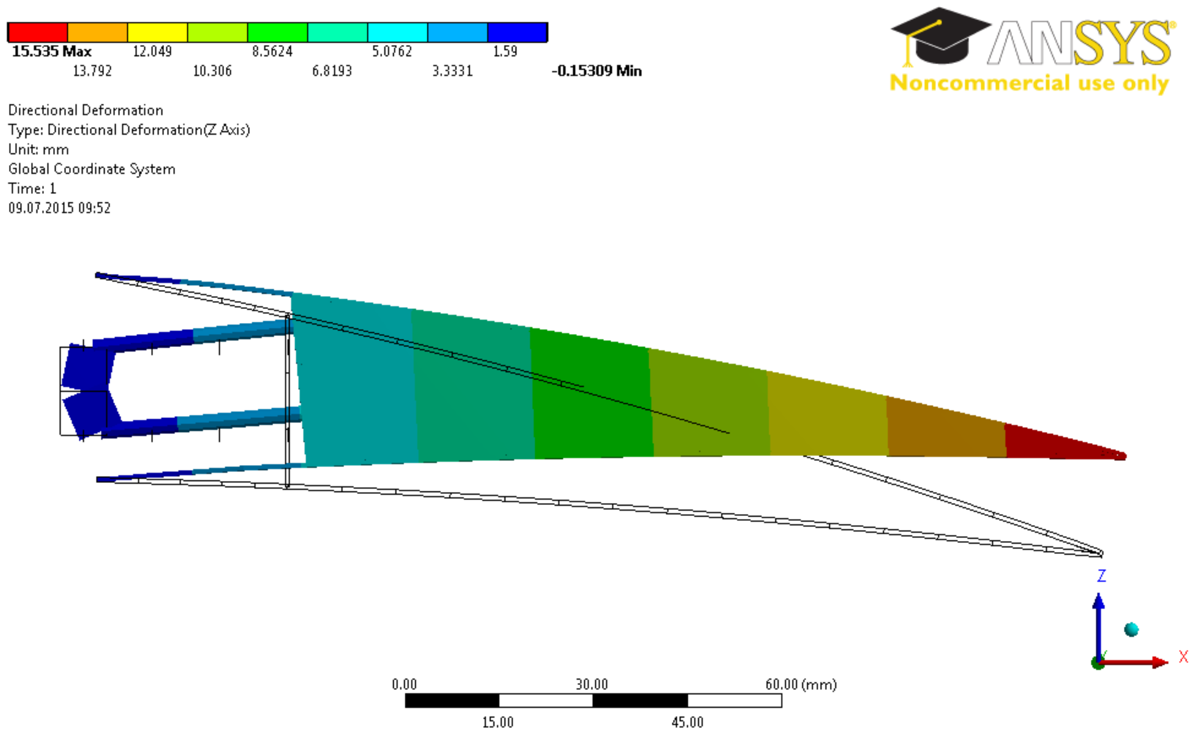

Figure 12. *Transverse Displacement Contours of the Control Surface for NACA3510 Morphing under Aerodynamic Loading*

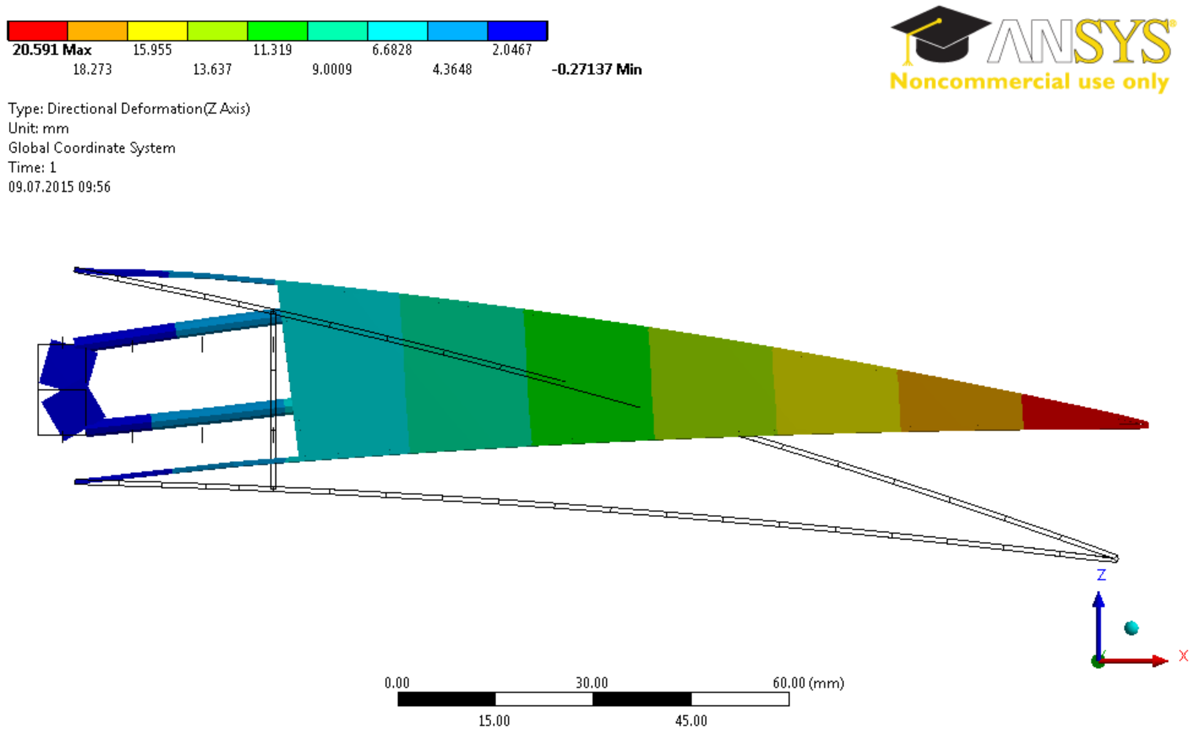

Figure 13. *Transverse Displacement Contours of the Control Surface for NACA2510 Morphing under Aerodynamic Loading*

SUMMARY AND CONCLUSIONS

In this paper, the design and analyses of a hybrid trailing edge control surface with camber and decamber capabilities are presented. The structural analyses in in-vacuo condition reveals that the control surface can morph into selected target profiles. After calculating the necessary aerodynamic loads corresponding to1g loads and the morph profiles, these load were applied to the structure. It was also shown that the control surface can maintain the morphed shape under aerodynamic loading.

ACKNOWLEDGEMENT

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