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A Hybrid Trailing Edge Control Surface Concept

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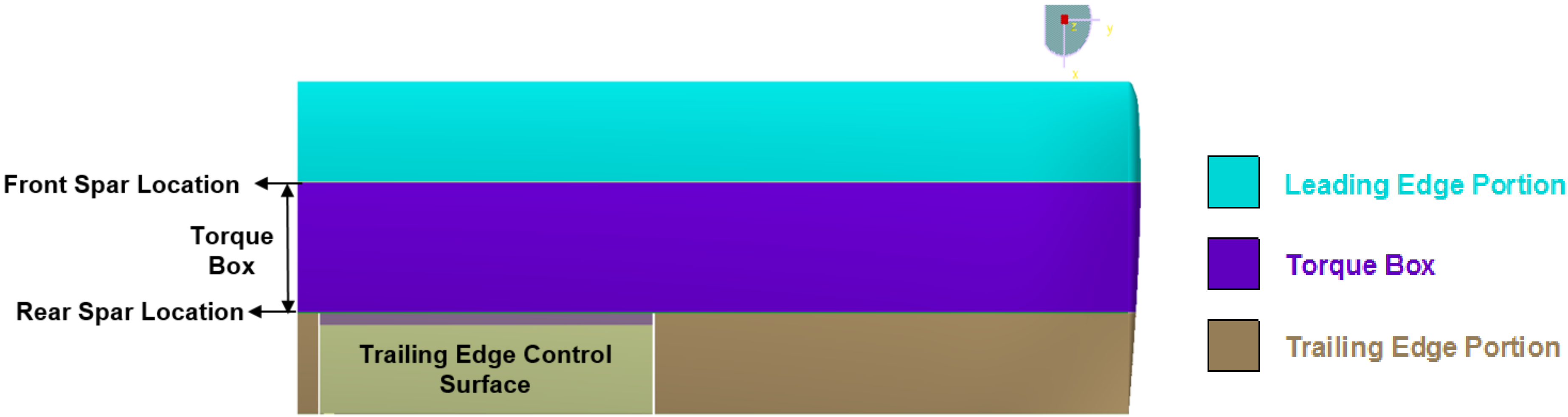
May 26, 2014

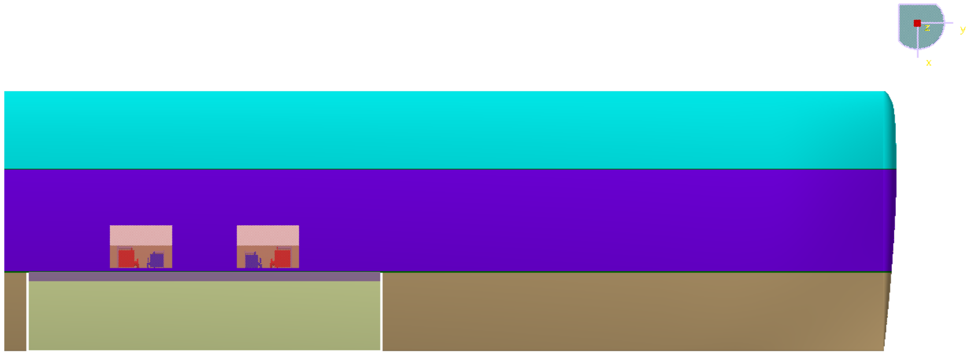
In this study, a hybrid trailing edge control surface having <u>pre-twist along its span</u> is analyzed both structurally and aerodynamically.



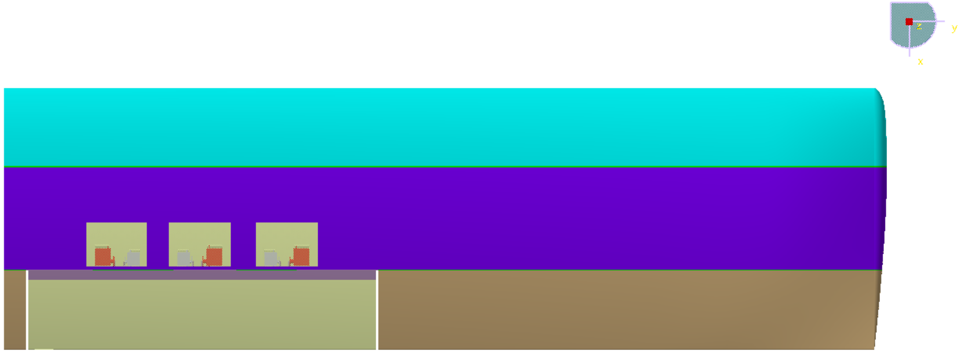
Study is conducted under the scope of 7th Framework Programme of the European Comission project CHANGE *"<u>C</u>ombined morp<u>H</u>ing <u>A</u>ssessment software usi<u>NG</u> flight <u>E</u>nvelope data and mission based morphing prototype wing development".*

Its geometry is generated by using wing geometry designed by ARA (Aircraft Research Association), which is one of the CHANGE Project Partners. Control surface has 0.8 [m] span and 0.18 [m] chord. Actuators are placed in the torque box.

DESIGN 1: Two servos actuate the upper surface, two servos actuate the lower surface.

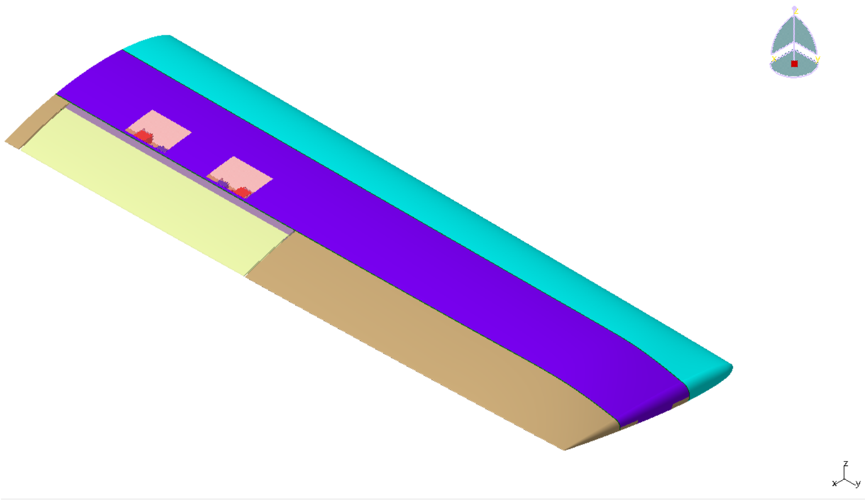


DESIGN 2: Three servos actuate the upper surface, three servos actuate the lower surface.

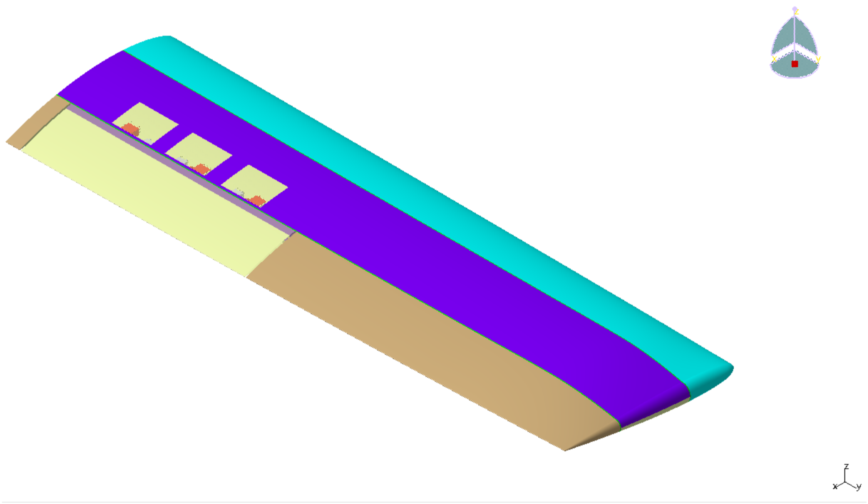


Isometric view of both design:

DESIGN 1

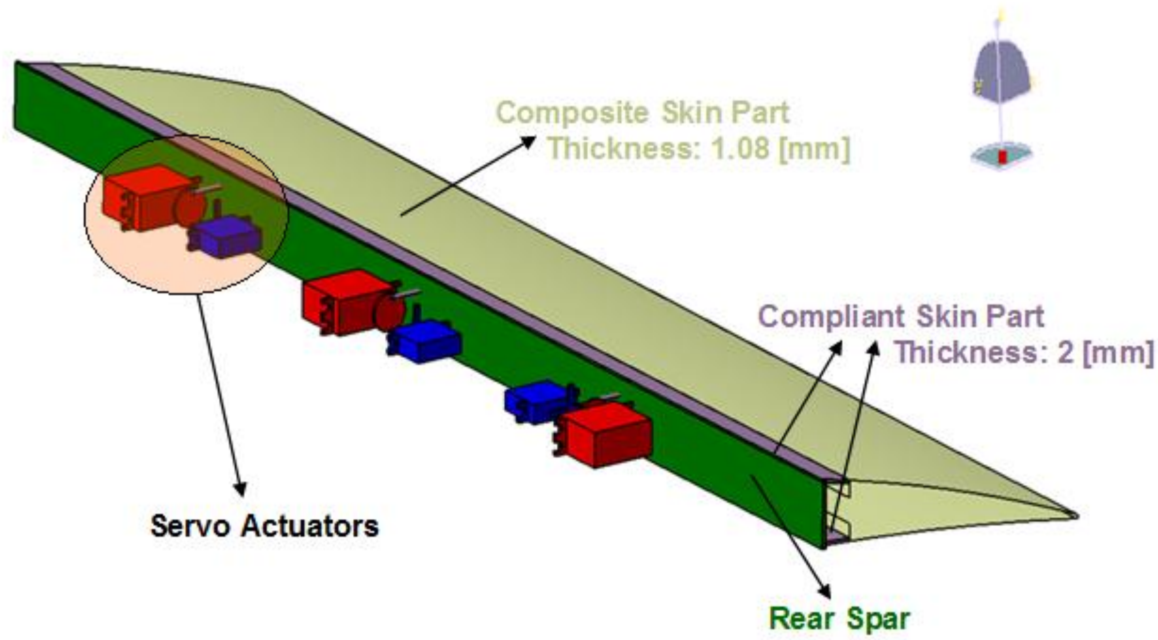


DESIGN 2



Solid models are created by CATIA V5-6R2012 package software.

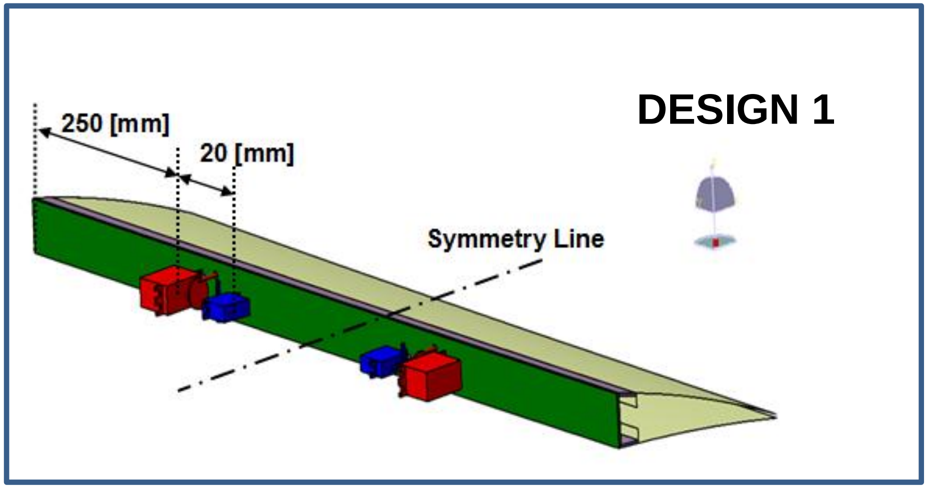
Hybrid trailing edge control surface mainly consists of three parts; namely, compliant skin part, composite skin part and actuation mechanisms (servo actuators).

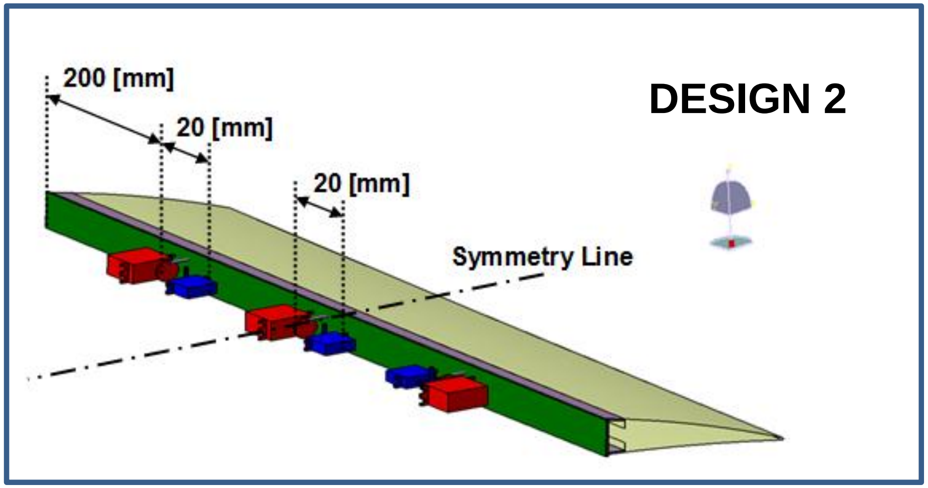


The concept is planned to be used as a flap on the wing that is being developed under the scope of the CHANGE Project.

Servos actuating the upper surface are shown in red.

Servos actuating the lower surface are shown in blue.





In the control surface concept,

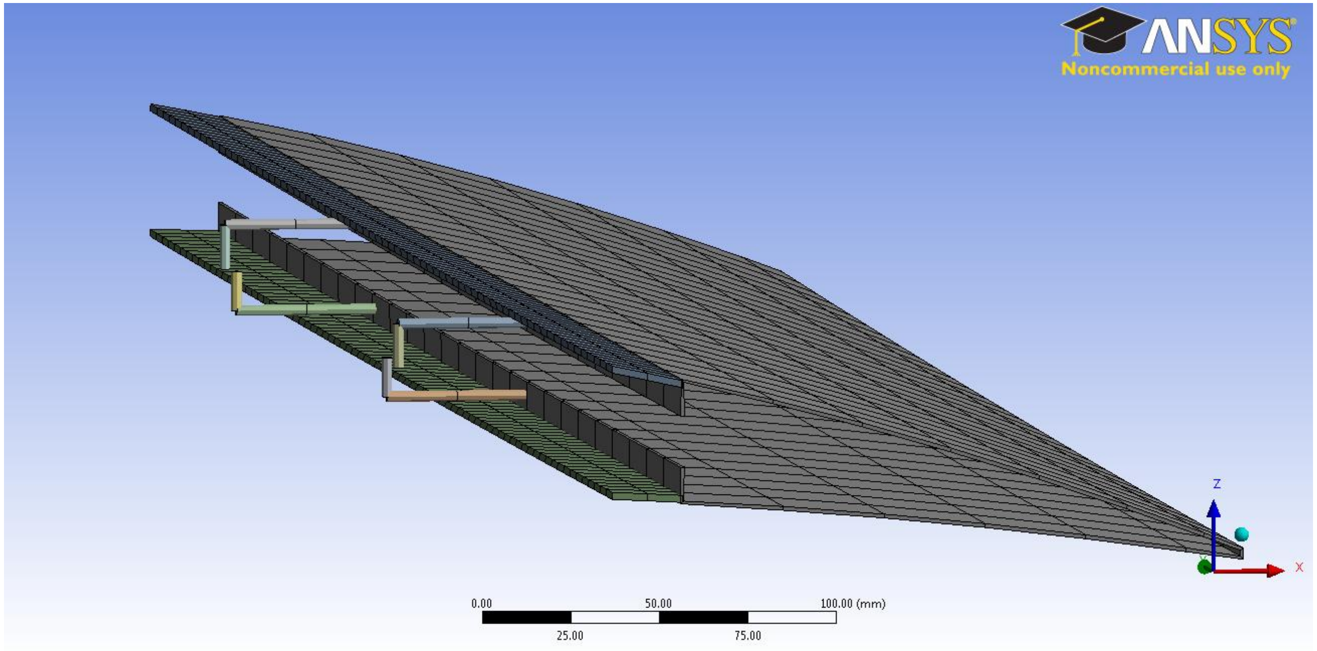
- **Neoprene Rubber is used as compliant material,**
- **7781 E-Glass Fabric – Araldite LY052 Resin – Aradur HY5052 Hardener Laminated material is used as composite material.**

Servo actuators attached to the upper surface are aimed to operate at higher torque level than their lower counterparts.

Due to torque difference, Neoprene Rubber at the upper surface elongates more than the lower one.

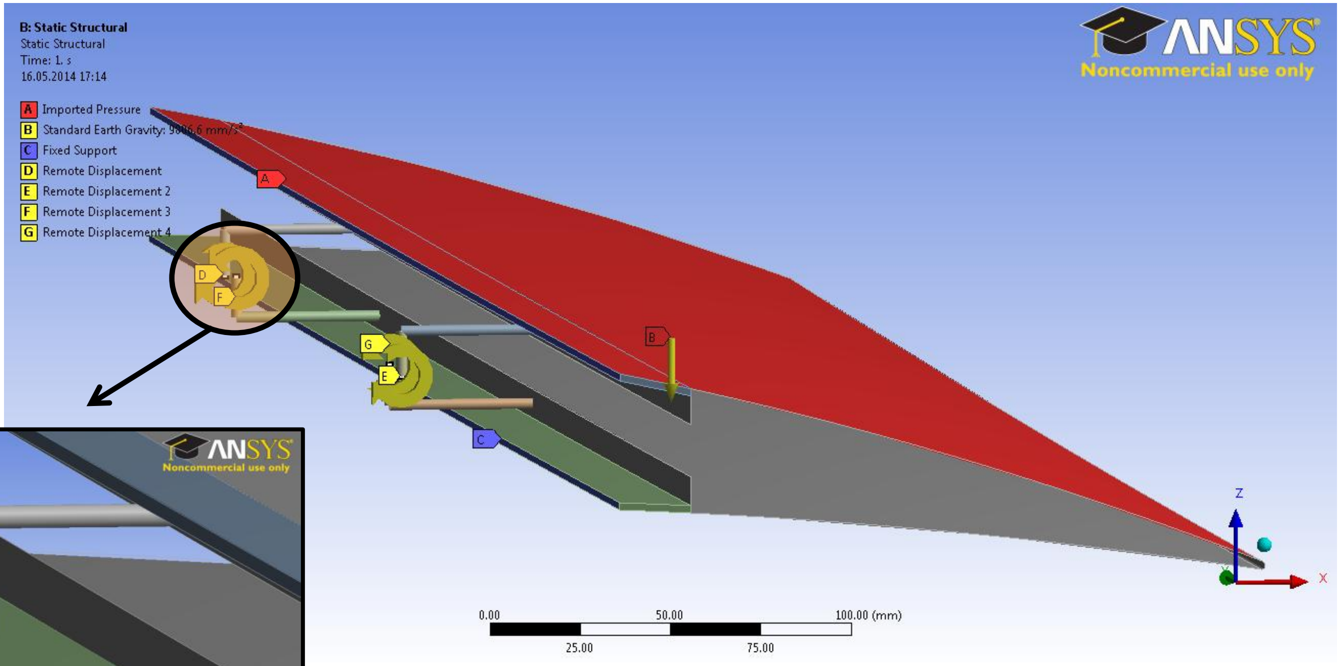
Since composite part is very stiff compared to Neoprene Rubber, no deformation occurs in composite part but it exhibits rigid body rotation. As a result, control surface deflects downwards.

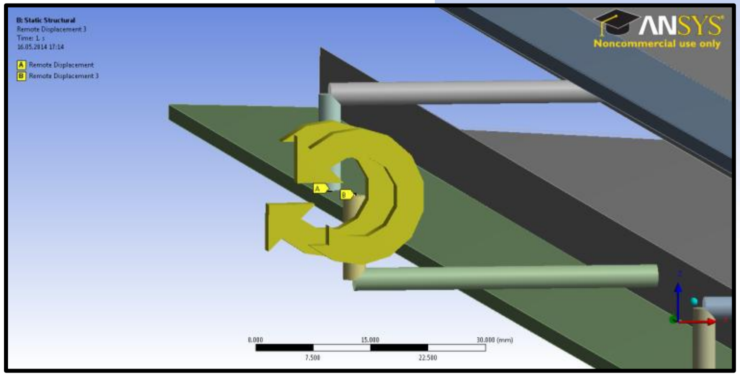
In order to determine the required servoactuator torques to deflect the control surface, finite element analyses are conducted by using Static Structural Module of ANSYS Workbench v14 package software. Shell, solid and beam elements are used in the modelling of the composite part, compliant part and actuation mechanisms, respectively. The mesh density used is obtained by considering the convergence analysis conducted in a similar study.



Finite Element Mesh for DESIGN 1

Pressure distribution of the wing for landing phase of the flight in the scope of CHANGE Project provided by ARA and control surface's own weight are given as external loading. The boundary condition of the control surface is taken as fixed at the edge of the compliant part. The boundary condition of the actuation mechanisms are given as rotations.

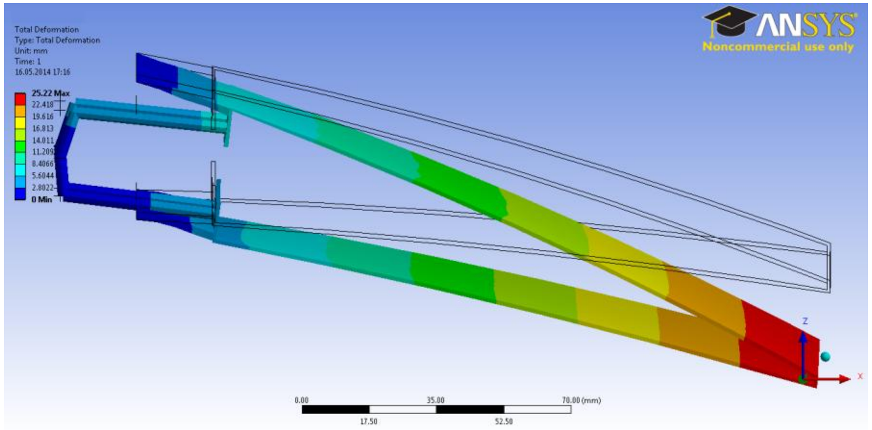




Boundary Conditions and Loading for DESIGN 1

The following total displacements of each designs are given below:

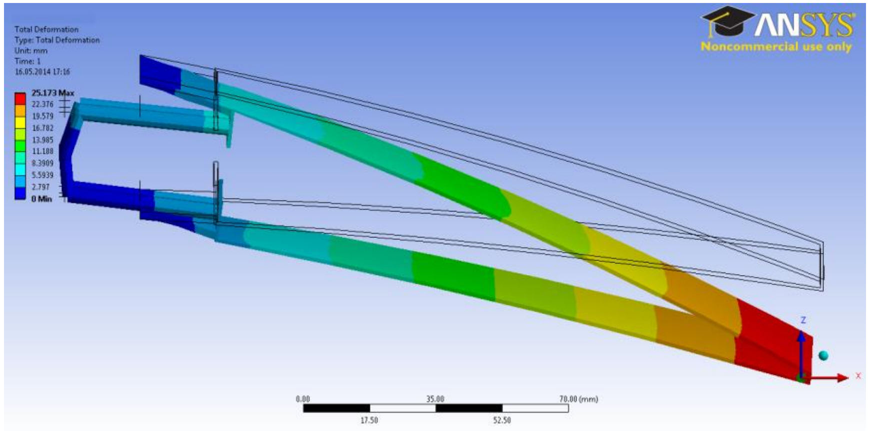
DESIGN 1



Two servos are actuating the upper and lower surfaces

Maximum Total Displacement: 25.220 [mm]

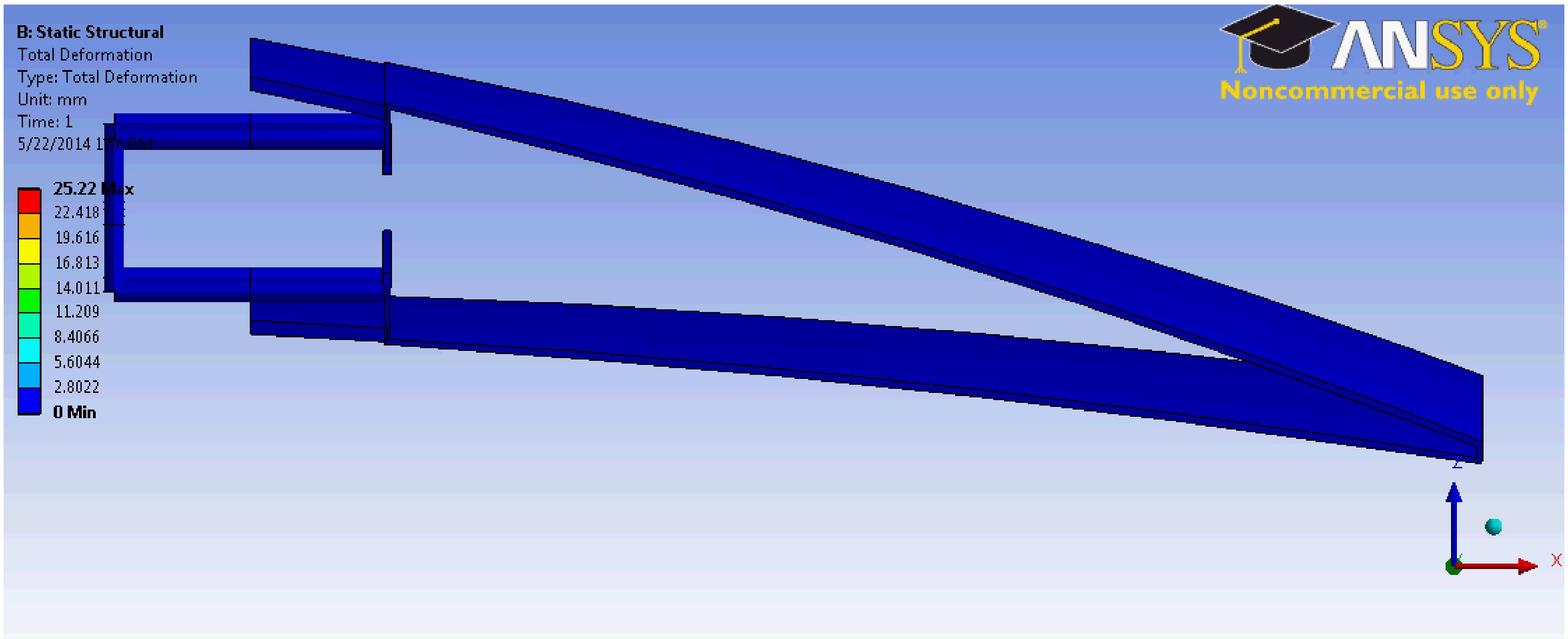
DESIGN 2



Three servos are actuating the upper and lower surfaces

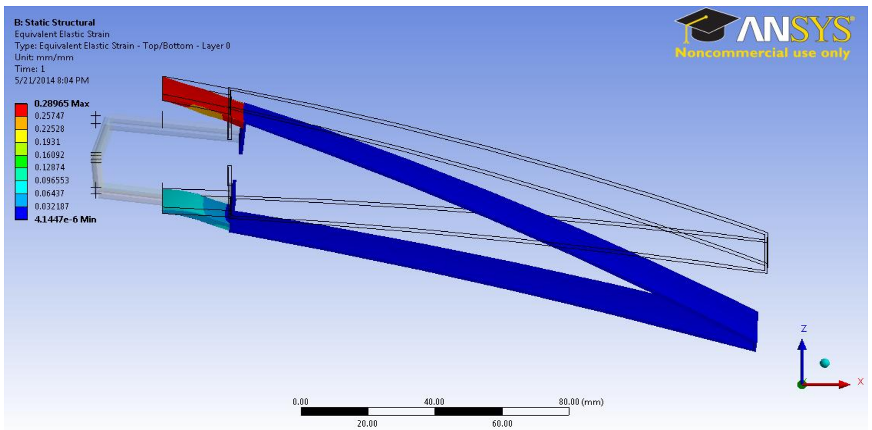
Maximum Total Displacement: 25.173 [mm]

Total displacement mechanism of the control surface for DESIGN 1:



The following von-Mises Strains of each designs are given below:

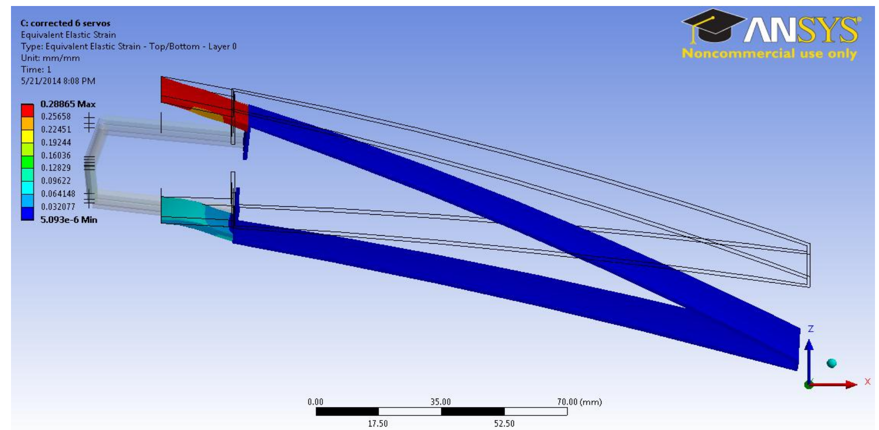
DESIGN 1



Two servos are actuating the upper and lower surfaces

Maximum von-Mises Strain in Neoprene Rubber: 0.28965
Maximum von-Mises Strain in Composite: 0.00039594

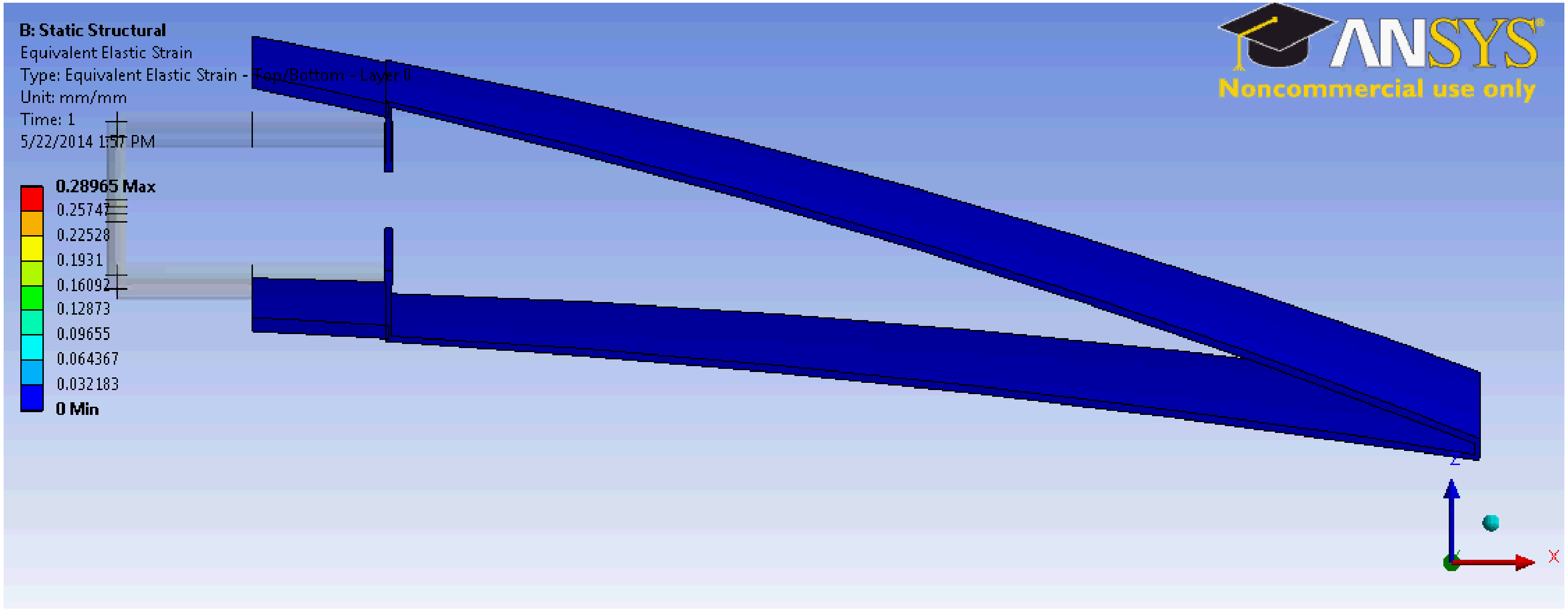
DESIGN 2



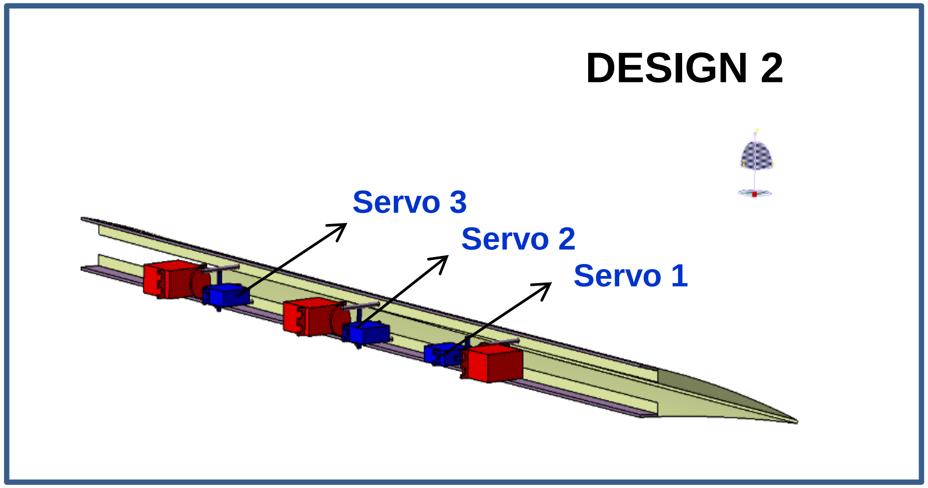
Three servos are actuating the upper and lower surfaces

Maximum von-Mises Strain in Neoprene Rubber: 0.28865
Maximum von-Mises Strain in Composite: 0.00043441

von-Mises Strains distribution of the control surface for DESIGN 1:



After checking torque reactions at servo actuators' boundary conditions, it is seen from DESIGN 2 that Servo 2 yields comparatively lower values. Therefore, it is decided to use two servos for the lower surface and retaining the initial design of three servos for upper surface in order to achieve lower weight.

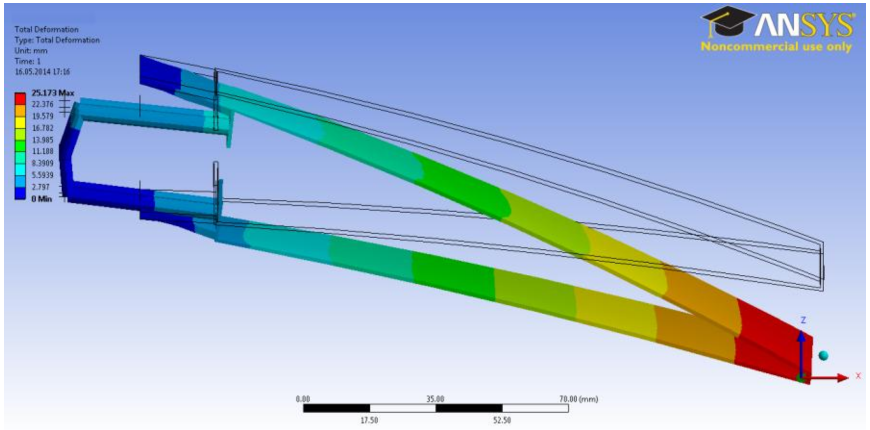


From now on, this design will be referred as MODIFIED DESIGN 2.

	Lower Surface FEM Torque Reactions of DESIGN 2	Lower Surface FEM Torque Reactions of MODIFIED DESIGN 2
Servo 1	2.43 [kg-cm]	2.26 [kg-cm]
Servo 2	0.17 [kg-cm]	-
Servo 3	2.67 [kg-cm]	2.47 [kg-cm]

After applying same external loading and boundary conditions to MODIFIED DESIGN 2, the following total displacements of each designs are given below:

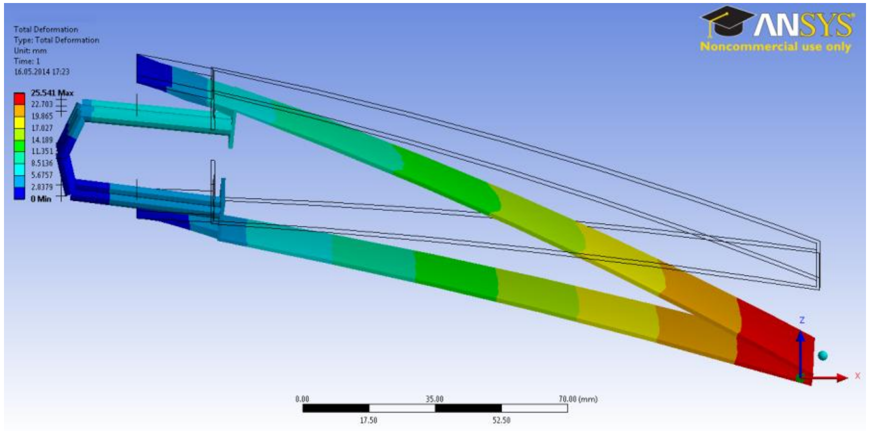
DESIGN 2



Three servos are actuating the upper and lower surfaces

Maximum Total Displacement: 25.173 [mm]

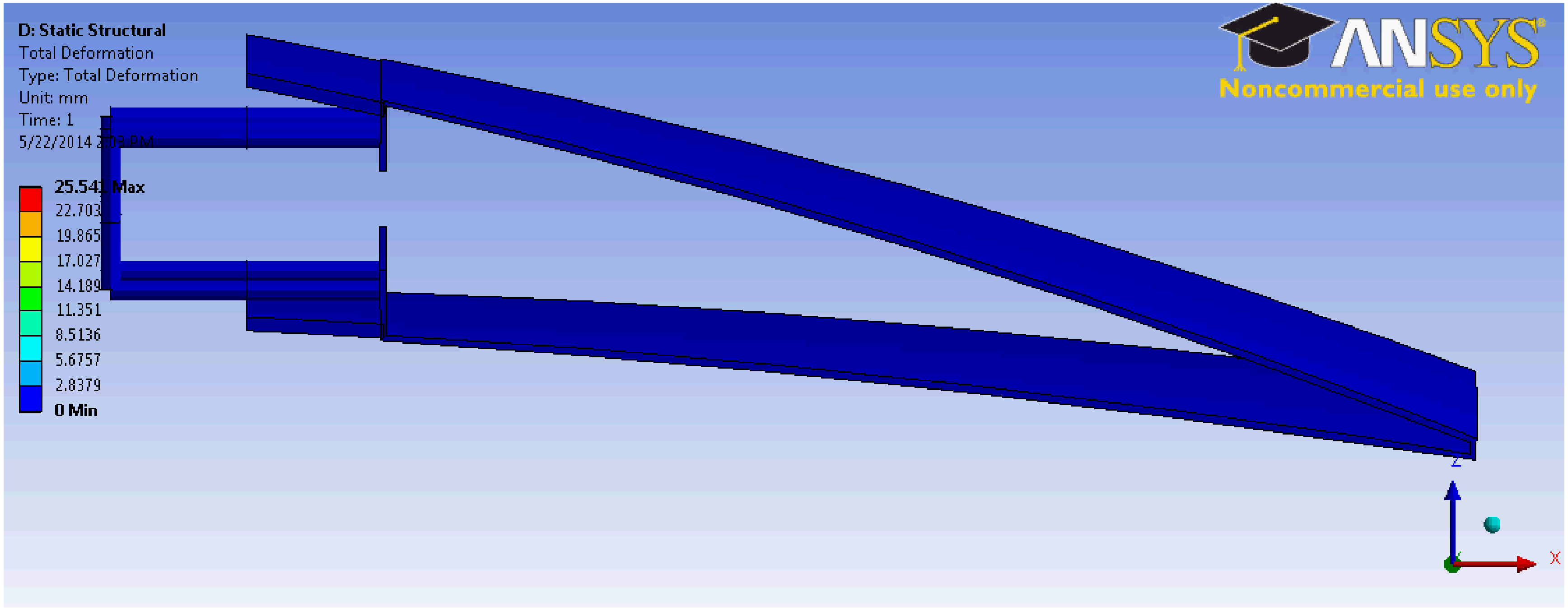
MODIFIED DESIGN 2



Three servos are actuating the upper surface, two servos actuating lower surface

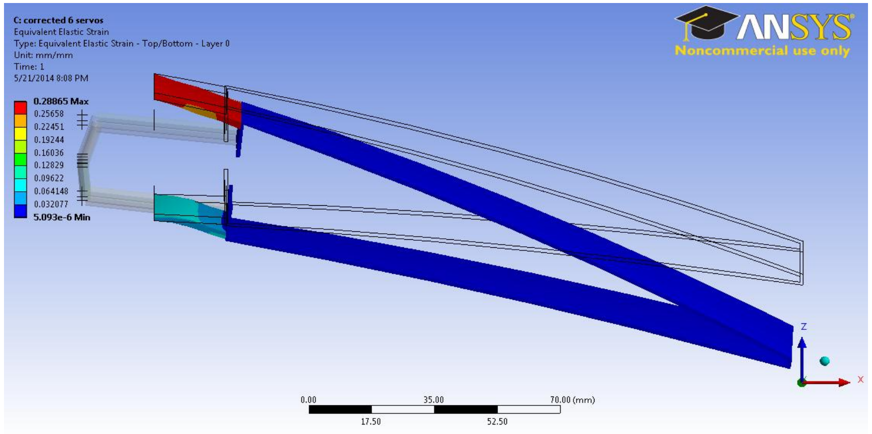
Maximum Total Displacement: 25.541 [mm]

Total displacement mechanism of the control surface for MODIFIED DESIGN 2:



The following von-Mises Strains of each designs are given below:

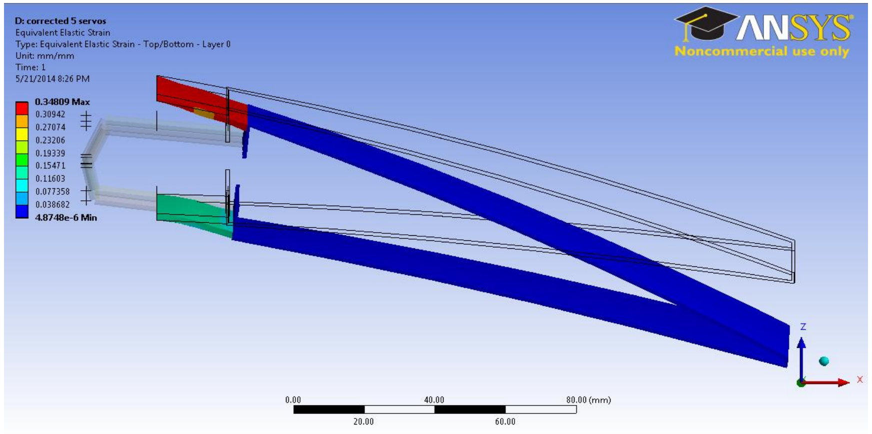
DESIGN 2



Three servos are actuating the upper and lower surfaces

Maximum von-Mises Strain in Neoprene Rubber: 0.28865
Maximum von-Mises Strain in Composite: 0.00043441

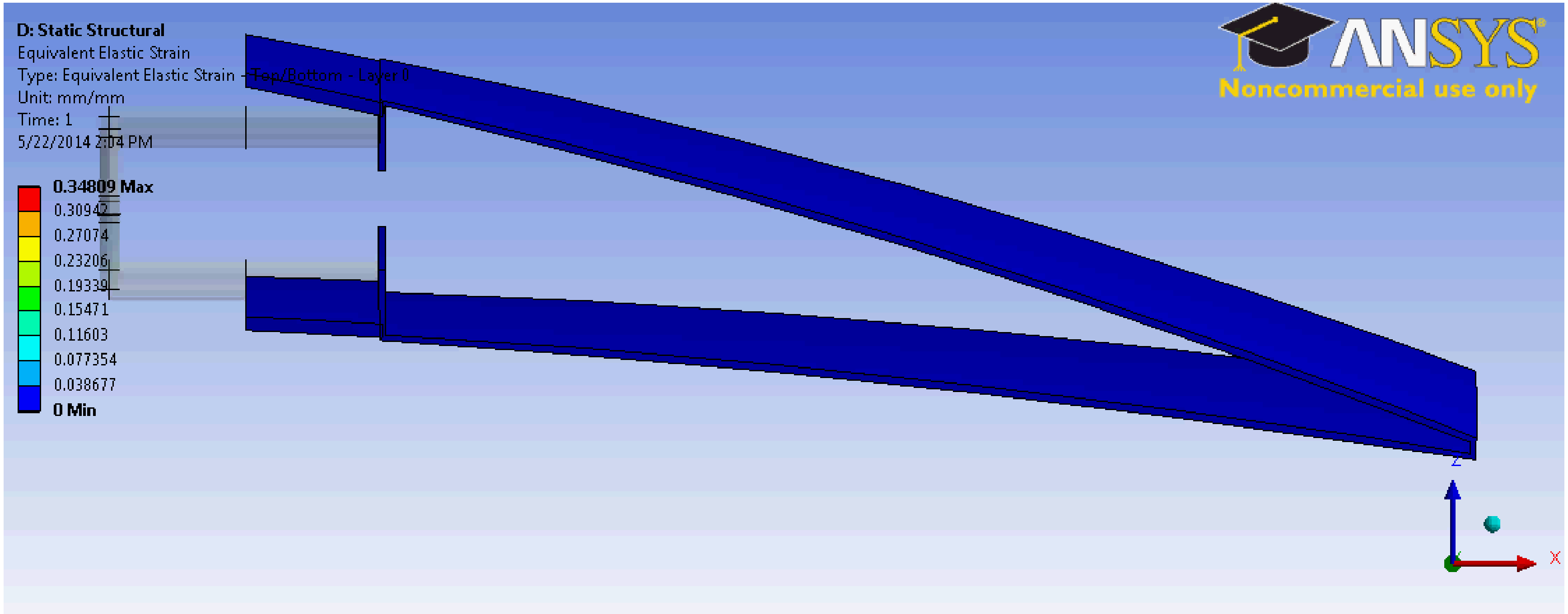
MODIFIED DESIGN 2



Three servos are actuating the upper surface, two servos actuating lower surface

Maximum von-Mises Strain in Neoprene Rubber: 0.34809
Maximum von-Mises Strain in Composite: 0.00050659

von-Mises Strains distribution of the control surface for MODIFIED DESIGN 2 :



The tables below indicate the highest values of servo actuators' reaction torques for each design case considered.

DESIGN 1	FEM Results	Safety Margin of 1.5
Maximum Required Servo Torque per Servo to Actuate the Upper Surface	4.07 [kg-cm]	6.10 [kg-cm]
Maximum Required Servo Torque per Servo to Actuate the Lower Surface	1.44 [kg-cm]	2.16 [kg-cm]

MODIFIED DESIGN 2	FEM Results	Safety Margin of 1.5
Maximum Required Servo Torque per Servo to Actuate the Upper Surface	5.03 [kg-cm]	7.55 [kg-cm]
Maximum Required Servo Torque per Servo to Actuate the Lower Surface	2.47 [kg-cm]	3.7 [kg-cm]

The actuation of the upper portion of the control surface is more critical than lower surface. This is because of the fact that control surface is planned to be used as a flap, i.e., downward motion of the control surface.

During flight, one of the servo actuators that actuates the upper surface may fail. In such cases, it is safer to use MODIFIED DESIGN 2.

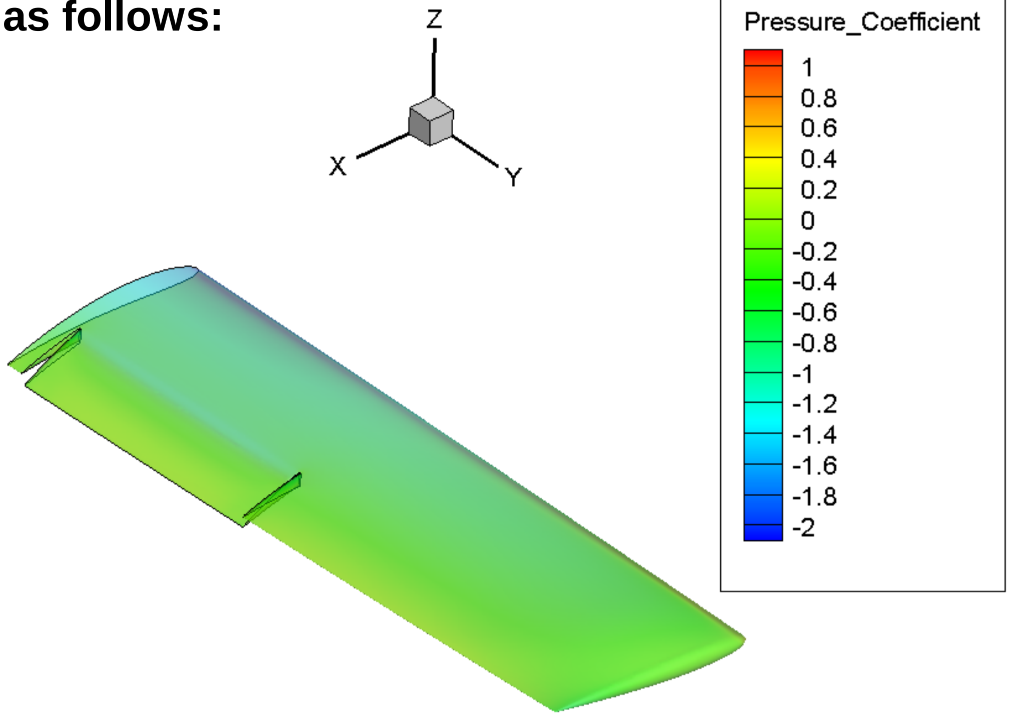
Even though one of the servos stops functioning, remaining two can still maintain the deflection of the control surface; yet, this is not possible for DESIGN 1 since there is only one servo actuating the upper surface.

After determining the deflected shape and required servo actuator torques, an aerodynamic analysis is conducted to determine the aerodynamic efficiency of the concept.

By using displacement results of Finite Element Analyses, solid model of the 'deformed control surface' is generated by using CATIA V5-6R2012 package software. Since tip displacements are on the same order of magnitude for both designs, aerodynamic analysis is performed only on MODIFIED DESIGN 2.

Solution domain and mesh generation for CFD analysis is then performed by Pointwise v17-R2 package software. Finally, Stanford University Unstructured (SU2) v3.0 package software is used as a solver for CFD analysis.

Pressure coefficient contours of wing having the 'deflected control surface' of MODIFIED DESIGN 2 are determined as follows:



Obtained CFD results are compared with the CFD results of the wing, which is provided by ARA, in terms of lift coefficients.

As expected, deflection of the control surface increases the lift coefficient, and it is approximately 20%.

	CL
ARA's Wing	0.964
MODIFIED DESIGN 2	1.141

As a conclusion;

- **A hybrid trailing edge control surface concept is considered via two different designs.**
- **After performing structural analyses by finite element method, safest design is chosen.**
- **CFD analysis is then performed on the chosen safest design in order to determine the lift coefficient of the wing with deflected control surface.**
- **It is observed that both concepts work and improve lift coefficient of the wing.**

Acknowledgments

The work presented herein has been partially funded by the European Community's Seventh Framework Programme (FP7) under the Grant Agreement 314139. The CHANGE project ("Combined morphing assessment software using flight envelope data and mission based morphing prototype wing development") is a L1 project funded under the topic AAT.2012.1.1-2 involving nine partners.

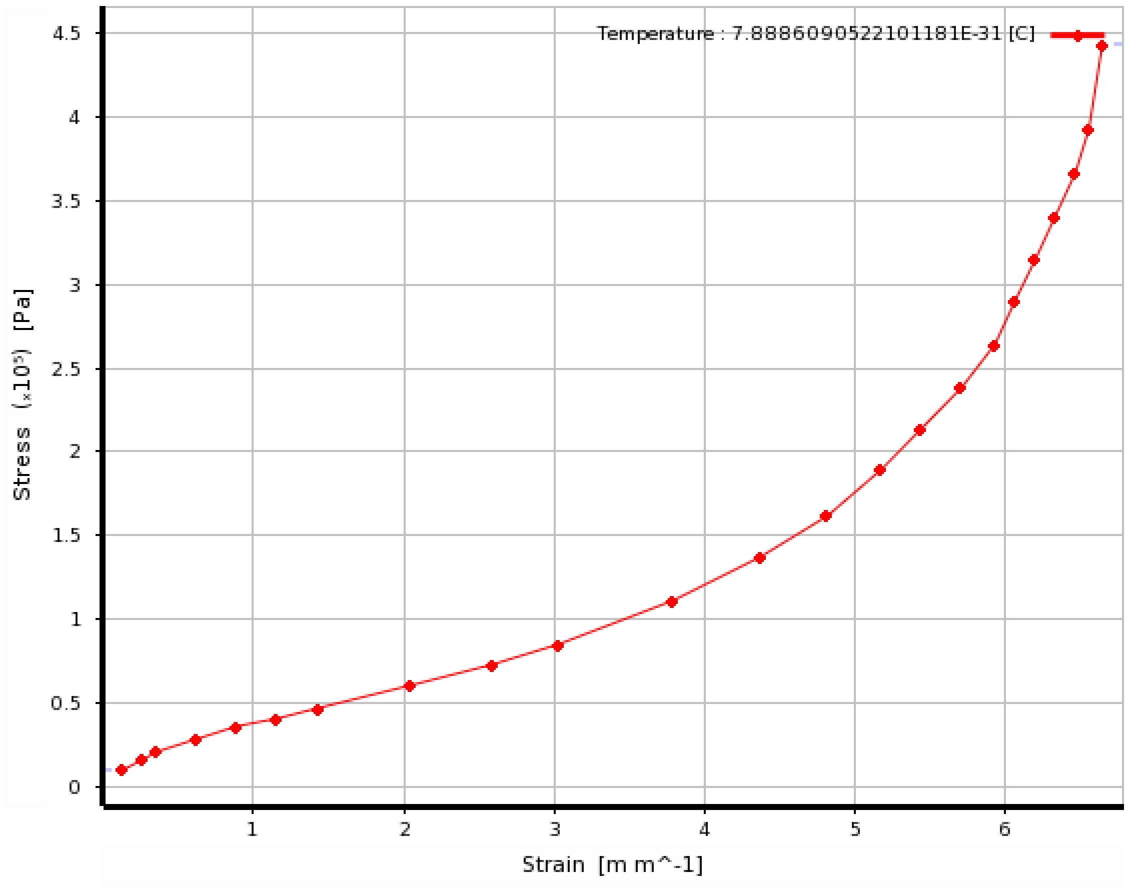
The project started in August ,1, 2012.

İlhan Ozan Tunçöz and Yosheph Yang thank to TUBITAK (The Scientific and Technological Research Council of Turkey) for supporting them during their graduate education.

Thank you,

Any Questions?

Uniaxial stress-strain data of Neoprene Rubber:



Material properties of composite part (modelled as linear isotropic elastic):

Density:	1513 [kg/cm^3]
Young's Modulus:	71 [GPa]
Poisson's Ratio:	0.33
Shear Modulus:	26.7 [GPa]

Rotation boundary conditions in "+Y" direction to model the servo actuations:

	Servos to Actuate the Upper Surface [deg]	**Servos to Actuate the Lower Surface [deg]**
Design 1	18.8	-5
Design 2	19	-5
Modified Design 2	26	-13

Aerodynamic run parameters for landing phase of the flight:

Solver Type:	Incompressible RANS
Velocity:	47.68 [km/h]
Mach Number:	0.039
Reynolds Number:	524567
Altitude:	1000 [ft]
Angle of Attack:	6.373 [deg]
Turbulence Model:	Spalart Allmaras