

Variable Cant Angle Adaptive Winglets for Improved Flight Performance

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Abstract

Induced drag caused by wingtip vortices affects Aircraft performance. Winglets, referred to as vertical or angled extensions at aircraft wingtips, are used to minimise the induced drag by reducing vortices formation to improve fuel efficiency. This paper describes a Computational Fluid Dynamics (CFD) analysis, performed on a NASA's CRM (Common Research Model) (with and without winglet) with the airfoil section of CRM 65- BTE. The objectives of the analysis were to compare the aerodynamic characteristics and to investigate the performance of winglet at cant angles 0°, 25°, 35°, -25 and -35° at various flight conditions (take off, landing and cruise conditions). The CFD simulations were performed different subsonic flow conditions according to the flight conditions of take-off, landing and cruise. This is solved in ANSYS FLUENT solver using Finite Volume Method. Spalart-Allmaras turbulence model and 3-dimensional unstructured tetrahedral mesh were used to compute the flow around the model and circular 'C' shaped fluid domain is used. The aerodynamic characteristics of lift coefficient (CL), drag coefficient (CD) were compared and it was found that each winglet configuration at a particular flight conditions had different CL, CD, indicating that fixed winglets do not provide optimum aircraft performance at different phases of flight.

Keywords: *Cant angle, NASA's Common research model (CRM), Adaptive winglets.*

INTRODUCTION:

Winglets being a small structure play an important role in reducing the induced drag in aircraft. Many types of winglets have been designed and their significance in reducing the drag is published. The induced flow pattern causes the relative velocity to cant downwards at each airfoil section of the wing, thus reducing the apparent angle of attack. The lift vector is tilted backwards and a force component in the direction of the drag appears, called induced drag. Reducing the size of this tip vortex and minimizing the induced drag is of great importance for the modern aircraft designers. For this purpose designers developed the winglet concept. Winglets are specially designed extensions adjusted to the wingtip that alter the velocity and pressure field and reduce the induced drag term, thus increasing aerodynamic efficiency. One of the main objectives of this master thesis work is to study about the winglet design and about their contribution in reducing induced drag. A brief overview of wing tip devices and their performance from the manufacturers as well as from airliner's point of view are discussed. Moreover, the role of winglet in reducing the drag of commercial civil jet aircraft is studied and the percentage of drag reduction is calculated by a conceptual approach.

Conventional winglets provide maximum drag cutback and improve L/D under cruise conditions only. During non-cruise conditions, these winglets are less likely to improve aircraft performance and subsequently, they do not provide optimal fuel efficiency during take-off, landing and climb. Non-cruise flight conditions add up to a significantly large fraction of a flight and therefore, winglet designs must be optimised to be able to function during both cruise and non-cruise flight conditions. Research on conventional winglets improvement methods have been more dominant compared to any other types of winglet. In recent years, extensive research has been ongoing, aiming to improve the design of winglets in order to boost the aircraft performance during flight, e.g. spiroid

winglets and sharklets. Limited work has been carried out on winglet designs that can alter the cant angle.

This thesis is to explain about the adaptive winglets, in which the Cant angle and Toe angle of the winglet can be varied according the flight conditions. These variable winglet can be controlled by an automated avionic control system which is connected with the flight management system, from which the data of flight speed, flap and elevator deflection are collected and according to that the winglet can be adapted easily. Also CFD analysis have been used to determine the aerodynamic characteristics of winglets and to predict flow behaviour around wingtips for different fixed Cant angles.

OBJECTIVES AND METHODOLOGY:

The main objectives of the project are explained as follows:

- To design an adaptive winglets by varying cant angles in different flight conditions for improving flight performance.
- To analyse the winglet using CFD solver and to compare the results with the wing without winglets.
- Choosing the correct winglets according to the flight condition, and to validate the best performing winglets on specific flight condition.
- On the other hand, the winglets are analysed through a FEM method to calculate the contributions and deflection due to aerodynamic loads which may increase the drag due to weight.

The methodology of the project is explained as follows:

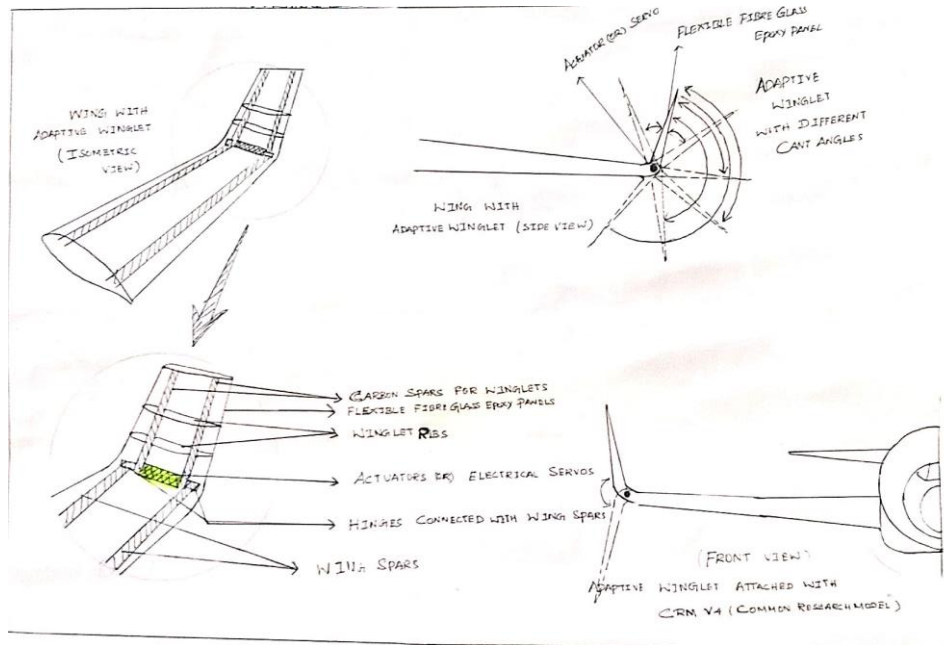
- Designing an Initial sketch to provide a basic Idea about the adaptive winglet.
- Designing a winglet with a various cant angle of 25°, 35°, 0°, -25°, -35° using a CRM sweptback wing, in CATIA V5 R20.
- Meshing the designed models using a three Dimensional Tetrahedral mesh in a C fluid domain, which is carried out using ANSYS ICEM CFD.
- The various meshed model with fluid domain is taken, then initial and boundary conditions are applied.
- After applying boundary conditions the models are analysed using CFD solver ANSYS FLUENT for various flight conditions.
- Results are post-processed and the Lift co-efficient and drag co-efficient values are obtained.
- Using the Cd and Cl values the Drag polar curve is drawn.
- Importing those pressure and forces values to MSC NASTRAN PATRAN to calculate the aerodynamic loads applied on the winglets.
- Validation of results is carried out.

DESCRIPTION:

Initial Sketch:

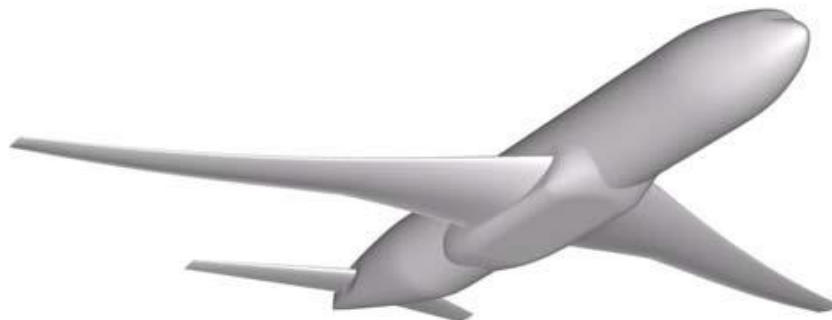
The initial sketch is advancements of latest winglets design used in commercial aircraft which are co-related together for further improvement in the performance by making it as variable angle adaptive winglets. By making the winglets as adaptable according to the flight condition, efficiency of the aircraft can be improved. (i.e) with a controlled actuators the winglets Cant angle can be varied according to the flight condition, this may improve the efficiency of the aircraft. This idea is a biomimicry of an eagle and an albatross, which is having a slotted winglets for better performance to reduce the induced drag, but by using those slotted winglets in fixed wings are difficult to construct. So

by biomimetics of those nature, the variable Cant angle winglet can be developed to reduce the wingtip vortices and induced drag. The major problem to be overcome is that it may increase the drag due to weight by installing actuators at the wingtip. The second problem is the materials used for this variable winglet should be smooth and flexible, this can be done by using a flexible fiberglass epoxy panels. The various flight conditions need to be captured, according to that winglets Cant angle can be varied, and the further development in this idea can be carried out.



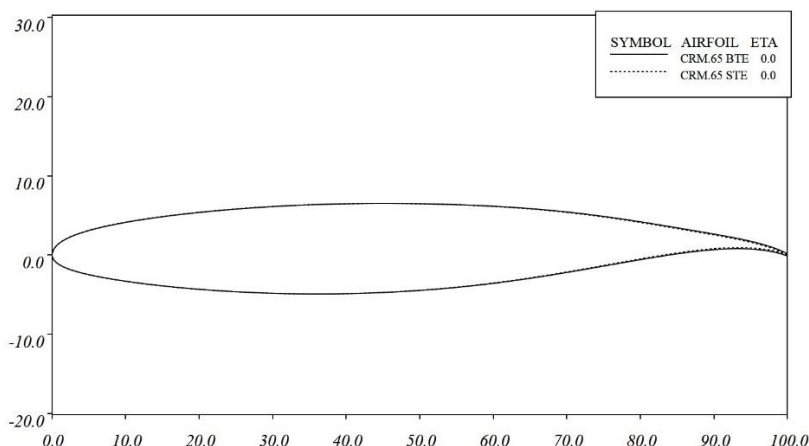
Geometry Description:

The common research wing is taken as a reference wing to fix the variable cant angle adaptive winglets. The baseline wing-body (WB) configuration for DPW-V is that of the NASA Common Research Model (CRM). The CRM is representative of a contemporary transonic commercial transport designed to cruise at $M = 0.85$ and $CL = 0.5$ at a nominal altitude of 37,000 ft. However, a couple of features have been designed into this shape solely for the purposes of research and developments. This provides a fairly controlled TE separation, which is a flow phenomena under study by the DPW organizing committee. This pressure architecture also amplifies the differences between the various turbulence models, e.g. skin-friction drag levels. With this model the adaptive winglets are attached to the wing with fixed cant angle. The five models of winglets have been designed and fixed with the CRM wing body. The Cant angles of 0° , 25° , 35° , -25° and -35° are designed and the **appendix 1** (attached as first attachment) showing the CRM wing body configuration and designed winglets with varied cant angles.



CRM wing body configuration used for winglets attachments

The airfoil used for designing the wing is CRM-65 BTE (Blunt Trailing Edge), the wing has a overall geometrical twist of 8°. 21 aerofoil sections have been used to design a complete wing and hence the winglets are designed in a toe angle of 2°



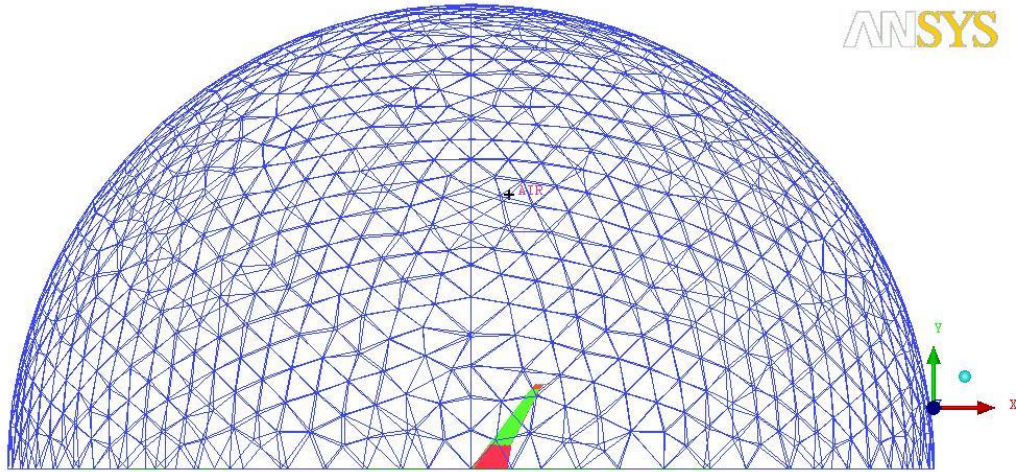
GRID GENERATION:

ICEM-CFD grid generator was used to develop the mesh for ANSYS FLUENT. Accurate representations of the geometry, along with generating a high quality mesh, are critical first steps in obtaining an acceptable solution. The IGES file was imported in ICEM-CFD with tri tolerance of 0.0001 and topo tolerance of 0.001. Geometry clean up carried out in ICEM with build topology tolerance 0.3. Mesh was carried out with patch dependent method and the surface are meshed with only trias elements. The grid details are given below.

Grid type	fine
Elements	263261
Nodes	121016
Surface mesh	All Trias
Volume mesh	All Tetrahedrons
Mesh type	Patch dependent

The surface mesh was carried out with only trias elements on the surface with patch dependent as mesh method. The volume mesh was initialised with tetra/mixed mesh type and mesh method as robust (octree)⁸. The volume mesh are generated with tetrahedral elements

The guidelines set forth by DPW for the grid-generation requirements were closely followed with the following exception. The coarse and medium grids were assessed to provide insufficient resolution on the leading edge of wing and horizontal tail. To remedy this, the leading edge spacing on the coarse and medium grids was set to be similar to the fine grid. This gives rise to the nomenclature coarse-fine and medium-fine grid used for the FLUENT work. A grid refinement study was performed by running simulations with different grid resolution, i.e. the number of elements. This was carried out in order to select an appropriate range for the number of elements in the mesh. In this particular case, the mesh consisted of around 2 to 2.5 million elements, which was very effective in terms of computational time as well as the results quality.



Meshed Fluid domain with wing and winglet

The above figure shows the fluid domain with the wing-winglet configuration. The complete grid which is generated using ICEM CFD for each type of varied cant angles have been shown in the figure in **appendix 2** (second attachment). The appendix 2 shows all the mesh which have been generated for winglets having the angles of 0° , 25° , 35° , -25° and -35° . And overall the average mesh elements created is about from 2 to 2.5 million.

CFD SOLVER SETUP:

For this study, the Reynolds Averaged Navier Stokes (RANS) equations coupled with a turbulence model was used. The solver (ANSYS CFX) discretizes the RANS equations over the grid elements, producing a set of nonlinear equations for every variable at each node. The turbulence model used was Spalart-Allmaras (SA). SA is a one-equation model, i.e. the model consists of one partial differential equation, which is used for the velocity component of the model. SA model solves for the turbulent viscosity, ν_t . This is then applied to the governing RANS equations. The solver was set to perform the simulations for 1000 iterations. At 1000 iterations, the solutions were fully converged.

Run Conditions:

Case 1 -: Cruise condition

1. Mach = 0.85
2. Drag Polar for $\alpha = 0^\circ$

Case 2 -: Take Off condition

1. Mach = 0.23
2. Drag Polar for $\alpha = 8.53^\circ$

Case 2 -: Landing condition

1. Mach = 0.23
2. Drag Polar for $\alpha = 8.53^\circ$

Grid refinement series from the Common Grid Sequence consisting of three grid levels with

- Chord Reynolds Number $RE = 5 \times 10^6$ based on $C_{REF} = 7.005$ m
- Reference Temperature = 100° f
- Moment reference center is $X_{REF} = 33.68$ m, $Z_{REF} = 4.52$ m
- Chord Reynolds Number $Rn = 5 \times 10^6$.
- Reference pressure = 201326.9 Pa

Preliminary Settings In Solver:

- Solver used : ANSYS FLUENT 14.0
- Solver type : Density-Based
- Model : Turbulent
- Solving Equation : Spalart Allmaras (1 eqn turbulence)
- Fluid used : Air (as Ideal Gas)
- Solution methods
 - Formulation : Implicit
 - Flux type : AUSM
 - Gradient : Least squares cell based
 - Flow type : second order upwind

RESULTS AND DISCUSSION:

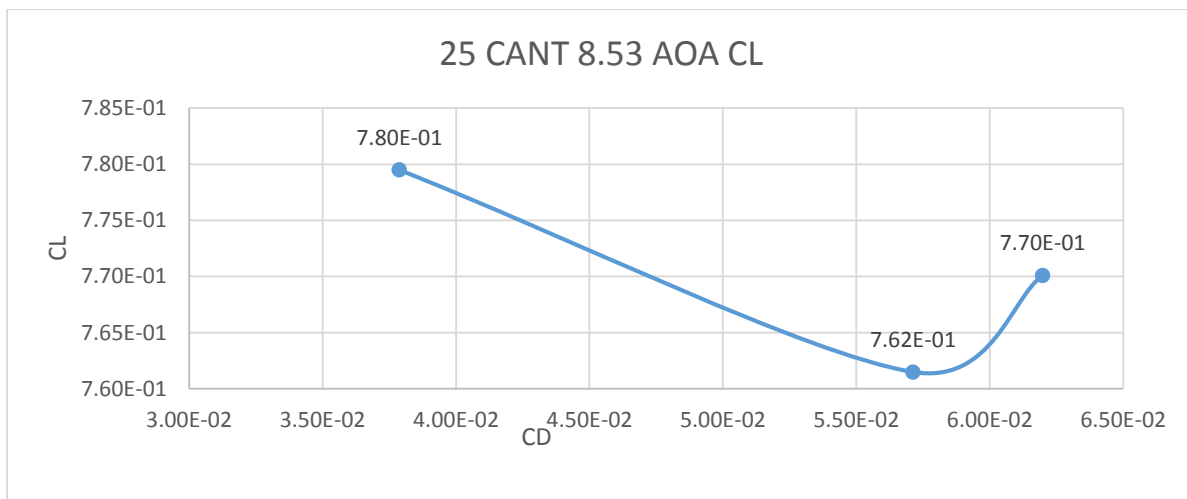
The iteration were stopped when the scaled monitor residual values showed alternate fluctuation and oscillations of same bandwidth. The lift, drag monitors are shown in **appendix 4 (fourth attachment)** . The results such as the pressure distribution, velocity vectors, mach number contours are shown in **appendix 3 (third attachment)**.

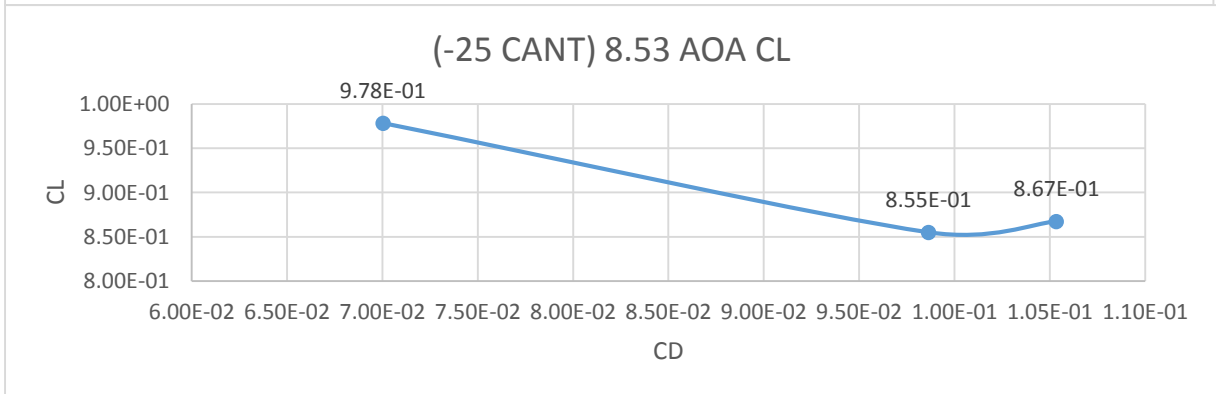
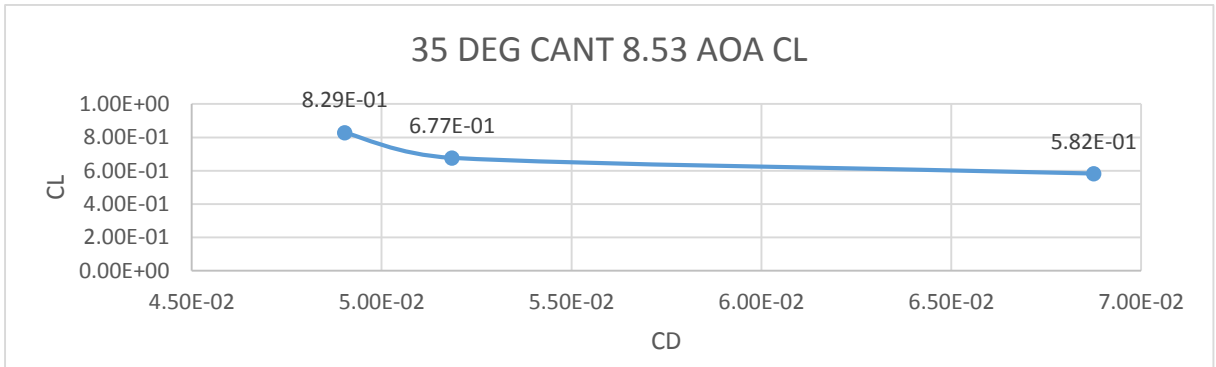
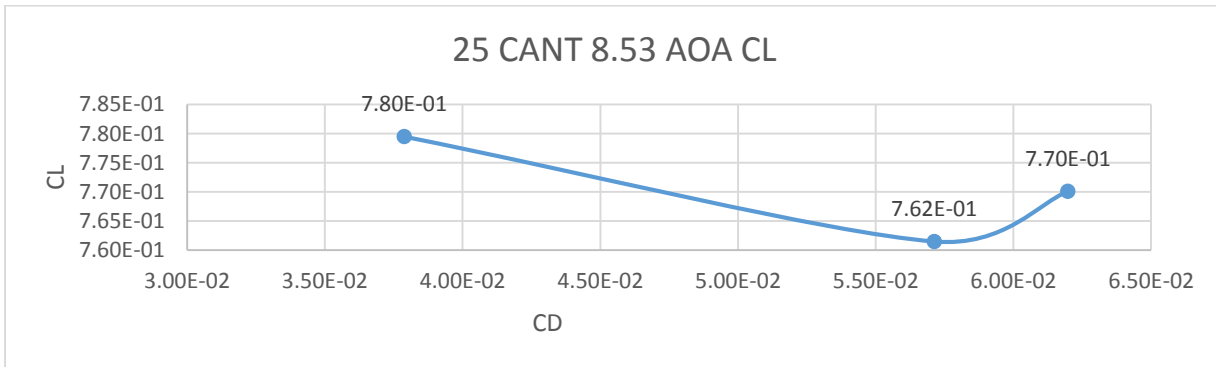
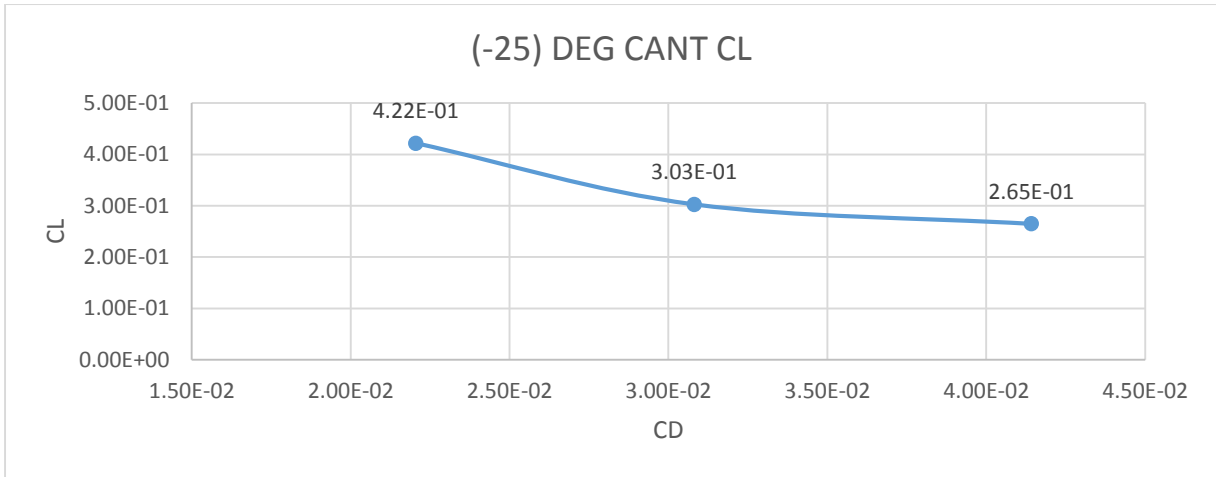
Lift Coefficient:

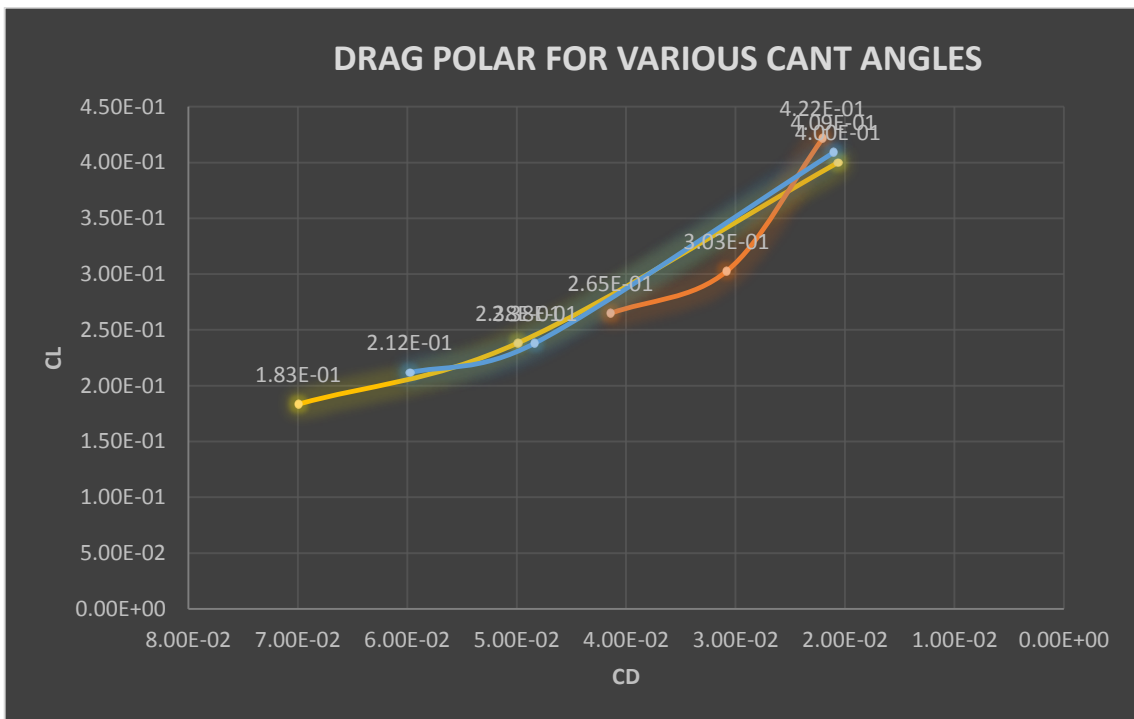
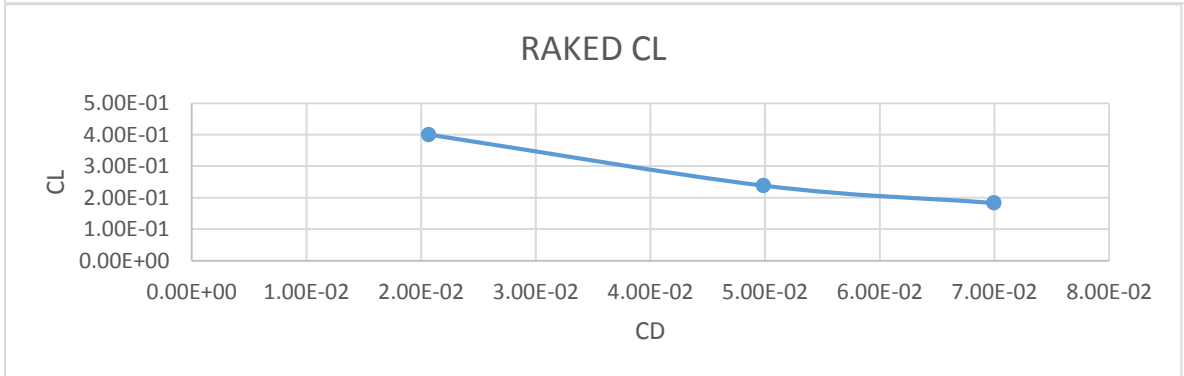
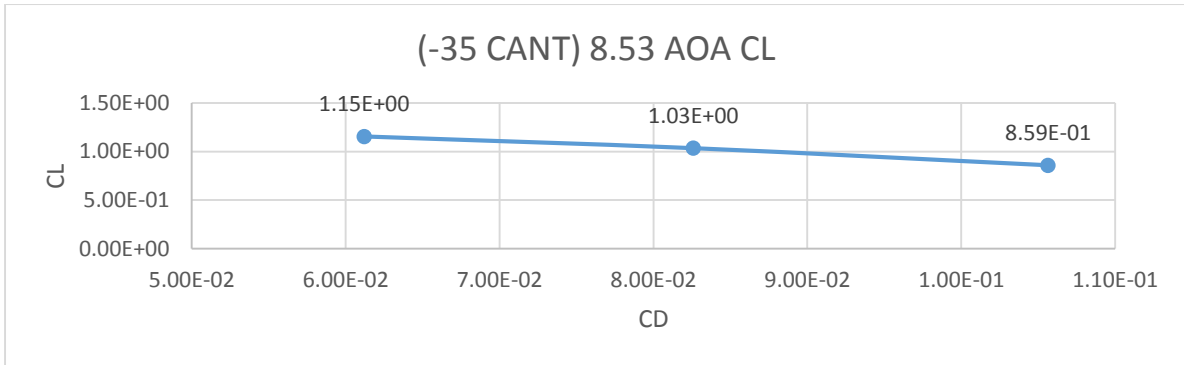
CL Winglets of cant angle 25° produced the highest lift in the cruise condition but it is not valuable in take off and landing condition. The results also indicated that the addition of winglets improves the lift. CL values for different winglet configurations vary at various angles of attack.

Drag Polar:

the cant angle 35° has the lowest possible drag when in cruise but it doesnot improves the lift and hence the drag polar curve is plotted for each winglets and are shown below.







FUTURE WORK:

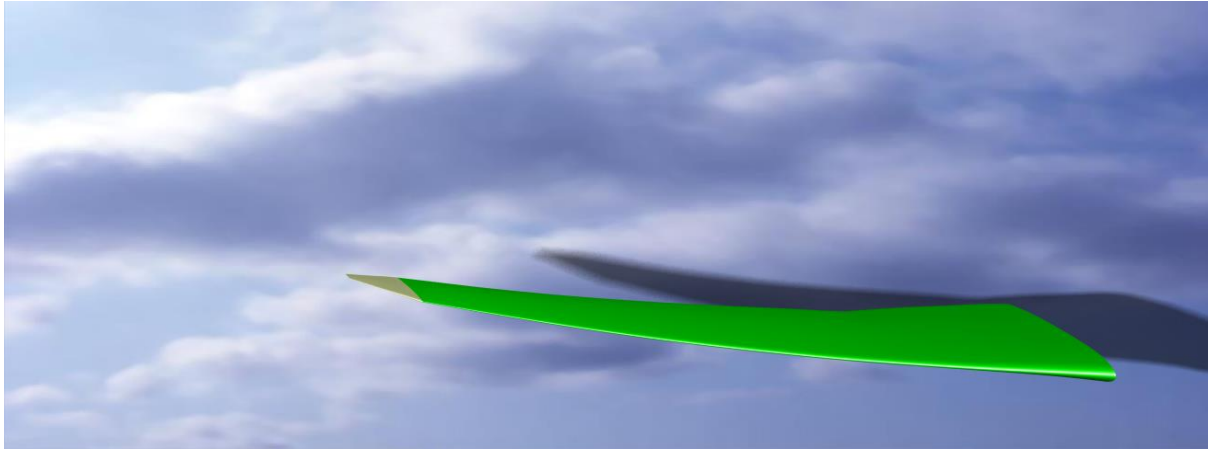
Our future work of this project is to fix a working actuator inside a flexible fiber glass panels to avoid hinge effect. And also using a graphite spar to control the winglet and to reduce the aerodynamic load effect also to reduce weight.

REFERENCES

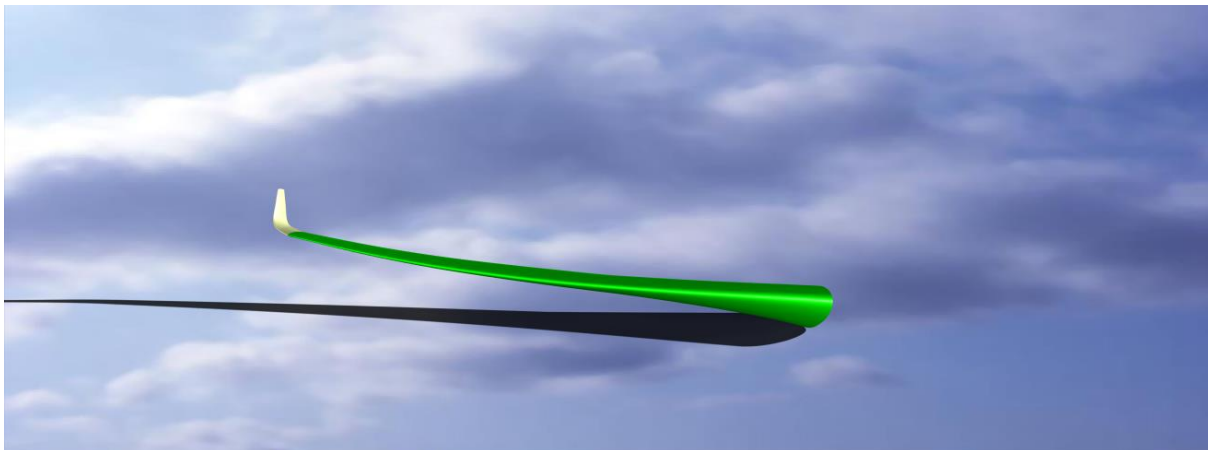
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APPENDIX 1
CATIA V5 R20 MODELS

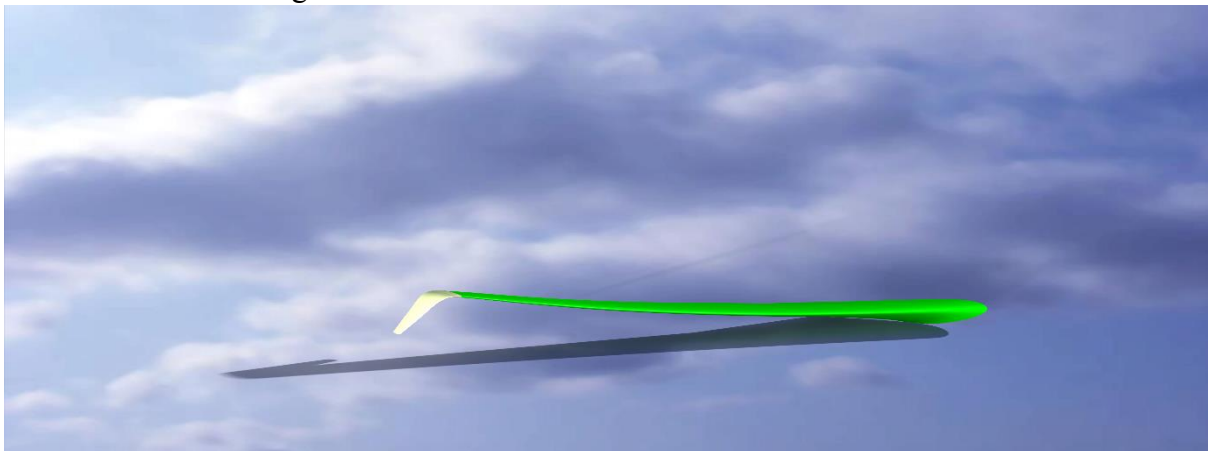
Model 1: '0' cant angle (flat tip (or) raked tip)



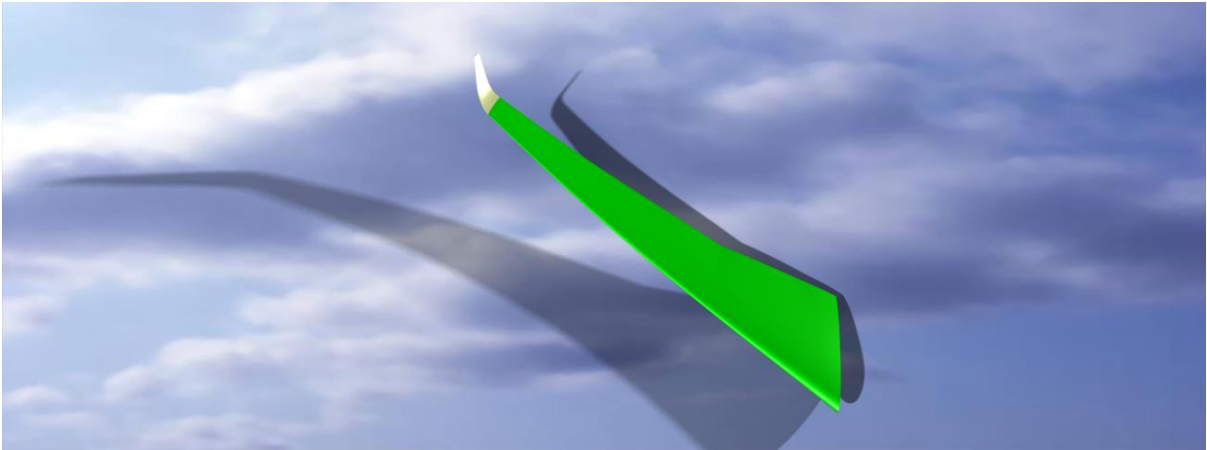
Model 2: '+25' cant angle:



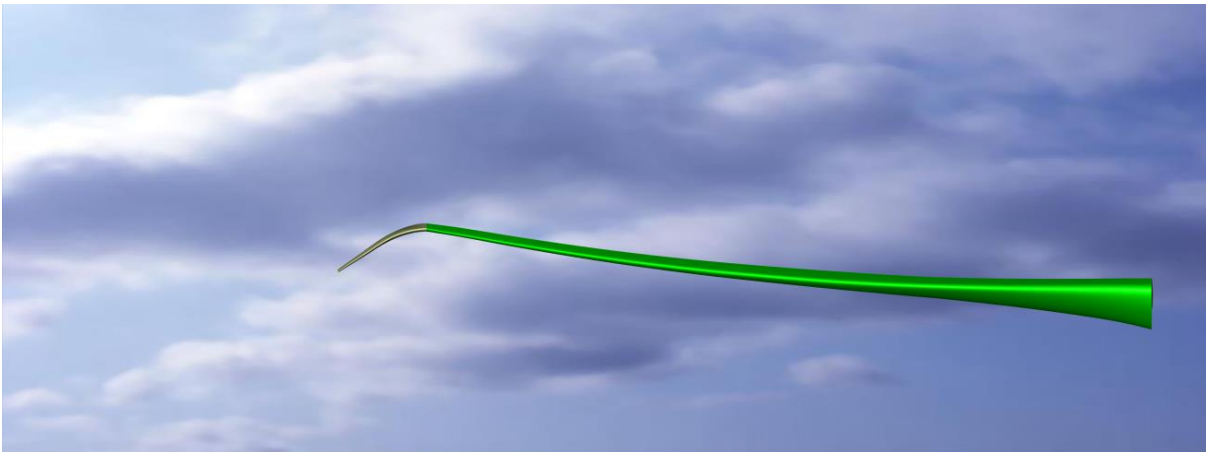
Model 3: '-25' cant angle:



Model 4: '+35' cant angle:



Model 5: '-35' cant angle:

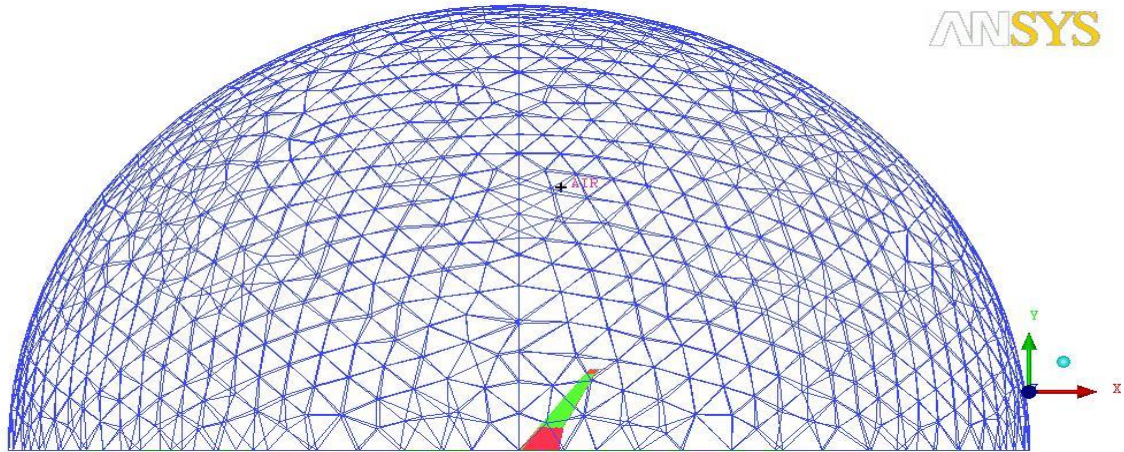


APPENDIX 2

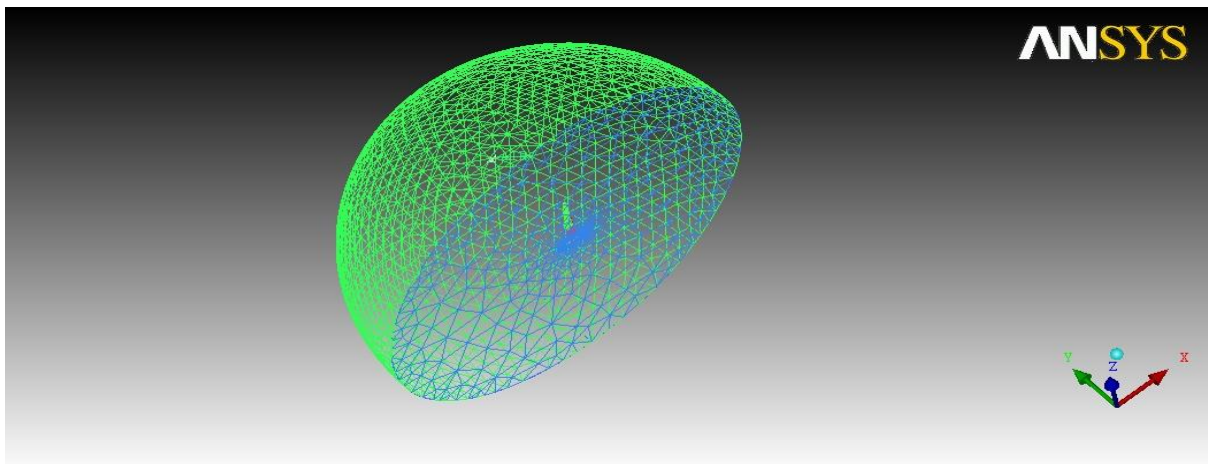
GRID GENERATION USING ICEM CFD 14.0

Mesh 1: Grid generation of wing with fluid domine:

(a):

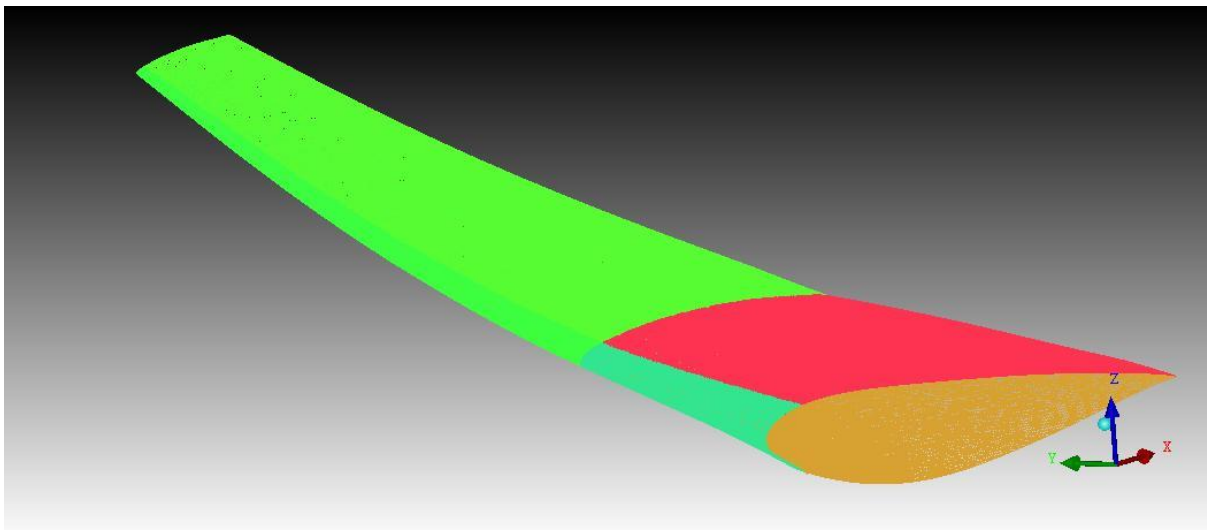


(b):

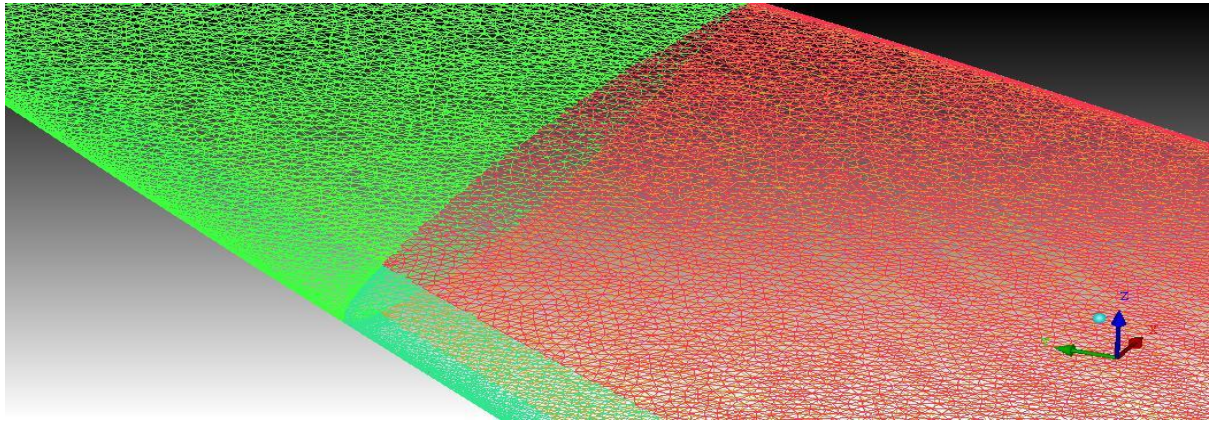


Mesh 2: Grid generation of wing without winglet:

(a):

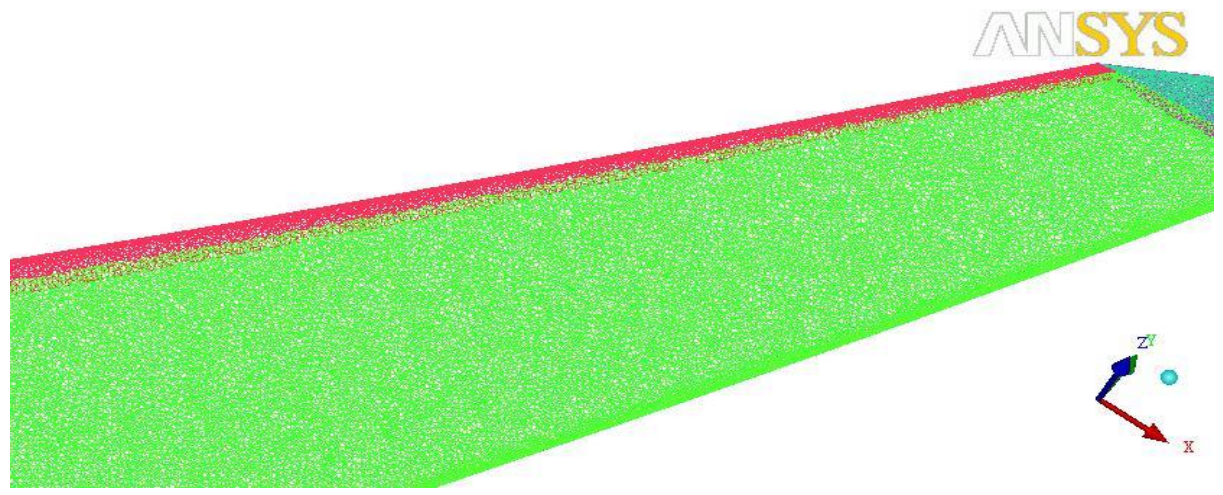


(b):

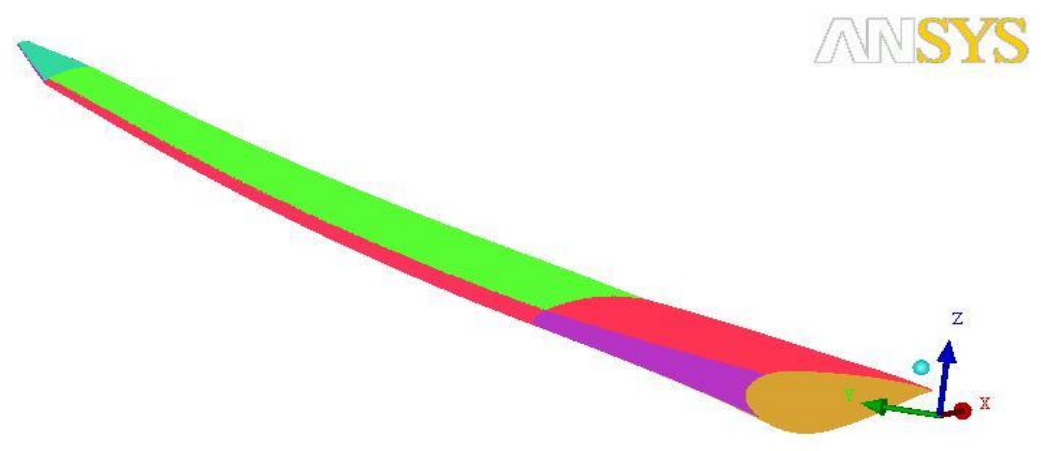


Mesh 3: Grid generation of wing with winglet at '0' cant angle:

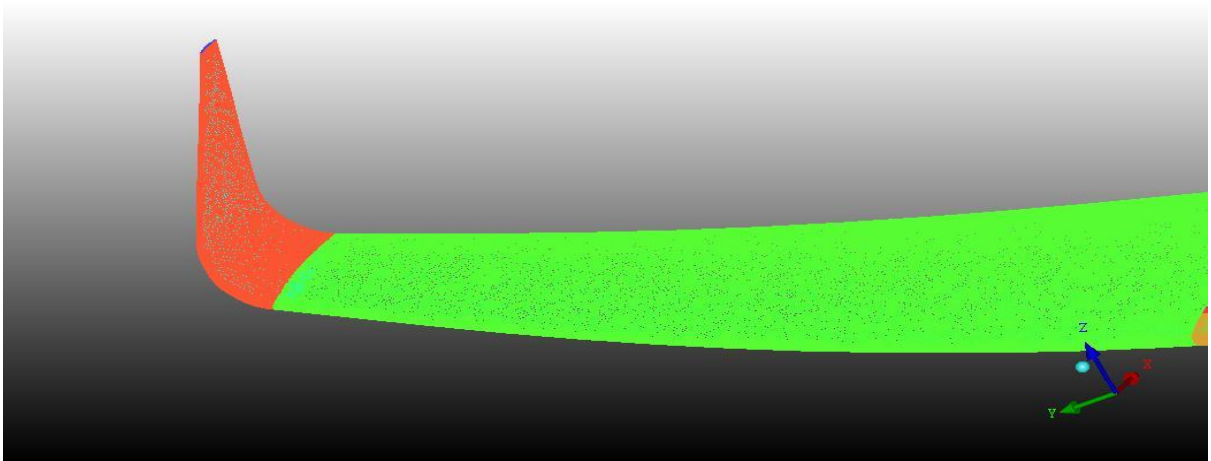
(a):



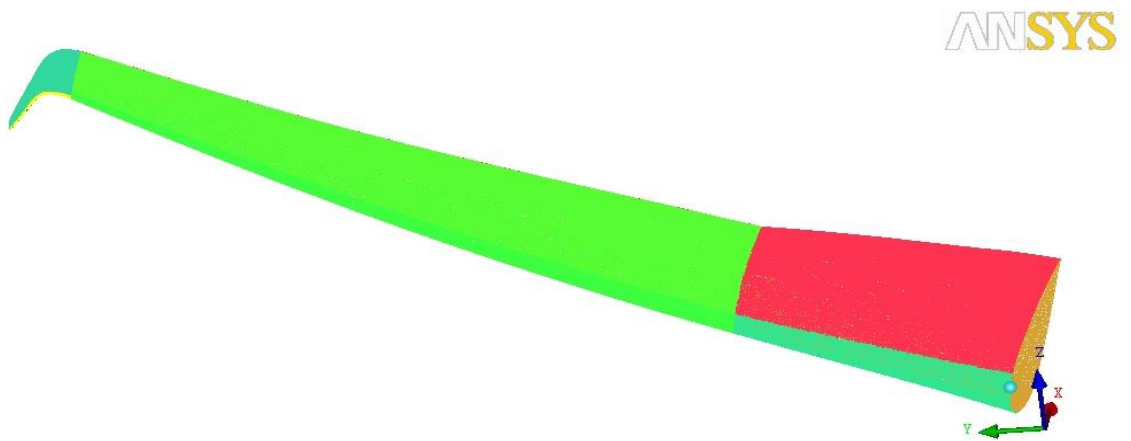
(b):



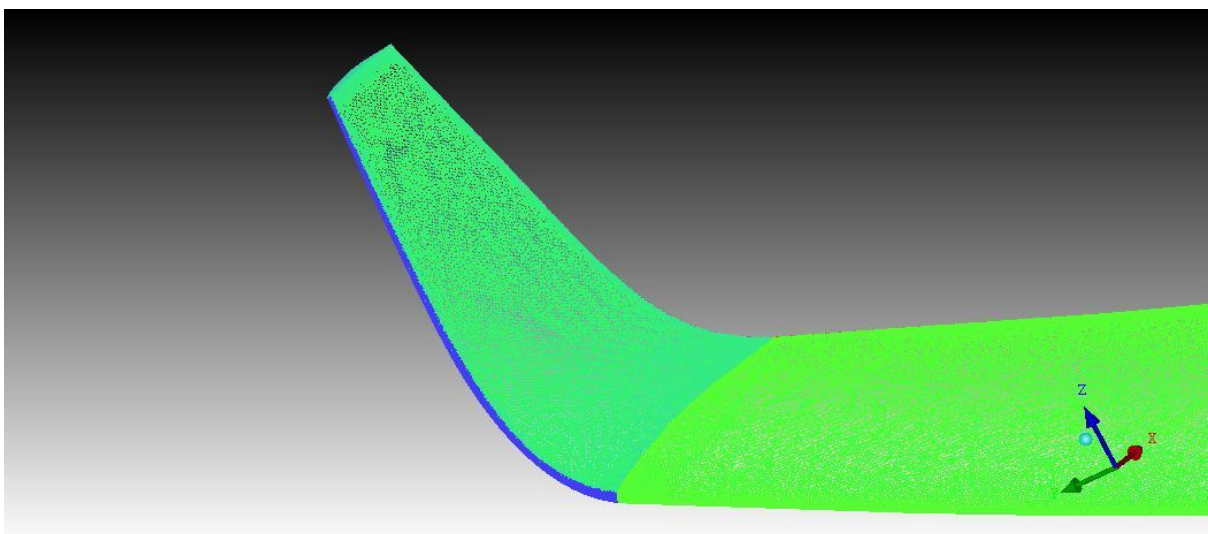
Mesh 4: Grid generation of wing with winglet at '+25' cant angle:



Mesh 5: Grid generation of wing with winglet at '-25' cant angle:

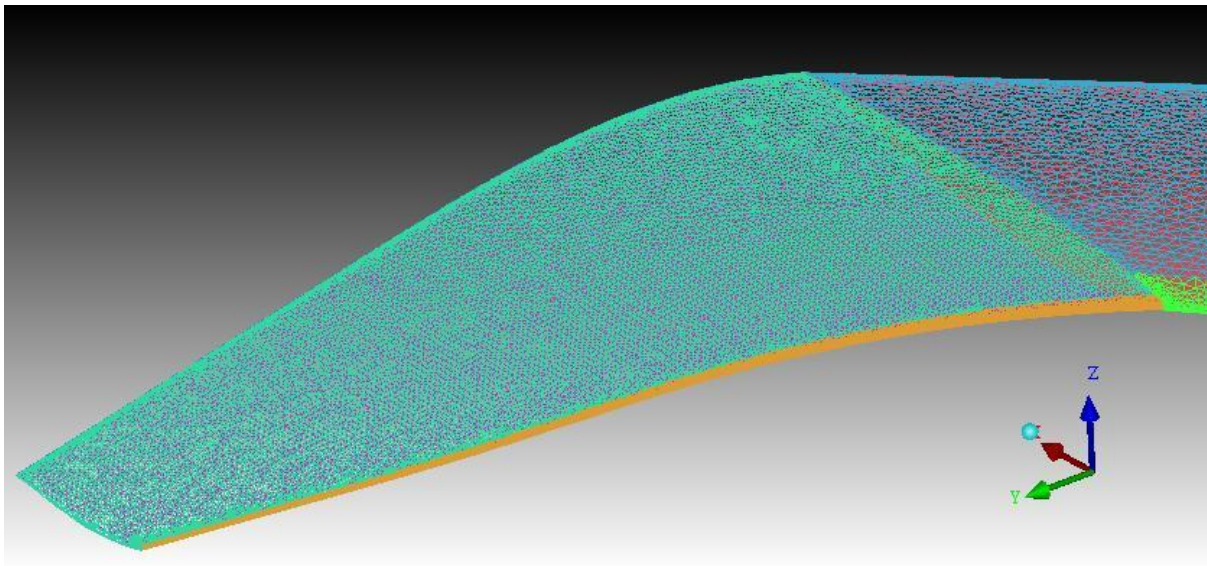


Mesh 6: Grid generation of wing with winglet at '+35' cant angle:

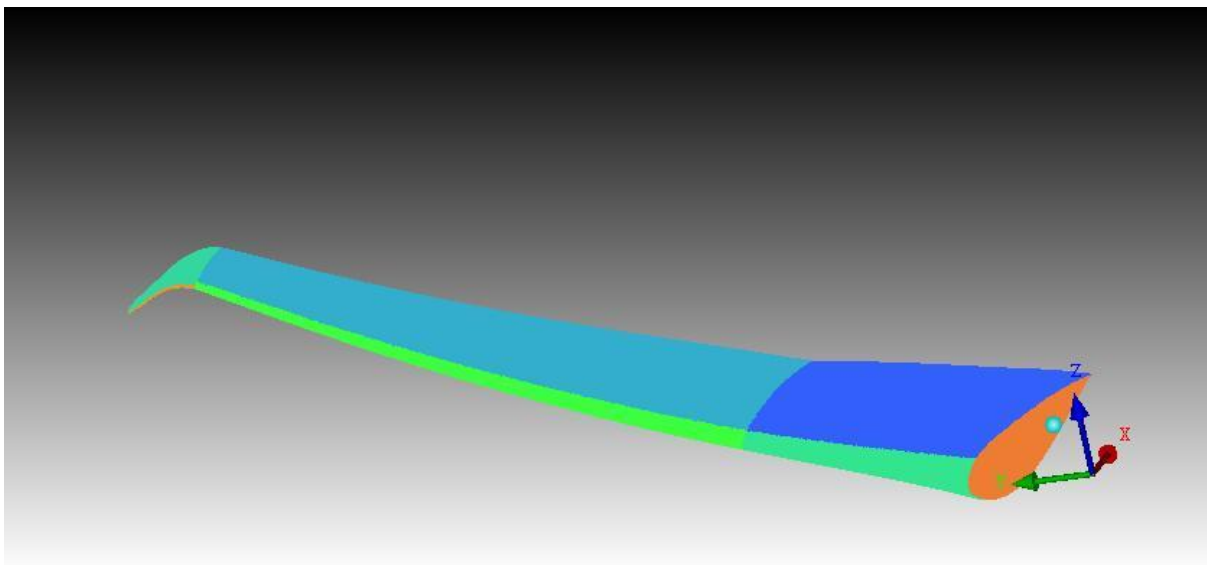


Mesh 7: Grid generation of wing with winglet at '-35' cant angle:

(a):



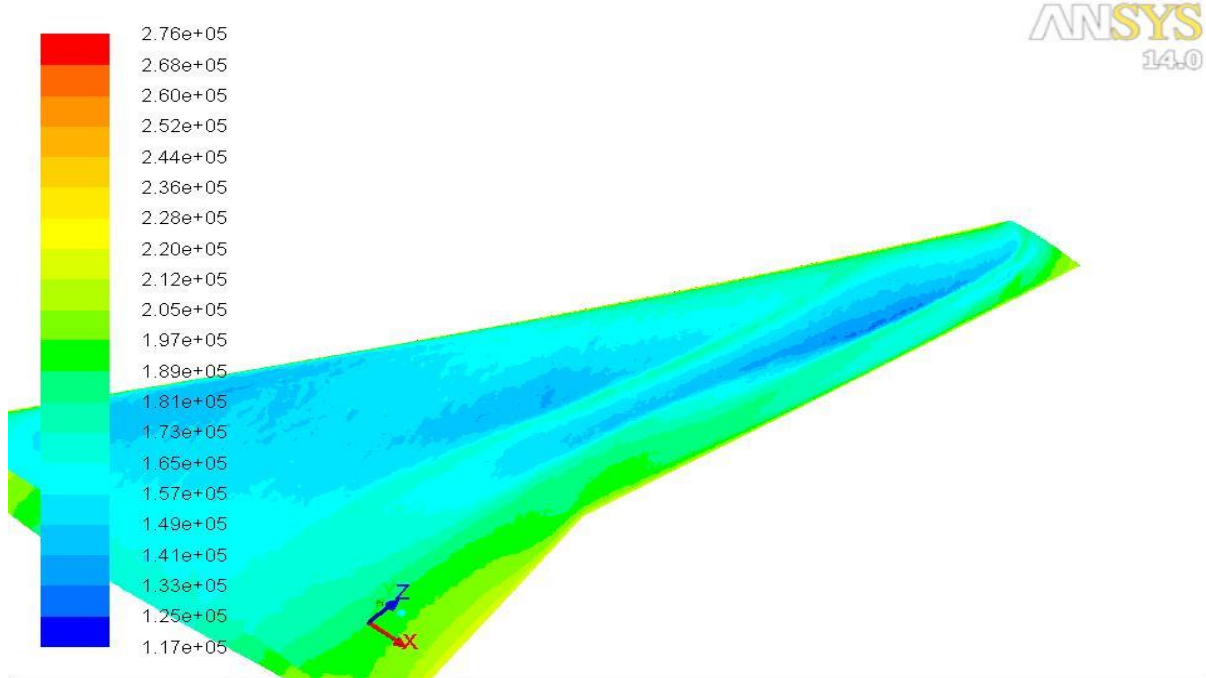
(b):



APPENDIX 3

VELOCITY AND PRESSURE COUNTERS OF THE WING BODY FROM ANSYS FLUENT 14.0

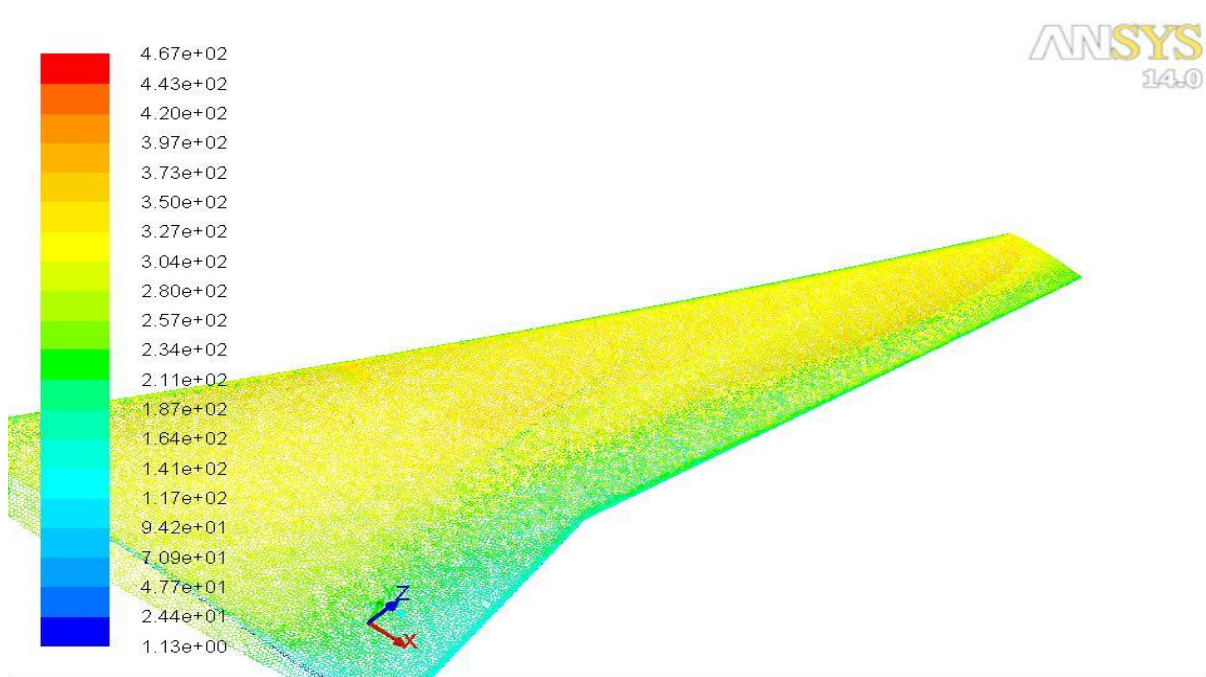
Result 1: Pressure contour without winglet at flight cruise condition:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, pbns, S-A)

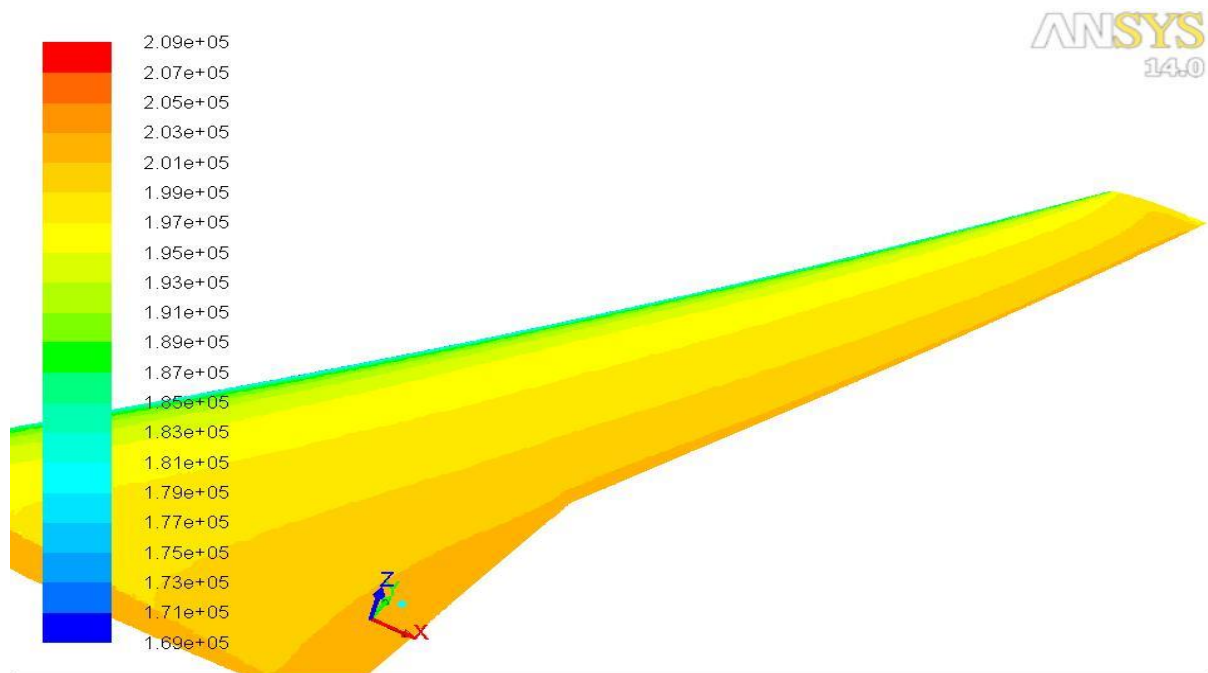
Result 2: Velocity contour without winglet at flight cruise condition:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, pbns, S-A)

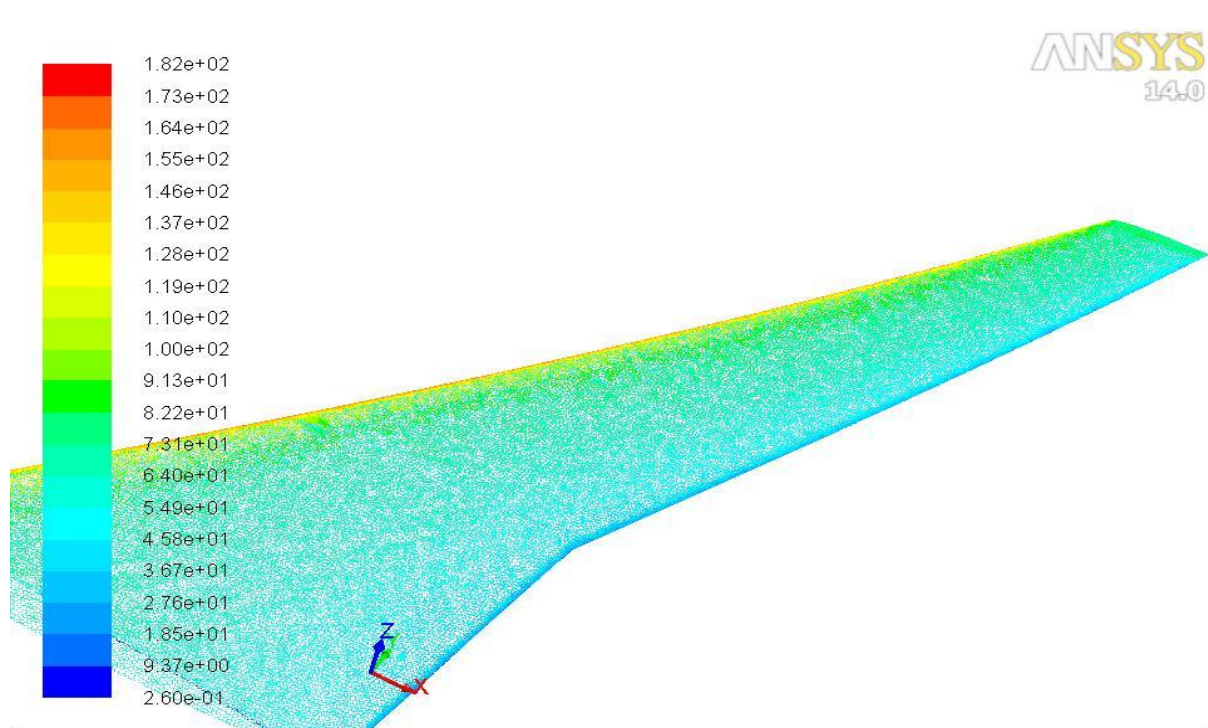
Result 3: Pressure contour without winglet at flight AOA 8.35:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

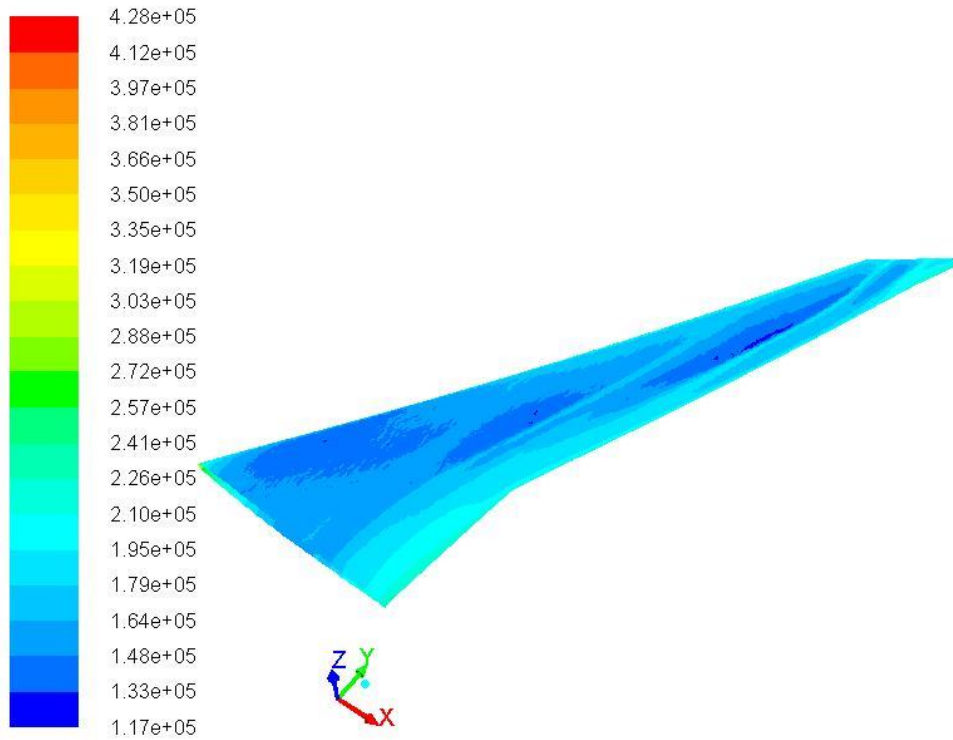
Result 4: Velocity contour without winglet at flight AOA 8.35:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

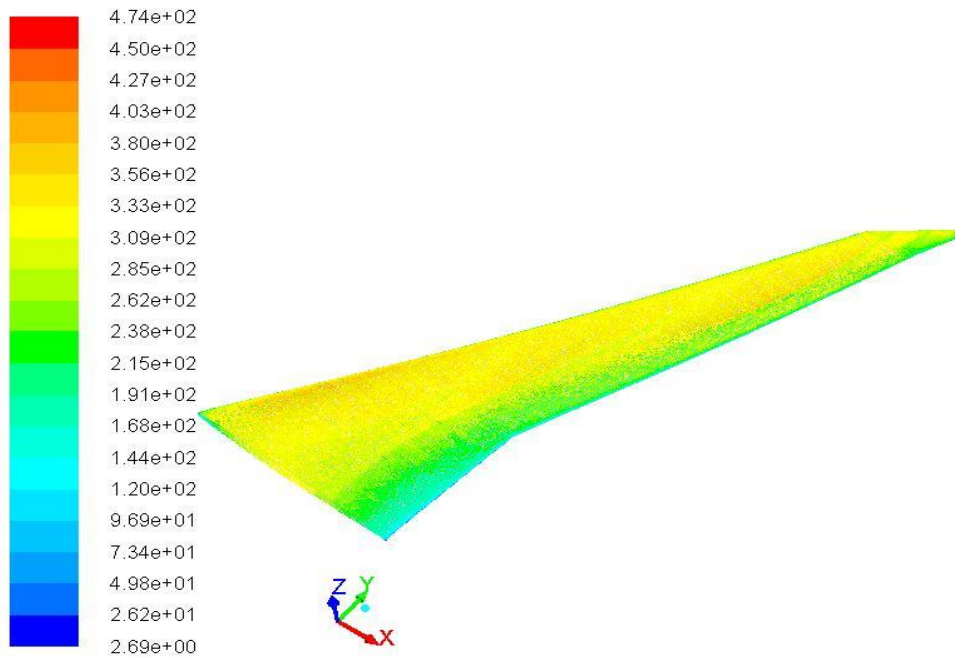
Result 5: Pressure contour with winglet at '0' cant angle at flight cruise condition:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

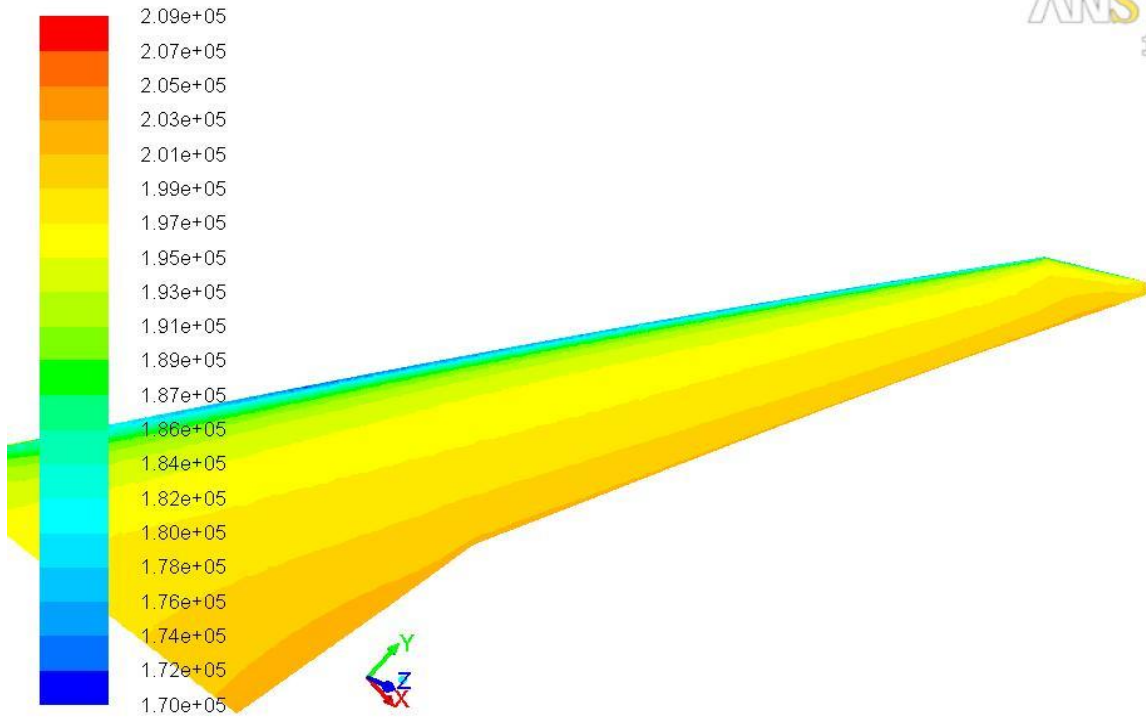
Result 6: Velocity contour with winglet at '0' cant angle at flight cruise condition:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
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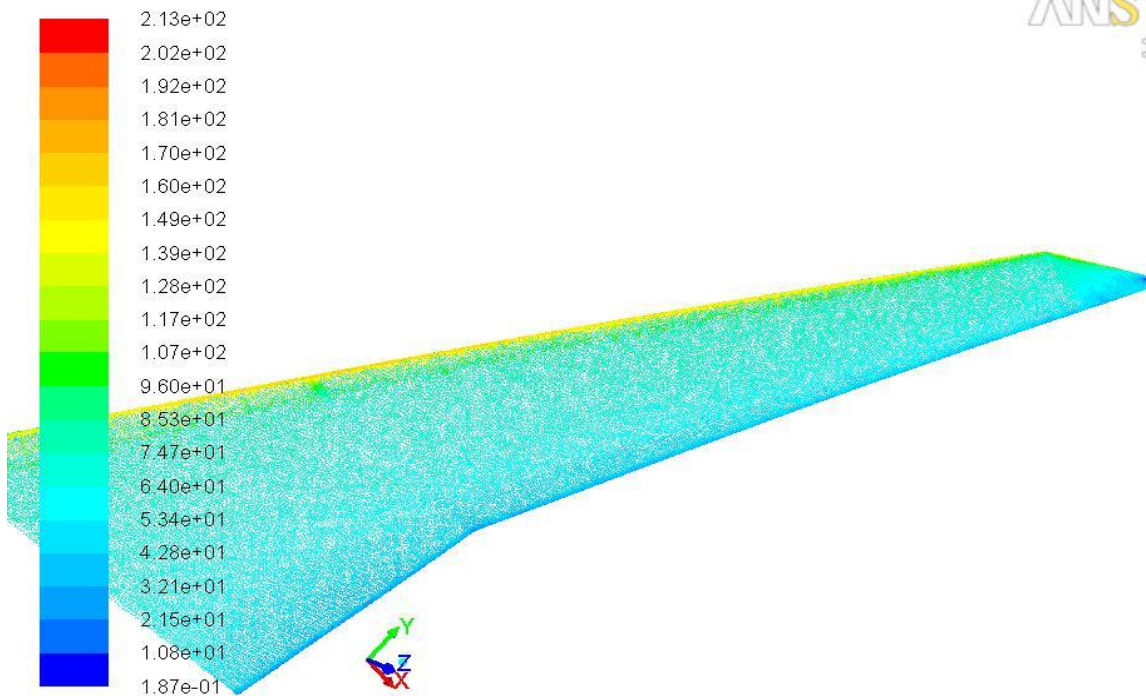
Result 7: Pressure contour with winglet at '0' cant angle at flight AOA 8.35:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

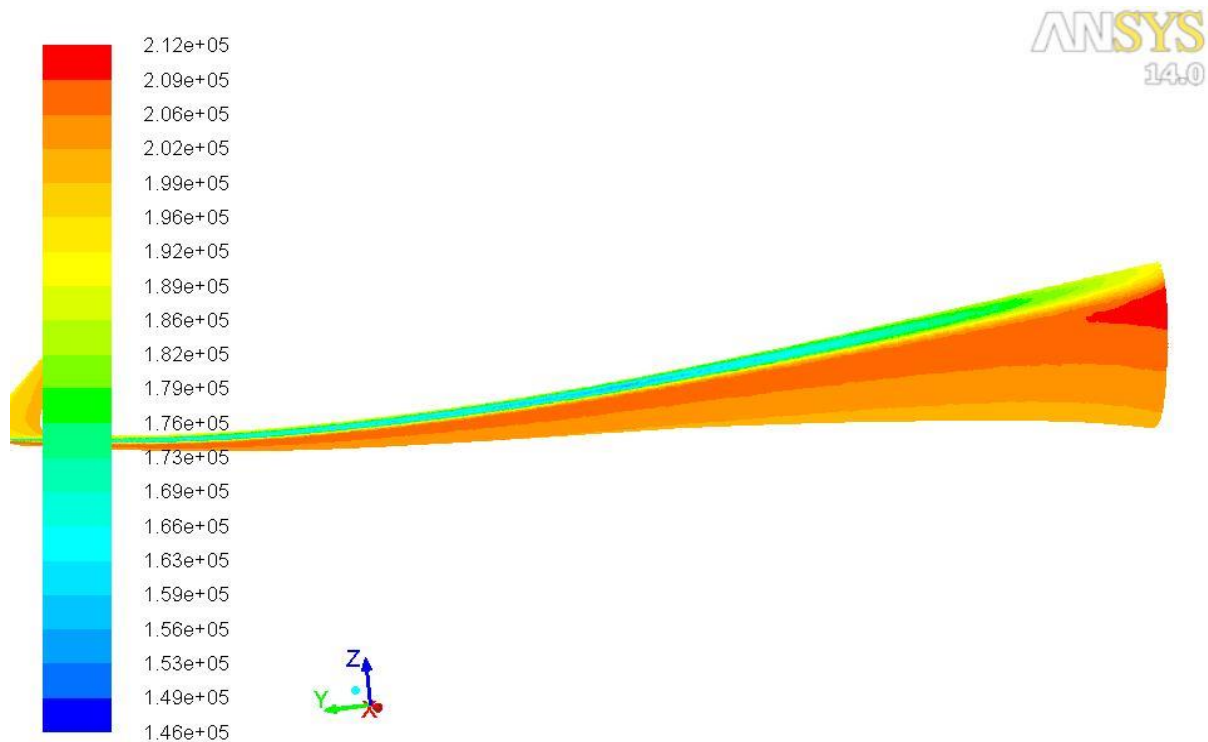
Result 8: Velocity contour with winglet at '0' cant angle at flight AOA 8.35:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

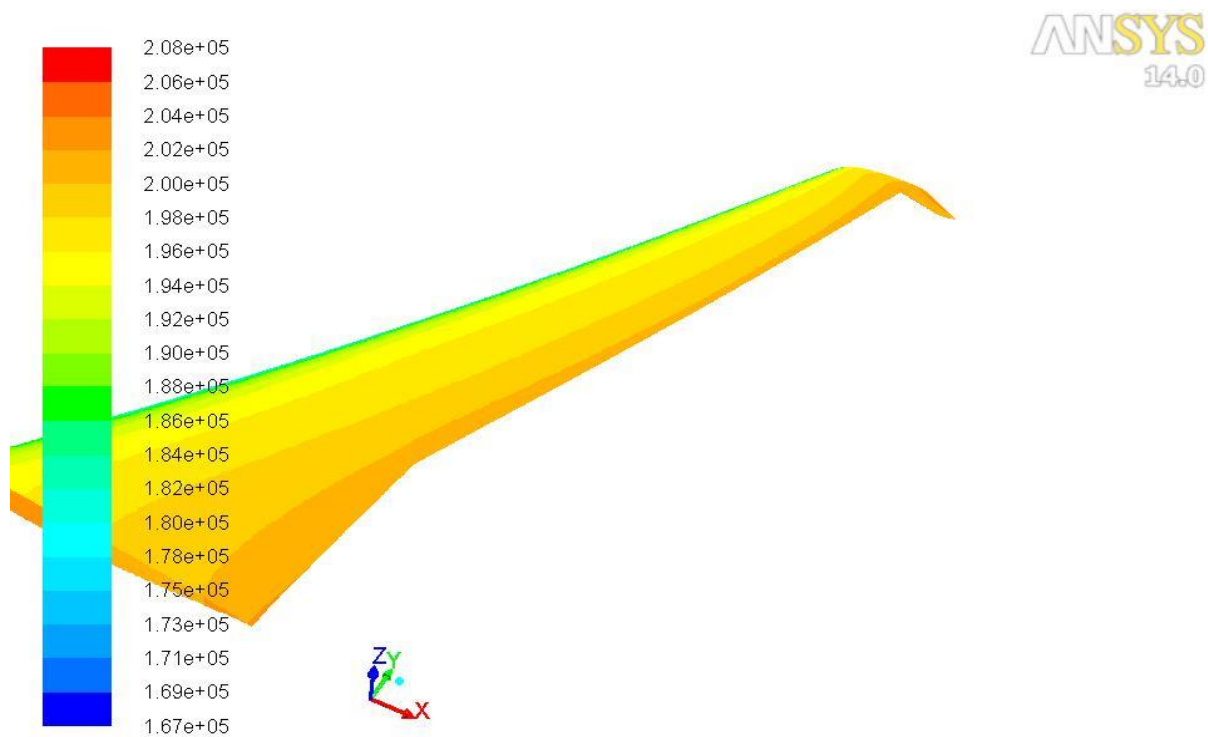
Result 9: Pressure contour with winglet at '+25' cant angle at flight cruise condition:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

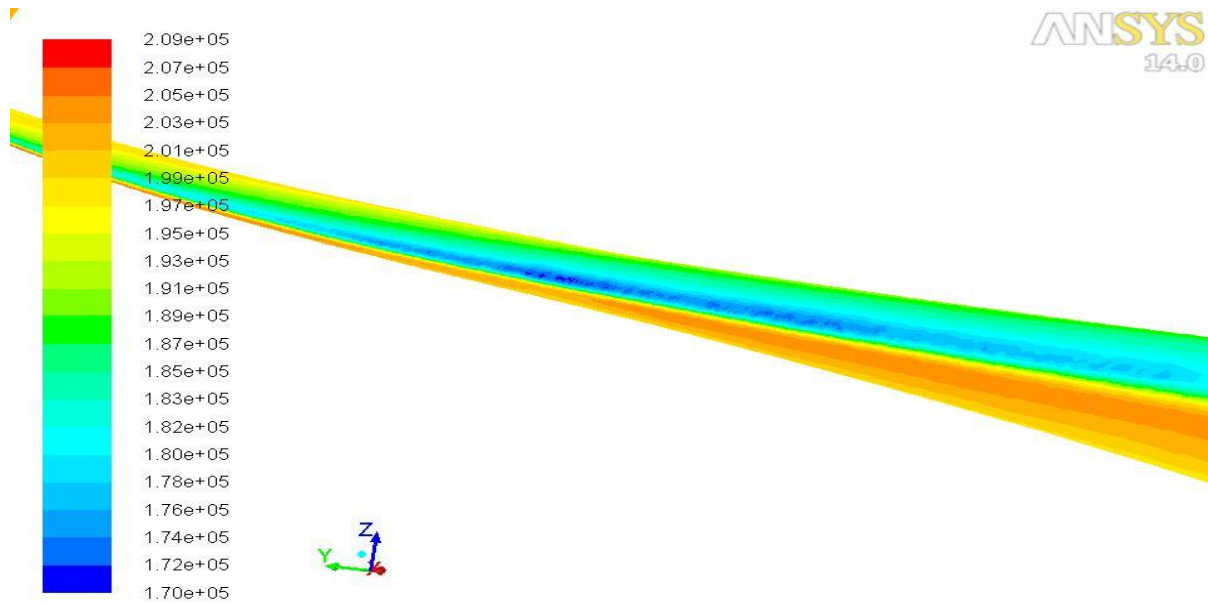
Result 10: Pressure contour with winglet at '-25' cant angle at flight AOA 8.35:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

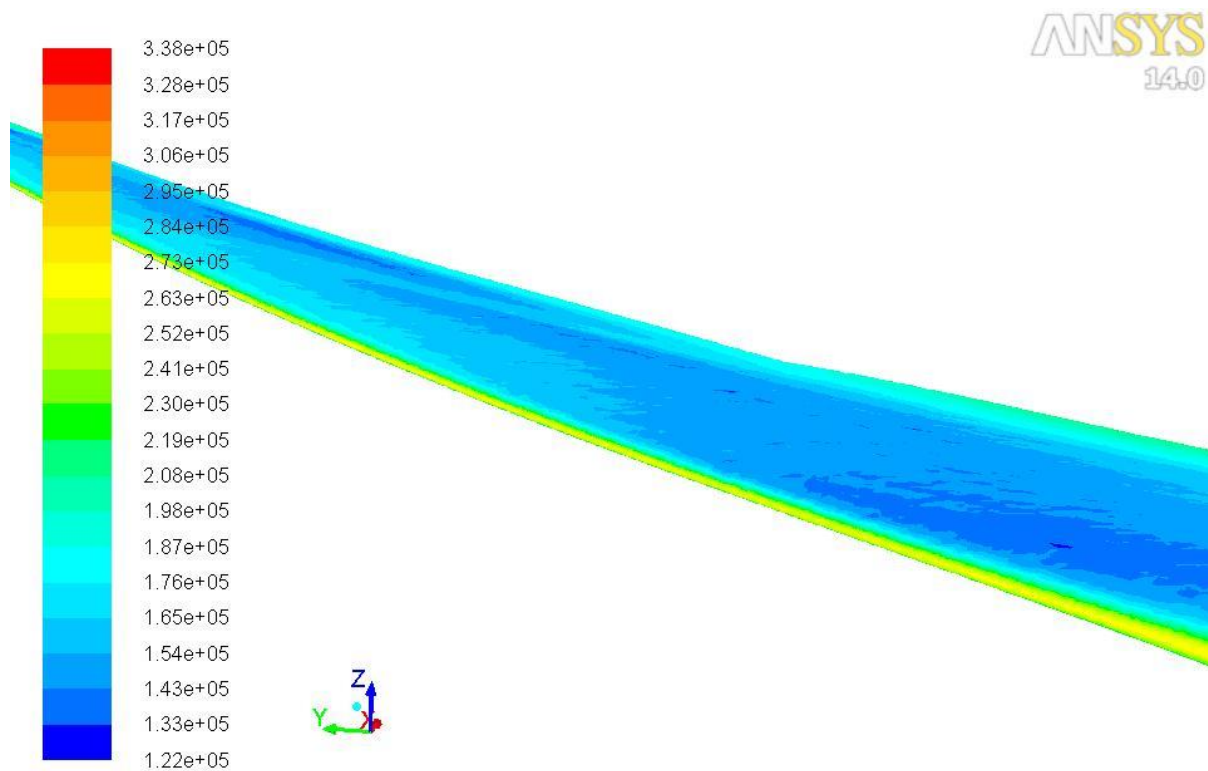
Result 11: Pressure contour with winglet at '+25' cant angle at flight AOA 8.35:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

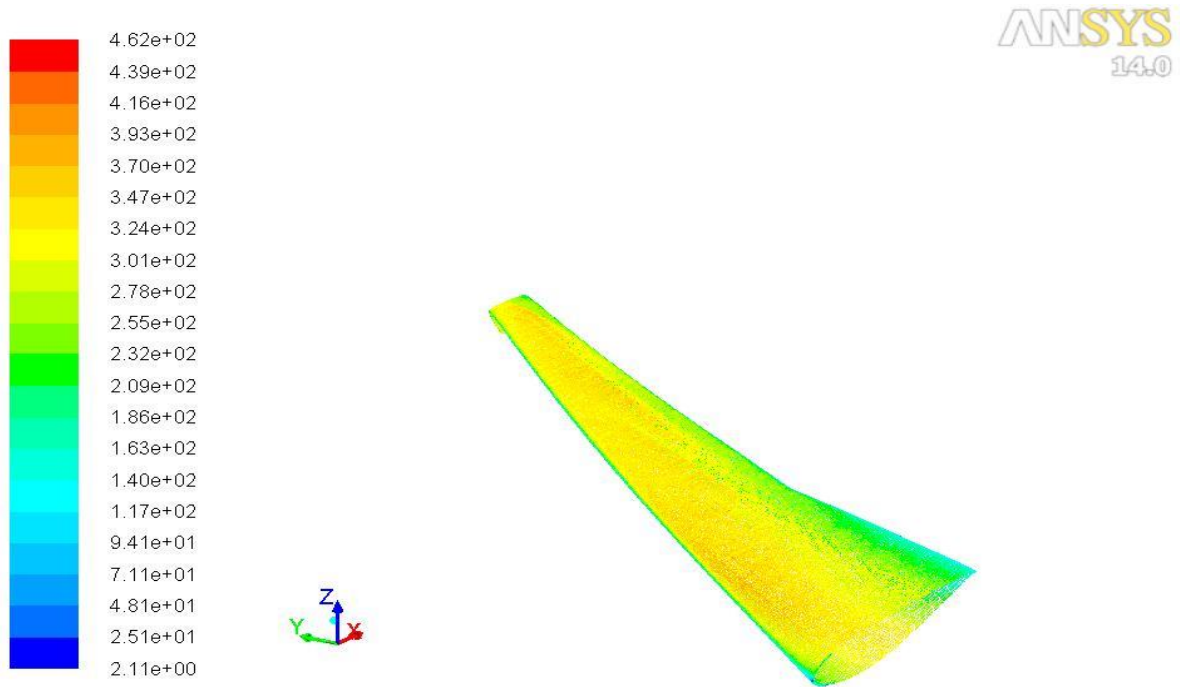
Result 12: Pressure contour with winglet at '-25' cant angle at flight cruise condition:



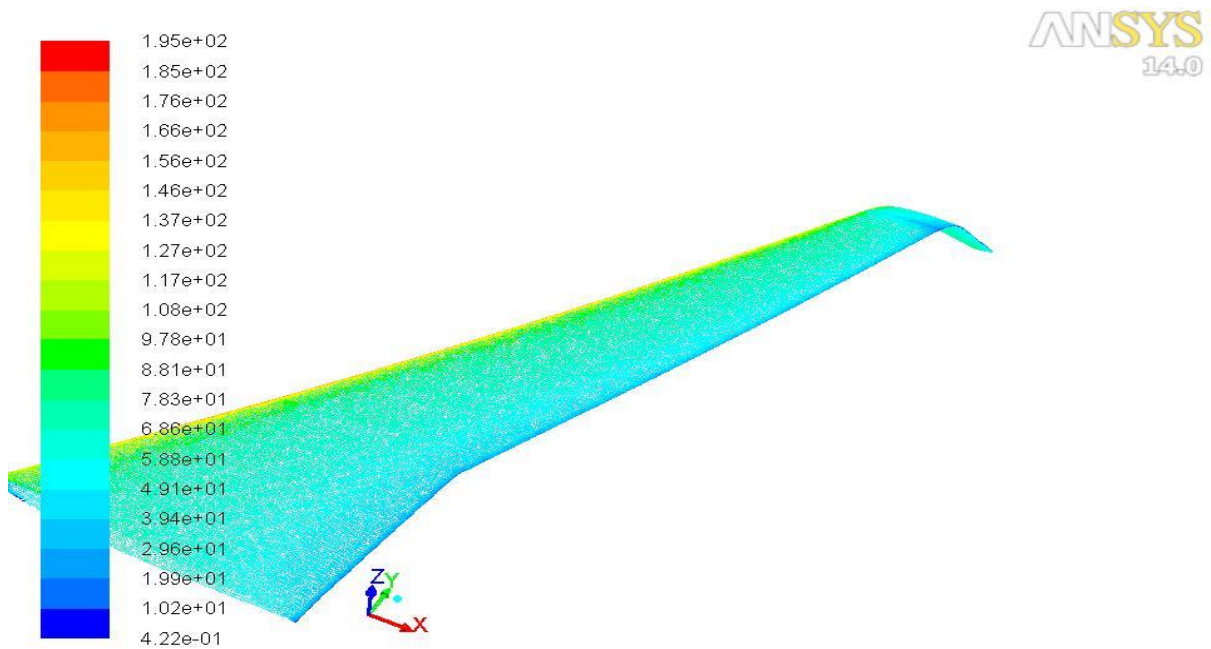
Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

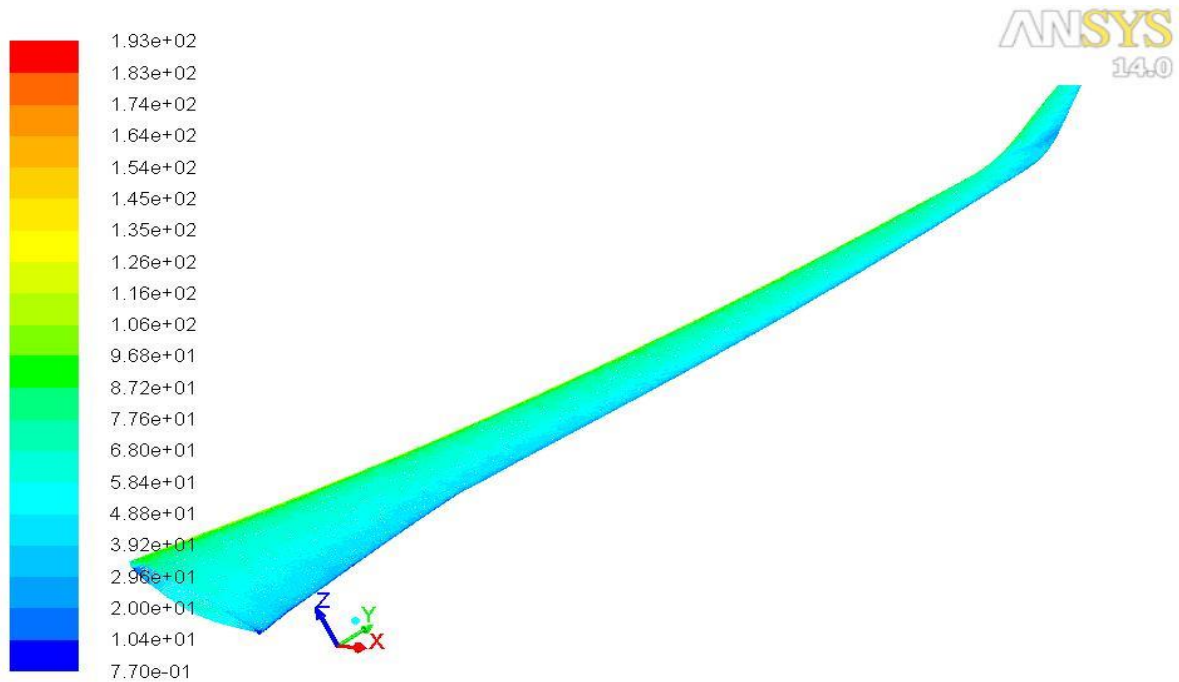
Result 13: Pressure contour with winglet at '-25' cant angle at flight cruise condition:



Result 14: Velocity contour with winglet at -25' cant angle at flight AOA 8.35:



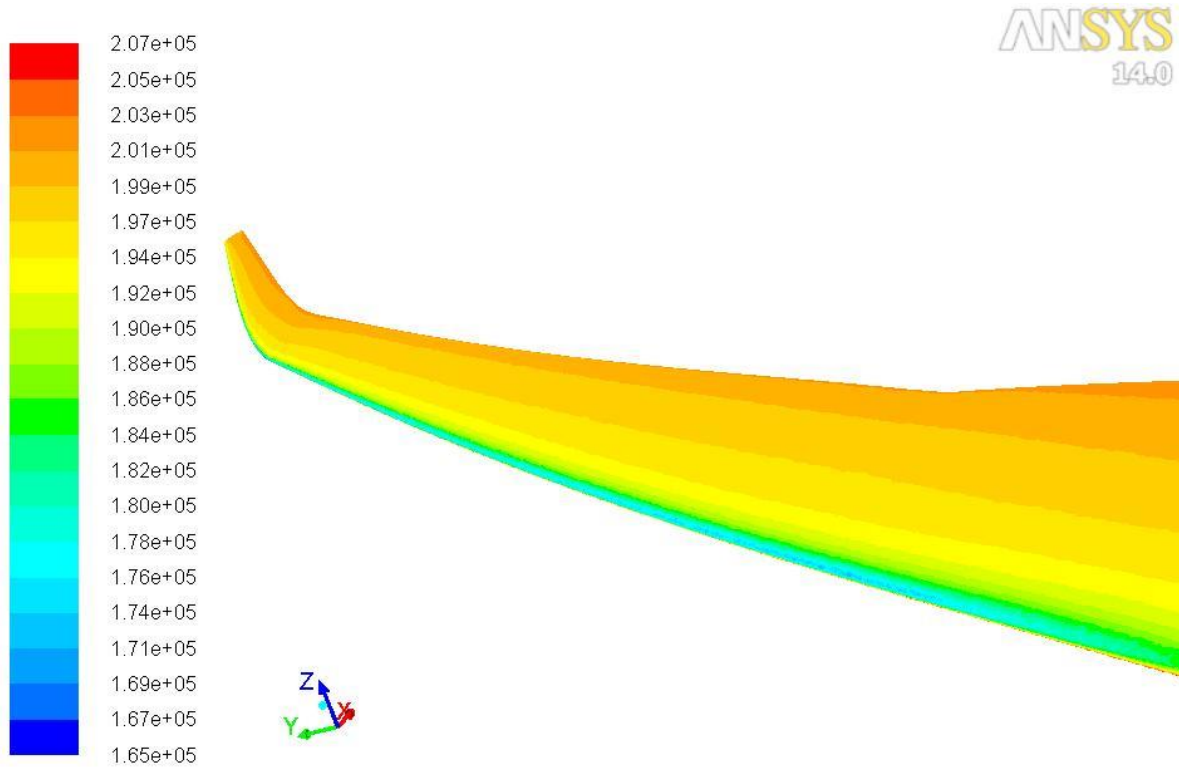
Result 15: Pressure contour with winglet at '+35' cant angle at flight AOA 8.35:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

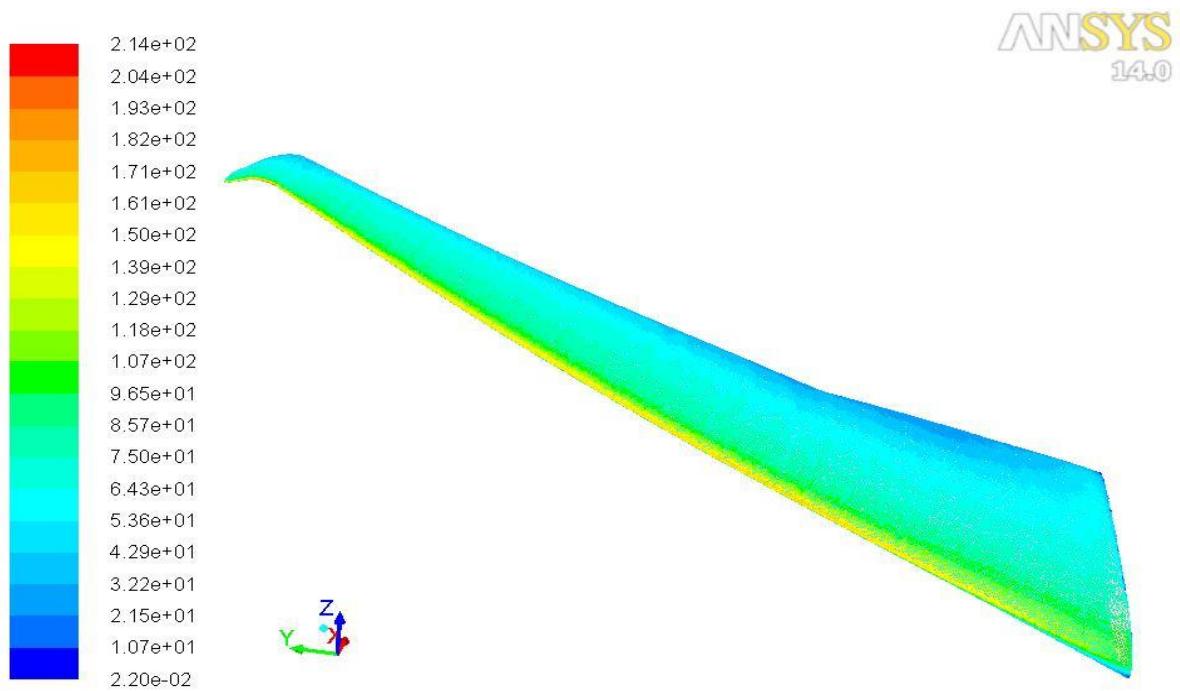
Result 16: Velocity contour with winglet at '+35' cant angle at flight AOA 8.35:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

Result 17: Pressure contour with winglet at '-35' cant angle at flight AOA 8.35:

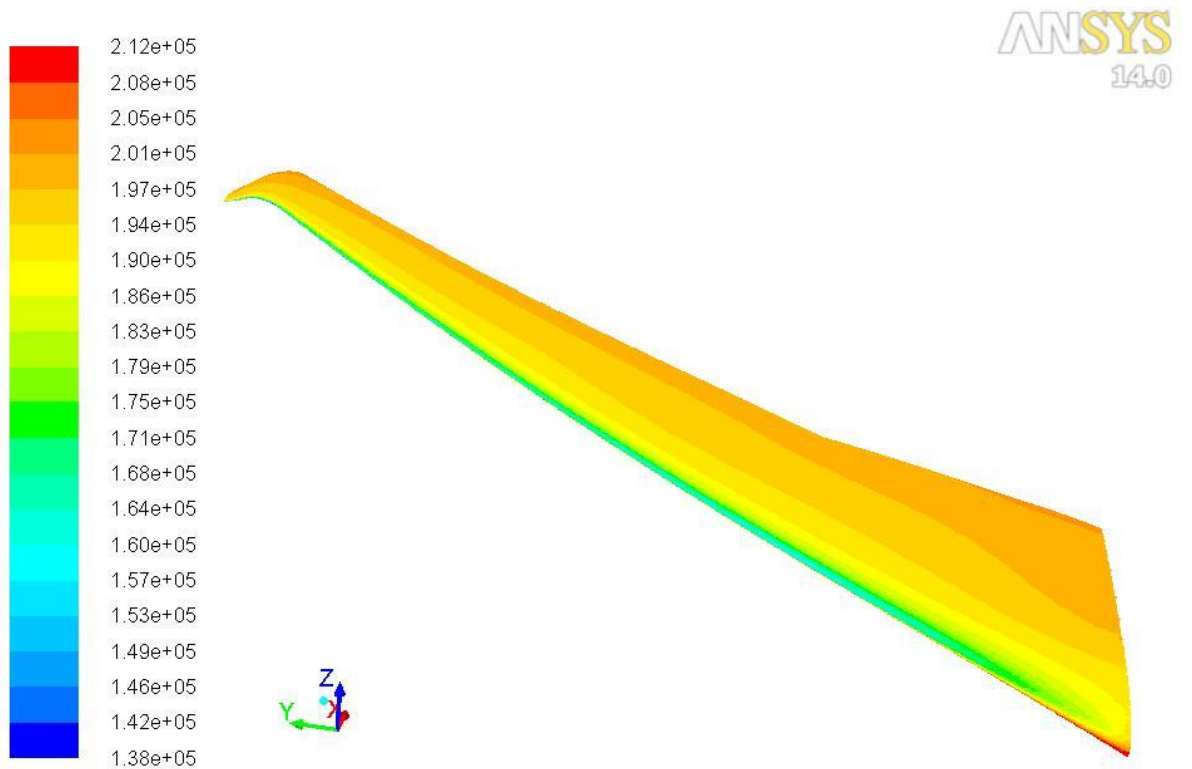


Velocity Vectors Colored By Velocity Magnitude (m/s)

ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

Mar 30, 2015

Result 18: Velocity contour with winglet at '-35' cant angle at flight AOA 8.35:

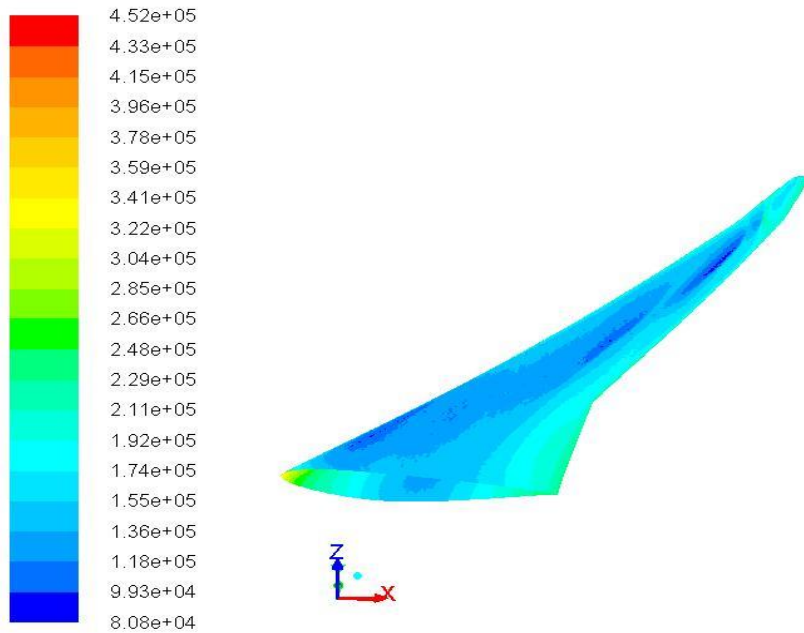


Contours of Static Pressure (pascal)

ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

Mar 30, 2015

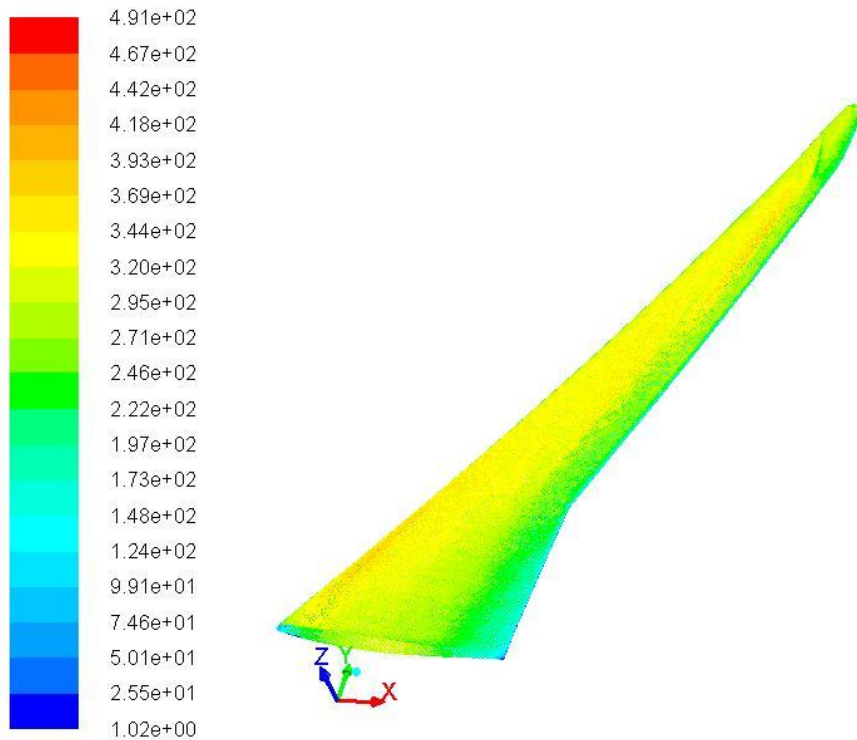
Result 19: Pressure contour with winglet at '+35' cant angle at flight cruise condition:



Contours of Static Pressure (pascal)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

Result 20: velocity contour with winglet at '+35' cant angle at flight cruise condition:



Velocity Vectors Colored By Velocity Magnitude (m/s)

Mar 30, 2015
ANSYS FLUENT 14.0 (3d, dp, dbns imp, S-A)

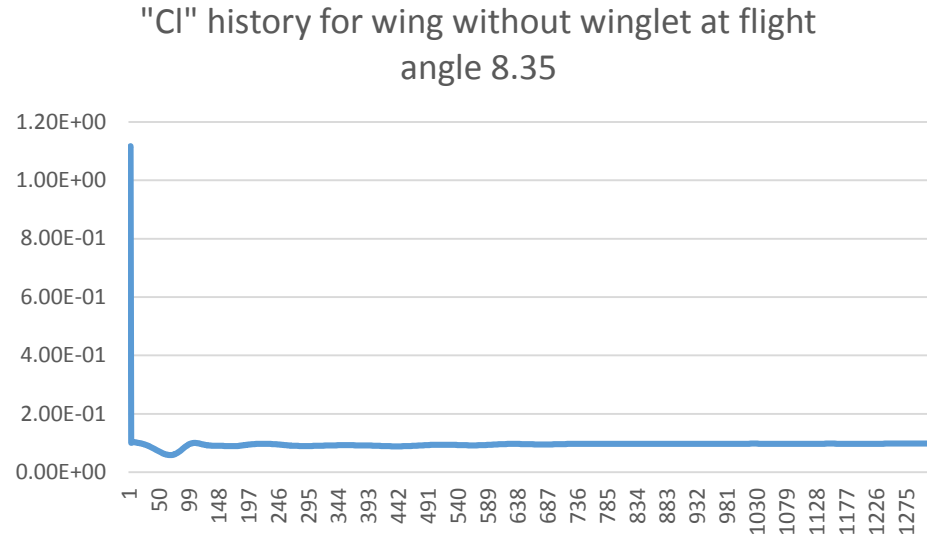
APPENDIX 4

GRAPH

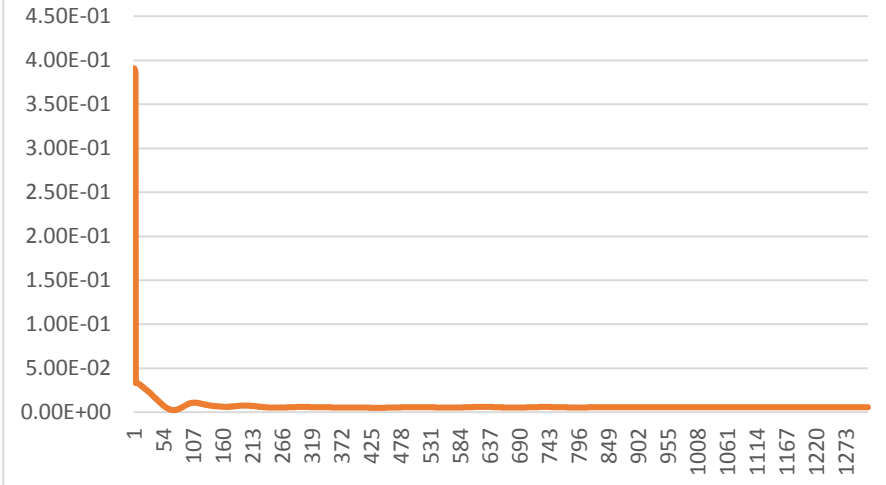
Graph No.	Winglet position	Cl history	Cd history																																																																																																										
1	Without winglet at fight cruise condition	<p>Convergence" iterations" "Cl"</p> <table border="1"> <caption>Approximate data for Cl history</caption> <thead> <tr> <th>Iteration</th> <th>Cl Value</th> </tr> </thead> <tbody> <tr><td>1</td><td>-0.2</td></tr> <tr><td>47</td><td>1.4</td></tr> <tr><td>93</td><td>-0.6</td></tr> <tr><td>139</td><td>0.1</td></tr> <tr><td>185</td><td>0.6</td></tr> <tr><td>231</td><td>0.7</td></tr> <tr><td>277</td><td>1.2</td></tr> <tr><td>323</td><td>0.6</td></tr> <tr><td>369</td><td>0.5</td></tr> <tr><td>415</td><td>0.6</td></tr> <tr><td>461</td><td>0.7</td></tr> <tr><td>507</td><td>0.7</td></tr> <tr><td>553</td><td>0.7</td></tr> <tr><td>599</td><td>0.7</td></tr> <tr><td>645</td><td>0.7</td></tr> <tr><td>691</td><td>0.7</td></tr> <tr><td>737</td><td>0.7</td></tr> <tr><td>783</td><td>0.7</td></tr> <tr><td>829</td><td>0.7</td></tr> <tr><td>875</td><td>0.7</td></tr> <tr><td>921</td><td>0.7</td></tr> <tr><td>967</td><td>0.7</td></tr> <tr><td>1013</td><td>0.7</td></tr> <tr><td>1059</td><td>0.7</td></tr> <tr><td>1105</td><td>0.7</td></tr> <tr><td>1151</td><td>0.7</td></tr> <tr><td>1197</td><td>0.7</td></tr> </tbody> </table>	Iteration	Cl Value	1	-0.2	47	1.4	93	-0.6	139	0.1	185	0.6	231	0.7	277	1.2	323	0.6	369	0.5	415	0.6	461	0.7	507	0.7	553	0.7	599	0.7	645	0.7	691	0.7	737	0.7	783	0.7	829	0.7	875	0.7	921	0.7	967	0.7	1013	0.7	1059	0.7	1105	0.7	1151	0.7	1197	0.7	<p>"Cd" history for wing without winglet</p> <table border="1"> <caption>Approximate data for Cd history</caption> <thead> <tr> <th>Iteration</th> <th>Cd Value</th> </tr> </thead> <tbody> <tr><td>1</td><td>1.55</td></tr> <tr><td>47</td><td>1.3</td></tr> <tr><td>93</td><td>1.6</td></tr> <tr><td>139</td><td>1.4</td></tr> <tr><td>185</td><td>1.35</td></tr> <tr><td>231</td><td>1.3</td></tr> <tr><td>277</td><td>1.3</td></tr> <tr><td>323</td><td>1.3</td></tr> <tr><td>369</td><td>1.3</td></tr> <tr><td>415</td><td>1.3</td></tr> <tr><td>461</td><td>1.3</td></tr> <tr><td>507</td><td>1.3</td></tr> <tr><td>553</td><td>1.3</td></tr> <tr><td>599</td><td>1.3</td></tr> <tr><td>645</td><td>1.3</td></tr> <tr><td>691</td><td>1.3</td></tr> <tr><td>737</td><td>1.3</td></tr> <tr><td>783</td><td>1.3</td></tr> <tr><td>829</td><td>1.3</td></tr> <tr><td>875</td><td>1.3</td></tr> <tr><td>921</td><td>1.3</td></tr> <tr><td>967</td><td>1.3</td></tr> <tr><td>1013</td><td>1.3</td></tr> <tr><td>1059</td><td>1.3</td></tr> </tbody> </table>	Iteration	Cd Value	1	1.55	47	1.3	93	1.6	139	1.4	185	1.35	231	1.3	277	1.3	323	1.3	369	1.3	415	1.3	461	1.3	507	1.3	553	1.3	599	1.3	645	1.3	691	1.3	737	1.3	783	1.3	829	1.3	875	1.3	921	1.3	967	1.3	1013	1.3	1059	1.3
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2

Without winglet at flight 8.35 AOA

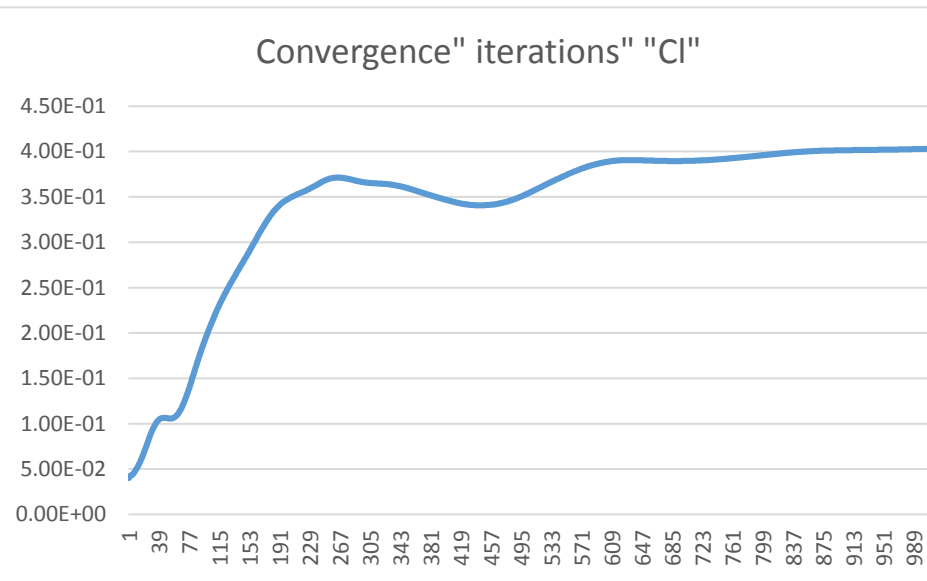


Convergence" iterations" "Cd"

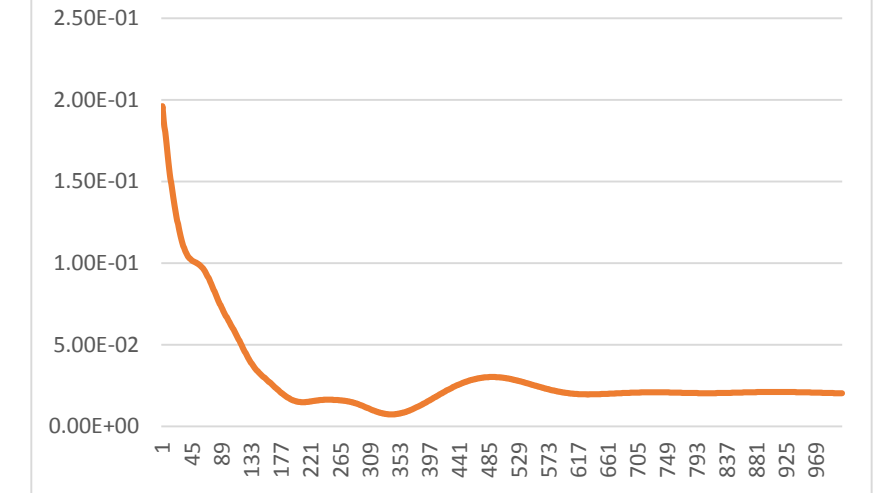


3

With winglet at '0' cant angle and in flight cruise condition

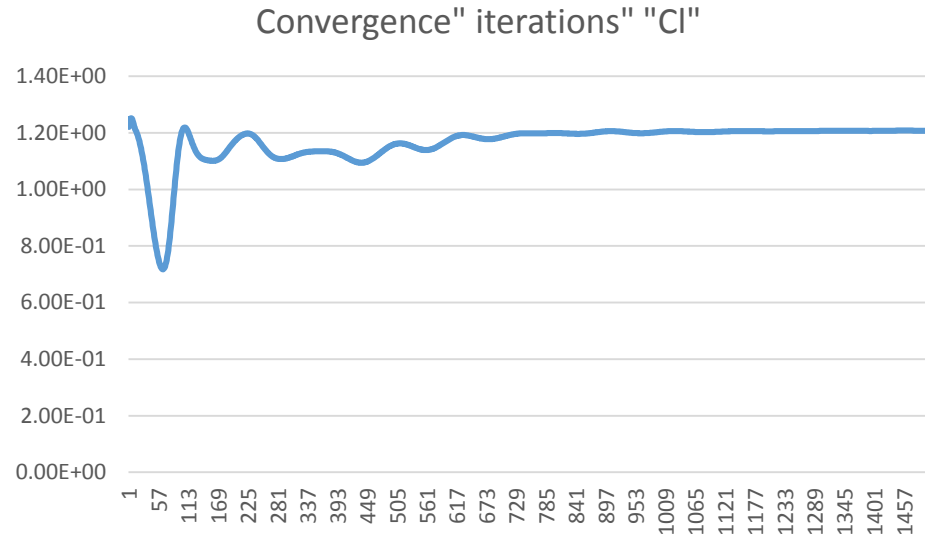


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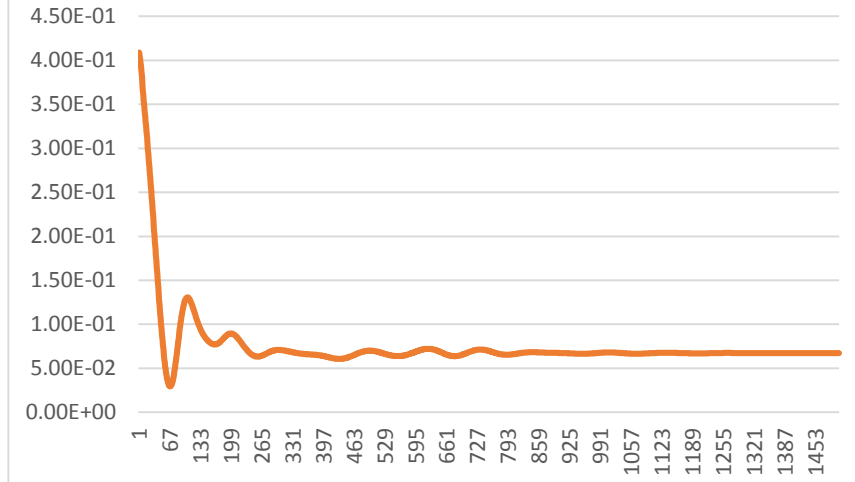


4

With winglet '0' cant angle and in flight
8.35 AOA

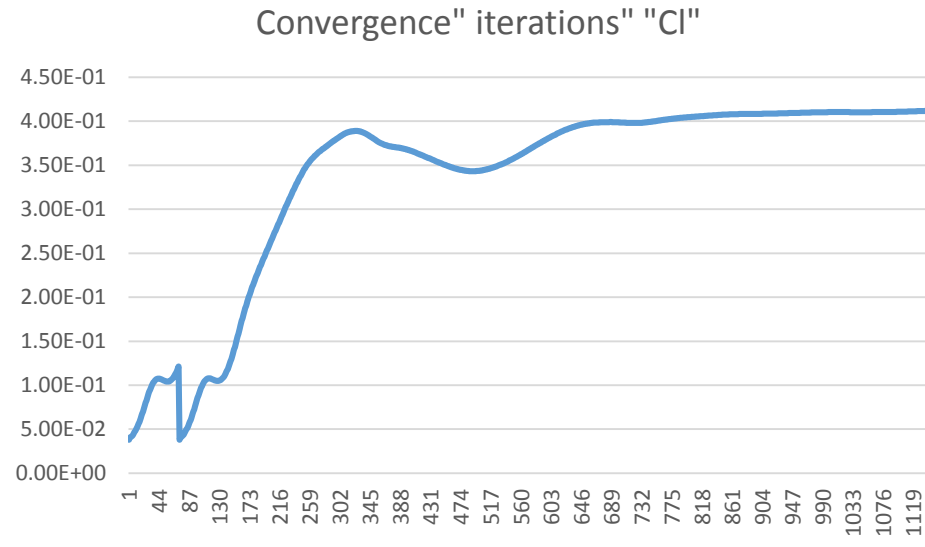


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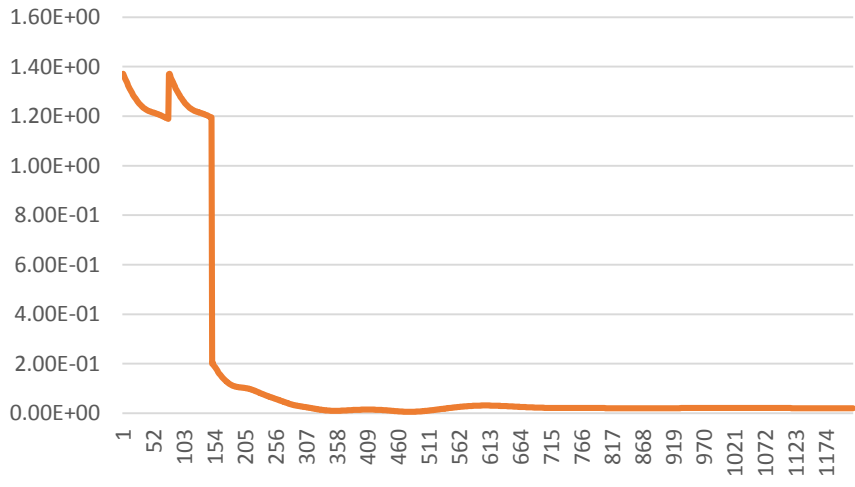


5

With winglet at '25' cant angle and in flight
cruise condition

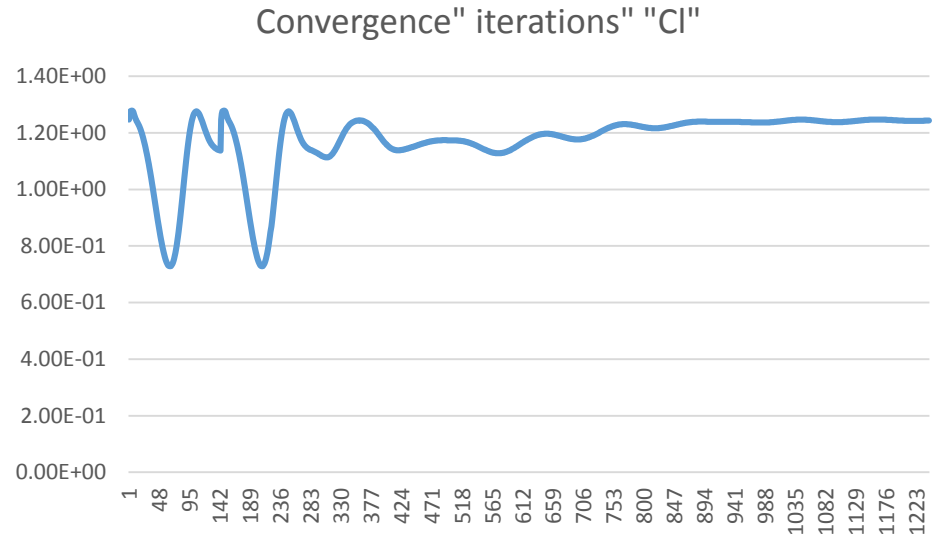


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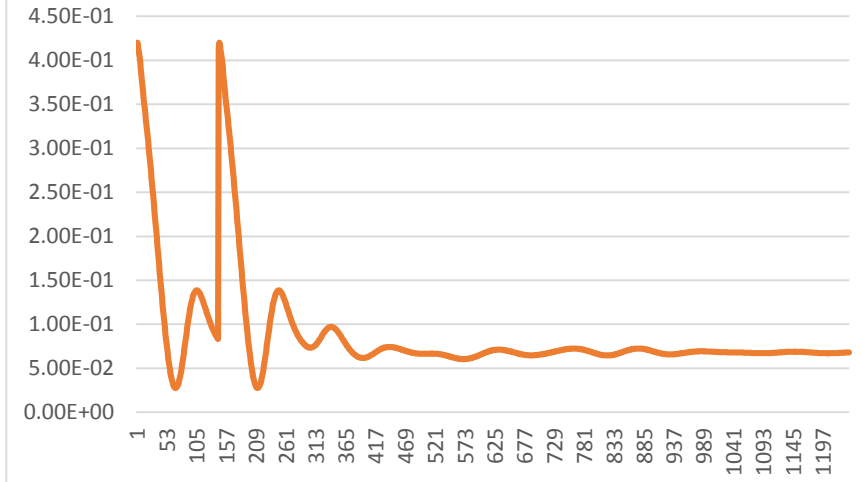


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With winglet '25' cant angle and in flight
8.35 AOA

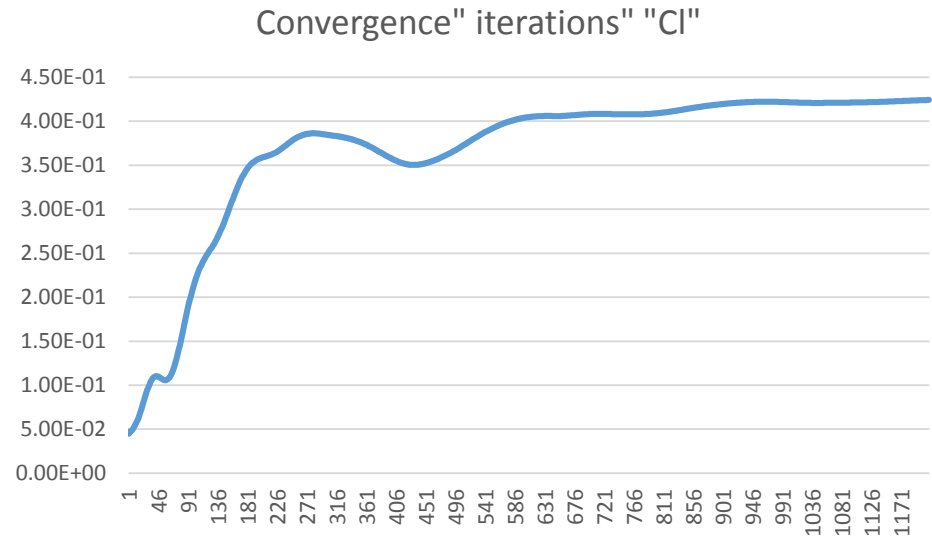


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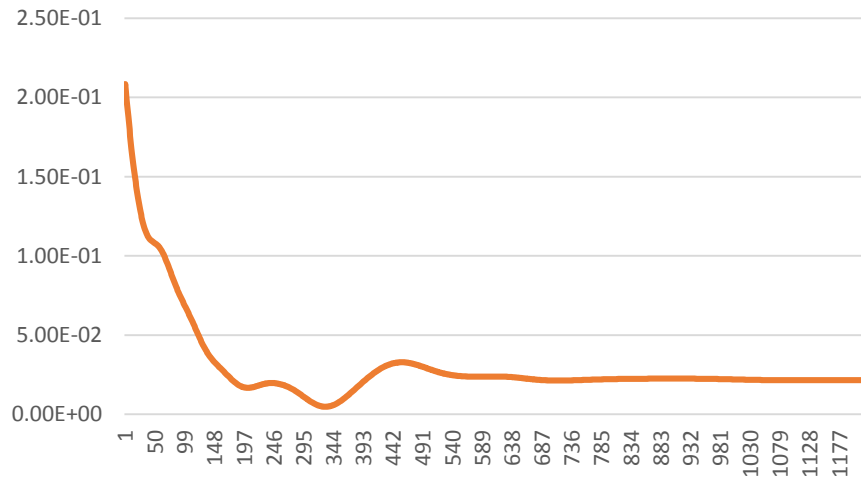


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With winglet at '-25' cant angle and in flight
cruise condition

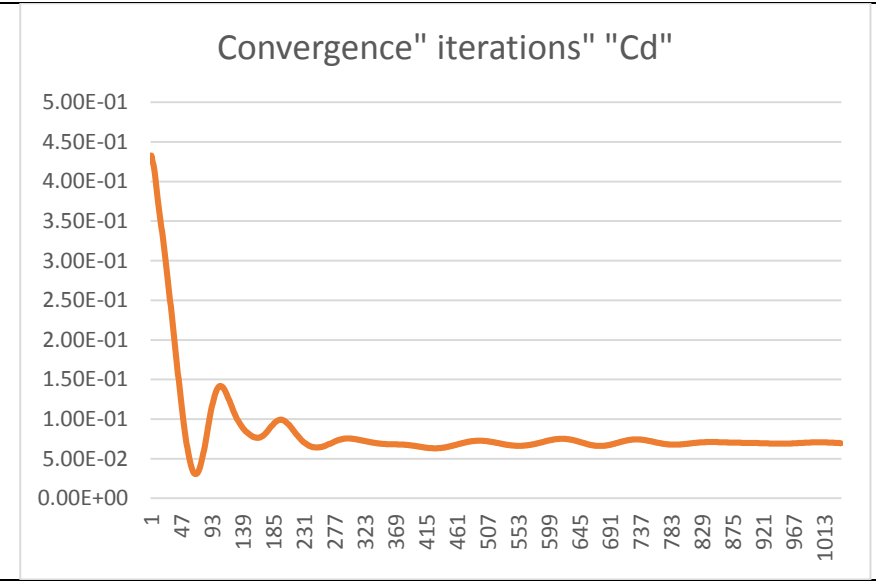
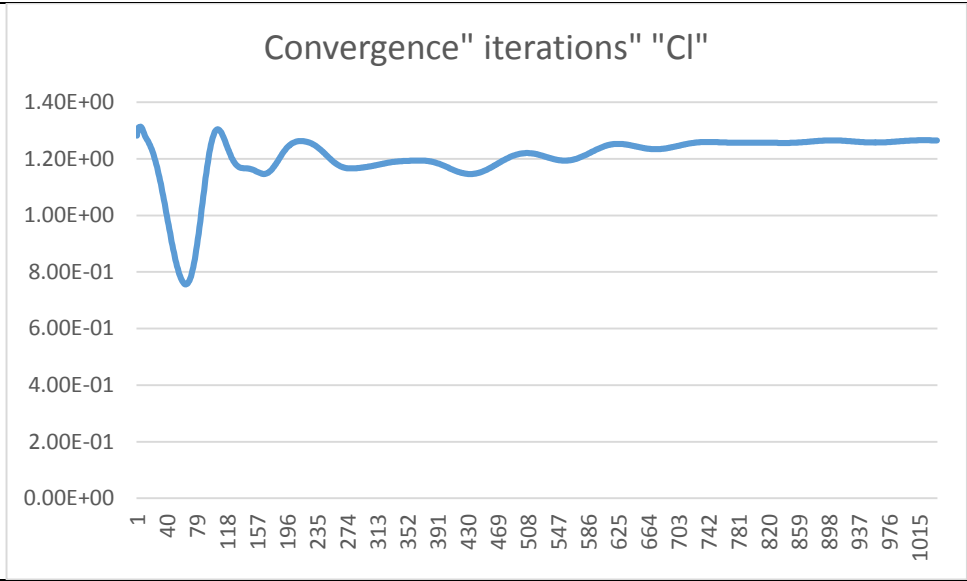


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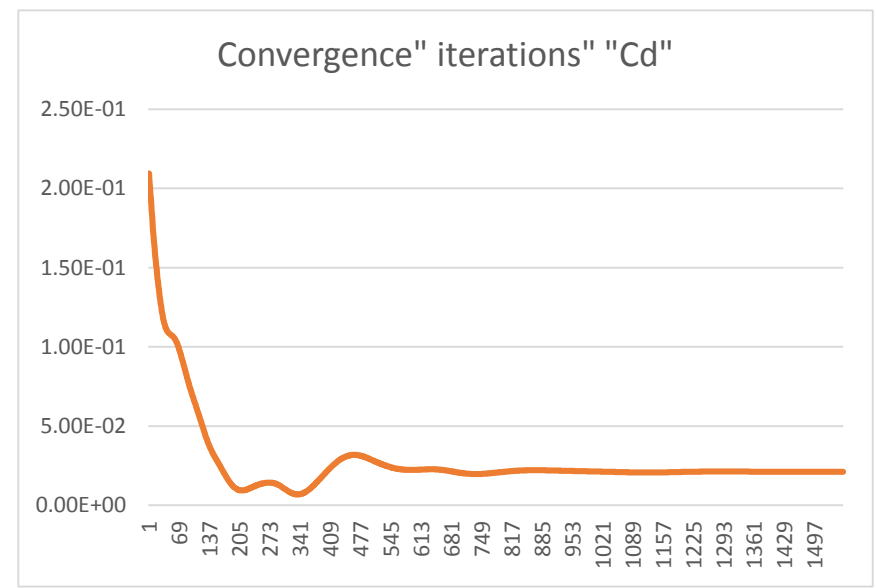
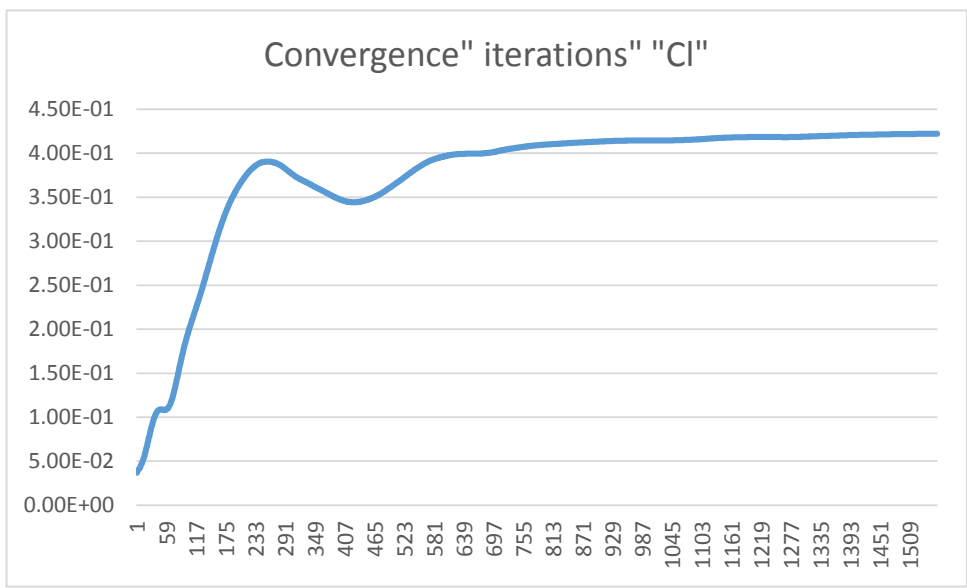
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With winglet '-25' cant angle and in flight
8.35 AOA



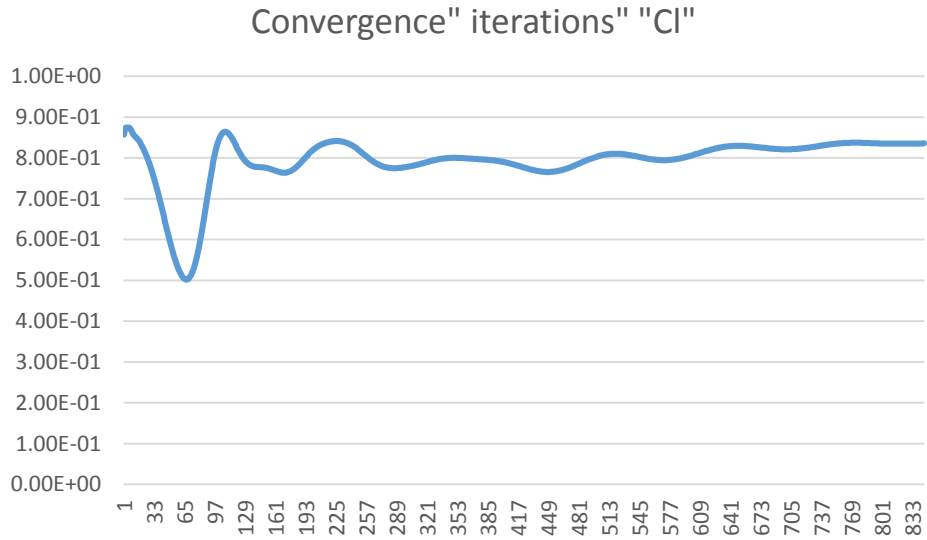
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With winglet at '35' cant angle and in flight
cruise condition

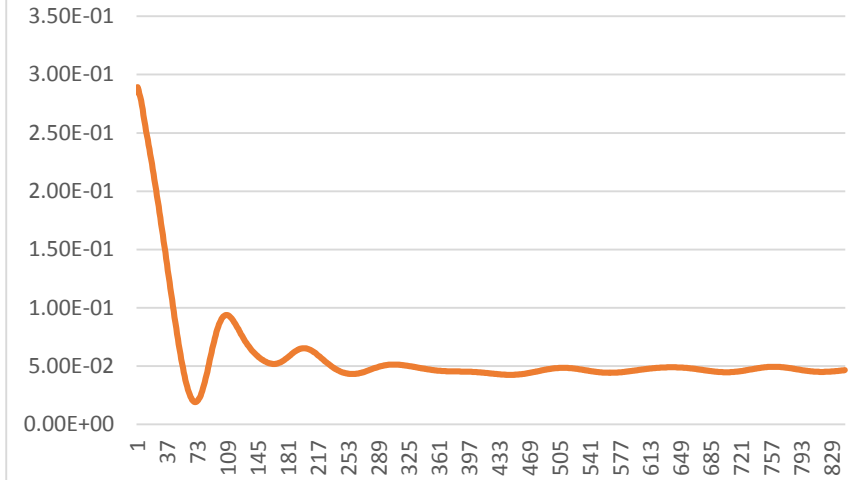


10

With winglet '35' cant angle and in flight
8.35 AOA

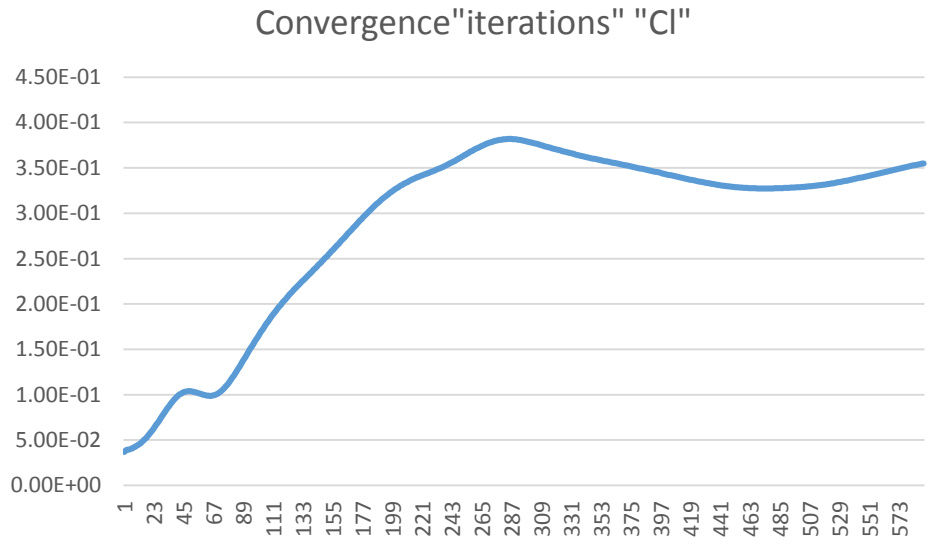


Convergence" iterations" "Cd"

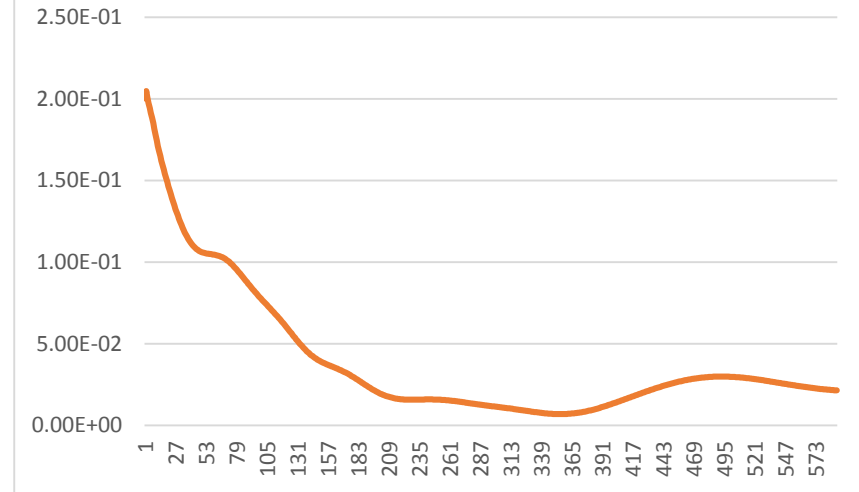


11

With winglet at '35' cant angle and in flight
cruise condition



Convergence" iterations" "Cd"



With winglet '-35' cant angle and in flight
8.35 AOA

