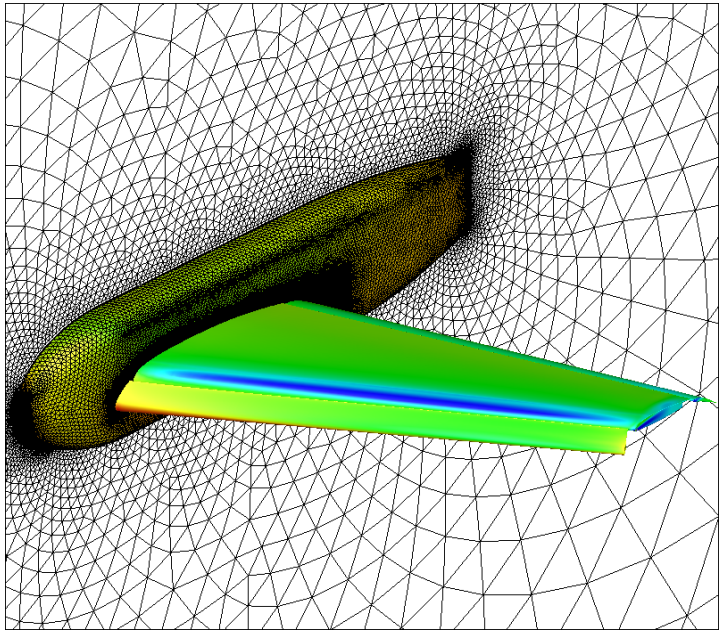
CFD simulations of flow over NASA Trap Wing Model



Andy Luo
Swift Engineering

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BETA CAE Systems

Introduction

- A cooperative study was undertaken by BETA and Swift Engineering to participate in the AIAA High Lift Prediction Workshop. Preliminary data were presented at the meeting. The study was continued after the meeting, and data were obtained on improved grids. Also, an additional turbulence model was run for the baseline configuration. This presentation contains the updated data on the new grids as well as the additional turbulence model data.

Overview

- ANSA, a commercial CAE pre-processing software from BETA CAE Systems, was used for grid generation.
- CFD++, a commercial CFD solver from METACOMP technologies, was used for numerical simulations.
- Realizable k-epsilon turbulence model was used for Turbulence modeling.
- Flow Conditions:
  - Mach = 0.2
  - Reynolds Number 4.3e6 based on MAC
  - MAC of 39.634 in
  - Reference Temp of 520 R
- Cases Studied:
  - Case 1: Grid Convergence
    - Angles-of-attack at 13 degrees and 28 degrees
  - Case 2: Flap Deflection Prediction Study
    - Flap deflection of 25 degrees and 20 degrees

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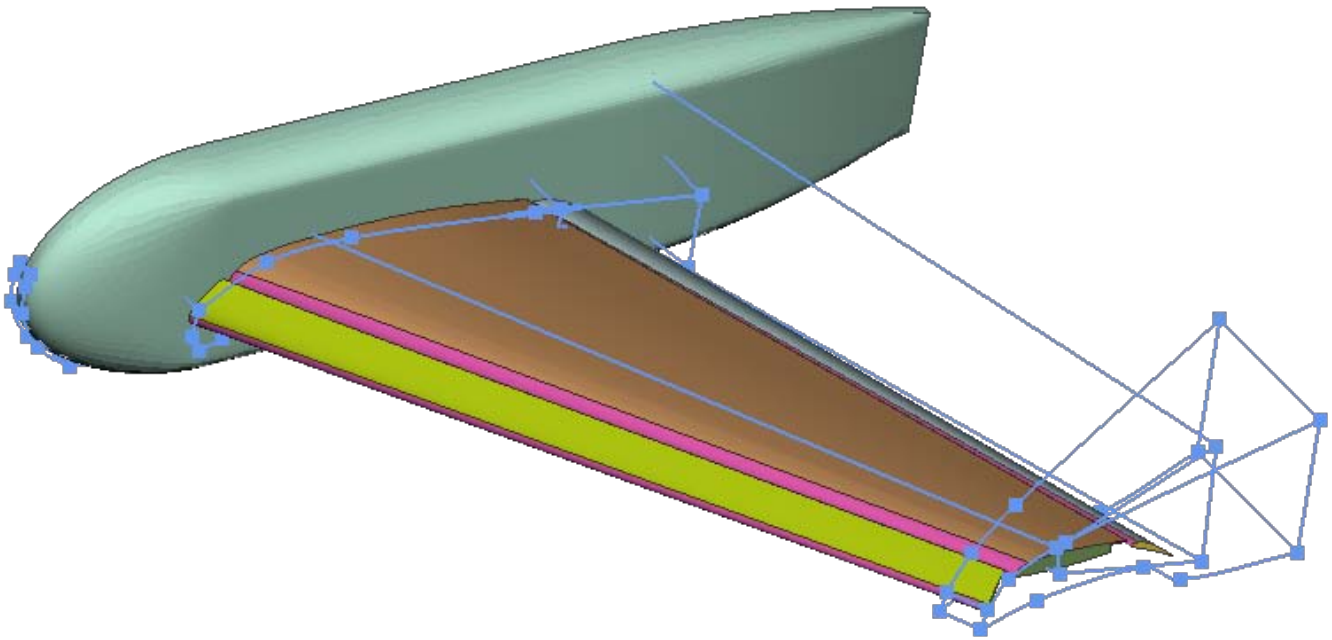
Grids – Statistics

	Config-1			Config-8
	Coarse	**Medium**	**Fine**	**Medium**
Field Nodes	3,438,517	11,339,107	36,890,922	11,401,724
Field Cells	10,697,988	30,785,946	91,675,985	30,954,927
Boundary Nodes	200,425	462,115	1,016,470	464,604
Boundary Faces	397,726	916,186	2,015,336	921,164
Boundary Layer, First height	2e-4"	1.3e-4"	9e-5"	1.3e-4"

Size Boxes



- Multiple size boxes were created to refine surface and volume mesh at critical areas such as body nose, wing-body intersection, wing-tips etc., without splitting the original domain

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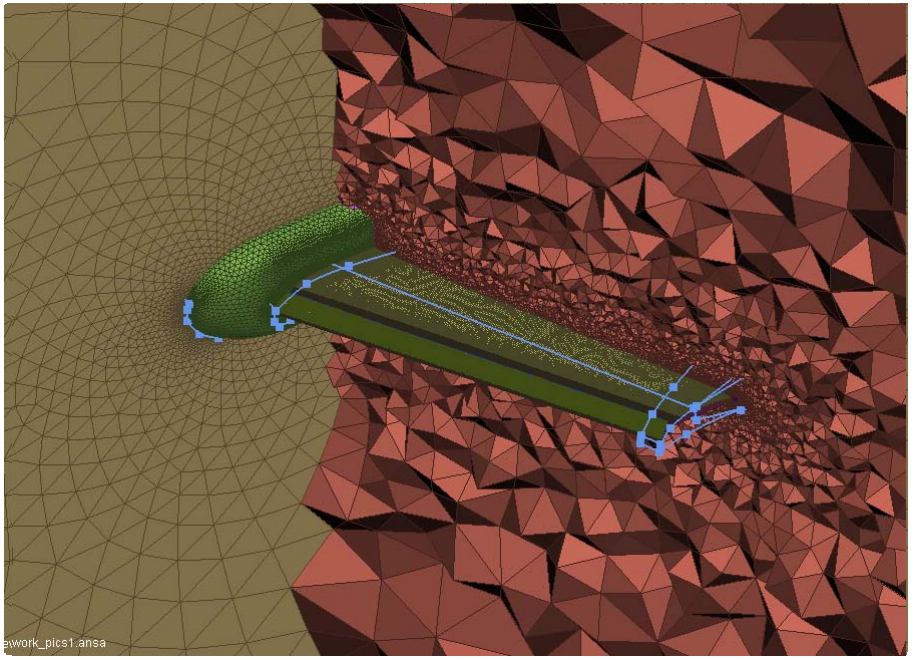
Meshing Automation

Batch Mesh Manager

New | Read Scenario | Autoload | Run

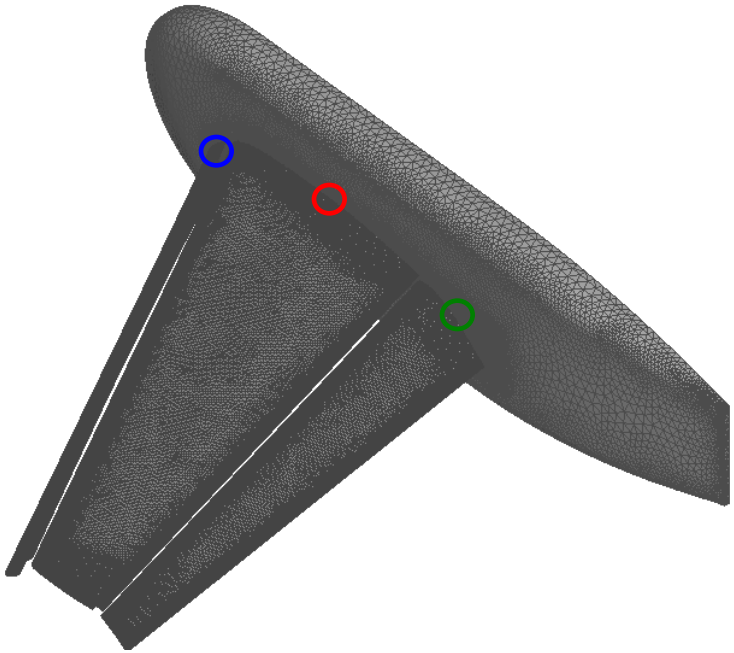
Name	Color	Contents	Mesh Parameters	Quality
Surface Meshing		**15**		
wingtip_Slat_flap		1	Tria_0.0865	CFD criteria
slat_tip_TE		1	cfd 0.086-0.086-0.173	CFD criteria
flap_tip_TE		1	cfd 0.06-0.06-0.0173	CFD criteria
wingtip_main		1	Tria 0.173	CFD criteria
wing_tip_TE		1	cfd 0.173-0.173-0.06	CFD criteria
leading_edges		1	cfd 0.086-0.173	CFD criteria
slat_upper		1	cfd 0.086-0.346-0.173	CFD criteria
slat_lower		1	cfd 0.346-0.692-0.346	CFD criteria
flap_upper		1	cfd 0.21-0.519	CFD criteria
flap_lower		1	cfd 0.43-0.86	CFD criteria
main_wing_upper		1	cfd 0.346-0.692-0.346	CFD criteria
main_wing_lower		1	cfd 0.60-1.2	CFD criteria
fuselage		1	cfd 0.173-1.73-0.346	CFD criteria
far_field		1	Tria 415	CFD criteria
symmetry		1	cfd 0.173-415	CFD criteria
Default_Session		*0*	*Untitled*	*CFD criteria*
Boundary Layers		**14**		
Default_Session		*14*	*Gr1.2_12_layers*	*CFD criteria*
Volume Meshing		**1**		
Default_Session		*1*	*Gr1.2_max_456*	*CFD criteria*

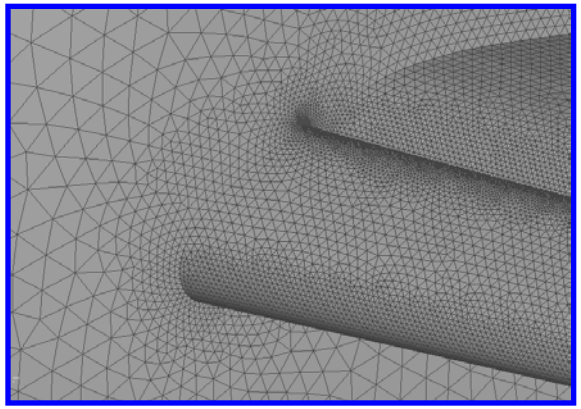


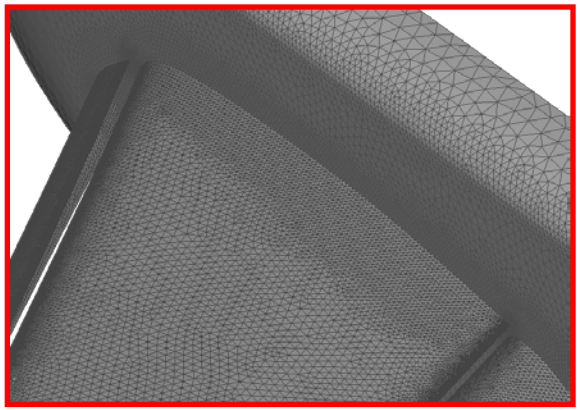
- Batch Meshing tool was used to automate all the meshing steps: 1) Surface Meshing, 2) Boundary Layer generation, and 3) Volume Meshing.
- Once the Batch Mesh frame work was defined for coarse mesh for Config1, the mesh parameter values were appropriately scaled to generate medium and fine meshes.
- The frame work for Config1 medium mesh was directly used to generate consistent mesh for Config8 medium mesh case.

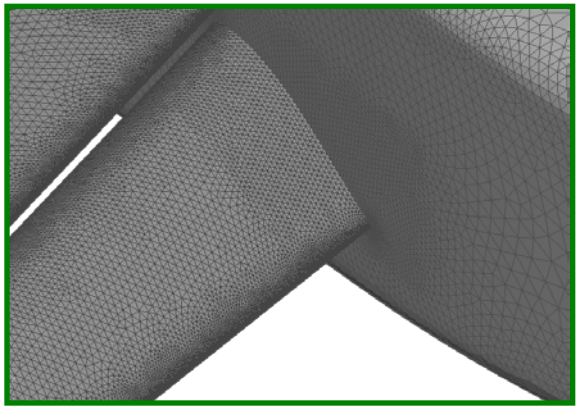
Grids – Surface Mesh

Coarse



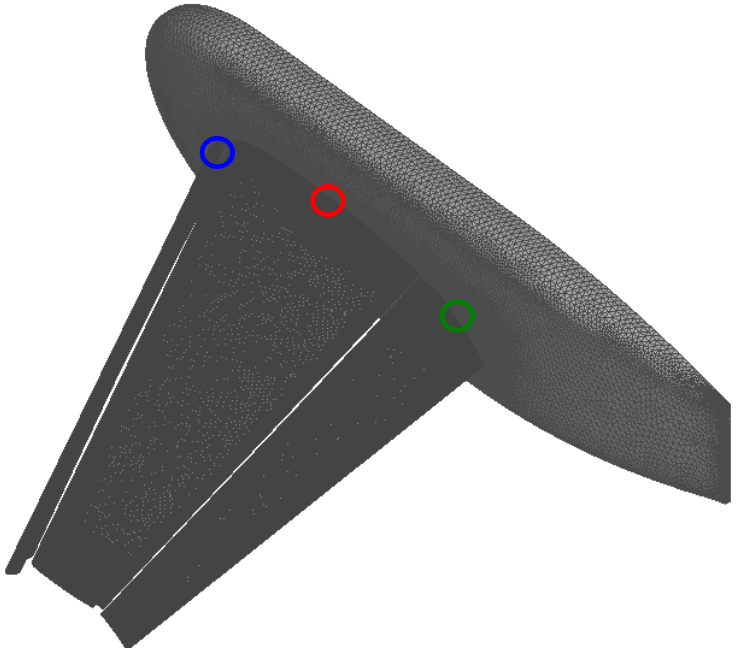


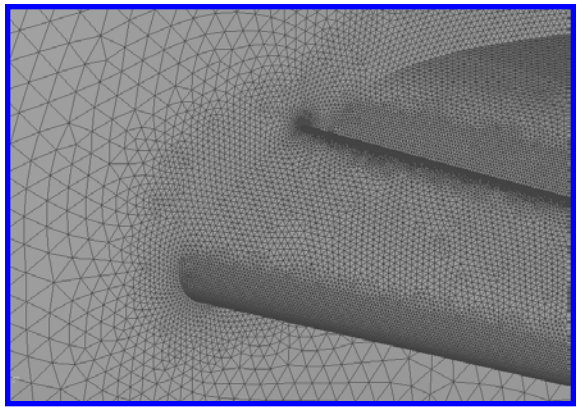


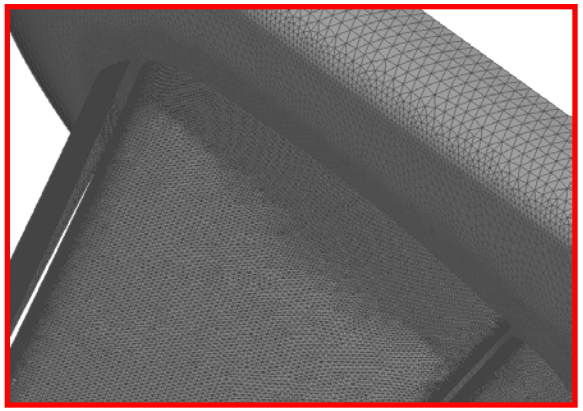


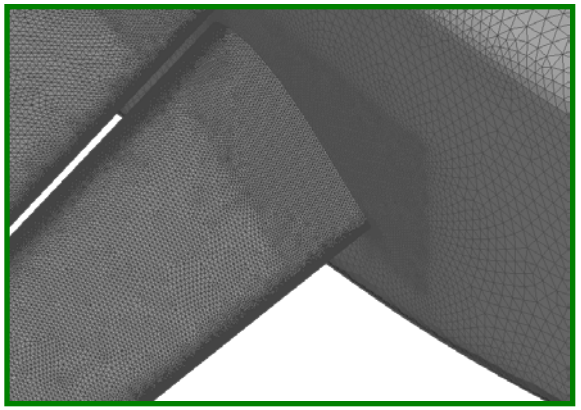
Grids – Surface Mesh

Medium



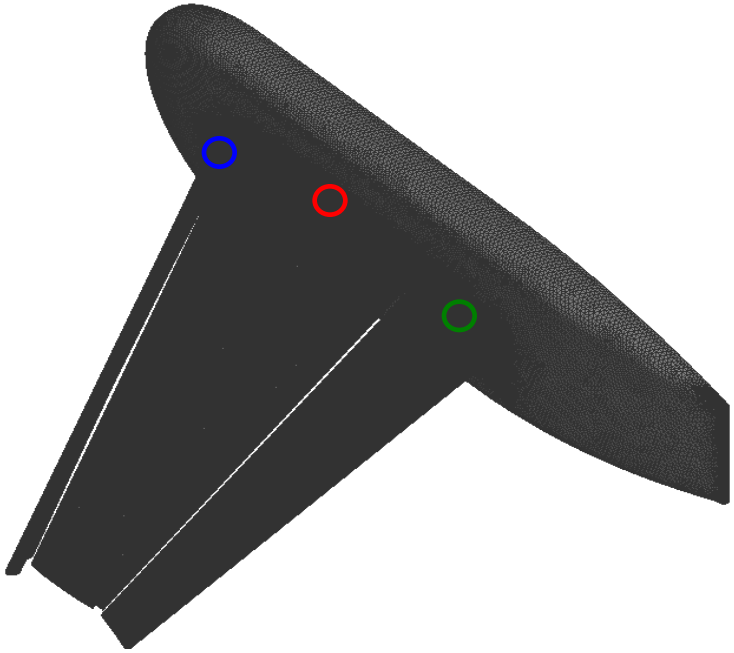


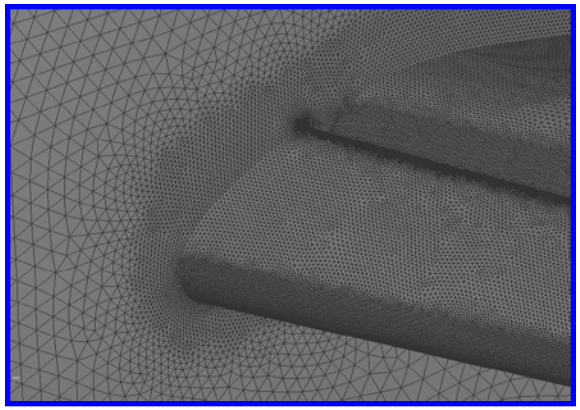


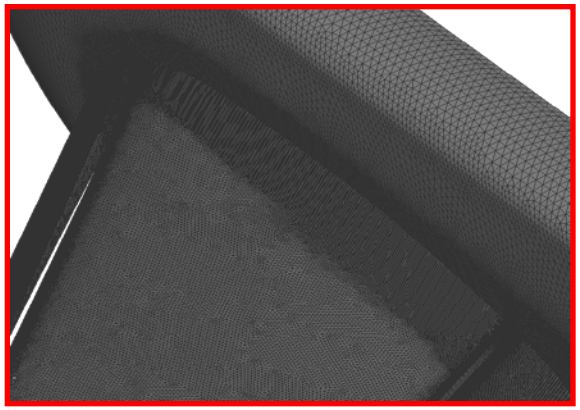


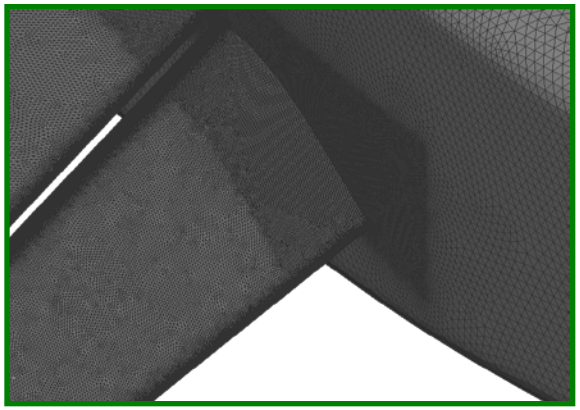
Grids – Surface Mesh

Fine



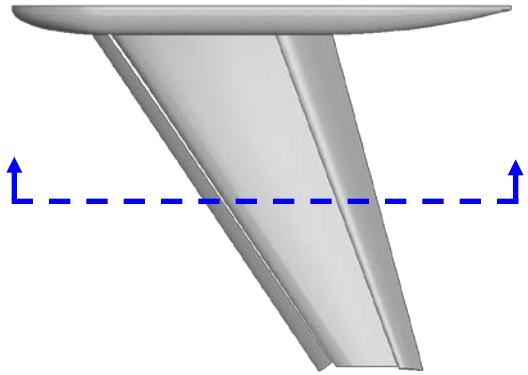




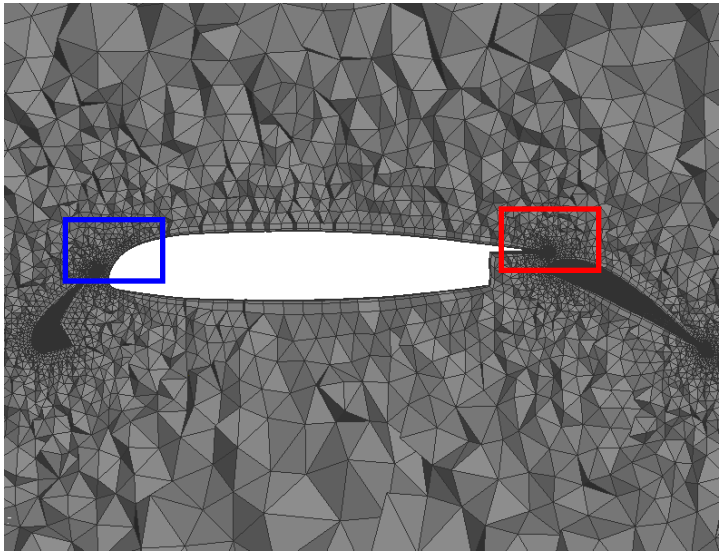


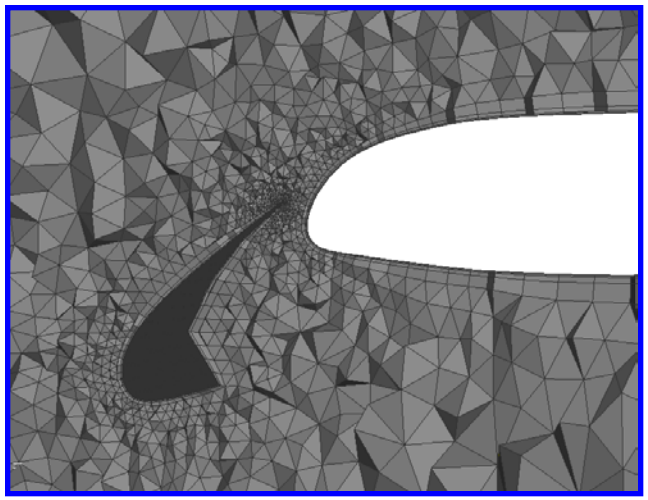
Grids – Volume Mesh

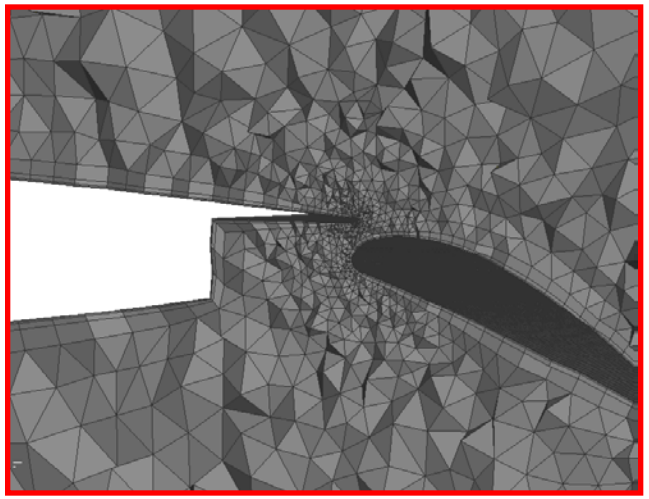
Coarse



Mid span cross-section

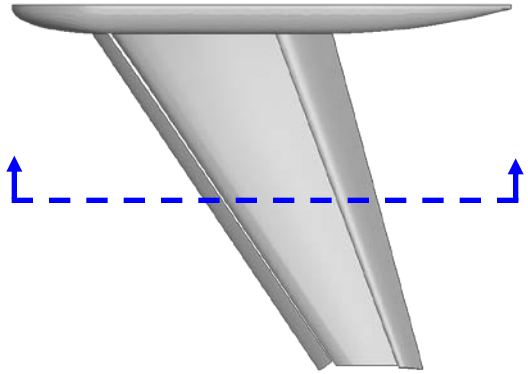




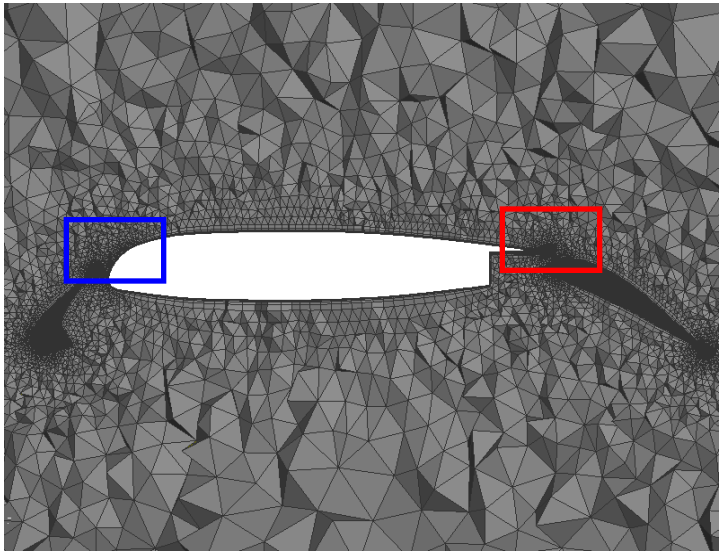


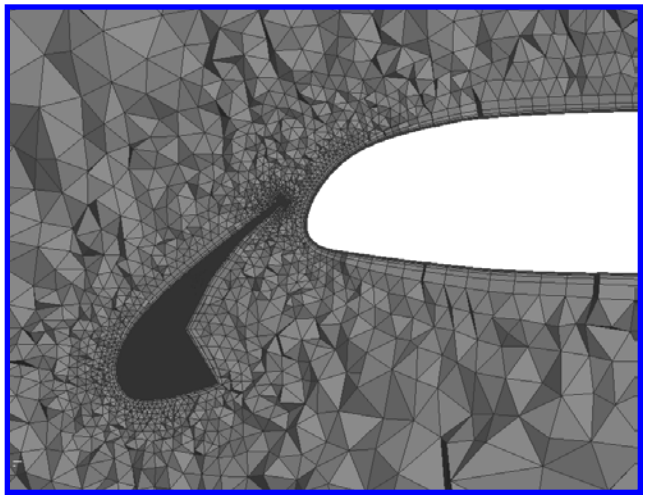
Grids – Volume Mesh

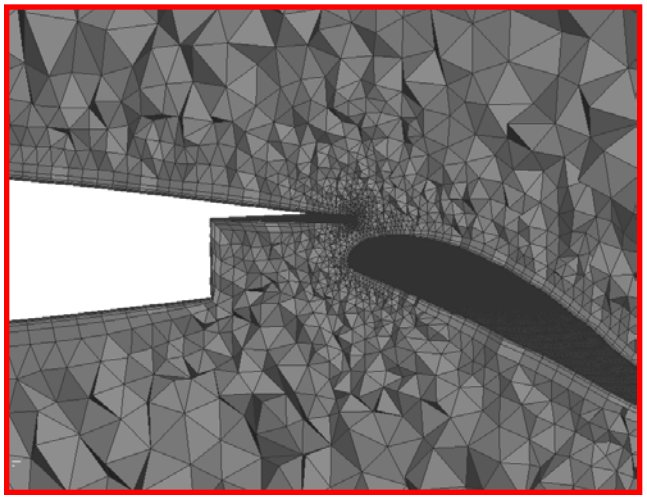
Medium



Mid span cross-section

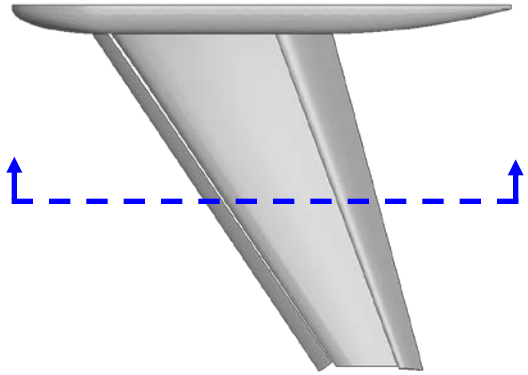




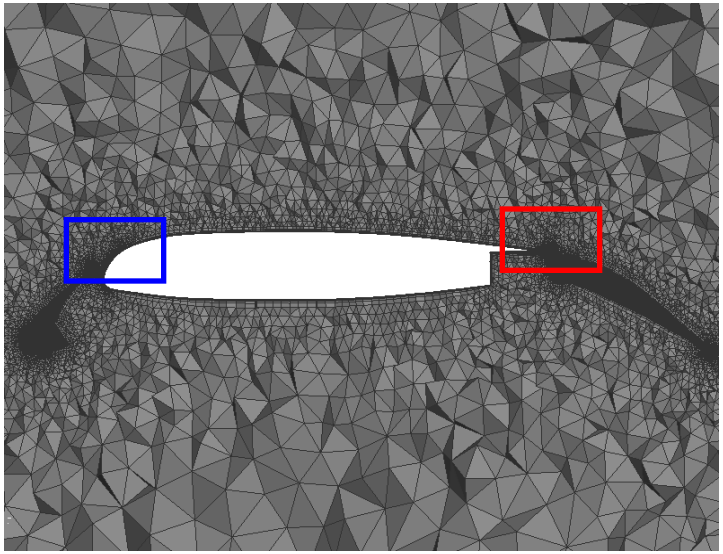


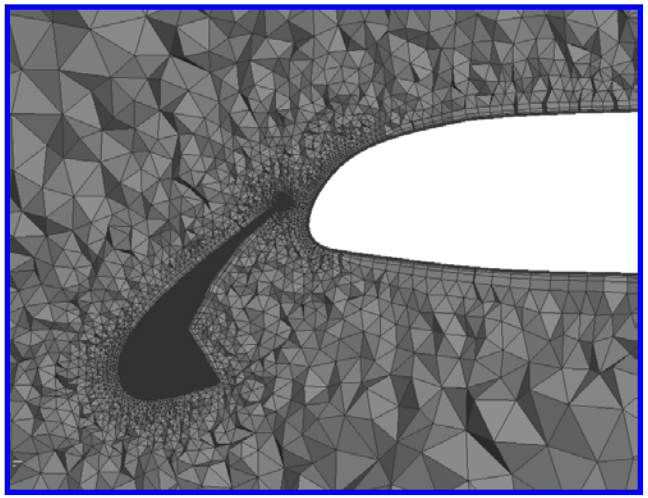
Grids – Volume Mesh

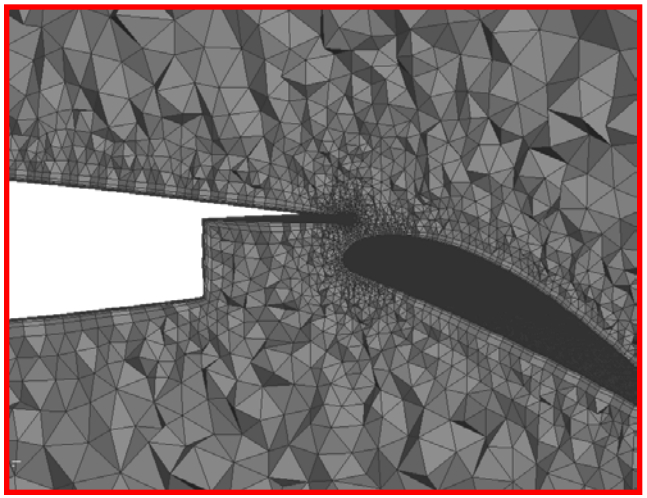
Fine



Mid span cross-section







Case 1: Grid Convergence Study

Alpha = 13 degrees

	Cell Count	CL	CD	CM
Coarse	10,697,988	1.9760	0.3220	-0.4627
Medium	30,785,946	1.9995	0.3259	-0.4753
Fine	91,675,985	2.0207	0.3290	-0.4845

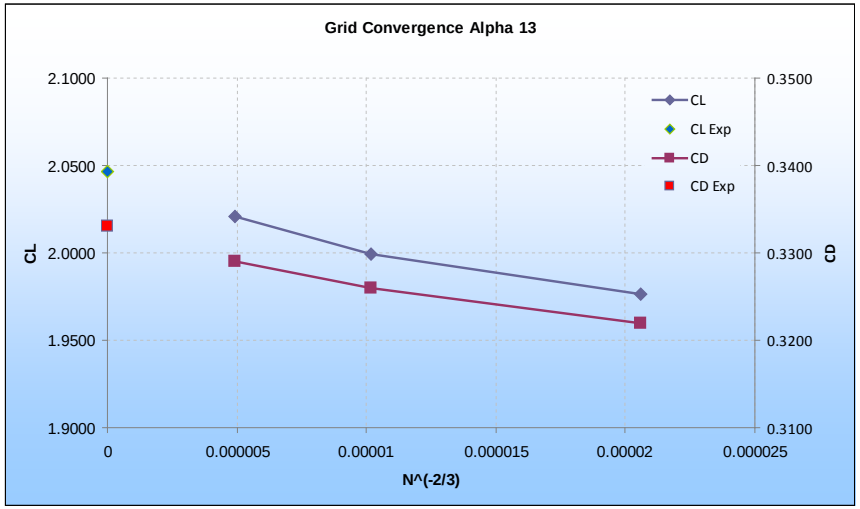
Case 1: Grid Convergence Study

Alpha = 28 degrees

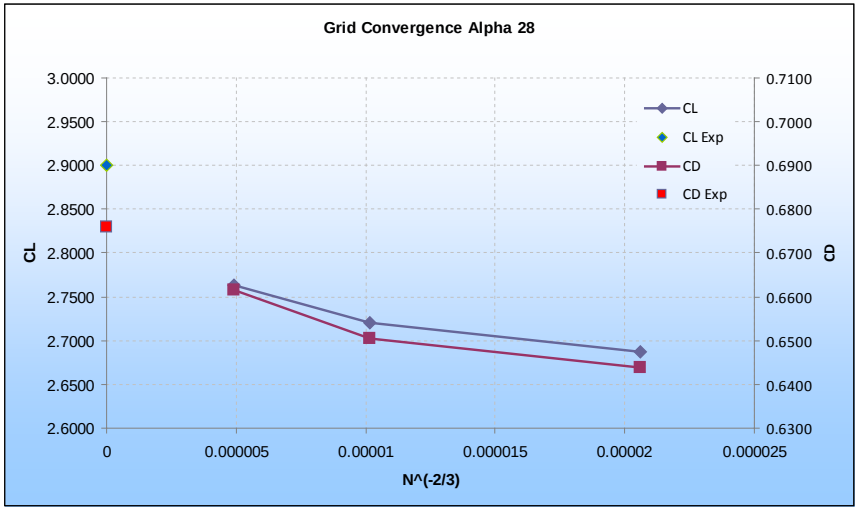
	Cell Count	CL	CD	CM
Coarse	10,697,988	2.6876	0.6437	-0.3572
Medium	30,785,946	2.7198	0.6505	-0.3627
Fine	91,675,985	2.7637	0.6616	-0.3782

Case 1: Grid Convergence Study

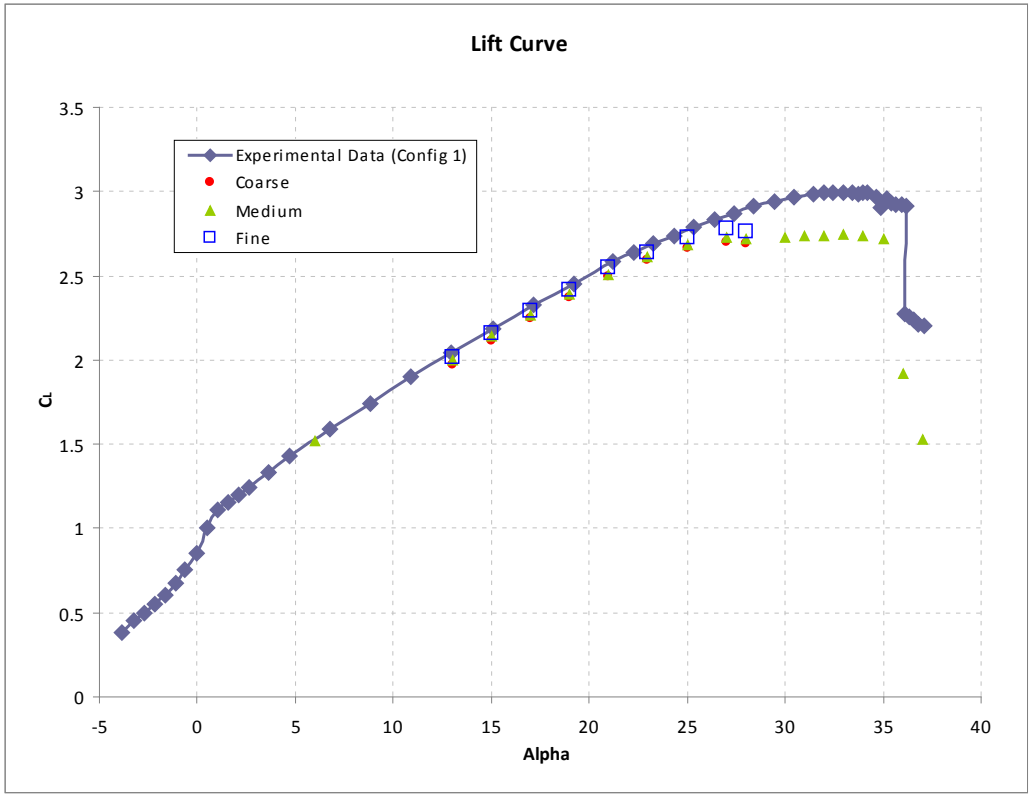
Alpha = 13 degrees



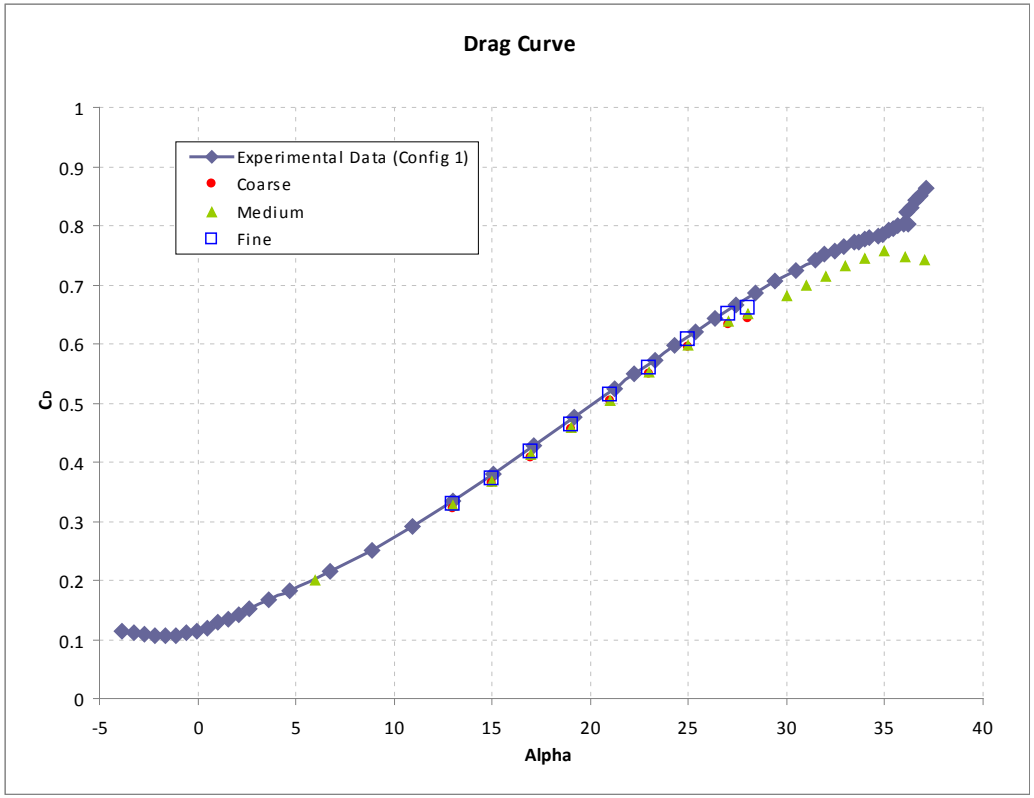
Alpha = 28 degrees



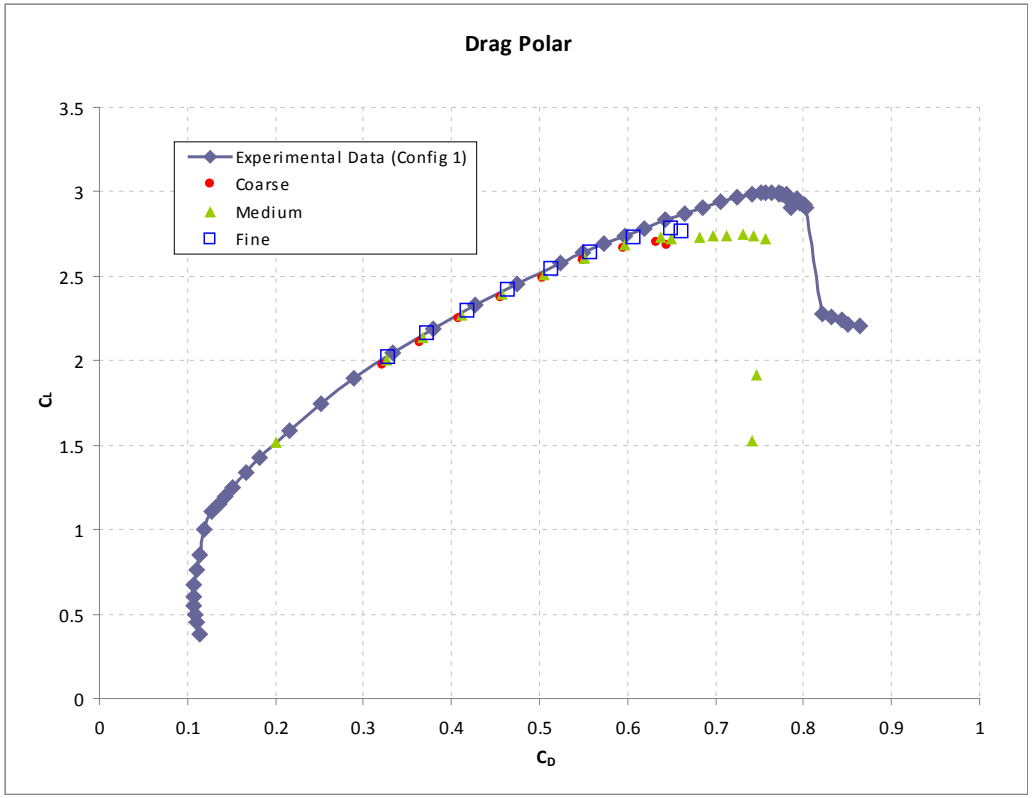
Case 1: Grid Convergence Study



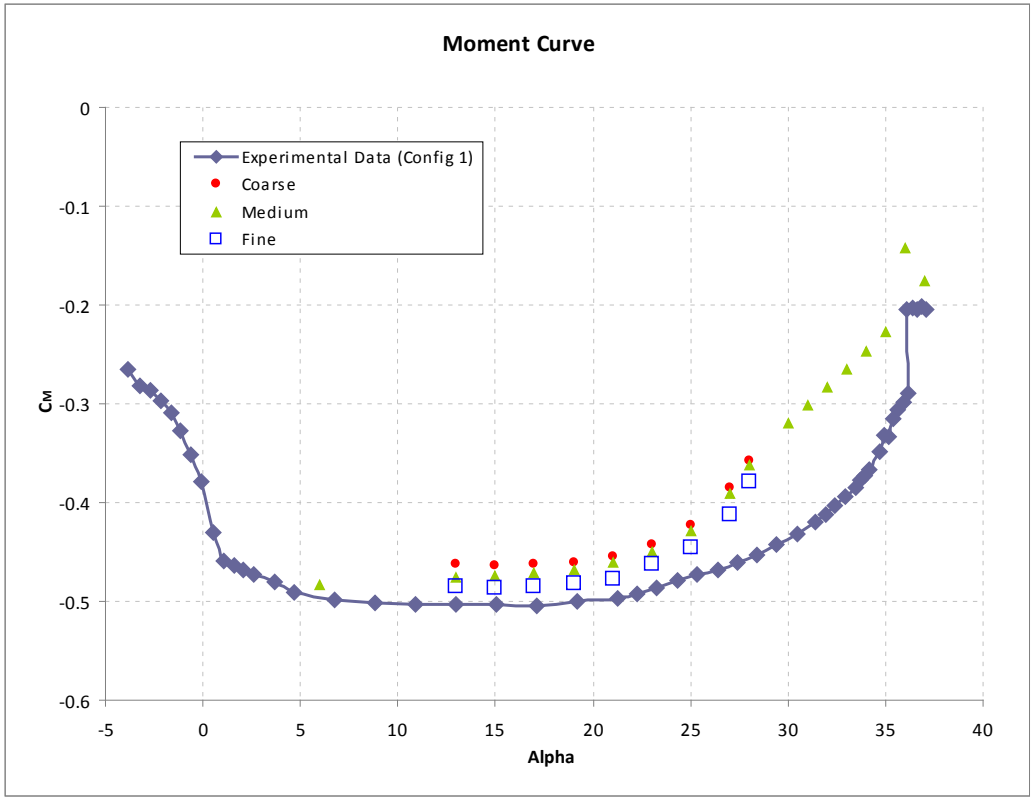
Case 1: Grid Convergence Study



Case 1: Grid Convergence Study



Case 1: Grid Convergence Study



Case 2: Flap Deflection Prediction Study

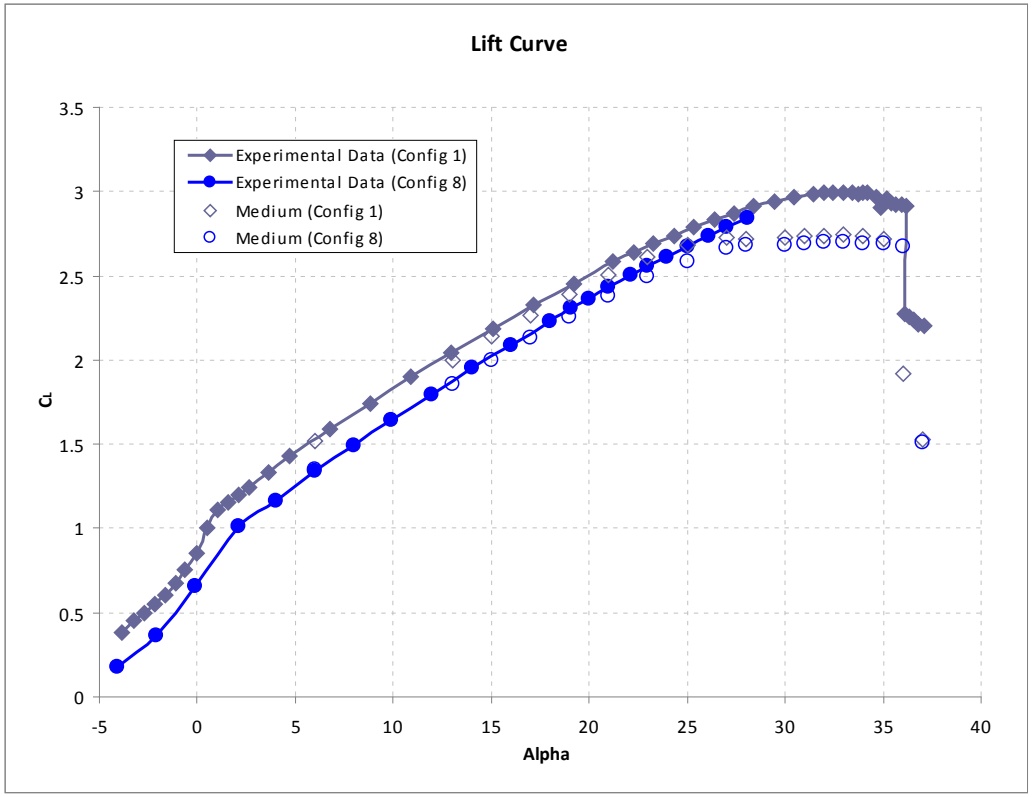
Configuration 1:Flap 25 degrees

Alpha	CL	CD	CM
6	1.5174	0.2007	-0.4836
13	1.9995	0.3259	-0.4753
21	2.5052	0.5043	-0.4613
28	2.7198	0.6505	-0.3627
32	2.7364	0.7131	-0.2830
34	2.7340	0.7432	-0.2462
37	1.5247	0.7407	-0.1764

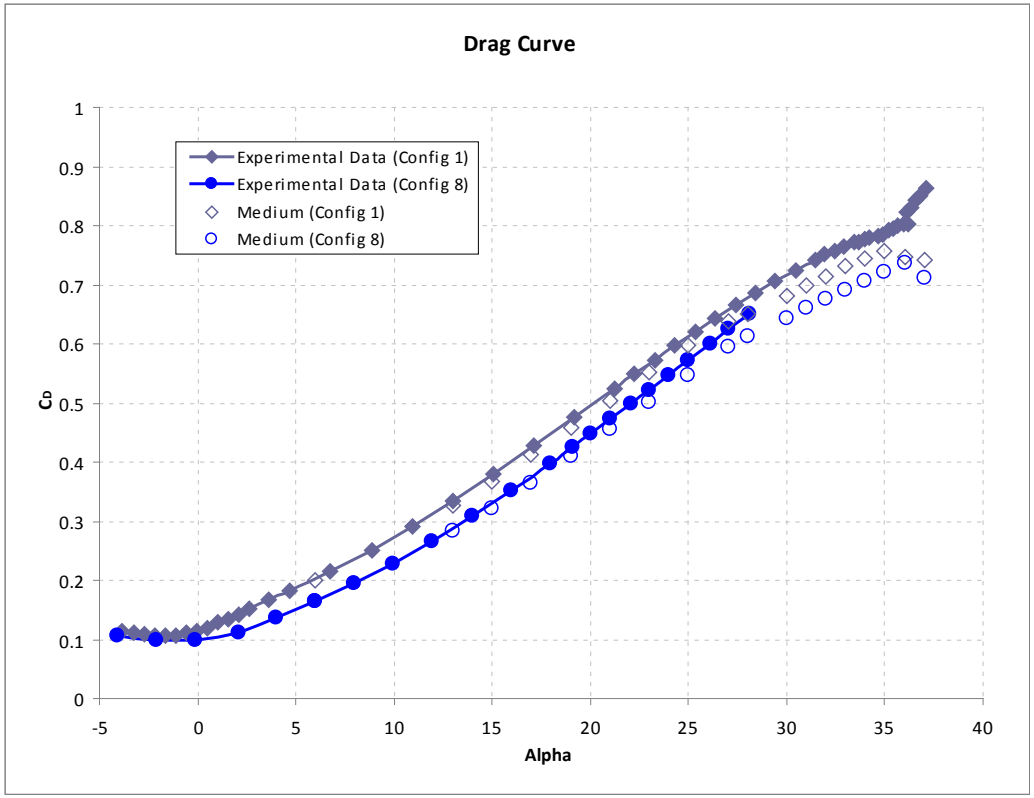
Configuration 8:Flap 20 degrees

Alpha	CL	CD	CM
6	1.3530	0.1643	-0.4301
13	1.8567	0.2824	-0.4290
21	2.3851	0.4560	-0.4231
28	2.6783	0.6129	-0.3619
32	2.6965	0.6765	-0.2712
34	2.6946	0.7064	-0.2356
37	1.5076	0.7126	-0.1671

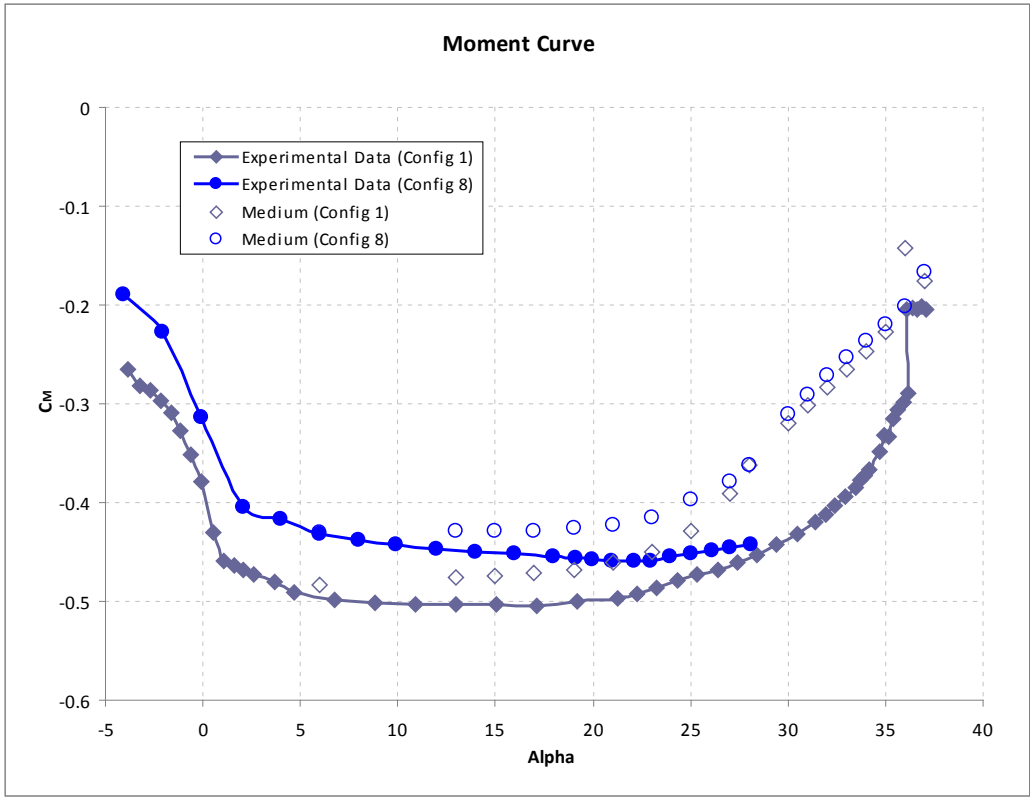
Case 2: Flap Deflection Prediction Study



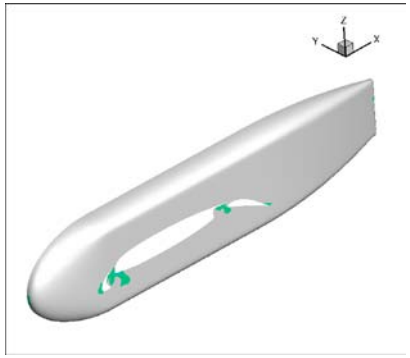
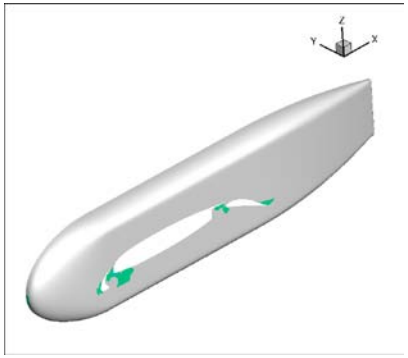
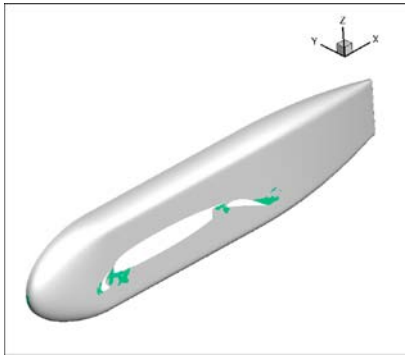
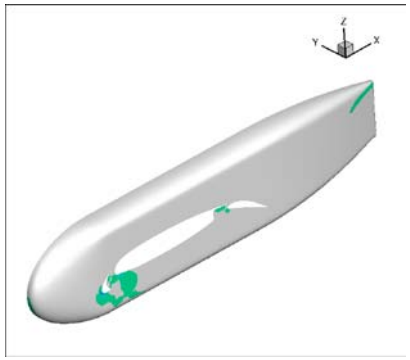
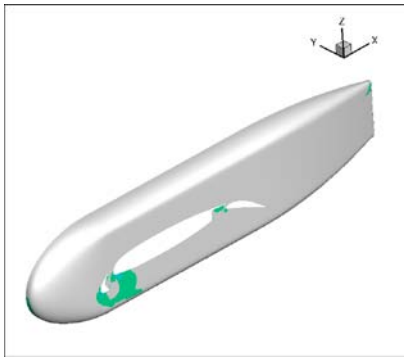
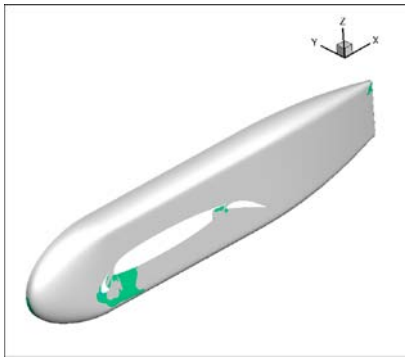
Case 2: Flap Deflection Prediction Study



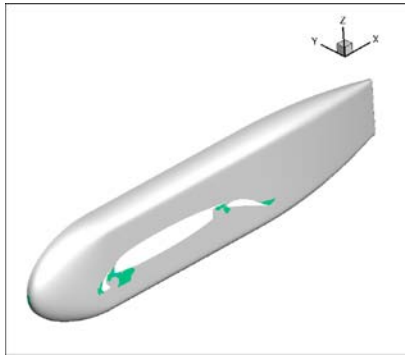
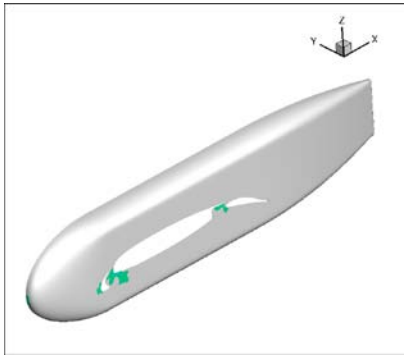
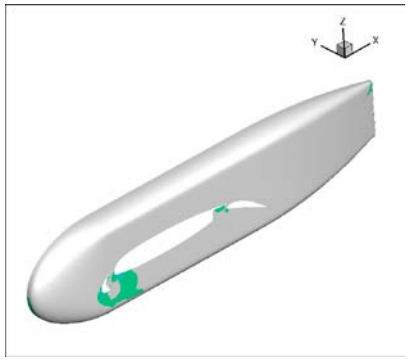
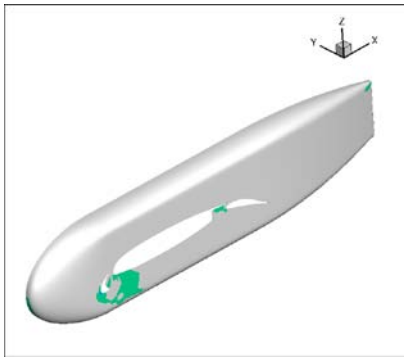
Case 2: Flap Deflection Prediction Study



Case 2: Flap Deflection Prediction Study

	Coarse	Medium	Fine
a13			
a28			

Body Pod Flow Reversal: Case 2

	Medium	Fine
a13		
a28		

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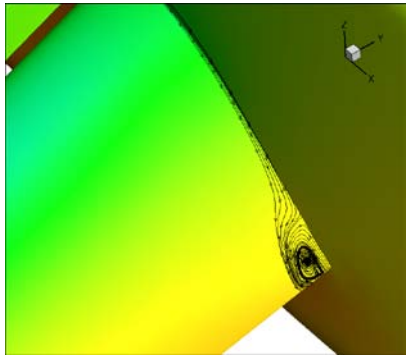
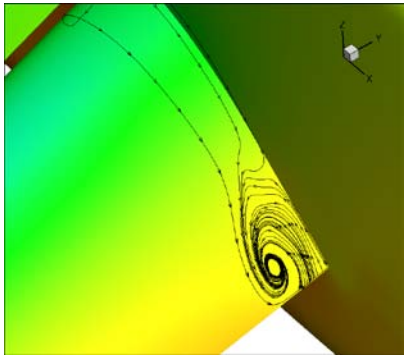
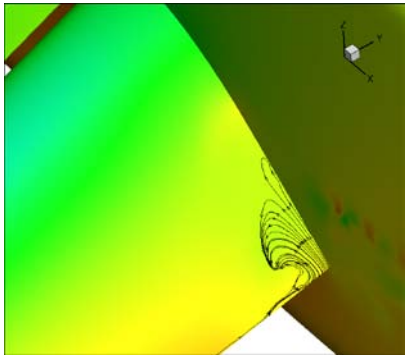
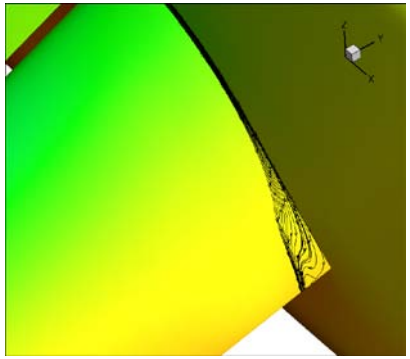
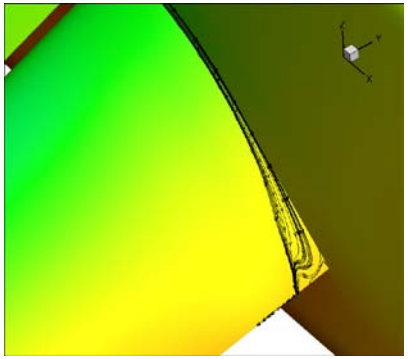
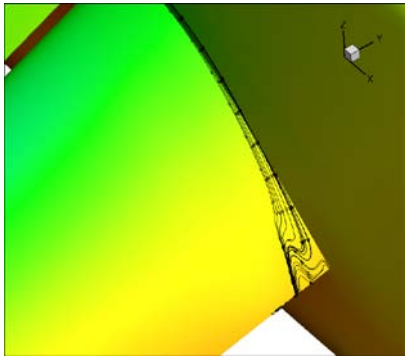
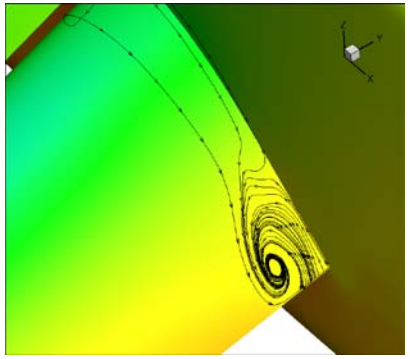
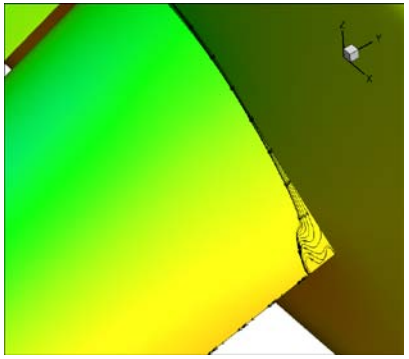
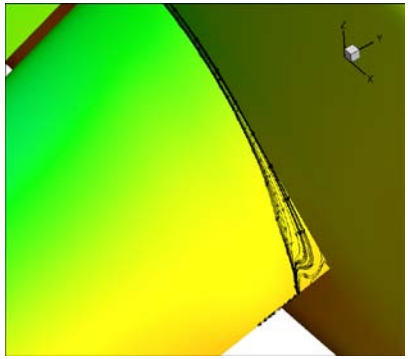
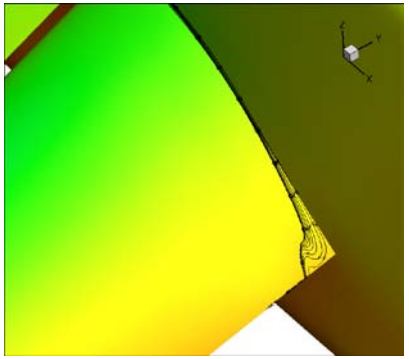
Flap Separation: Case 1

	Coarse	Medium	Fine
a13			
a28			

Flap Separation: Case 2

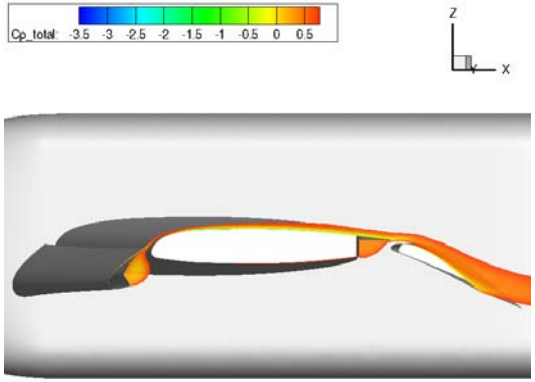
	Medium	Fine
a13		
a28		

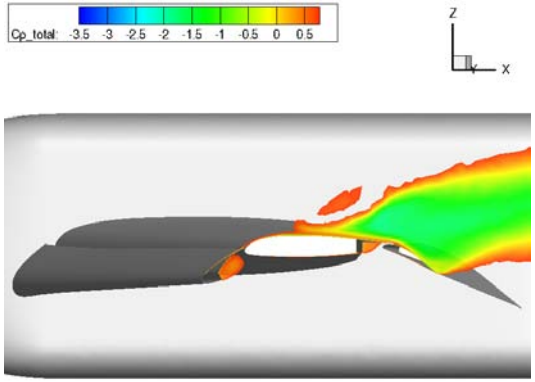
Flow Confluence: Coarse

MidSpan

Tip

a13





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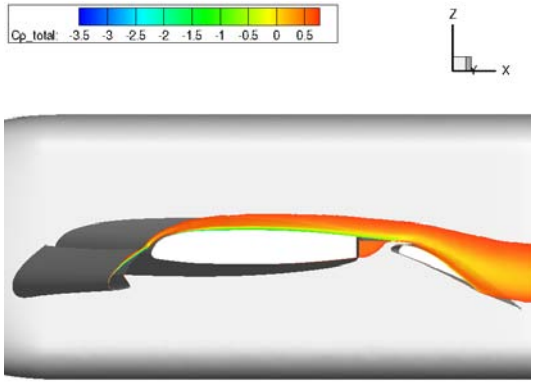
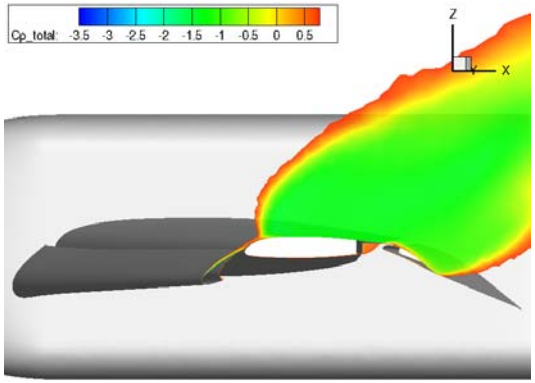


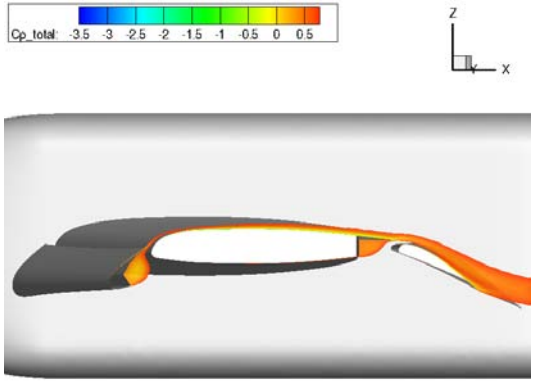


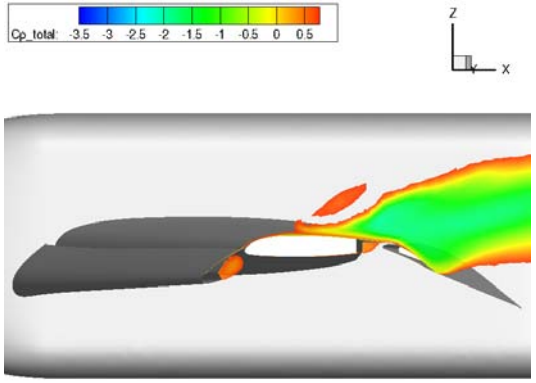
Flow Confluence: Medium

MidSpan

Tip

a13





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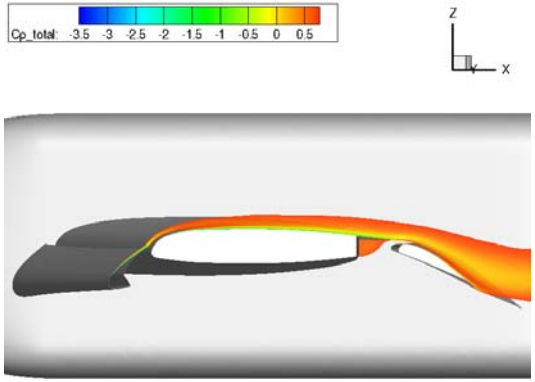
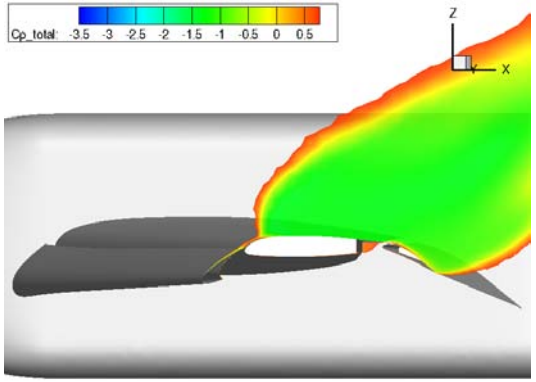


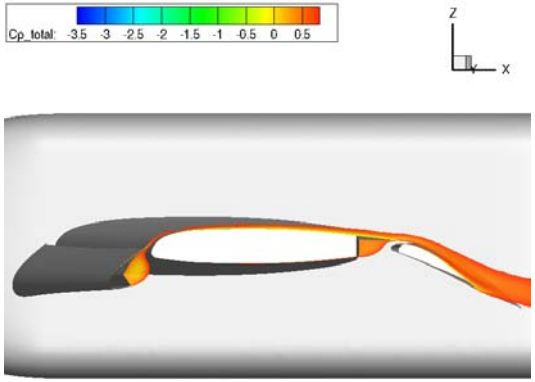


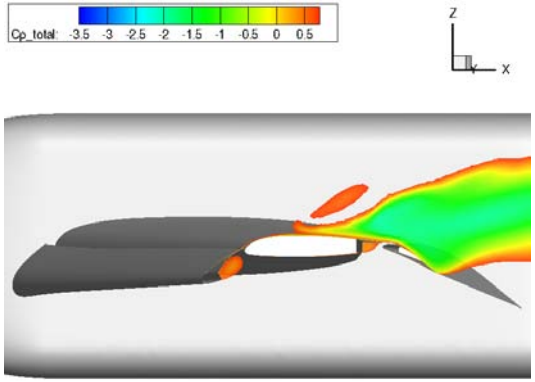
Flow Confluence: Fine

MidSpan

Tip

a13





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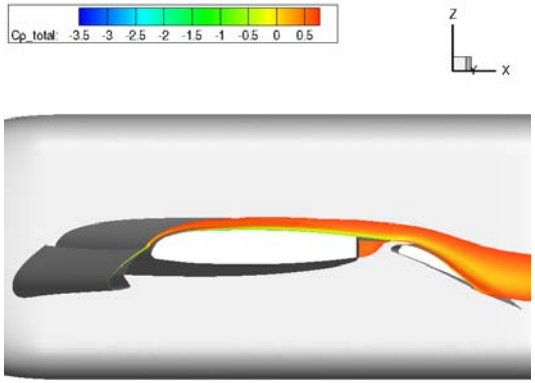
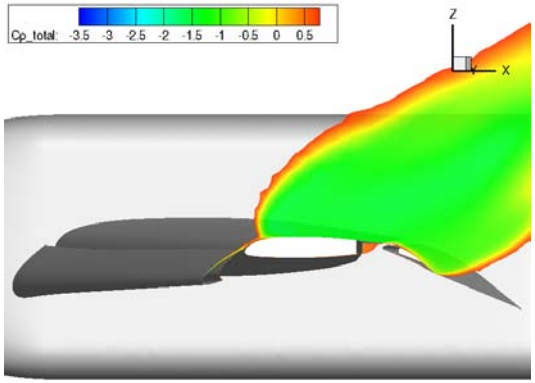


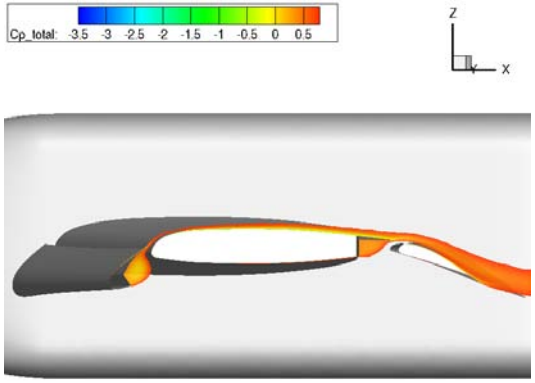


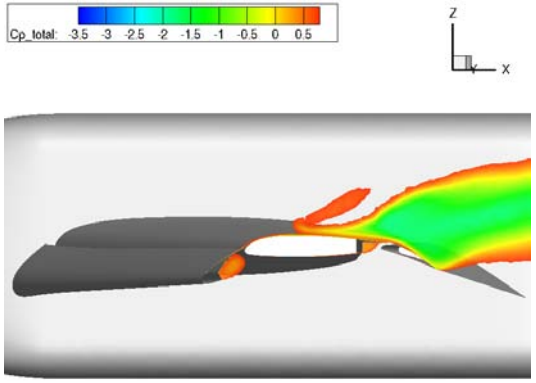
Flow Confluence: Stowed Medium

MidSpan

Tip

a13





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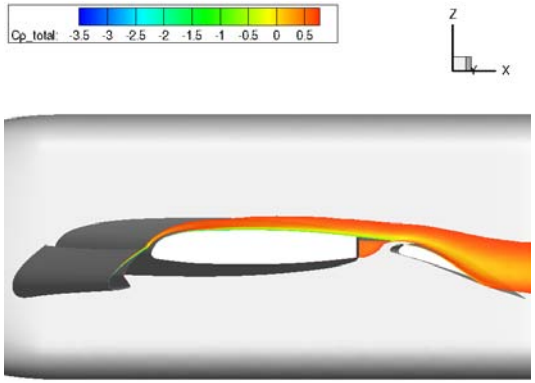
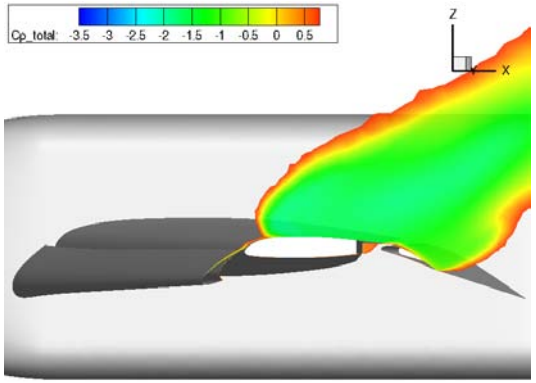
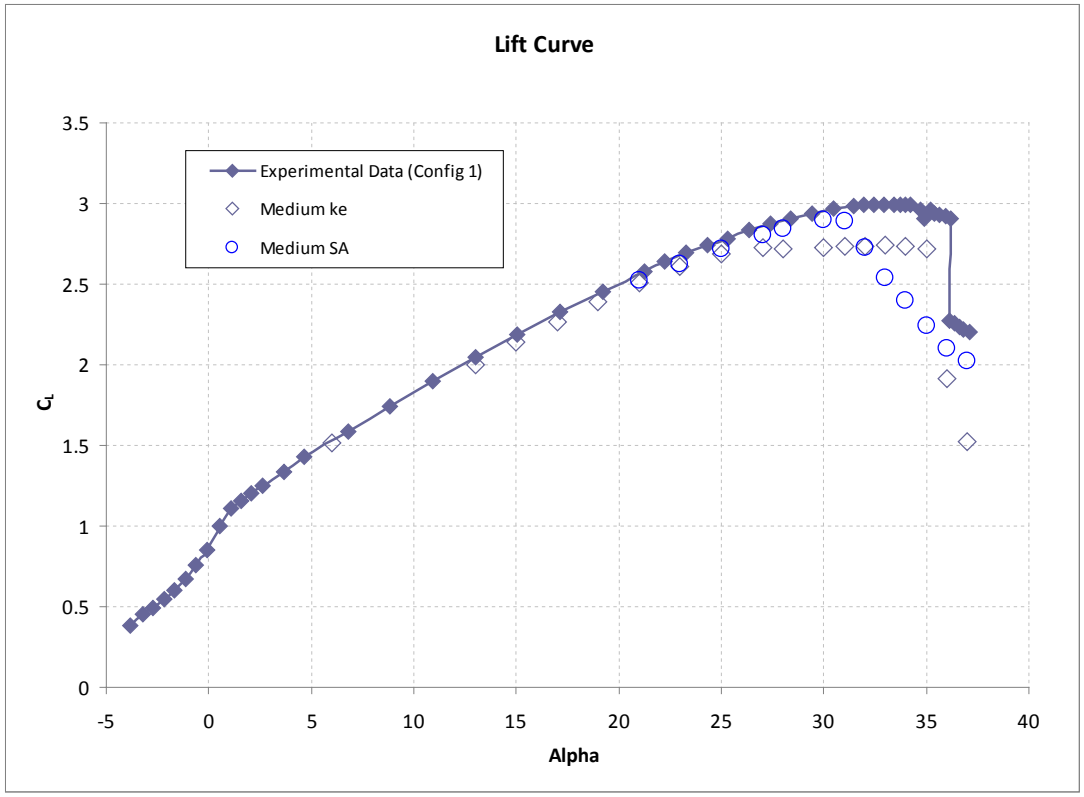
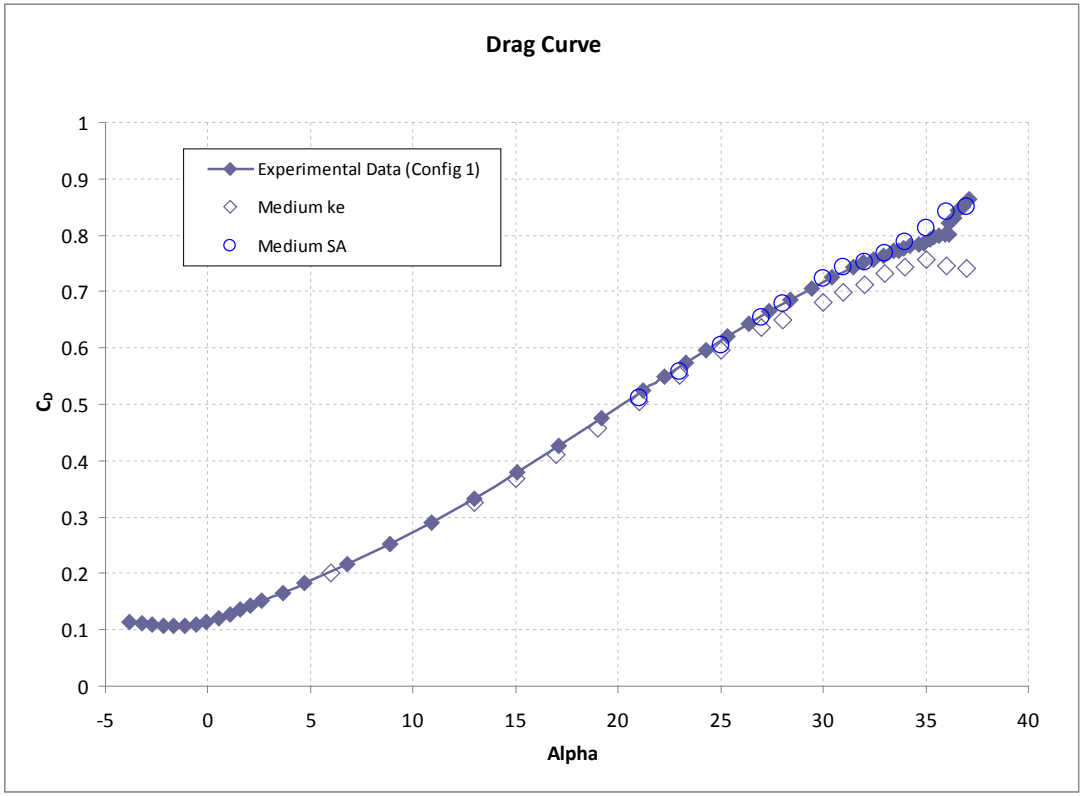




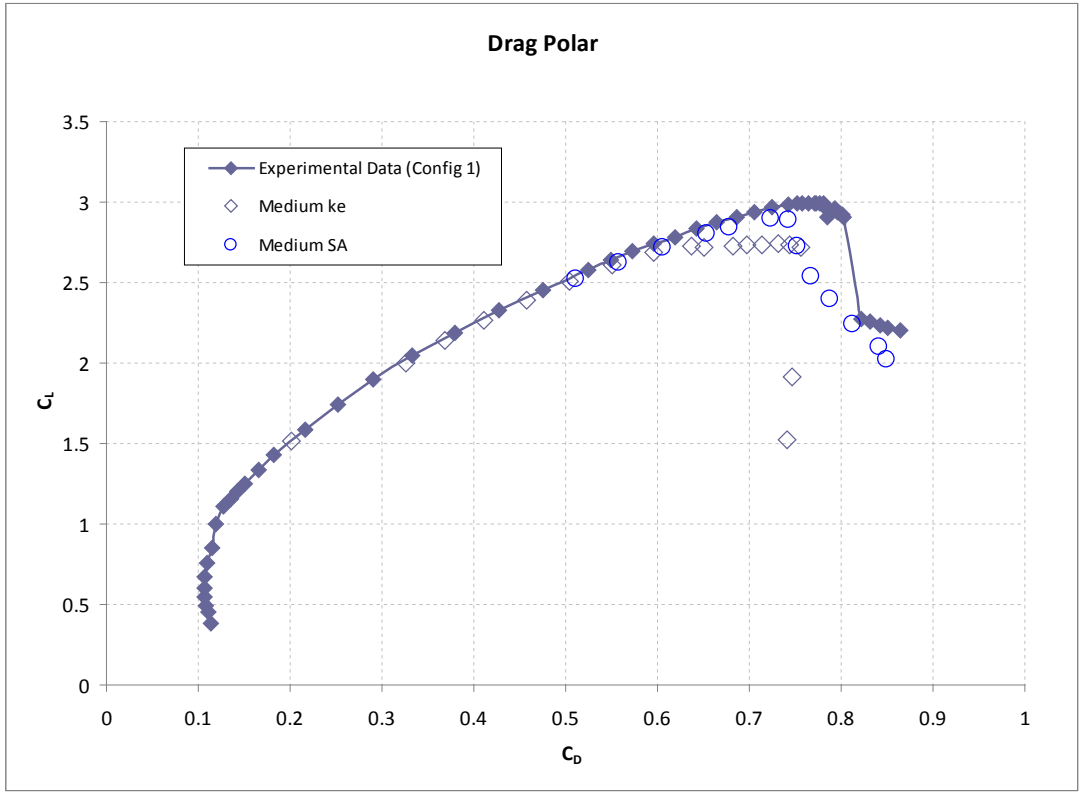
Turbulence Model Study



Turbulence Model Study



Turbulence Model Study



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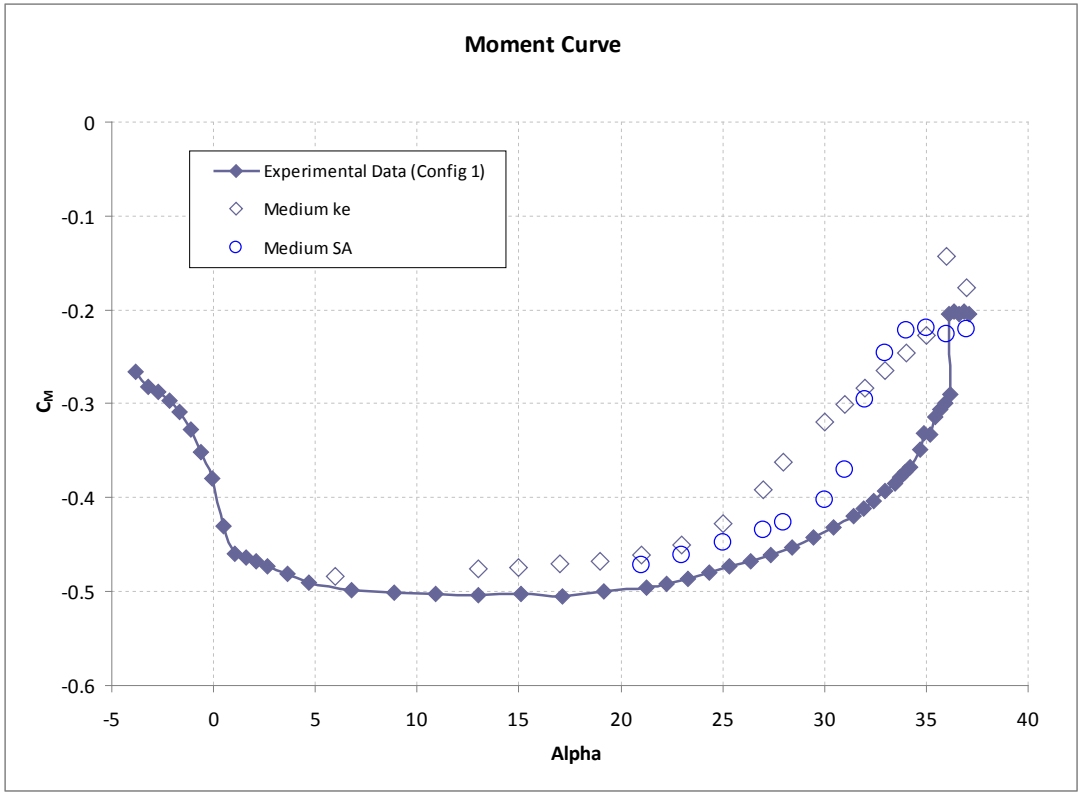
Turbulence Model Study



Summary

- Cooperative effort between Swift Engineering and BETA CAE Systems
- 100 Million cell limit is a very tight constraint for High Lift Prediction
- Solution was path dependent
  - Restart from previous alpha is preferable
- Solution was grid dependent
  - Improved correlation on revised grids
- Solution was turbulence model dependent
  - Realizable K-Epsilon Model under-predicted CLmax relative to Spalart Allmaras model on the same grid
  - Realizable K-Epsilon Model did a better job of predicting the stall angle than Spalart Allmaras on the same grid.
- Medium Grid level begins to accurately capture flow phenomenon
  - Flap Side of Body separation
  - Confluent Boundary Layers
- Grid convergence at lower angles was reasonable
- Grid convergence not achieved at angles close to CLmax

Conclusions on Revised Study

- Initial grid effort resulted in poor correlation with experimental data
  - Larger grids yet poorer convergence
  - Key areas too coarse (e.g., Leading Edge Regions)
- Revised grids showed better correlation with experimental data
  - Fewer prism layers
  - Refinement on the surface as well as Slat and Flap gaps
  - Lower cell count in Coarse and Medium grids
- Results still under-predicted CLmax region

Conclusions on Revised Study

- Grid refinement study emphasized importance of proper grid modeling to obtain good correlation
  - Results presented by Metacomp at the workshop using CFD++ on AIAA provided grids with the Spalart Allmaras turbulence model showed slightly better correlation with the experimental data than those obtained in this study with Spalart Allmaras
  - ➢ Further grid refinements could improve correlation
- Realizable K-Epsilon turbulence model was likely not the proper choice
  - Spalart Allmaras correlation was better than Realizable K-Epsilon
  - Metacomp's workshop results using CFD++ with the K-Epsilon RT model showed noticeably better correlation with the experimental data than the Realizable K-Epsilon results presented in this study
  - ➢ K-Epsilon RT model should be investigated

Proposed Future Work

- Run AIAA provided grids for comparison
- Refine grids further
- Investigate other turbulence models such as K-Epsilon RT