NUMERICAL SIMULATION OF NASA WING-TRAP MODEL AS A COLOMBIAN CONTRIBUTION TO THE HIGH-LIFT PREDICTION WORKSHOP

Jaime A. Escobar MEng.
Santiago Ramírez M.Sc.
Rodrigo A. Jiménez M.Sc.
Andrés M. Giraldo AE
Carlos Silva
Omar D. López Ph.D.
Nicolas Ochoa M.Sc.
Juan C. Mahecha GRA
Sebastián Leguizamón ME

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Outline

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3. Methodology
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Introduction

Universidad de Los Andes

- 2 professors, 1 undergraduate student, and 1 graduate student
- Research group in Computational Mechanics.
- Department of Mechanical Engineering
- Primary interests: Dynamics of turbulent flows.

Universidad de los Andes

Universidad de San Buenaventura

- 3 professors, 2 undergraduate students.
- Research group in Aerospace Technologies (AeroTech)
- Department of Aerospace Engineering
- Primary interests: CFD in Aerospace and Automotive applications; design and construction of low cost UAV.

UNIVERSIDAD DE SAN BUENAVENTURA SEDE BOGOTÁ

Introduction (Cont'd)

Motivation

- There is a growing interest in Colombia to develop a local aerospace and defense industry. Around 500 companies, academia and government are getting involved.

- Three universities are currently offering undergraduate programs in aerospace engineering and correlated professional development programs. Others have ongoing research projects in aerospace related problems.

- Special interests in:
  - building-up experience in applied computational aerodynamics.
  - testing our computational capabilities with world class problems.

- First time we participate in an AIAA workshop.

- Events such as the High-Lift and Drag Prediction workshops are valuable for sharing experiences around a common real-live problem.

Objectives

- Case 1 validation: 13° and 28° grid convergence study.
- Case 2 validation: 28°, 32°, 34° and 37° performance study.
- Evaluation of grid adaptation techniques, based on pressure and velocity gradients (Str-OnetoOne-D-v1 grid).
- Evaluation of region grid adaptation techniques for hybrid turbulence models (Str-OnetoOne-A-v1 grid).

Methodology

Experimental Data

- Model configuration 1: three element wing with flap and slat deployed 30° and 25° respectively.
- Aerodynamic forces, moments and pressures obtained in the NASA Langley 14ft x 22ft wind tunnel.
- Flight conditions set to Mach number 0.2, angle of attack varied from -4° to 37° and Reynolds Number base on MAC equal to $4.3x10^6$.
- Pressure tabs mounted over the upper surfaces of the wing at several locations.

Methodology (Cont'd)

Grids Used and Solver

Srt OnetoOne A-v1 (StrA)

Created by: Boeing – Huntington Beech

Extra coarse:	5.96 M
Coarse:	20.1 M
Medium:	47.6 M
Fine:	160.8 M

ANSYS FLUENT v13
Solver: Coupled, pressure based
Gradient: Green-Gauss Node based
Pressure velocity coupling: Coupled
Spatial discretization: Second order
Explicit relaxation factors: Default

Transient Formulation: First order implicit (DES model)

Srt OnetoOne D-v1 (StrD)

Created by: RAUG and CFS Engineering

Coarse:	5.99 M
Medium:	19.96 M
Fine:	47.9 M

ANSYS FLUENT v13
Solver: Segregated, pressure based
Gradient: Green-Gauss Node based
Pressure velocity coupling: SIMPLEC
Spatial discretization: Second order
Under-relaxation factors: Default

Methodology (Cont'd)

Adaptation approach:

StrA:

- For the DES turbulence model a region adaptation was performed in the near wake field (Departure region).
- A filter size of approximately 0.05m was obtained in the adapted region. However, isotropic mesh was not achieved.

StrD:

- Large pressure gradients base on p+, where:

$$p^+ = \frac{\nu}{\rho u_\tau^3}\frac{\partial P}{\partial x} \geq 0.05$$

- Values of pressure gradient parameter above 0.05 are located close to regions where pressure and velocity gradients change rapidly.
- Local refinement was performed with the solution-adaptive feature of ANSYS FLUENT, based on gradient and curvature approach.

Methodology (Cont'd)

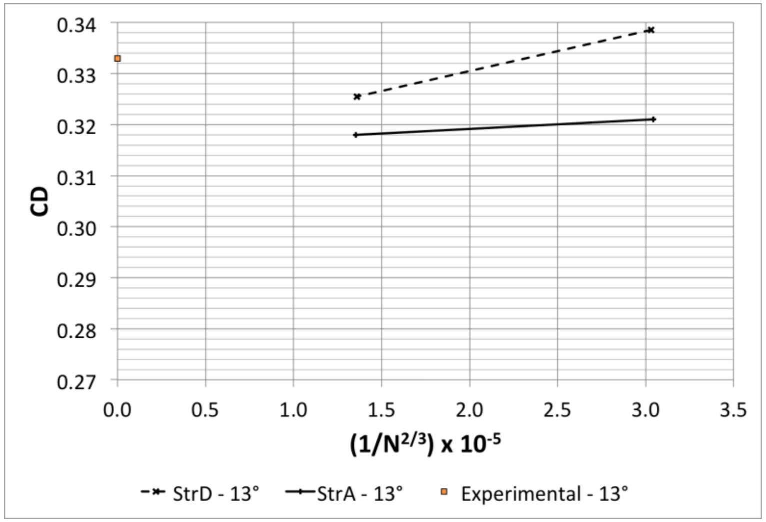
Cases:

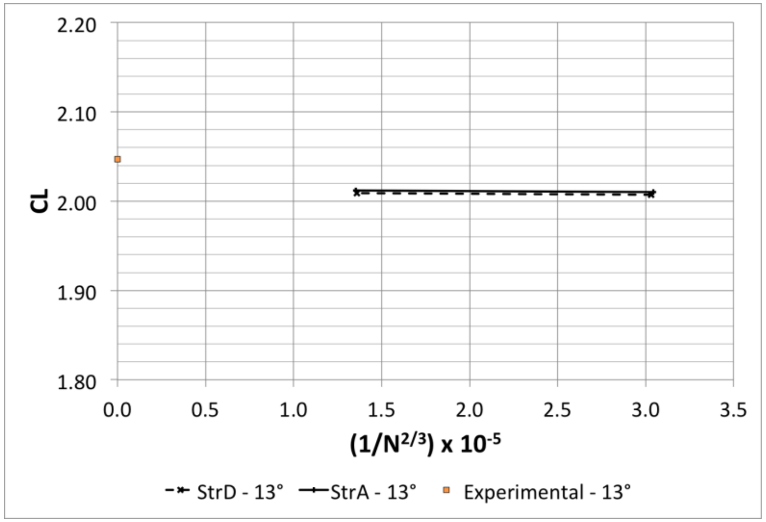
Mesh	Size	Simulated angles of attack
	Extra-coarse	13^o, 28^o, 32^o, 34^o, 37^o and 40^o
Str-OnetoOne-A-v1	Coarse	13^o, 28^o, 32^o, 34^o and 37^o
	Adapted	34^o, 36^o, 37^o and 40^o
	Coarse	13^o, 21^o, 28^o, 32^o, 34^o and 37^o
Str-OnetoOne-D-v1	Medium	13^o, 21^o, 28^o, 32^o, 34^o and 37^o
	Adapted	32^o, 34^o and 37^o

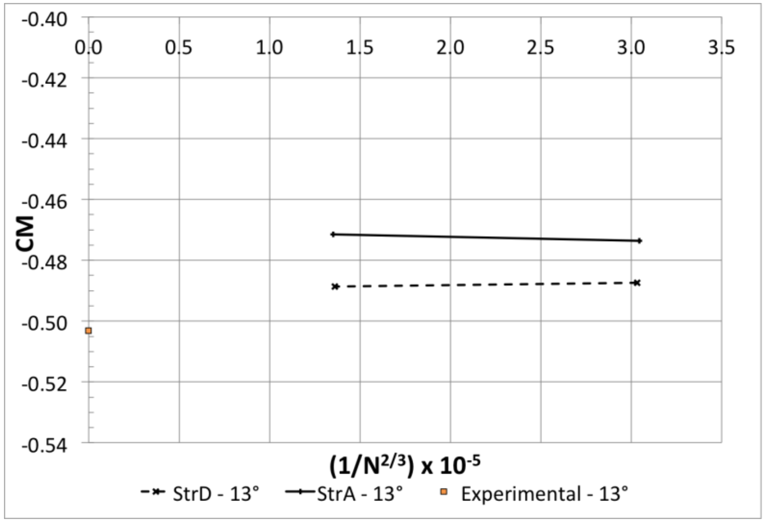
Total number of sumulations: 30

Results

Grid Convergence Study (Case 1 HLPW)



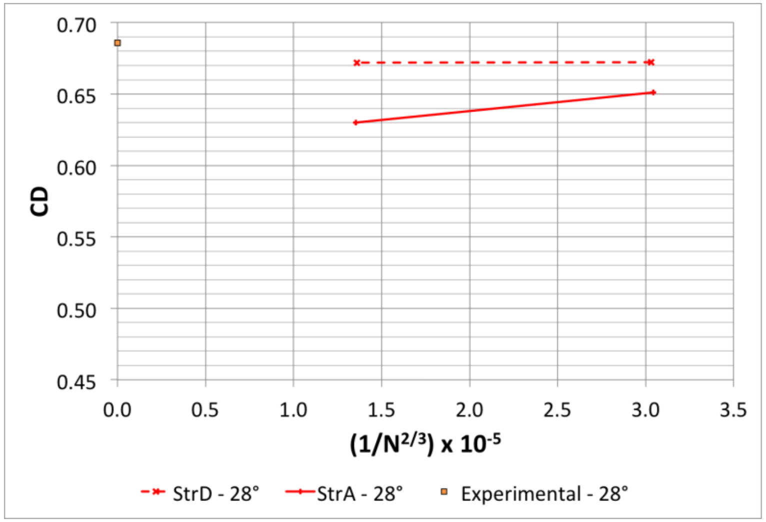


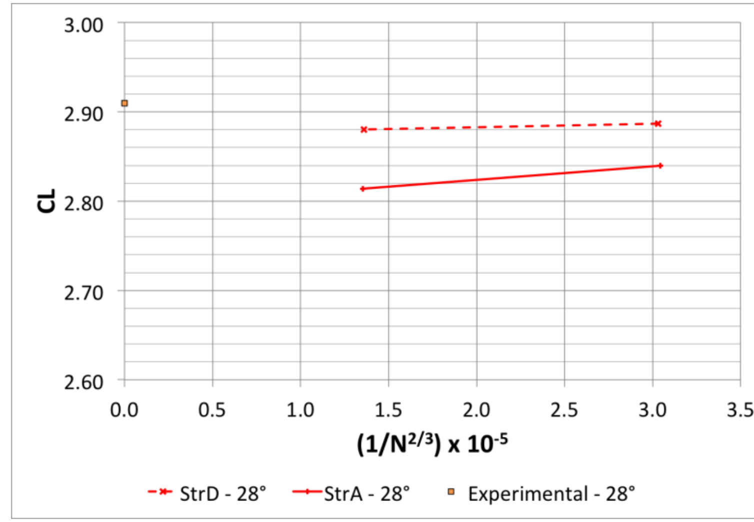


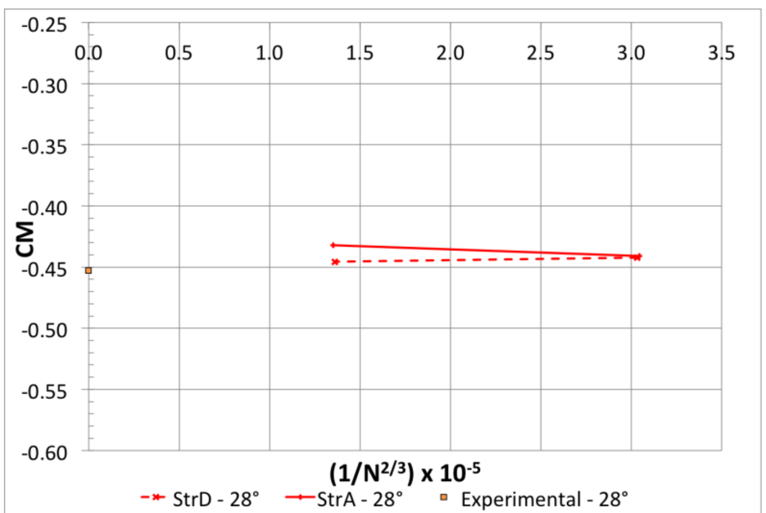
- Due to limitations in computational resources, finer meshes (50M) were not simulated.
- If solutions are in the asymptotic region, StrA tends to converge to CD=0,3156, CL=2,0141, CM= -0,4696.
- StrD tends to converge to CL=2,0136 CD=0,3149, CM= -0,4898

Results (Cont'd)

Grid Convergence Study (Case 1 HLPW)



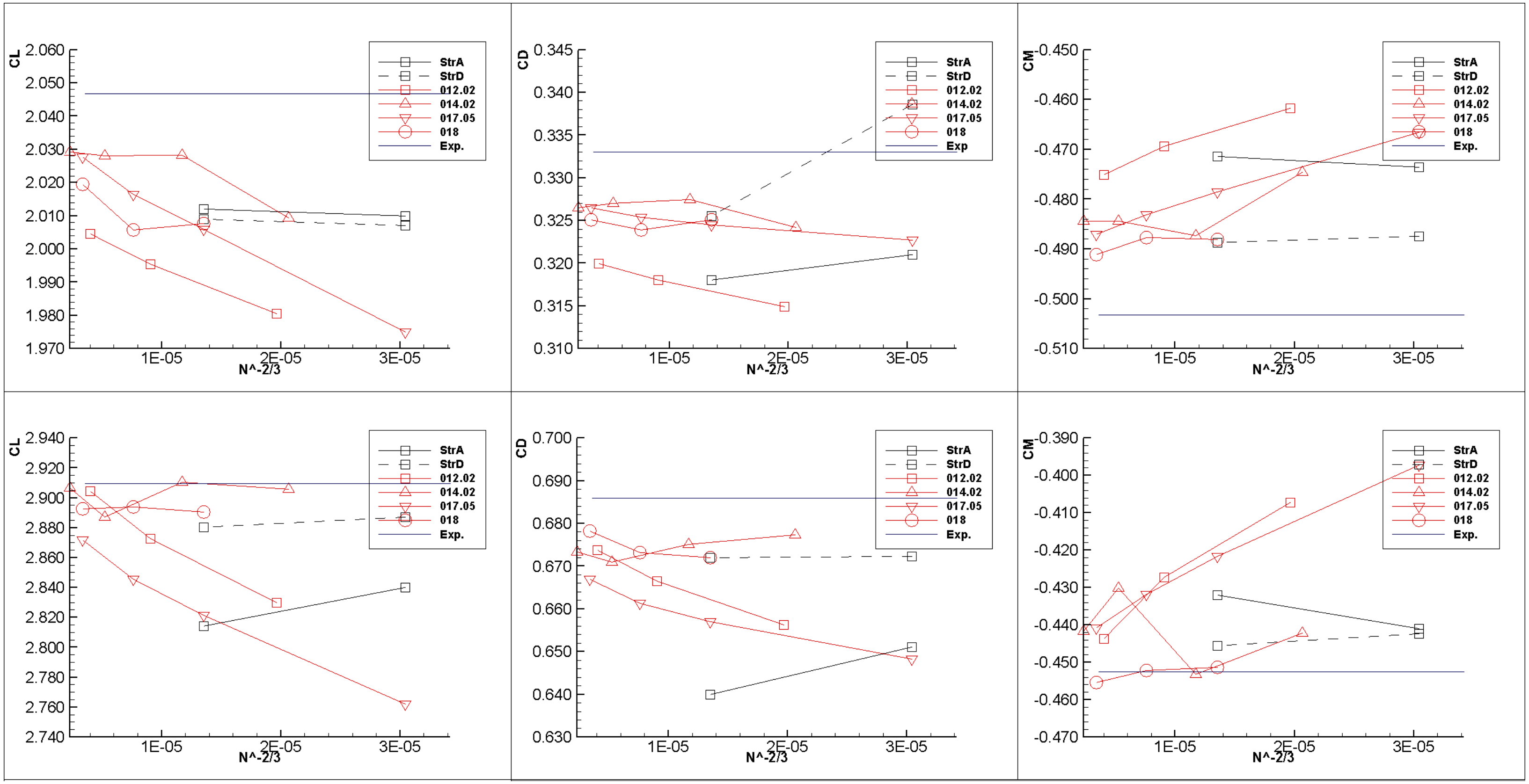




- If solutions are in the asymptotic region, StrA tends to converge to CD=0,6132; CL=2.7932; CM= -0,4248
- StrD tends to converge to CL=2,8749; CD=0,6718; CM= -0.4483.

Results (Cont'd)

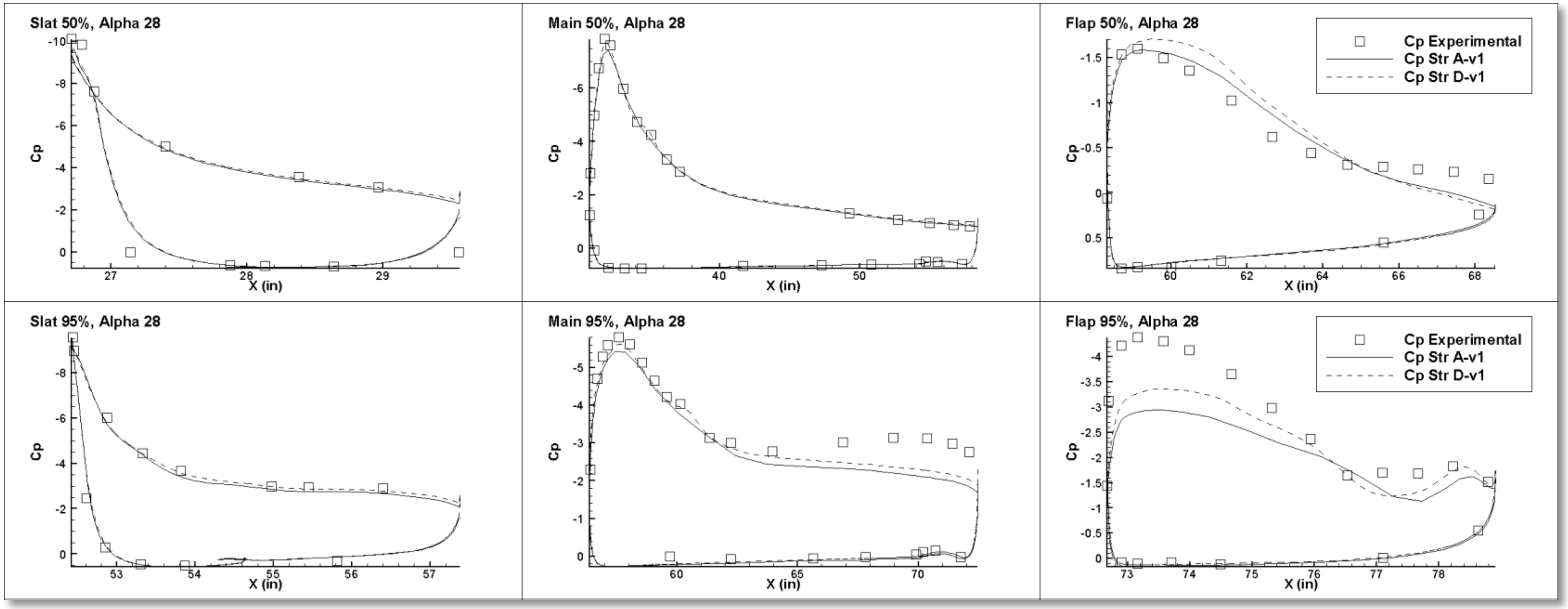
Where are we?



Information taken from HiLiftPW-1

Results (Cont'd)

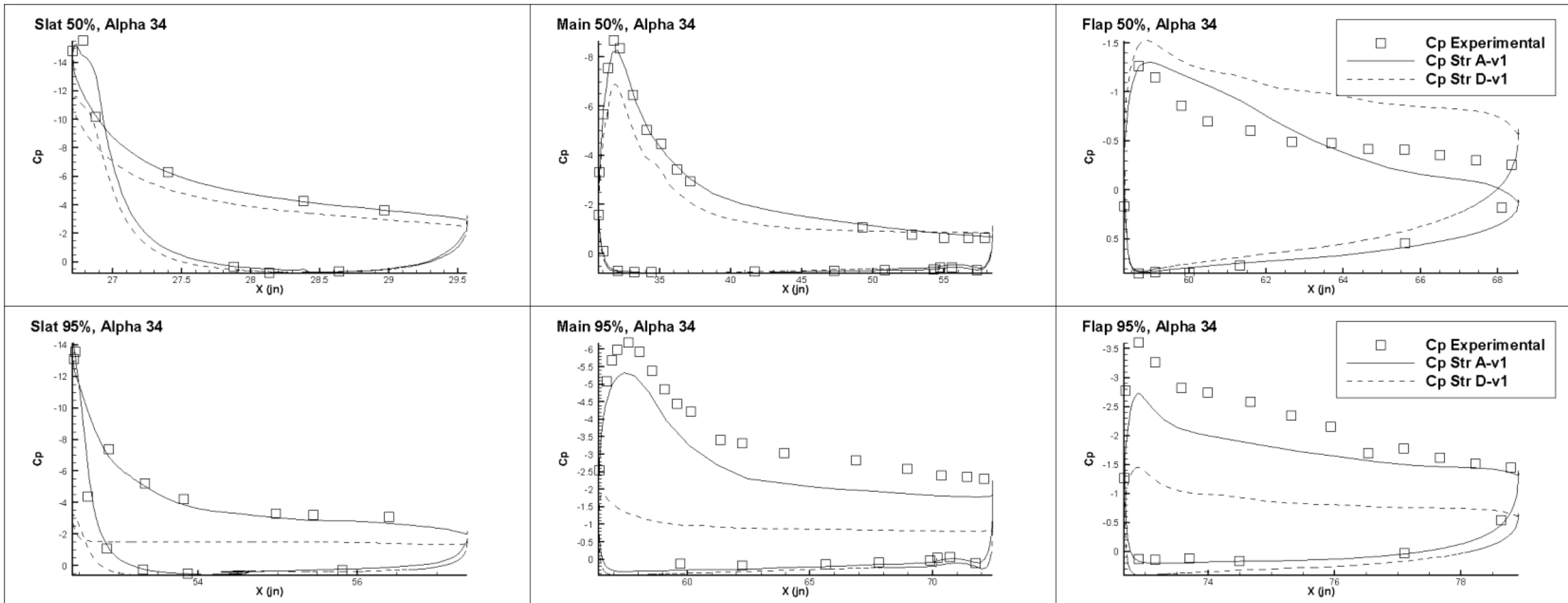
Alpha 28 – 6M Grids (Case 2 HiLiftPW-1)



- Fairly good prediction on the slat
- Good over the main element except towards the trailing edge
- Not well predicted on the flap, in special for stations close to the wing tip.

Results (Cont'd)

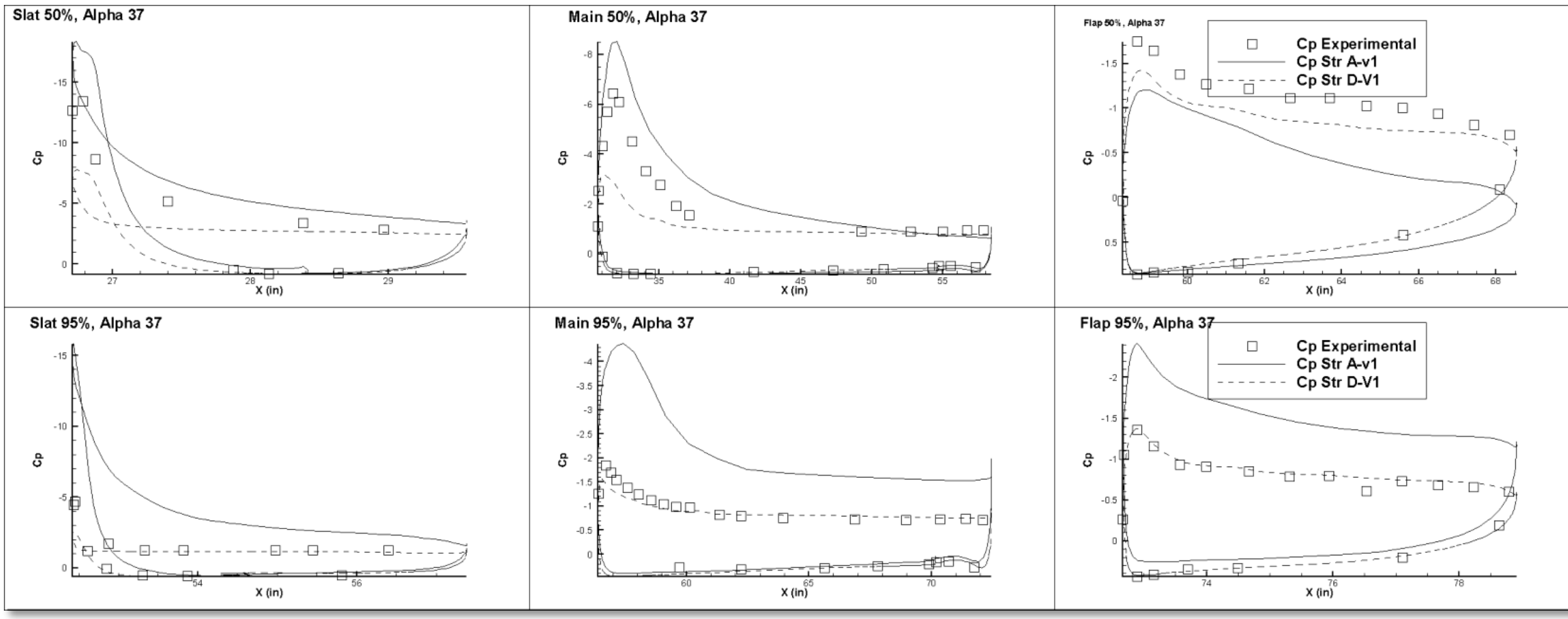
Alpha 34 – 6M Grids (Case 2 HiLiftPW-1)



- Solver failed to predict Cp in the StrD mesh and stall occurred earlier than expected.
- The solver did a better job with the StrA mesh.
- Prediction still fails at stations close to the wing tip

Results (Cont'd)

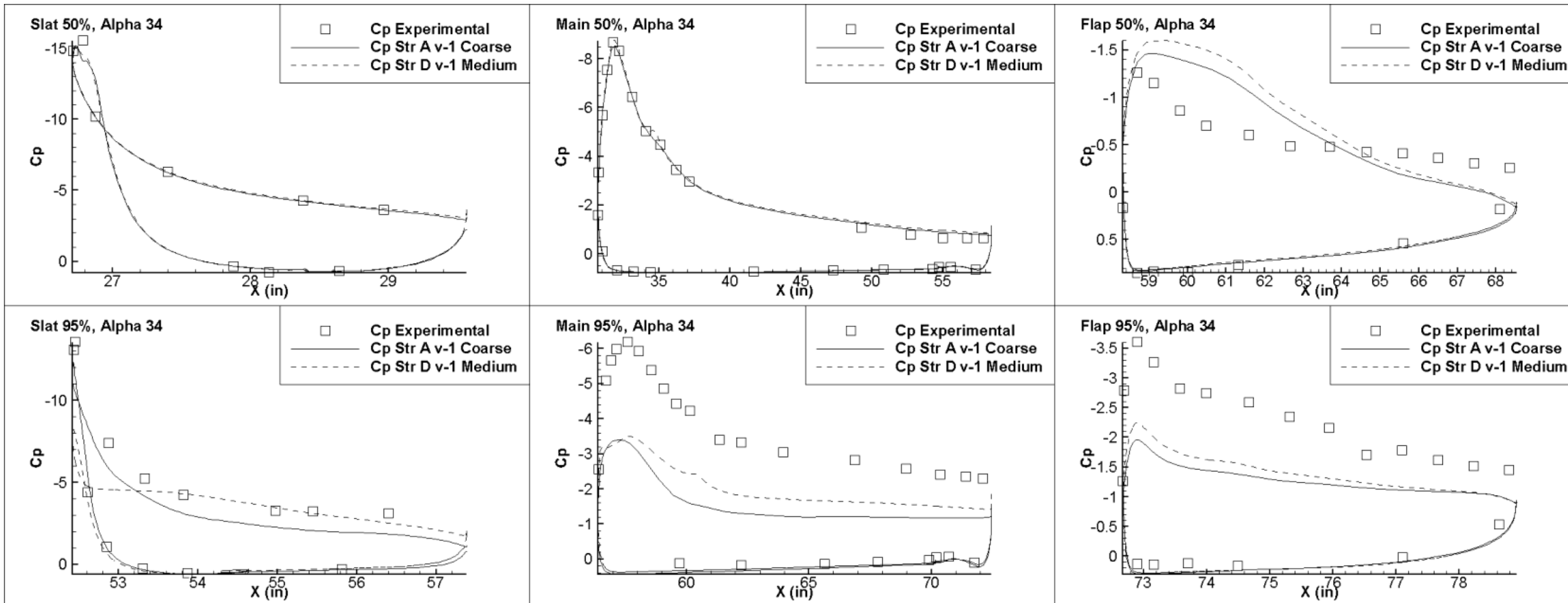
Alpha 37 – 6M Grids (Case 2 HiLiftPW-1)



- Cp was better predicted in the StrD grid than in the StrA grid.
- The solver fails to predict stall in the StrA mesh.

Results (Cont'd)

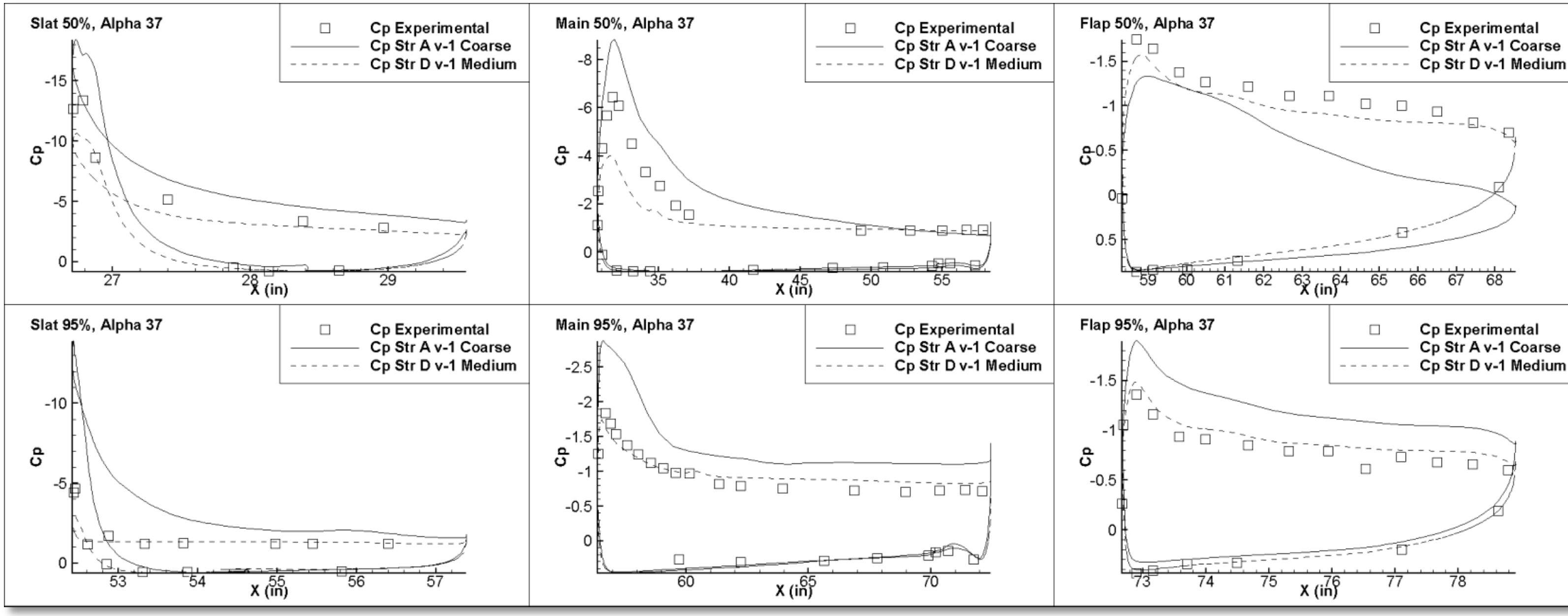
Alpha 34 – 20M Grids (Case 2 HiLiftPW-1)



- There are not significant differences in Cp prediction between the 6M and 20 Grids for 13° and 28° angles of attack (see paper).
- Grid refinement improves Cp predictions.
- The 20M StrA mesh has similar performance than the 6M mesh.

Results (Cont'd)

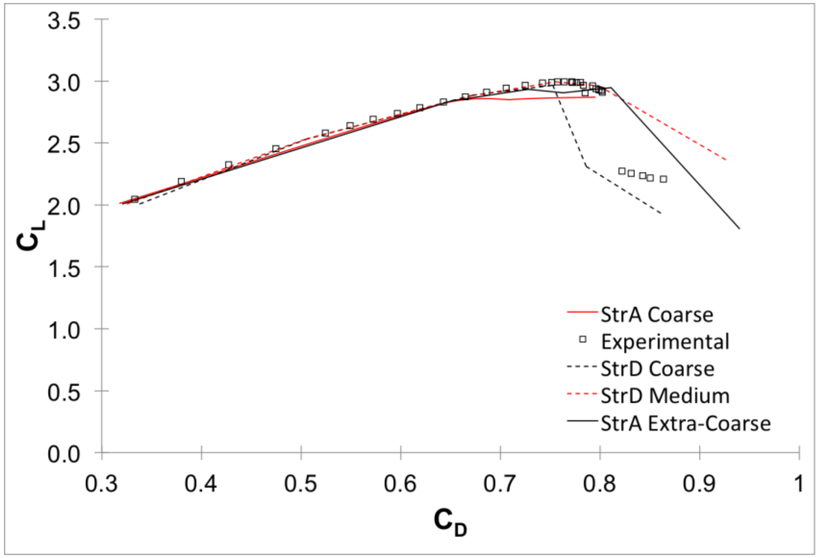
Alpha 37 – 20M Grids (Case 2 HiLiftPW-1)

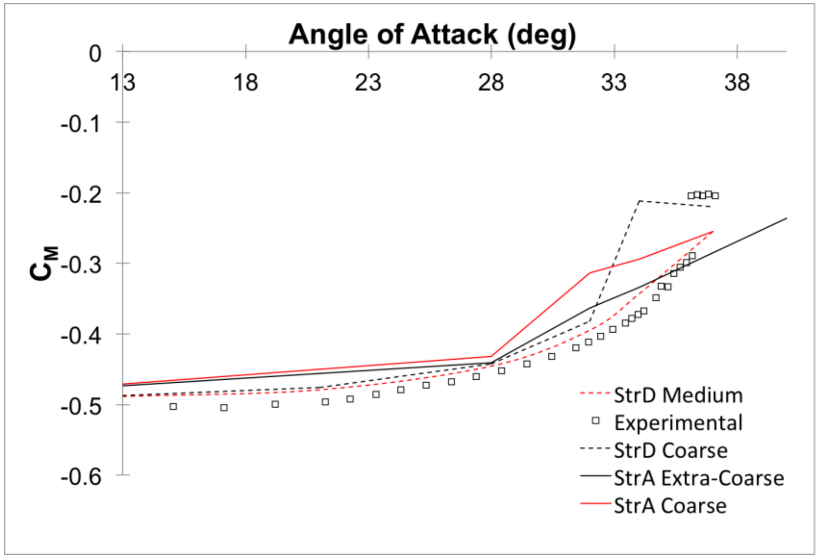


- StrA mesh still over predicts the Cp distribution. Cp prediction improves particularly close to the wing tip.
- The 20M StrD mesh has similar performance than the 6M mesh.

Results (Cont'd)

Aerodynamic Coefficients

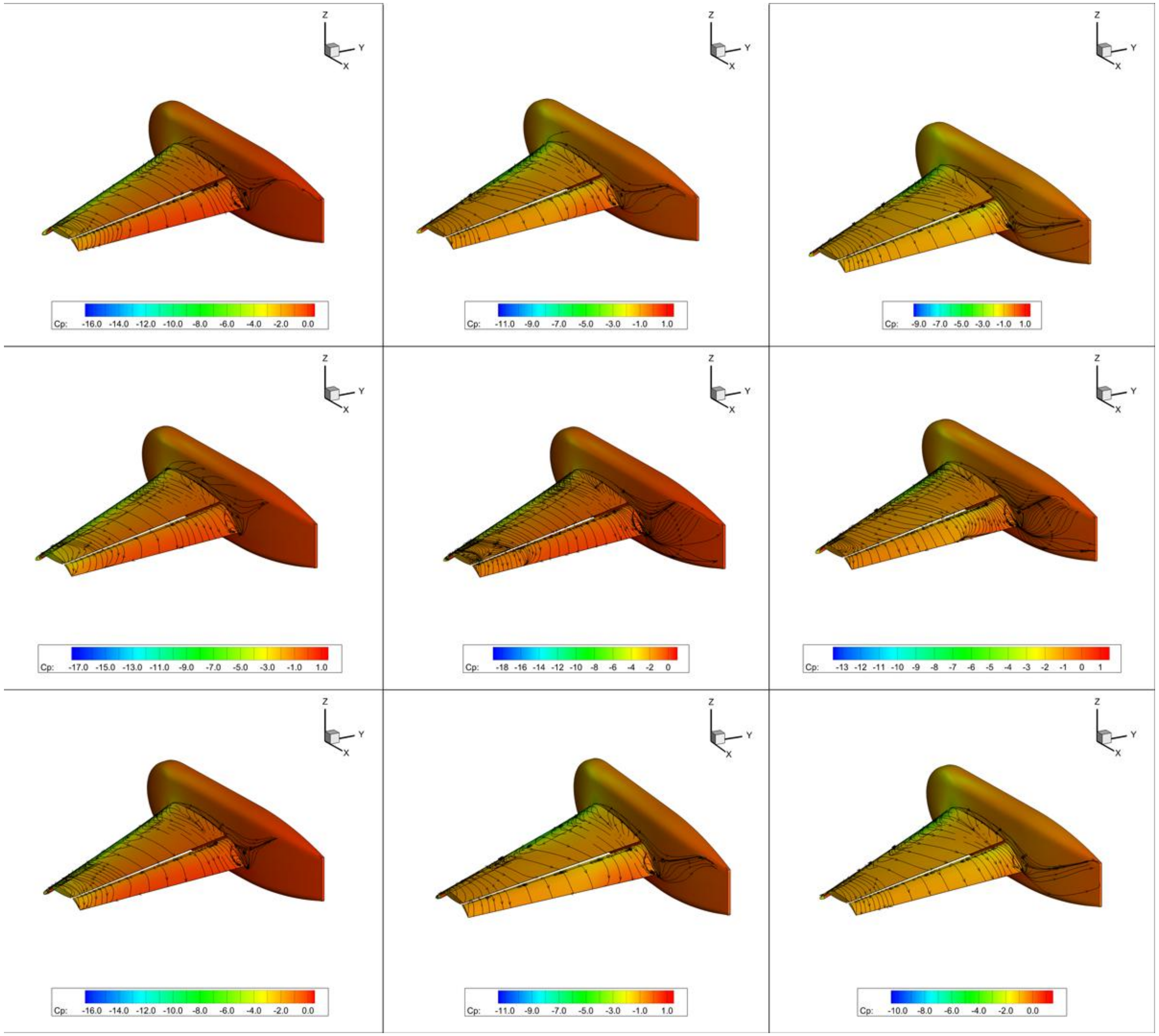




- StrA meshes failed to predict the stall (40° AoA).
- Both StrD meshes have similar prediction of CL except for CLmax.
- CL and CM is under predicted for all cases (turbulence model).
- Even though Cp distribution for the coarse version of StrA mesh was improved with refinement, CL prediction did not.
- More resolution is required in the CL curve close to CLmax

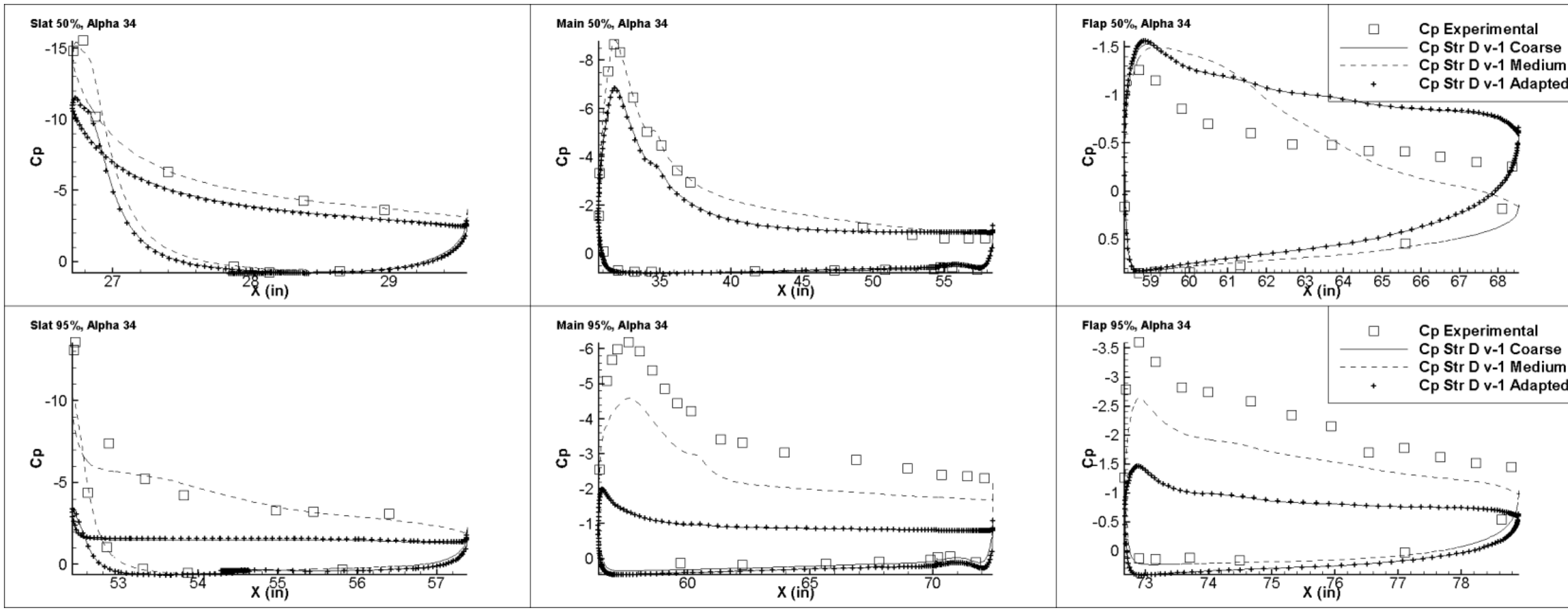
Results (Cont'd)

Flow Visualization – SOB separation



Results (Cont'd)

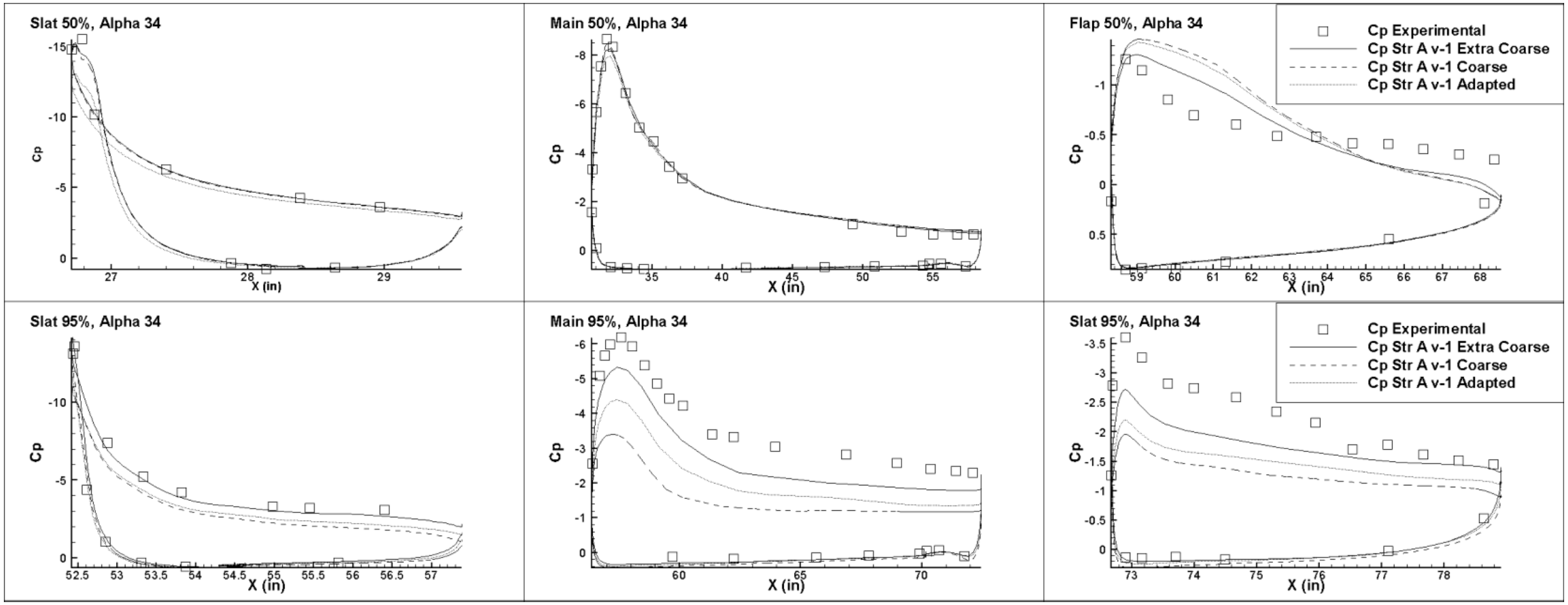
Local Grid Adaptation Based on Flow Solution



- There was not a significant improvement in the prediction of Cp at 34 degrees angle of attack.
- Probably mesh adaption over the surface has to be included.
- More adaptation steeps need to be performed in order to improve Cp prediction.

Turbulence modeling

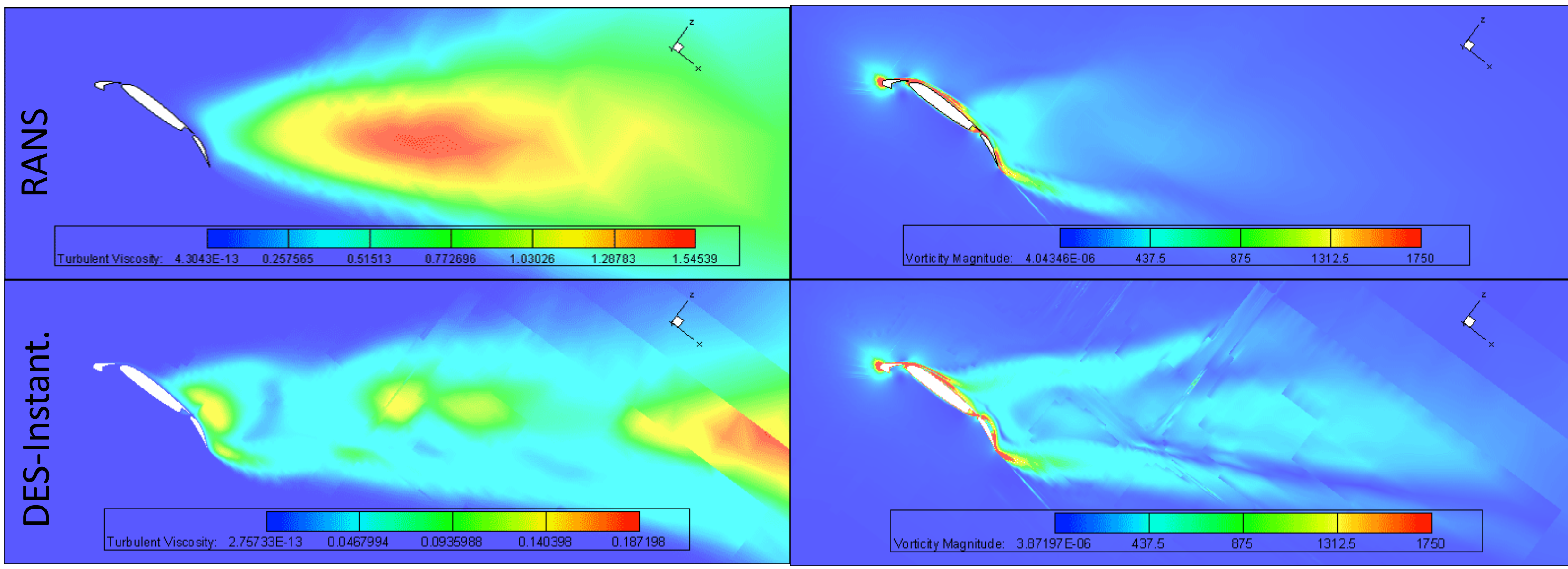
Local Grid Adaptation for DES



- Significant improvement in Cp prediction for a small increment in computational resources (6M to 7M).
- Still, the solver fails to predict stall at 37° angle of attack.

Turbulence modeling (Cont'd)

Flow variables at 85%



- A reduction of magnitude of the turbulence viscosity was observed in the wake of the wing.
- Change in vortical structures were observed in the near wake.
- "Better" prediction of the flow dynamics. Aerodynamic performance did not improve.
- Evidence of activation of the LES mode of DES .

Conclusions

- A Colombian contribution for the HiLiftPW was presented with satisfactory results given the limitation of computational resources.
- Two structures meshes (StrA and StrD) were compared with experimental data using ANSYS FLUENT v13 as the NS solver.
- No final conclusion of convergence study since numerical results of at least one more finer mesh is needed.
- Predicted aerodynamic coefficients (for 13° and 28°) are in good agreement with other HiLiftPW1 participants using SA model on structured grids.
- Overall, predictions with the StrD mesh were better than the predictions of the StrA mesh.
- StrD coarse mesh predicted stall conditions at 32°. This was overcome with grid refinement.
- StrA meshes did not predicted stall conditions lower than 37°. Simulations for 40° with these meshes did predict stall.
- Local grid adaptation techniques for the StrD coarse mesh did not show improvements in the prediction of aerodynamic properties
- Region grid adaptation + DES model (for the extra coarse StrA mesh) show some improvement in the flow dynamics and turbulent vorticity field. Cp predictions (wing tip) improved at low computational cost increment.

Future Work

- Increase our computational resources to run finer meshes (i.e. between 50M and 80M cells).
- Implement the Spallart-Almaras model with Rotation/Curvature Correction.
- More postprocesing of the obtained solutions in order to visualize other flow properties (streamlines, vorticity field/isosurfaces, separation/reattachment lines, pressure coefficient over the forward flap in the span wise direction).
- Implement more steps in the local adaptation technique based on the solution variables.
- Submit solution data to the HiLiftPW committee.

- Look forward to participate in the HiLiftPW-2.
- Generate our own grids?
- Test other NS solvers? (i.e. OpenFoam)

References

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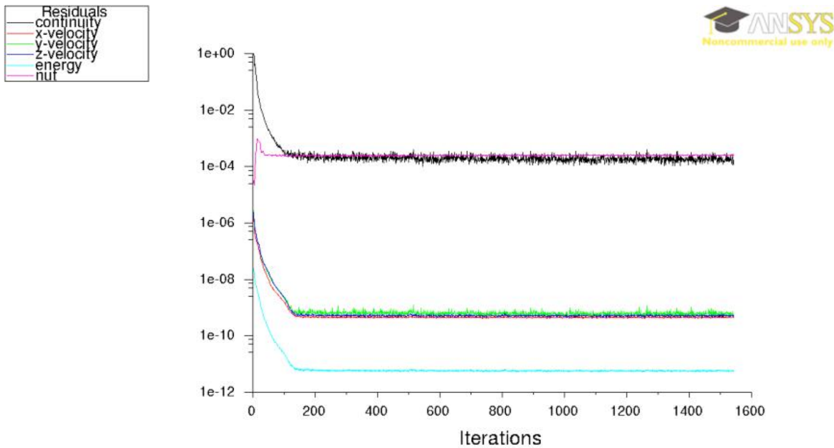
- Spalart, P. R., "Young-Person's Guide Simulation Grids," Tech. rep., National Aeronautics and Space Administration, 2001.

Thank you!

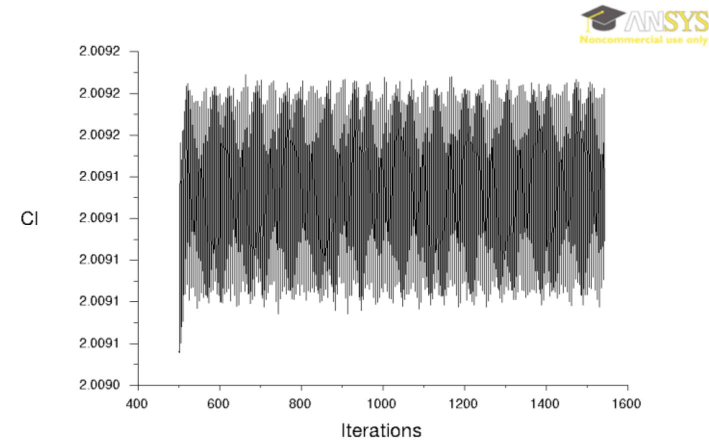
Questions?

Convergence



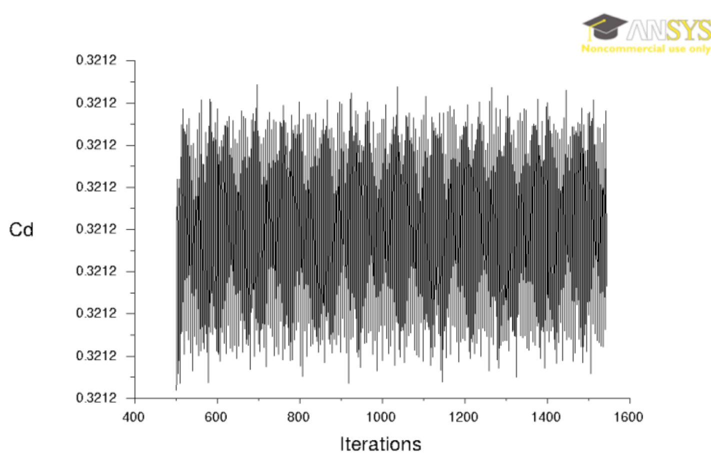
Scaled Residuals

Jun 24, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, S-A)



Lift Convergence History

Jun 24, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, S-A)



Drag Convergence History

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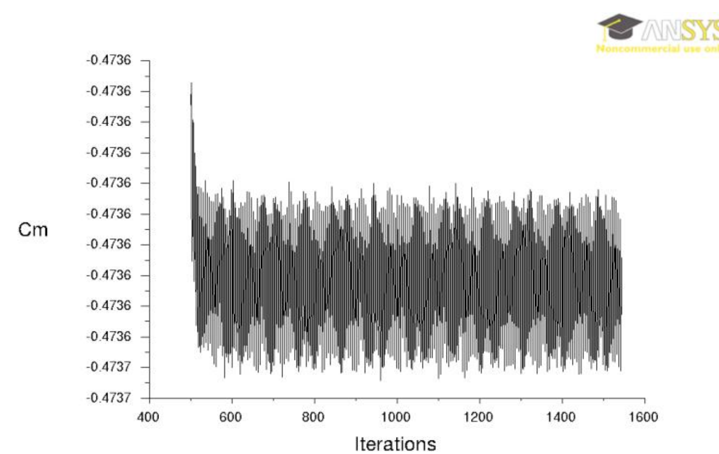

Moment Convergence History About (0 1 0)

Jun 24, 2012
ANSYS FLUENT 13.0 (3d, dp, pbns, S-A)

Computational Resources and Cost

Universidad de Los Andes

- HPCC with 128 compute nodes.
- 160Gb shared memory RAM.
- 12 Tb of storage capacity.
- OS is ROCKS Cluster V5.4 with Linux CentOS.
- Typical wall clock per 1000 iterations: 8hr

Universidad de San Buenaventura

- Two Dell Precision T5500 Workstations
- Quad Core Intel Xeon E5606
- 48Gb memory RAM
- OS is Windows 7.
- Typical wall clock per 1000 iterations: 12 hr.