LAVA Simulations for the 3rd AIAA CFD High Lift Prediction Workshop with Body Fitted Grids

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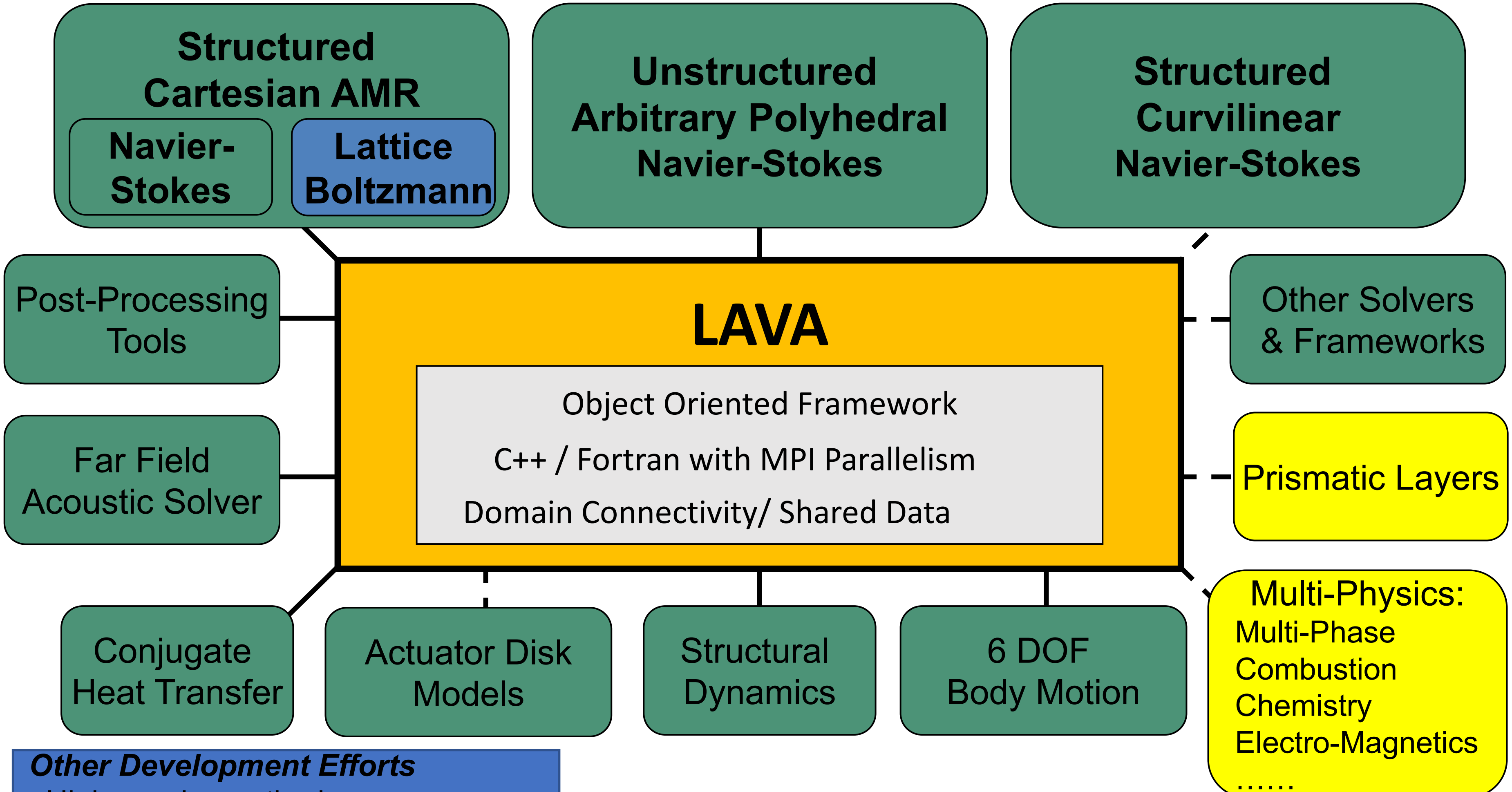
Outline

- Introduction
  - Workshop Introduction
  - Flow Solver and Methodologies
- Test Cases
  - 2D DSMA661 Model A Airfoil
  - High Lift Common Research Model
  - JAXA Standard Model
- Summary

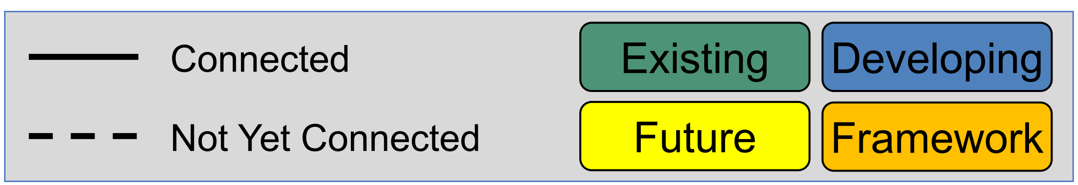
Workshop Introduction

- 3rd Workshop in the High Lift Prediction series
- Took place the weekend prior to AIAA Aviation 2017 in Denver Colorado (June 3-4)
- Objectives
  - Assess the prediction capability of current generation CFD codes for conventional high-lift configurations
  - Identify areas where improvements could be made to enhance predictions
- Geometries and Test Case
  - 2D DSMA661 Model A (2D Airfoil) ← Test Case 3
  - High-Lift Common Research Model (HL-CRM) ← Test Case 1
  - JAXA Standard Model (JSM) ← Test Case 2

Launch Ascent and Vehicle Aerodynamics Framework (LAVA)



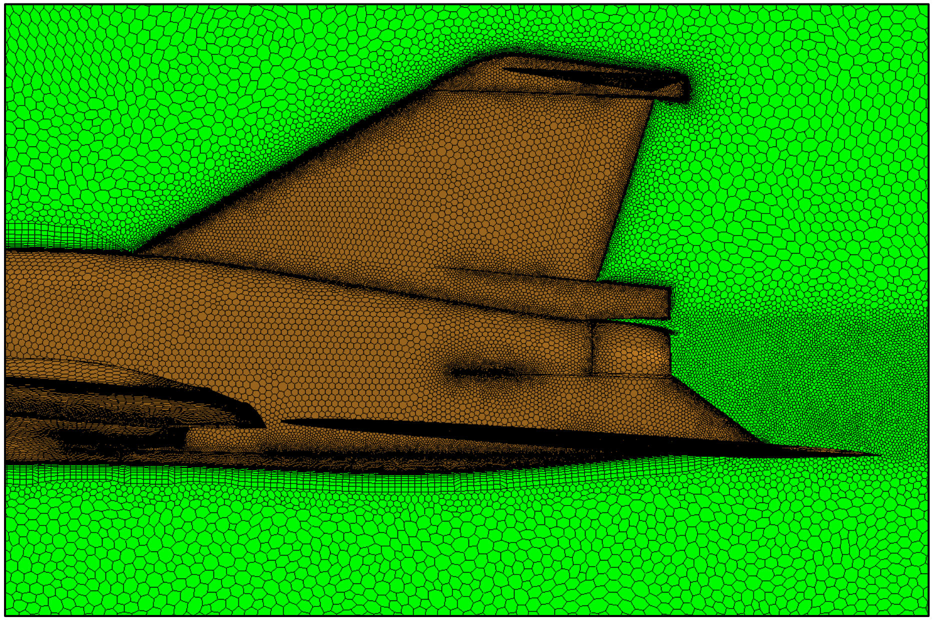
Other Development Efforts
- Higher order methods
- Curvilinear grid generation
- Wall modeling
- LES/DES/ILES Turbulence
- HEC (optimizations, accelerators, etc)

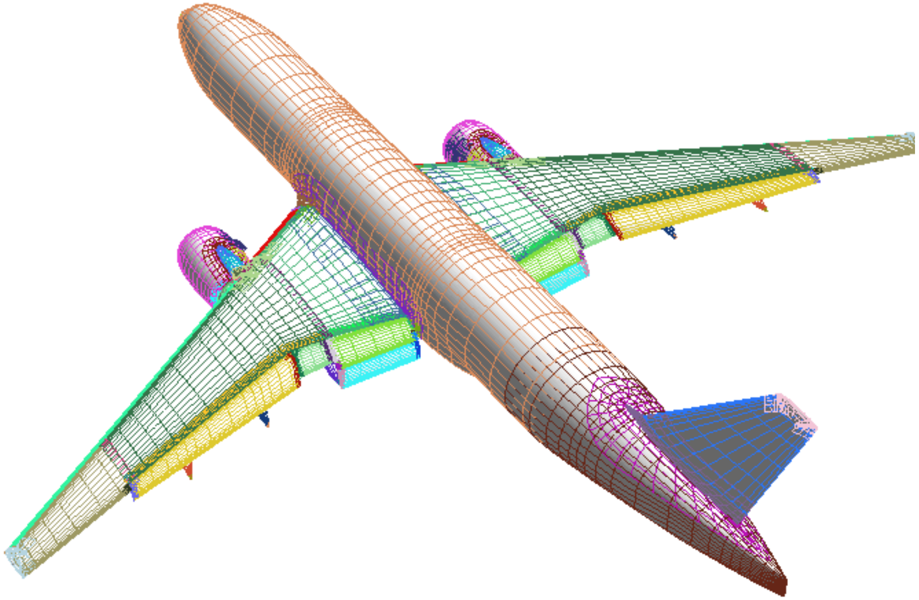


Kiris at al. AST-2016 and AIAA-2014-0070

LAVA Solver Details

Unstructured Arbitrary Polyhedral	*Structured Curvilinear*





Unstructured Arbitrary Polyhedral

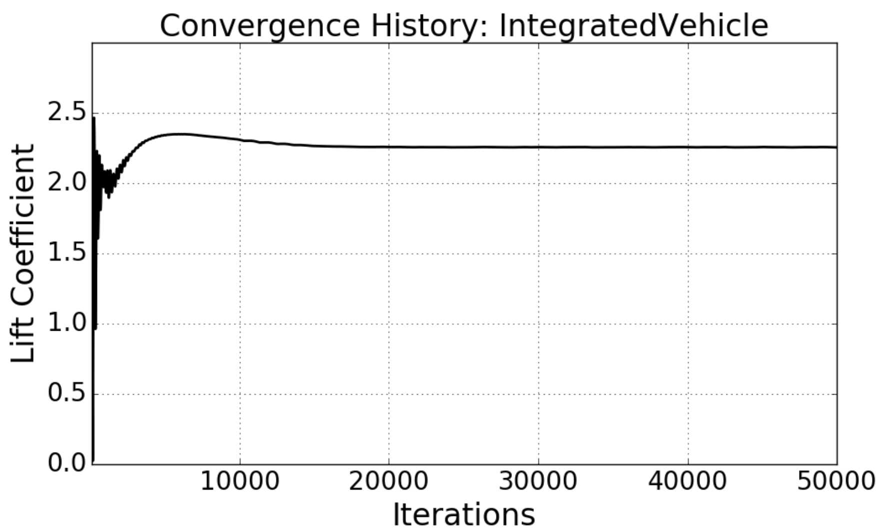
- 2^{nd} order cell centered
- MUSCL Scheme
- AUSMPW+ convective flux function
- BDF2 with GMRES linear solver (PETSc)
- SA turbulence model with RC and QCR-2000
- Case 3 & Case 2

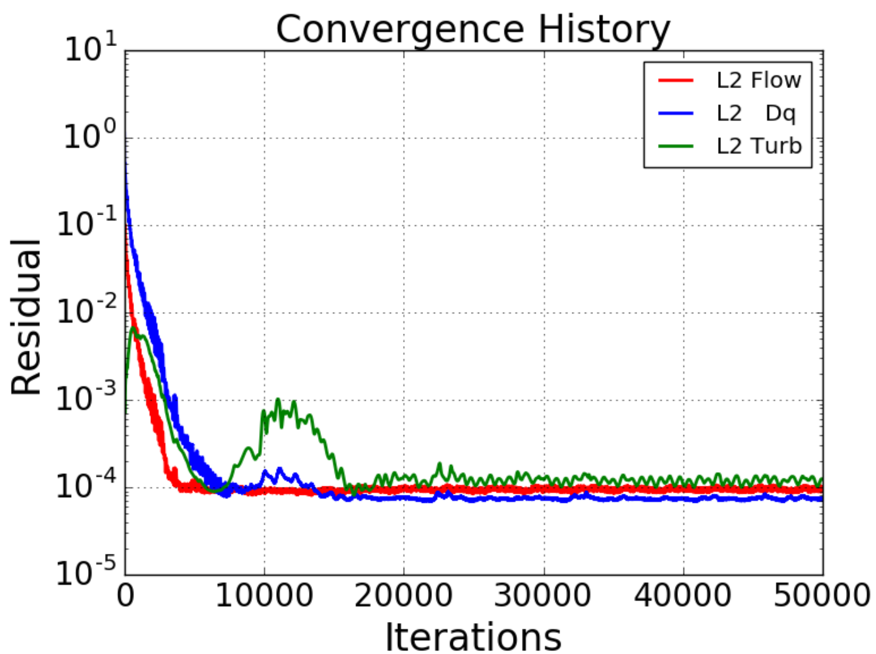
Structured Curvilinear

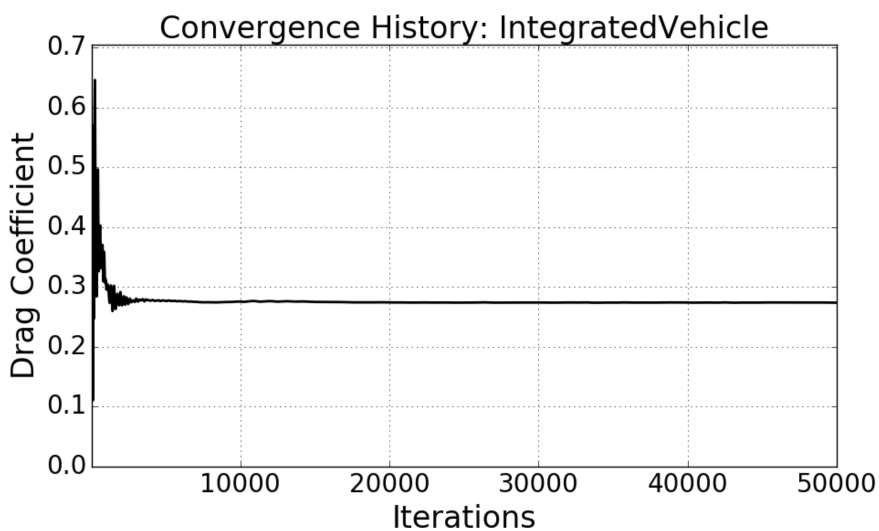
- 2^{nd} order accurate Modified Roe Flux Difference Splitting for the convective terms
- 2^{nd} order central differencing for the viscous terms
- SA turbulence model for all cases and with RC and QCR-2000 for select cases
- All Cases

Convergence Criteria

- Cases were considered to have converged once the standard deviation of the drag coefficient from the last 1000 iterations of the simulation was within a tenth of a drag count







Plots are from a simulation done for Case 2

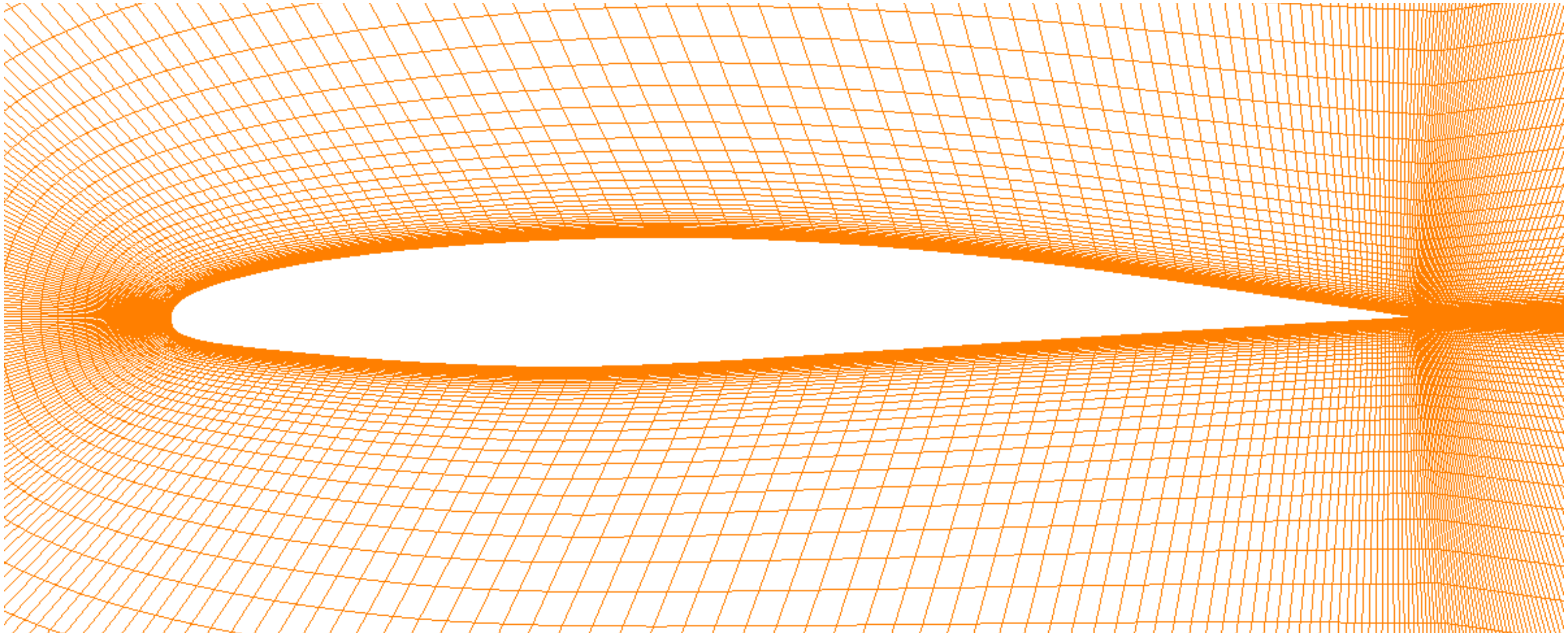
Test Case 3 (2D Airfoil): Introduction

- Case was taken directly from the Turbulence Modeling Resource
- Goal was to compare the data from the simulations with the published data on the website to verify the turbulence model implementation
  - Used a mesh refinement study to compare the convergence behavior of the lift and the drag
  - Compared to experimental wake profiles

Quantity	Value
Mach Number	0.088
Alpha	0°
Reynolds Number Based on Chord	1.2 Million
Reference Static Temperature	540°R

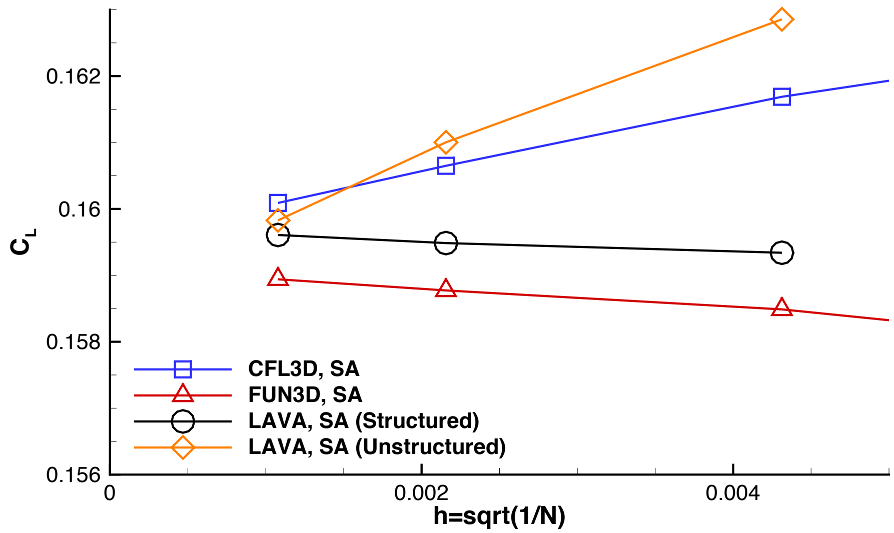
Test Case 3: Mesh Generation

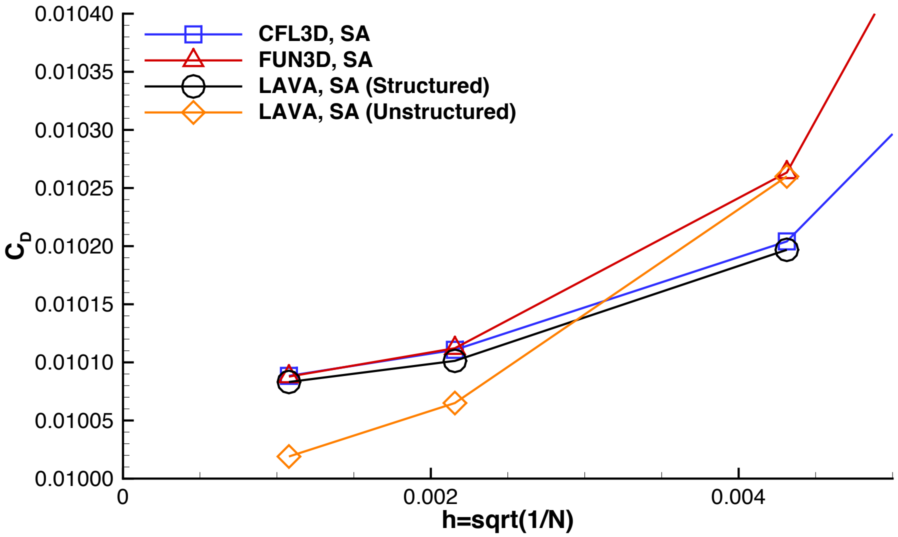
- Structured Grid
  - Downloaded the 2D PLOT3D mesh family
  - 2D mesh was converted into a 3D mesh by extruding the airfoil grid in the span directions



- Unstructured Grid
  - Utilized the 2D CGNS grids without any modifications

Case 3: Force Comparison

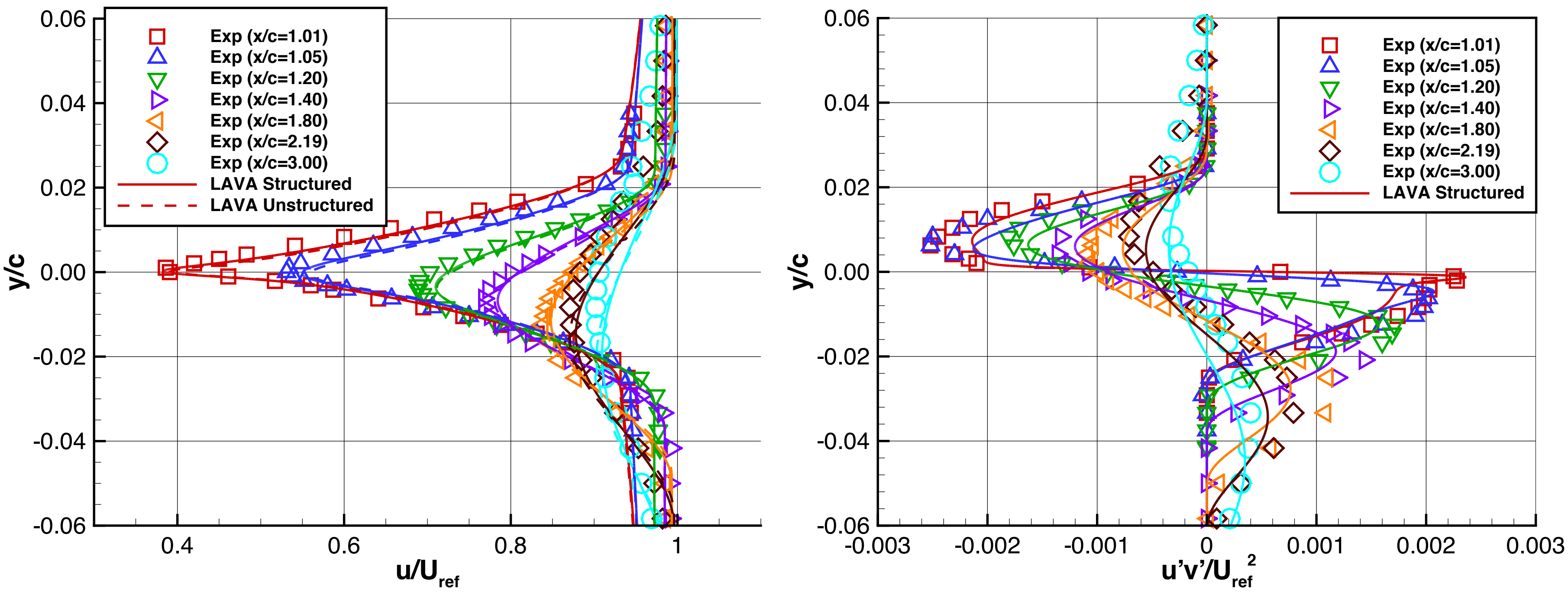




- Lift is converging with mesh refinement for both solvers
- Structured solver is converging to a drag value similar to CFL3D and FUN3D but the unstructured is under predicting the drag by about 1 count
- Difference in the drag is being caused by a cell skewness issue in the viscous layers of the grid. This issue was discussed in more depth in the summary paper written by Ashton et al.

Neil Ashton, Marie Denison, and Marian Zastawny, 3rd High-Lift Workshop Summary Paper – OpenFOAM,STAR-CCM+ & LAVA simulations on Unstructured Grids, AIAA-2018-1253

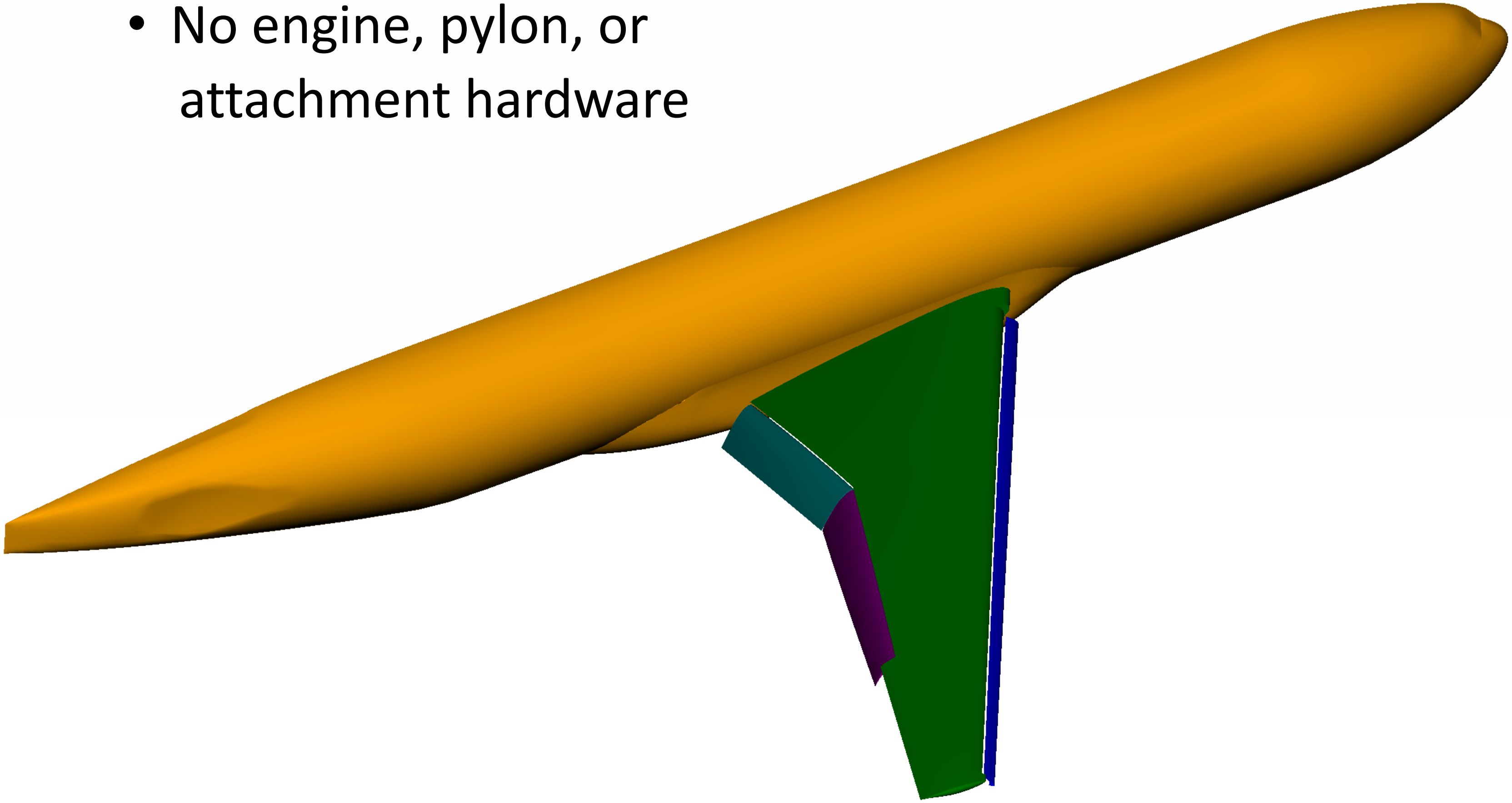
Case 3: Wake Profile Comparison



- ➢ Wake profile is showing good agreement between CFD and experimental data

Test Case 1: Geometry (HL-CRM)

- Representative High-Lift configuration based off the Common Research Model that had previously been developed by Boeing and NASA
  - Slat deployed at 30° and flaps deployed at 37°
  - No engine, pylon, or attachment hardware



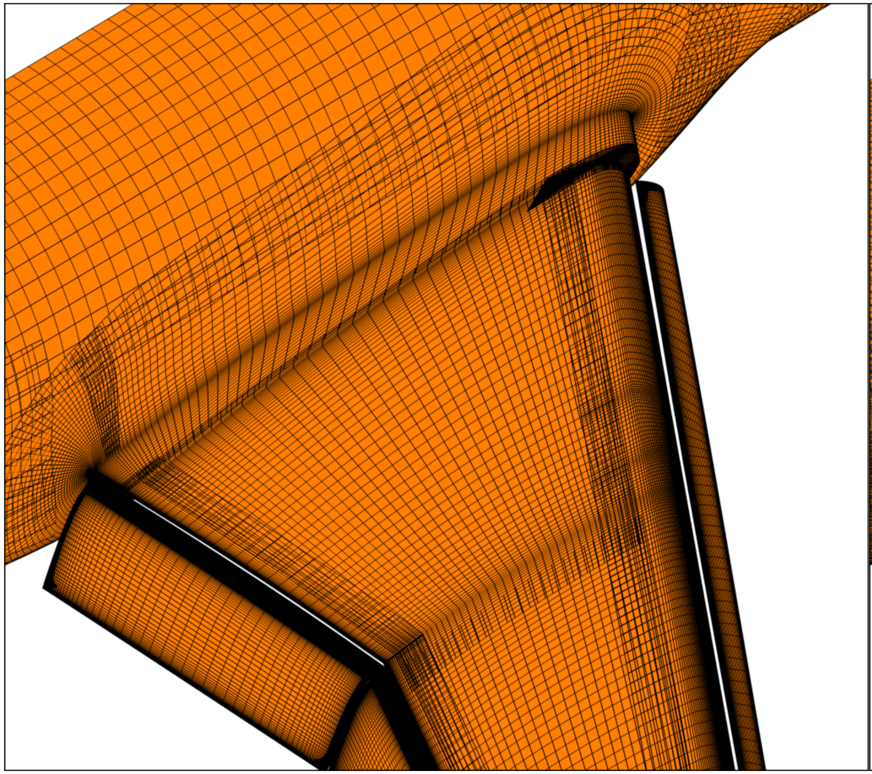
Test Case 1: Description

- Objective was to perform a grid refinement study using the HL-CRM Geometry
  - 4 Grid Levels (Coarse, Medium, Fine, and Extra Fine)
  - The solver was run in steady-state mode using the SA turbulence model
  - Conditions were meant to be representative of a wind tunnel test
  - No experimental data to compare against

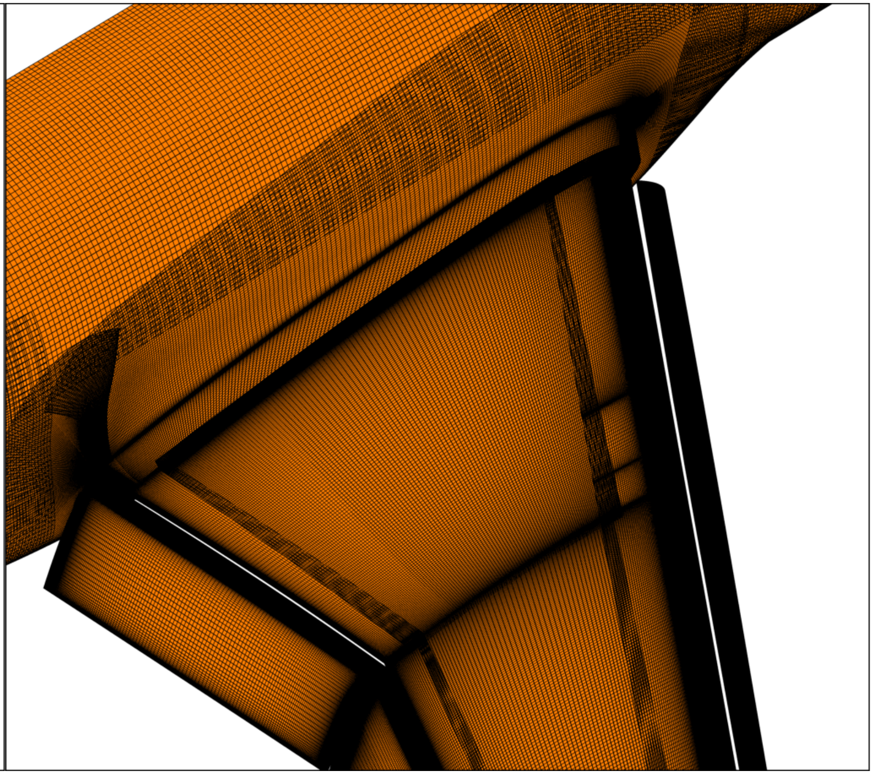
Quantity	Value
Mach Number	0.2
Alphas	8 and 16°
Reynolds Number based on MAC	3.26 Million
Reference Static Temperature	518.67°R
Reference Static Pressure	760.21 mmHg
MAC	275.8 in

Test Case 1: Grid Family

Grid	Nodes	Cells	Blocks
Coarse	24,059,957	23,097,216	72
Medium	65,423,213	63,537,195	72
Fine	189,285,377	185,201,725	76
Extra Fine	564,384,433	554,523,792	102



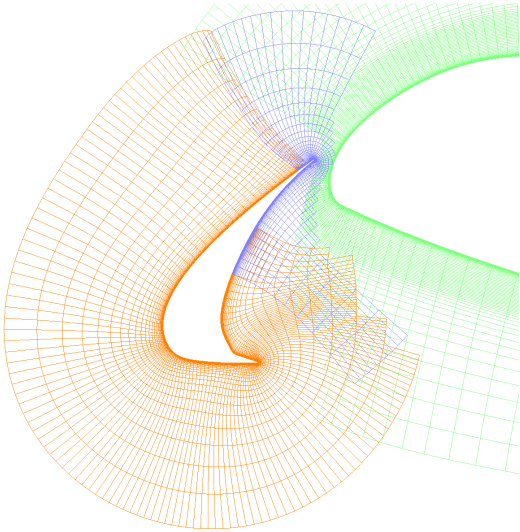
Coarse Grid



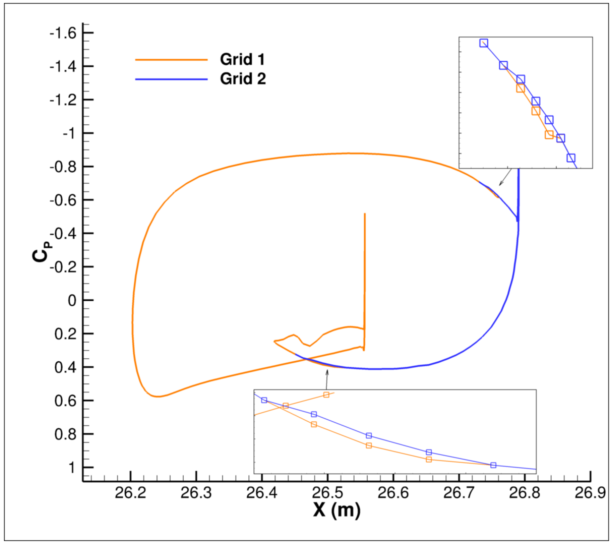
Extra Fine Grid

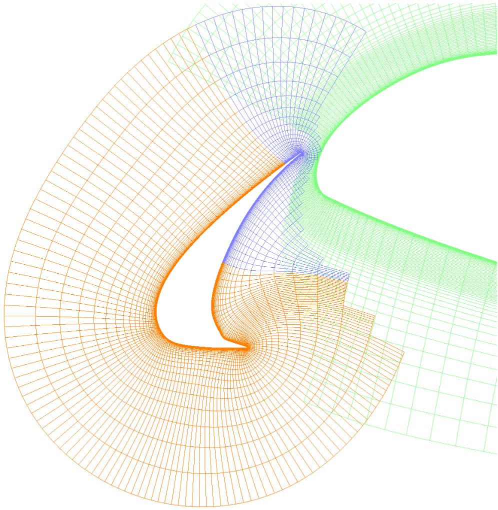
Test Case 1: Mesh Issues

- Structured Overset mesh was provided by the workshop committee
- Had large amount of solution decoupling in the slat region
- Decoupling was found to be result of splitting the periodic surface grid prior to growing of the volume mesh
- Workshop mesh was improved to resolve this issue

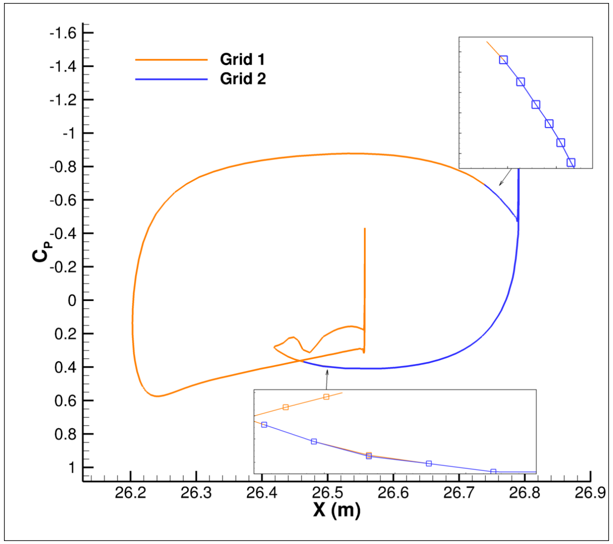


Original Mesh

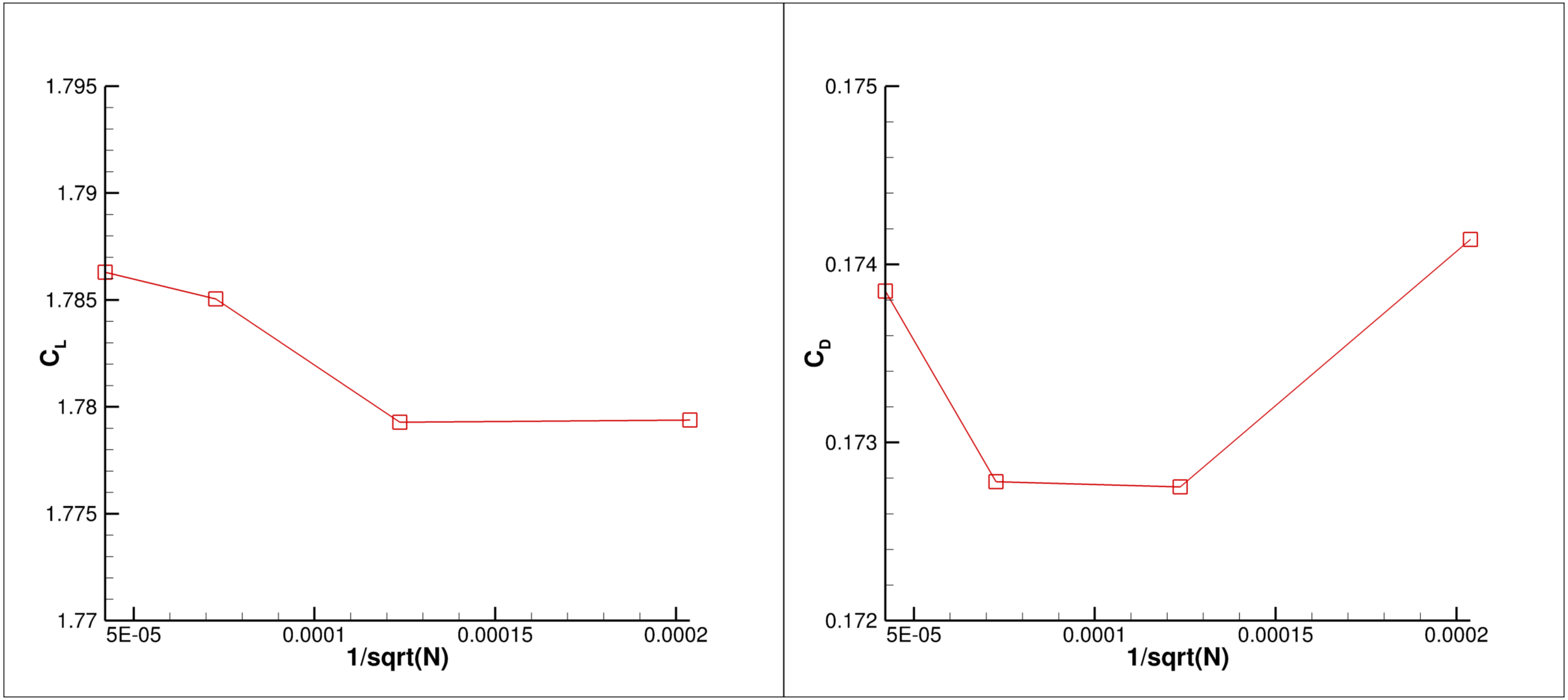




Final Mesh

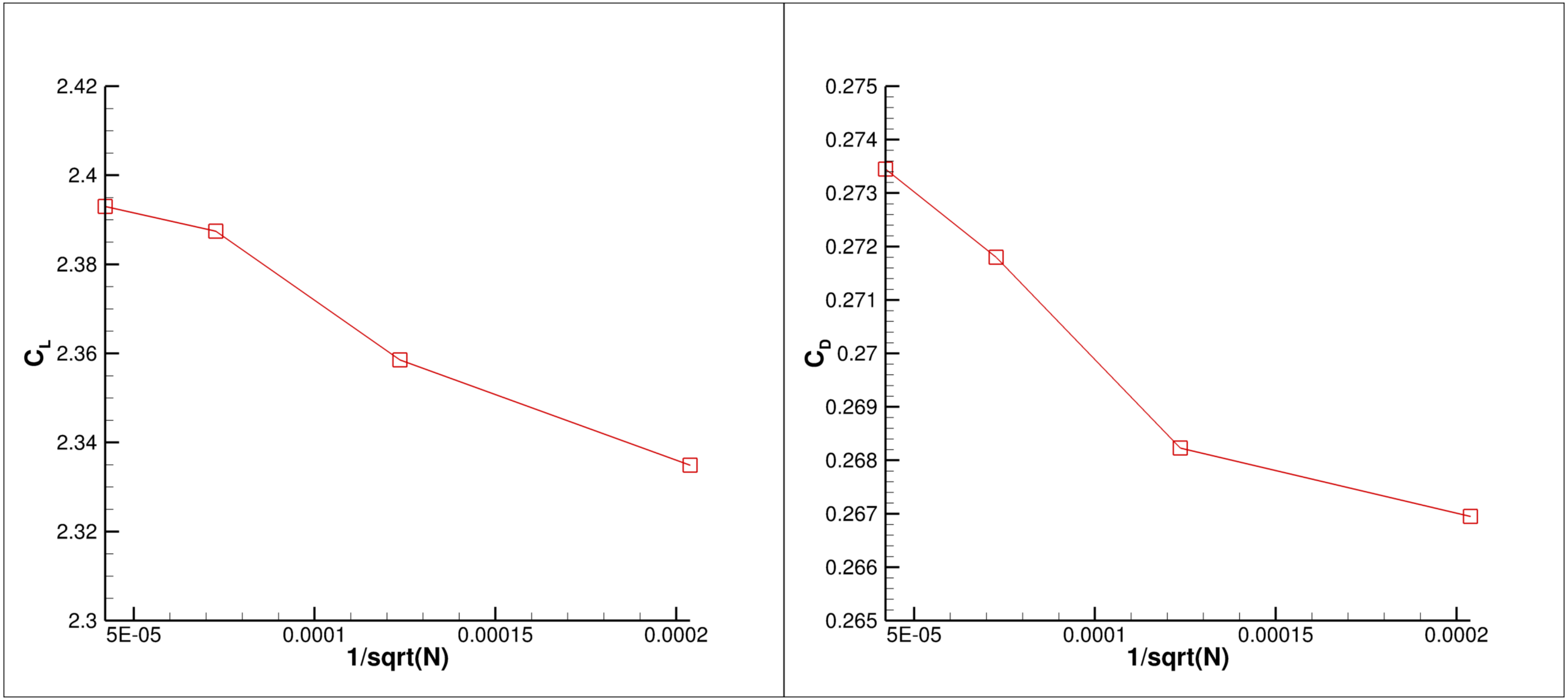


Case 1 (HL-CRM) Mesh Refinement Study Results, α=8°



- Lift is converging across as the mesh is refined but the drag values do not show convergence

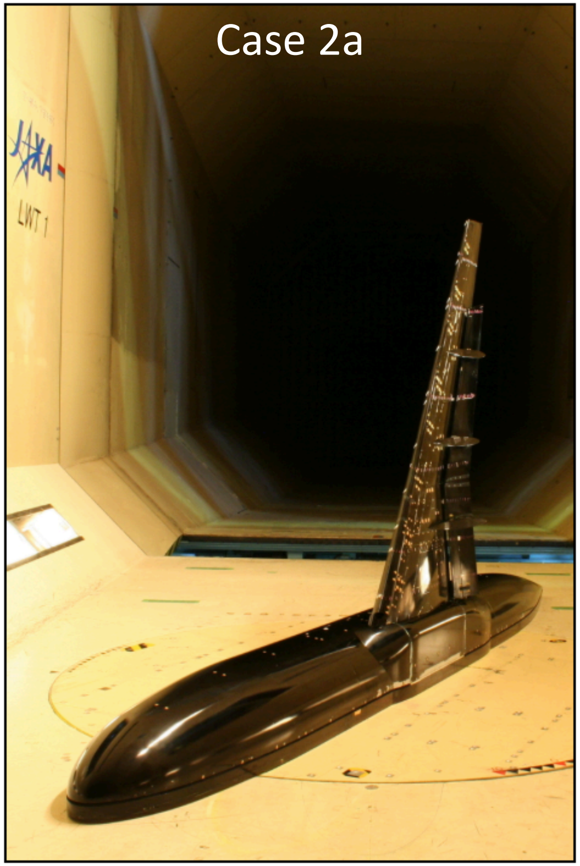
Case 1 (HL-CRM) Mesh Refinement Study Results, α=16°



- Lift is showing convergence across the different mesh levels
- Drag appears to be converging on the finest mesh levels, which contrasts with what was observed in the lower alpha results

Test Case 2: Geometry (JSM)

- Representative of a typical 100-person class regional airliner with a modern high-lift system
  - Slat deployed at 25° and flap deployed at 35°
  - Had both a nacelle/pylon off (Case 2a) and nacelle/pylon on (Case 2c) configuration

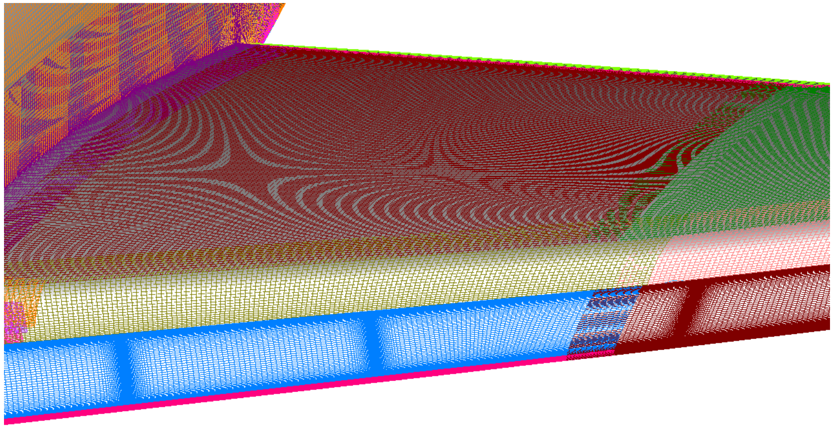


Test Case 2: Introduction

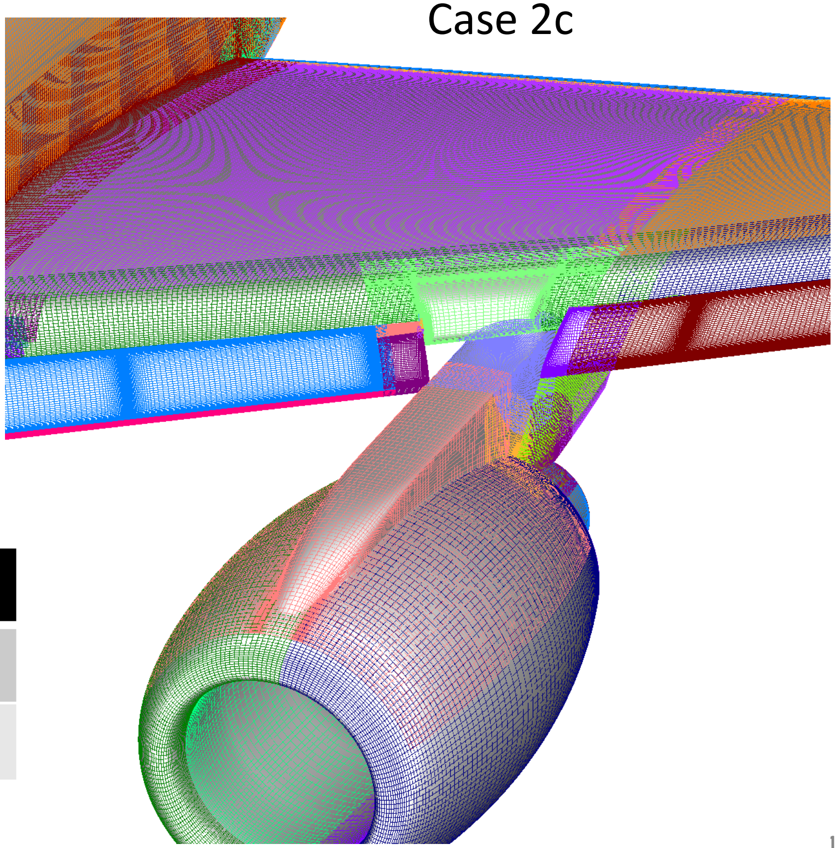
- Objective was to compare the CFD predictions with real world data for both nacelle/pylon on and off configurations
  - Cases were run at conditions identical to those of the wind tunnel test and using the steady-state and fully turbulent assumptions
  - A turbulence model study was performed on the nacelle/pylon on geometry by varying the inclusion of the RC and QCR-2000 modifications to the SA turbulence model
  - Studied the effects of using a free stream initialized flow field (cold starts) with initializing the flow field from previous angles of attack (warm starts)
- Wanted to also use this case to compare the unstructured and structured solvers to each other

Test Case 2: Structured Mesh Generation

- Generated the committee overset structured grid for Case 2a and Case 2c
  - Grids were generated using Chimera Grid Tools (CGT)
  - Grids were made to be medium grids based on the workshop guidelines



Case 2a

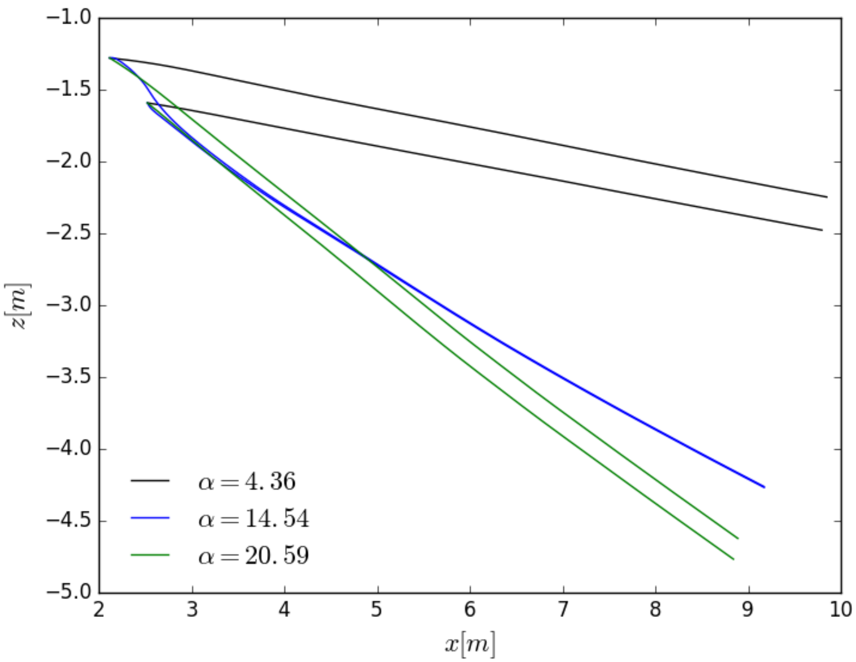


Case 2c

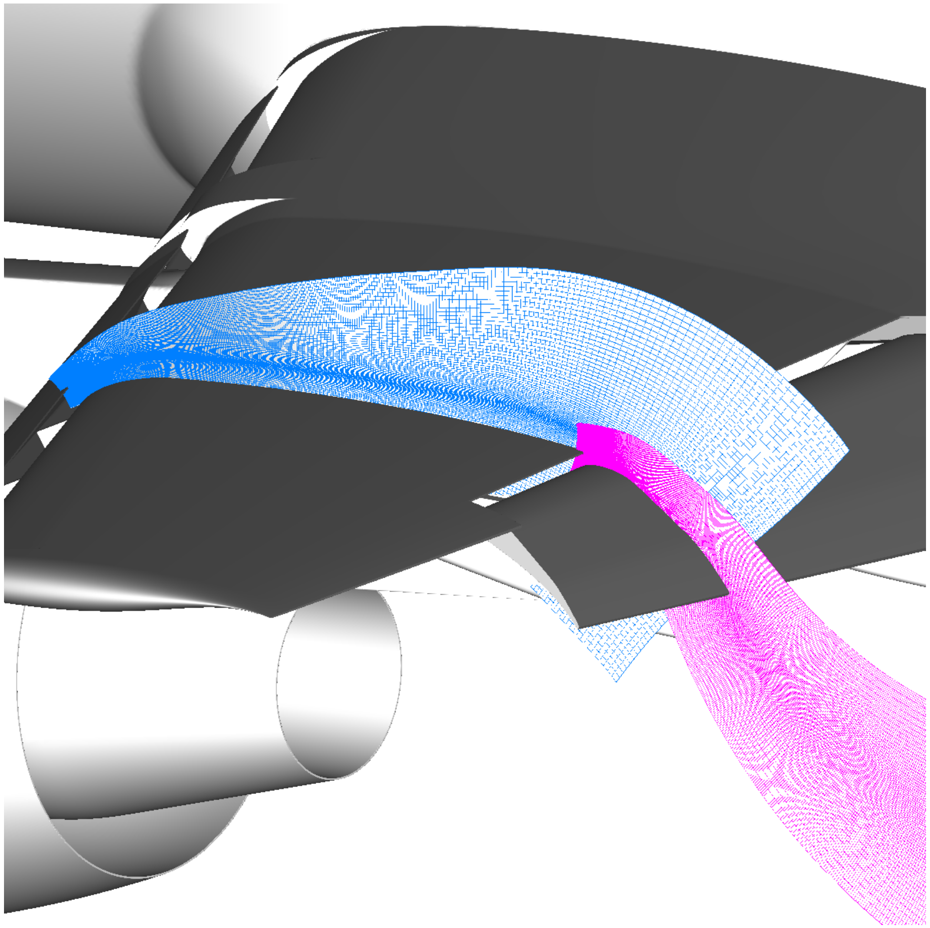
Grid	Nodes	Blocks
2a	228,769,229	196
2c	242,966,062	231

Test Case 2: Structured Wake Grids

- Why use wake grids?
  - Wanted to use wake grids to mimic the effect of having a C-grid topology (grid uses O-meshes)
  - Wanted to have only one grid system for the entire angle of attack sweep
- Originally generated the wake grids based on the streamlines from a solution at 14.54°
- These grids were not sufficient at other angles so it was decided to use a "geometric" based wake grid



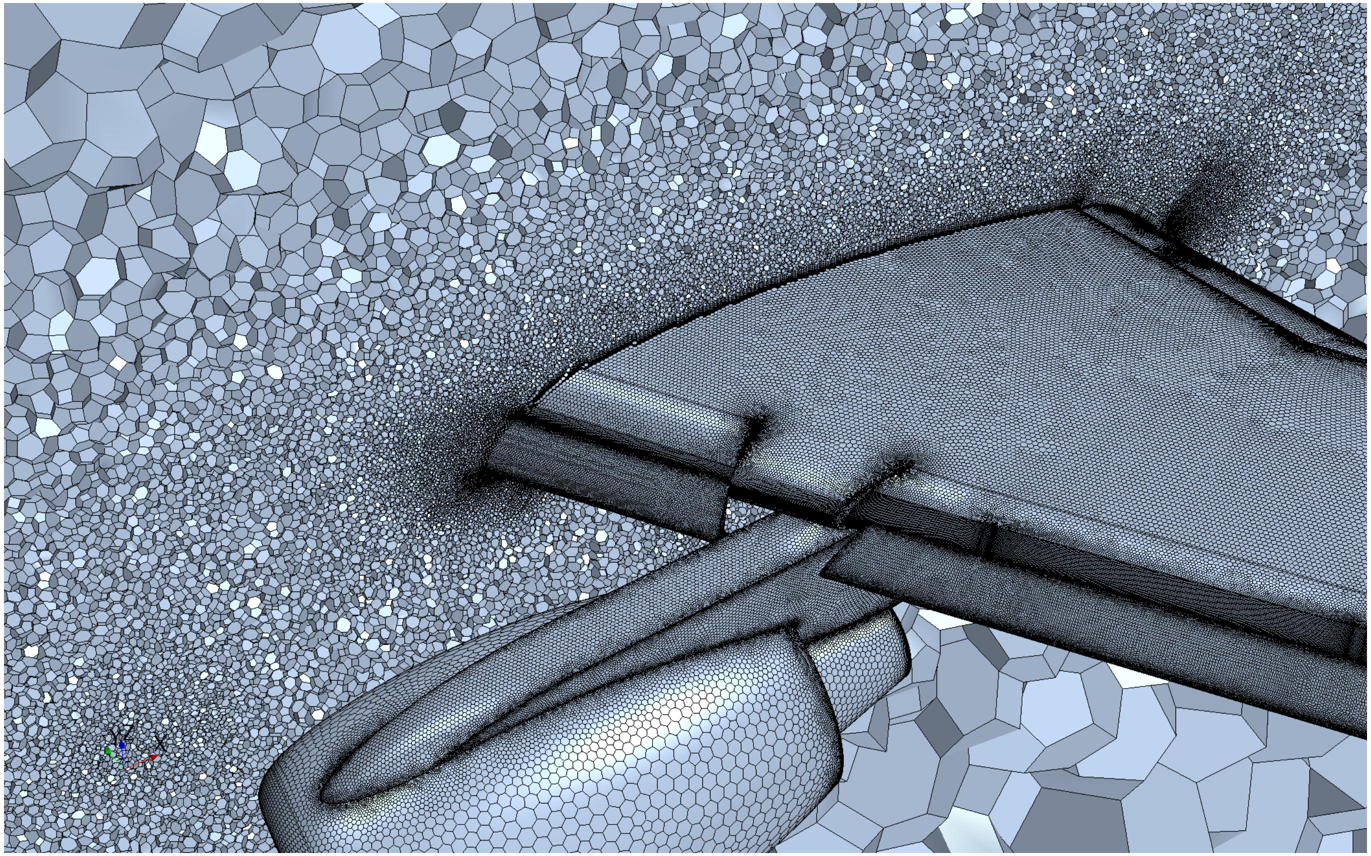
Wake Streamlines



Final "Geometric" Wake Grids

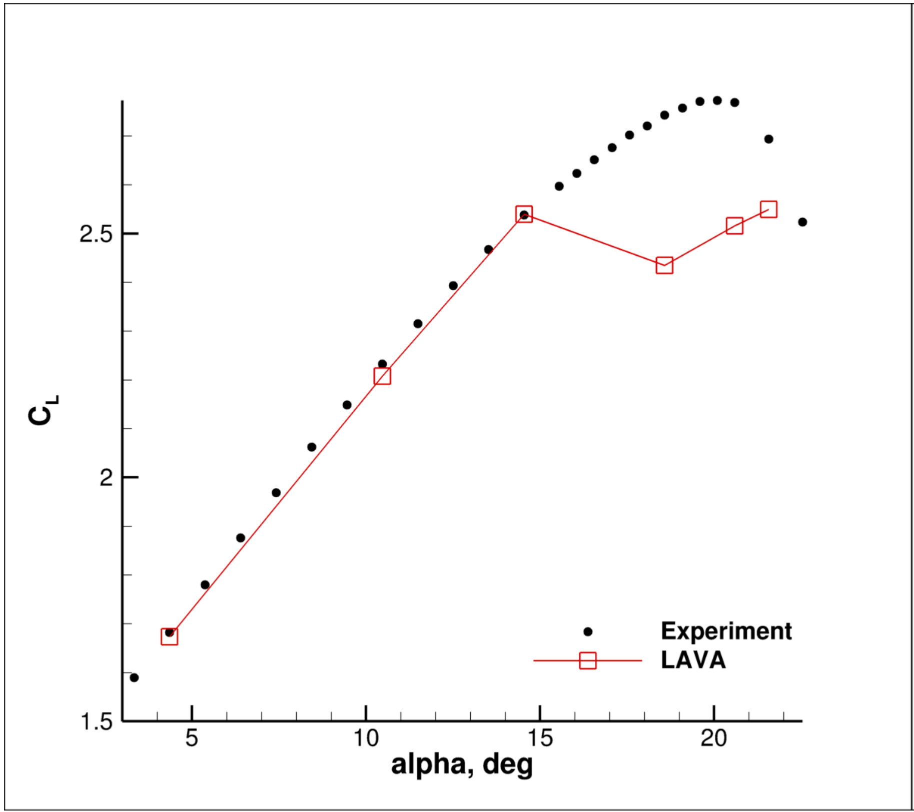
Mesh Generation: Test Case 2 (Unstructured)

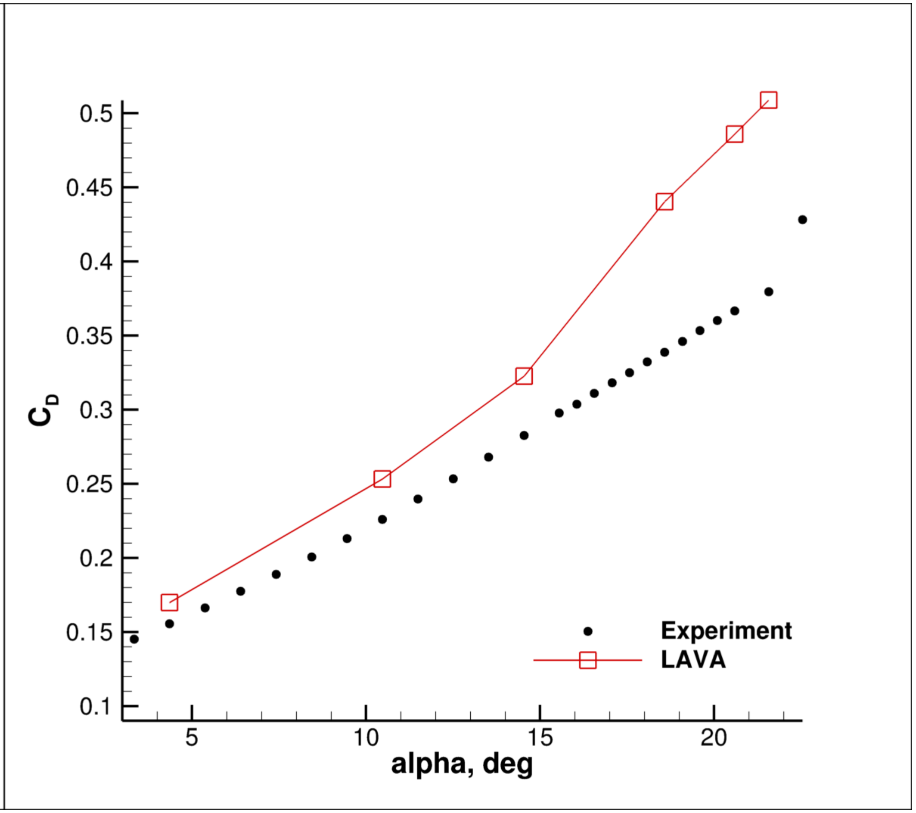
- Triangular surface mesh was generated using ANSA
- Surface mesh was then read into STARCCM+ and used to generate a polyhedral volume mesh
- Generated to be a medium mesh, as defined by the gridding guidelines



Slice Through Unstructured Volume Mesh

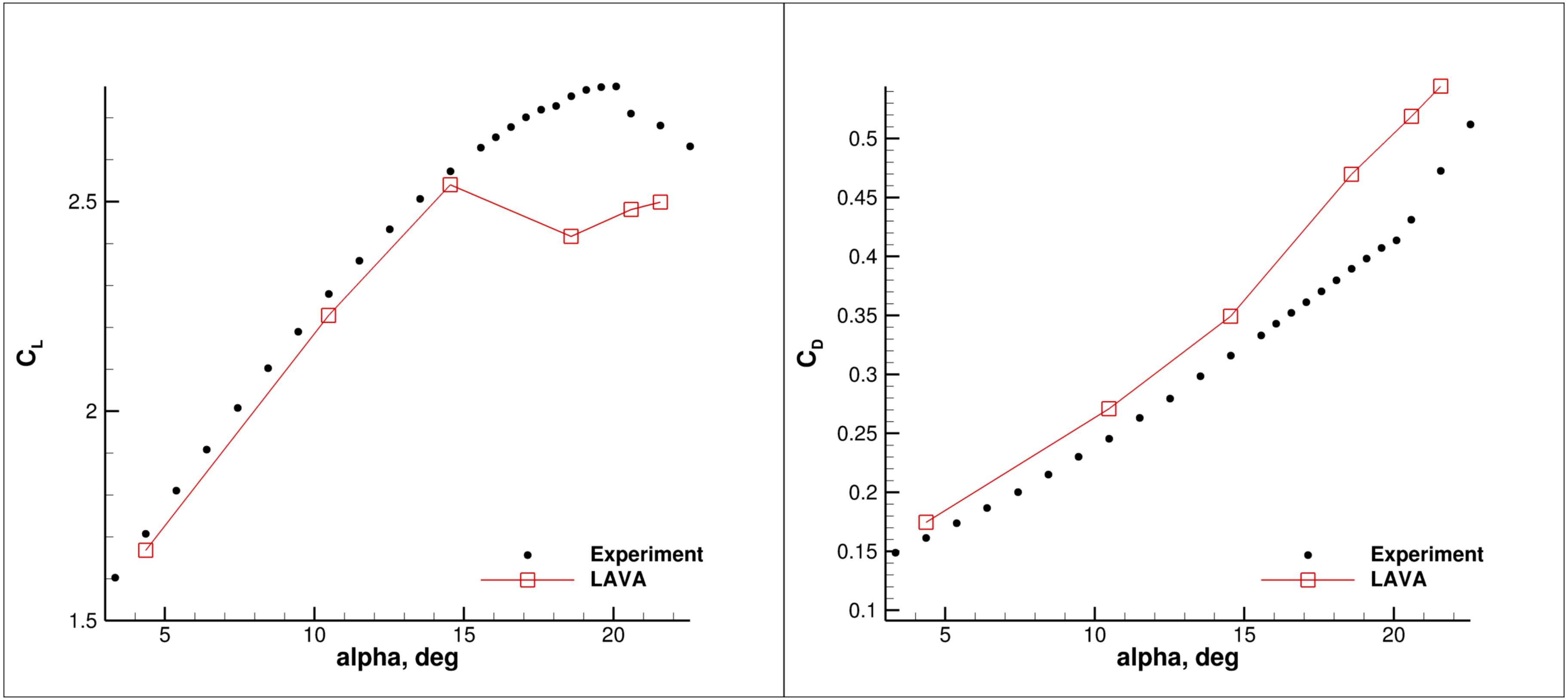
Case 2a (JSM, Nacelle/Pylon off) Initial Results





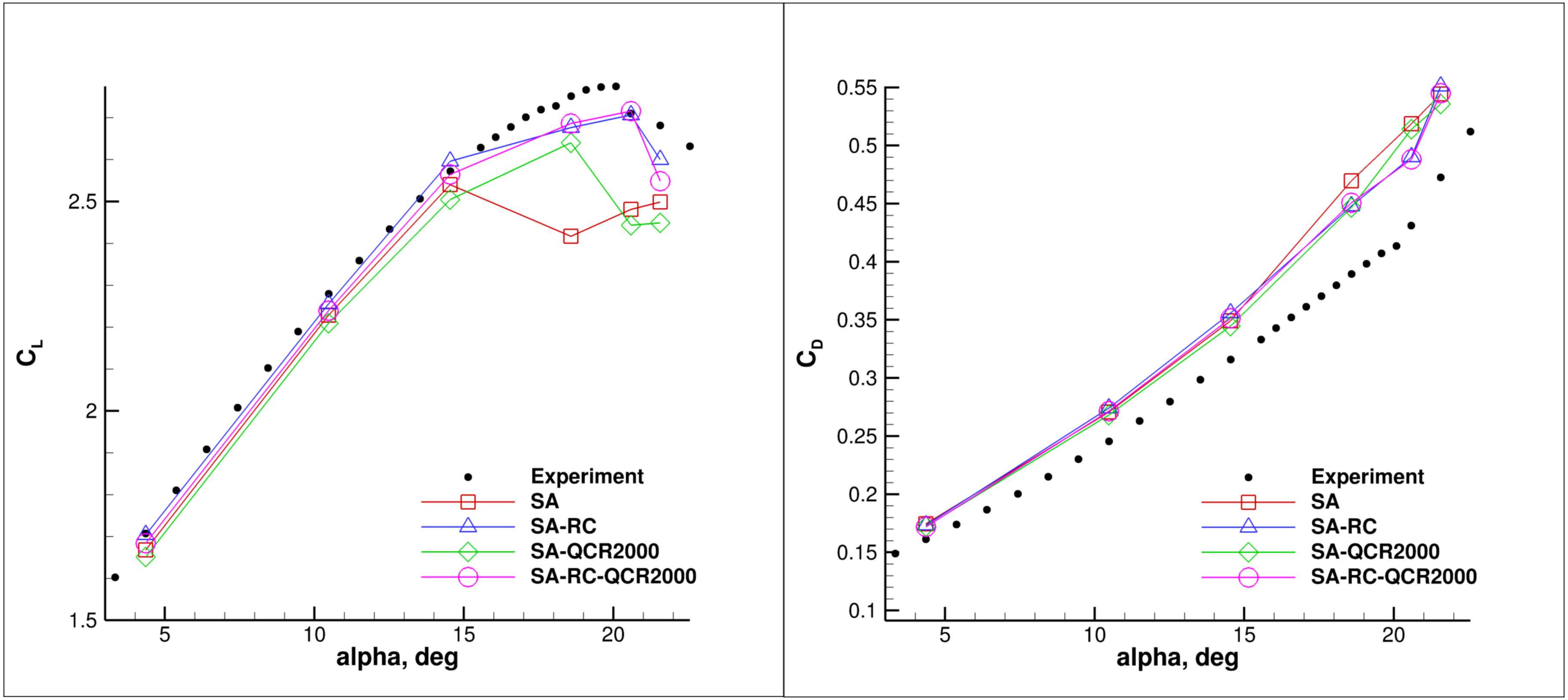
- Lift is slightly under predicted at the lower angles of attack but is largely under predicting the lift in the high angle region
- Drag is over predicted across the whole range of angles of attack but the over prediction becomes much worse at the highest angles of attack

Case 2c (JSM, Nacelle/Pylon on) Initial Results



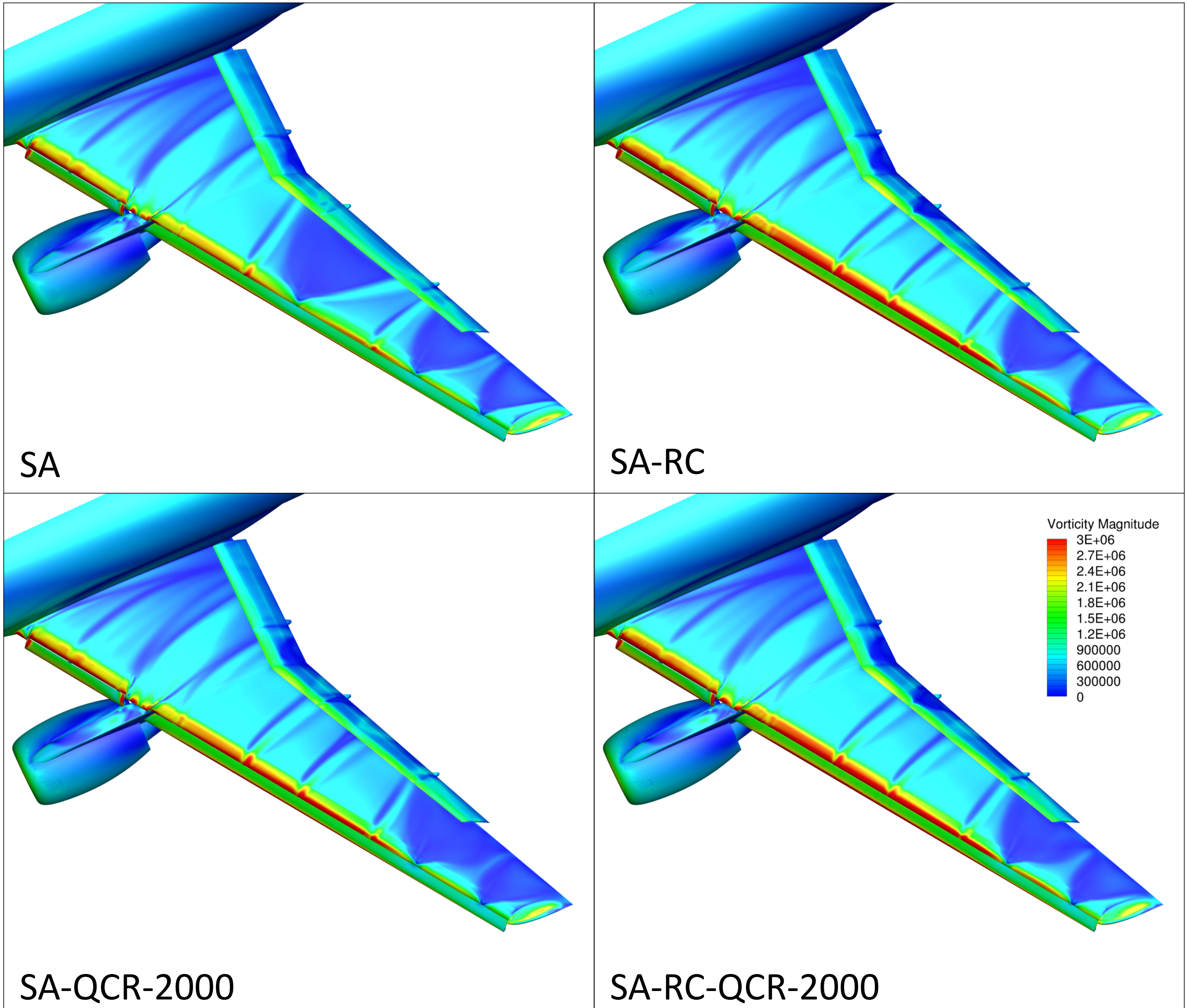
- Trends in both the lift and drag are similar to what is seen in the Case 2a results
- The under prediction of the lift and over prediction of the drag are more pronounced for this configuration

Turbulence Model Study (Case 2c)

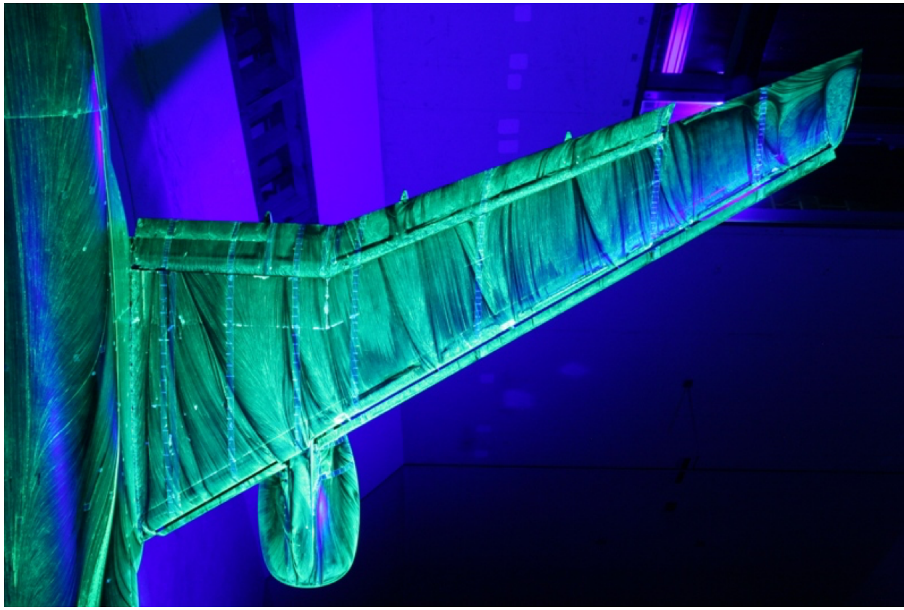


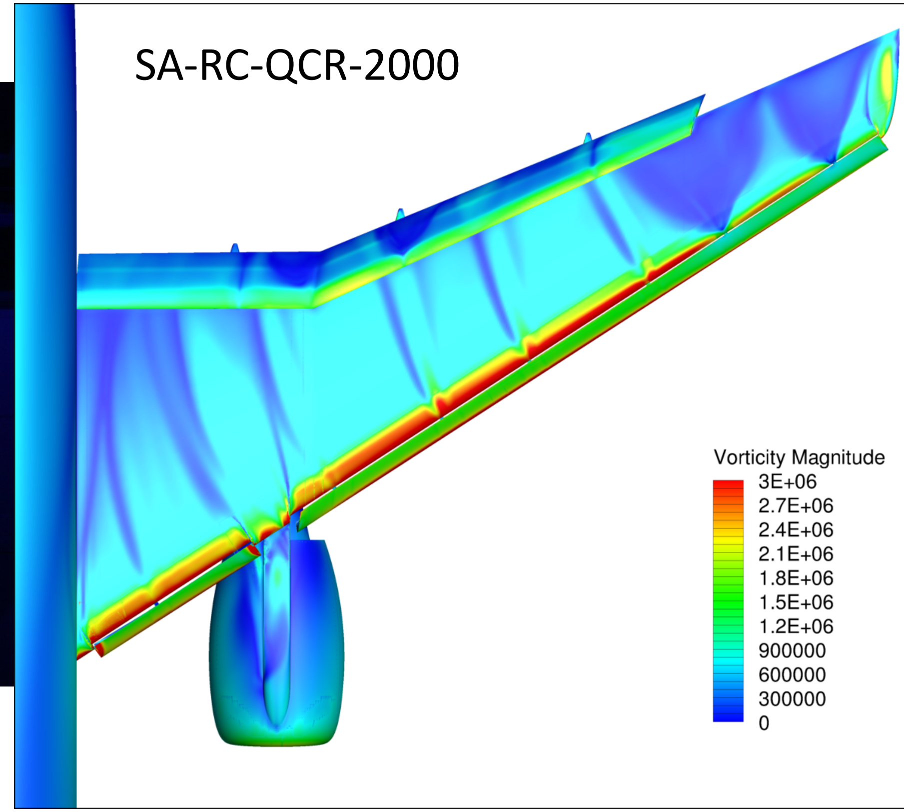
- Both RC and QCR-2000 offer improvements over using plain SA
- When both modifications are included, the RC is having more of an effect on the force predictions

Turbulence Model Study Visualization (α=18.58°)



Flow Visualization Comparison of Case 2c (α=18.58°)

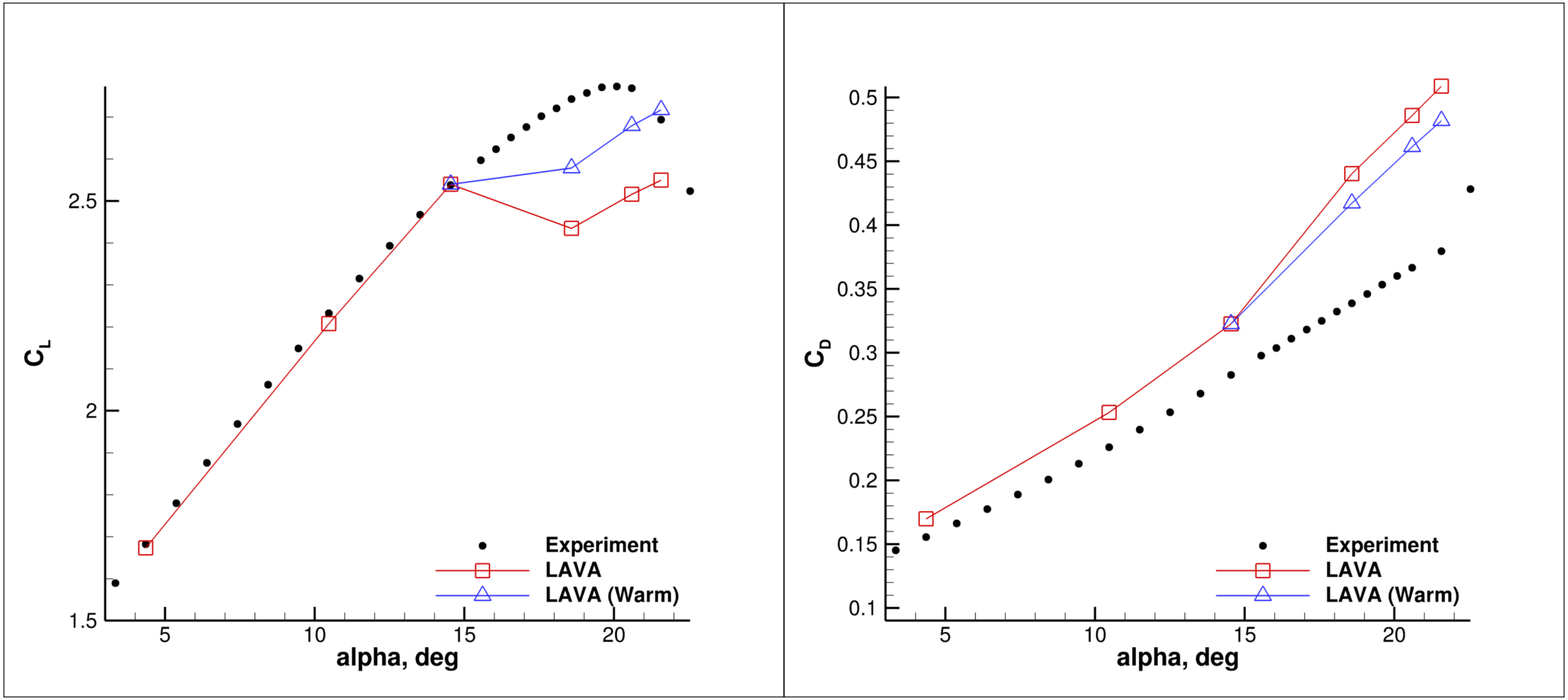




- The forces predicted by the CFD compare well with the experimental data, but the flow field is still not matching the experiment
- This is most likely caused by the lack of transition modeling in the solver
- Jim Coder presented his work including a transition model into the Overflow solver and showed some promising results

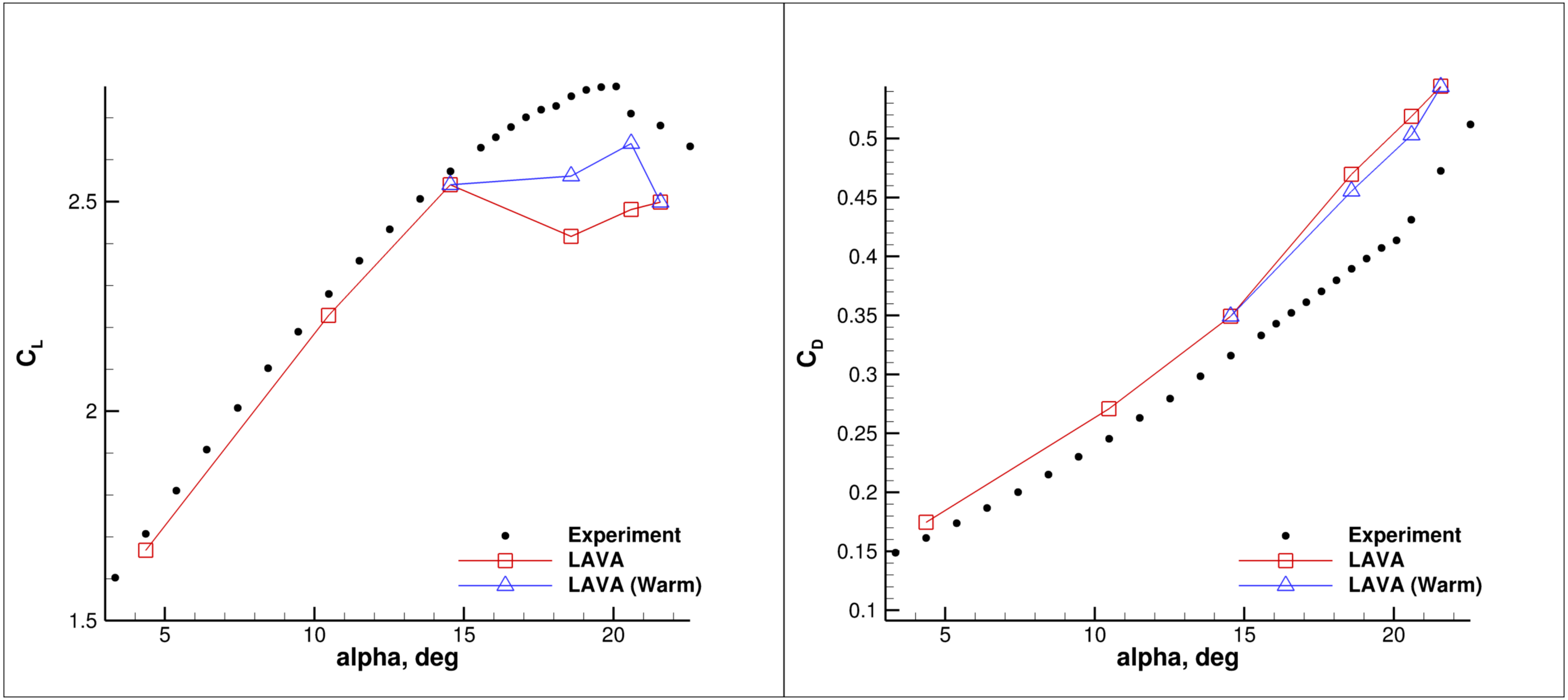
Jim Coder, Tom Pulliam, and James Jensen, Contributions to HiLiftPW-3 Using Structured, Overset Grid Methods, AIAA-2018-1039

Cold vs Warm Start (Case 2a)



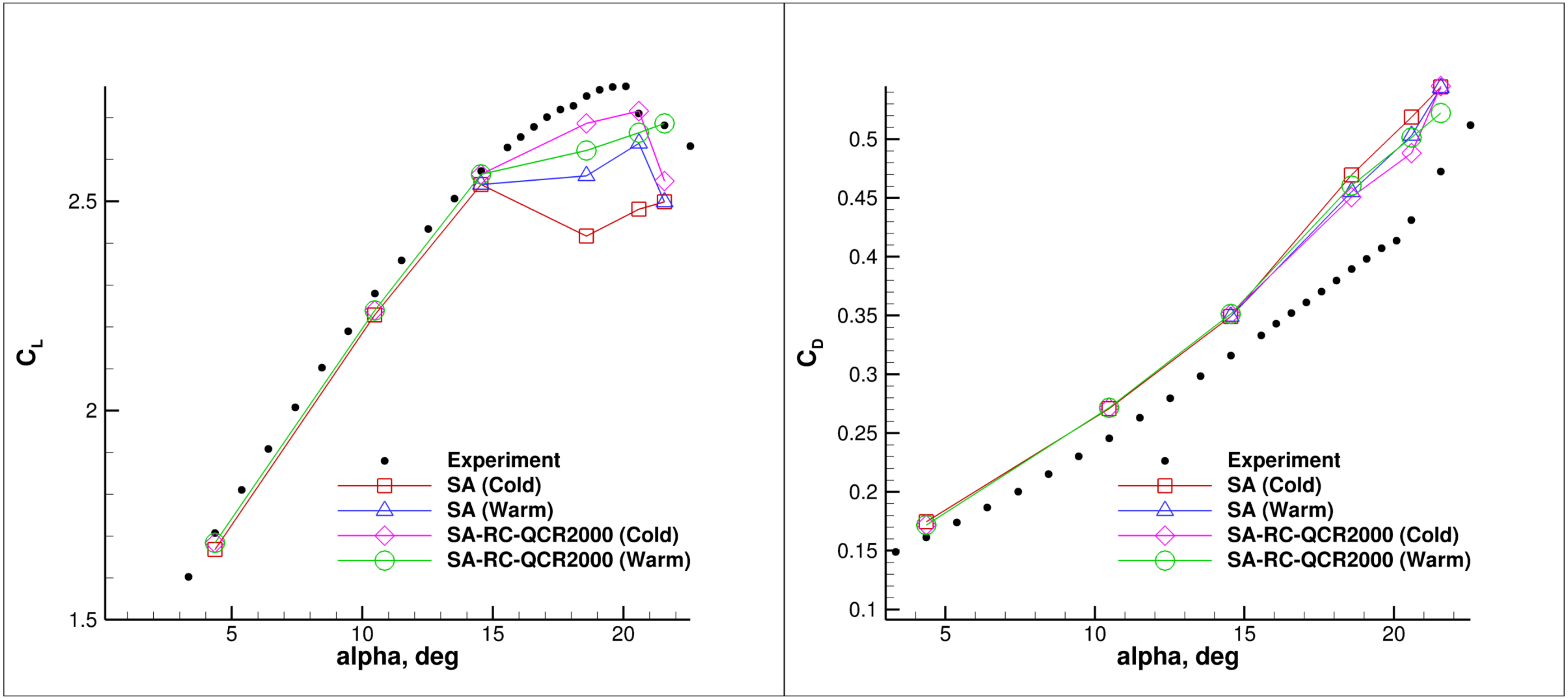
- Lift prediction has been improved but still does not match the experimental results
- Drag prediction improves but still shows a major over prediction in the high angle region

Cold vs Warm Start (Case 2c)



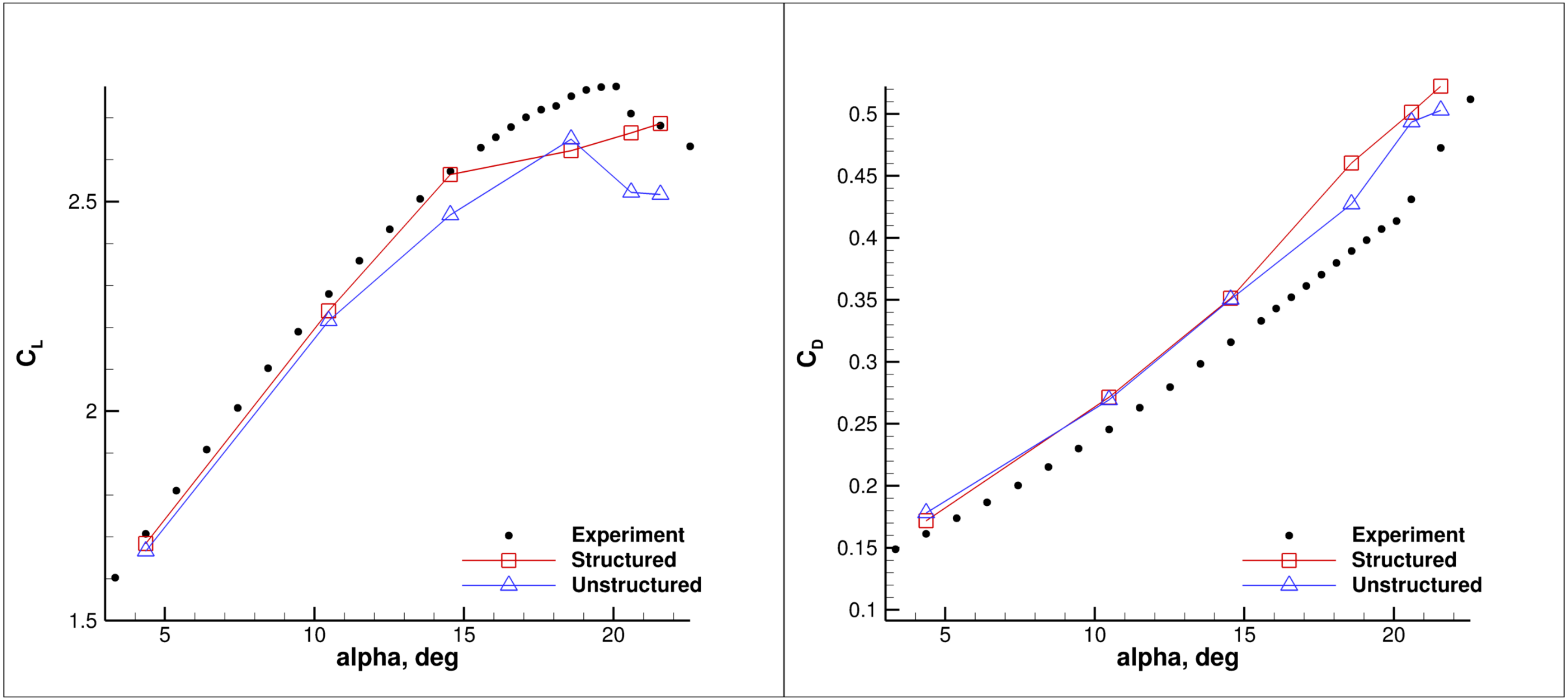
- Lift and drag show similar improvements to what was shown with Case 2a
- The values for the α=21.57° case happen to be nearly identical for both initialization strategies

Inclusion of Warm Starts and More Advanced Turbulence Modeling



- Using warm starts with the more advanced turbulence model does not show the same improvement that was observed when only using the plain SA model

Comparison Between Structured and Unstructured Solvers



- Both solvers were run using the SA-RC-QCR2000 turbulence model and using warm starts
- Both solvers show similar predictions with some differences

Summary

- Learned lessons with the generation of the overset mesh generation
  - Overlap on slat grids for Case 1
  - Wake mesh generation for Case 2
- Case 1 showed mesh convergence for the lift values but not for the drag
- Case 2
  - Warm starts showed improvement in the results for the SA model but the same improvement was not observed for the SA-RC-QCR2000 results
  - Case 2c turbulence model study showed that including the RC and QCR modifications improve the force prediction, predominantly the RC
- More advanced turbulence modeling improved the loads prediction but still did not match the flow field

Next Steps

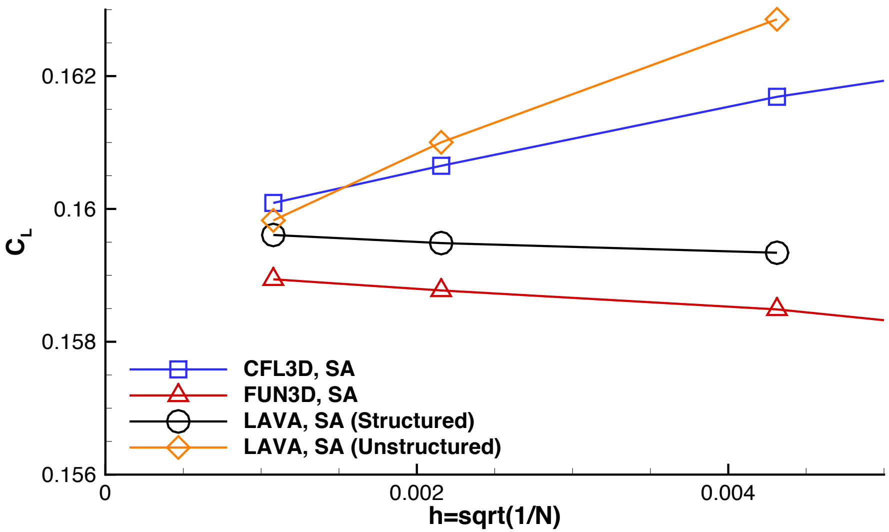
- Inclusion of transition model into the solver
- Use higher fidelity numerical schemes like zonal detached eddy simulations (ZDES) or delayed detached eddy simulations (DDES)

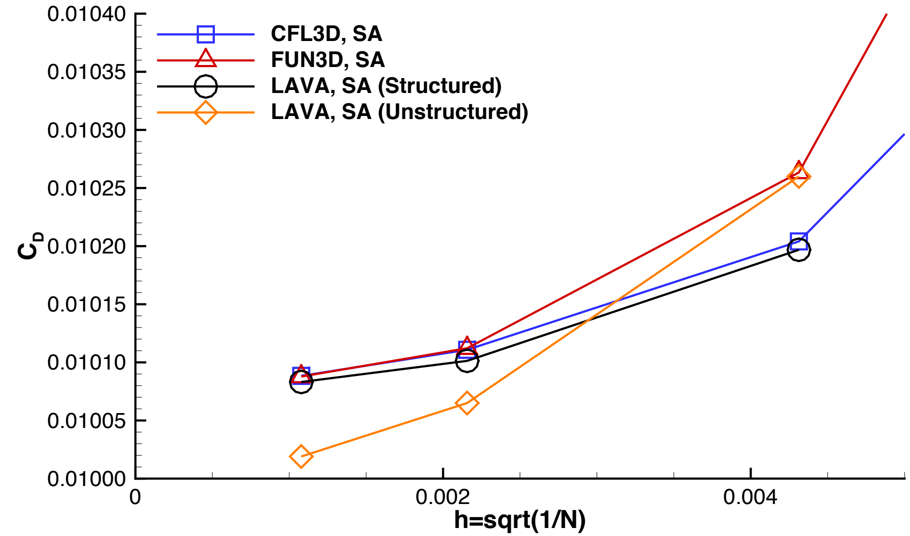
Acknowledgments

- HLPW3 Committee
- Transformational Tools and Technologies (T^3) project under Aeronautics Research Mission Directorate (ARMD)
- NAS facility at NASA Ames for computer time on Pleiades

Backup Slides

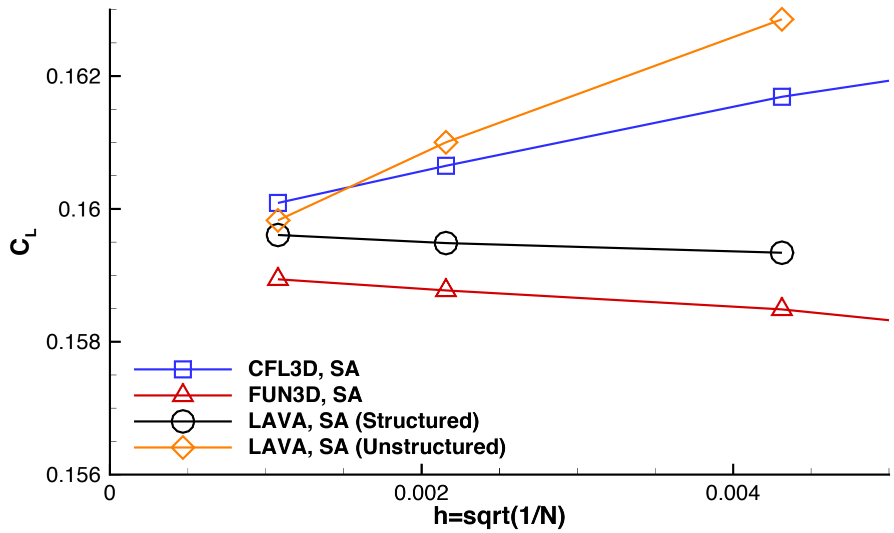
Case 3: Force Comparison

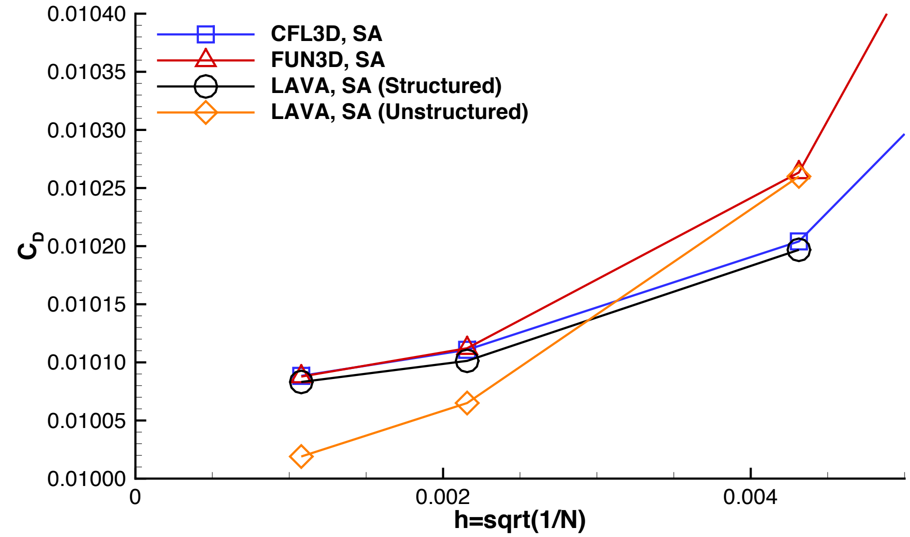




- Both solvers are converging within the FUN3D and CFL3D results for lift but are under predicting drag
- The structured solver's finest mesh value for drag is very close to the FUN3D and CFL3D results but the unstructured solver is much lower (it is within 1 drag count)

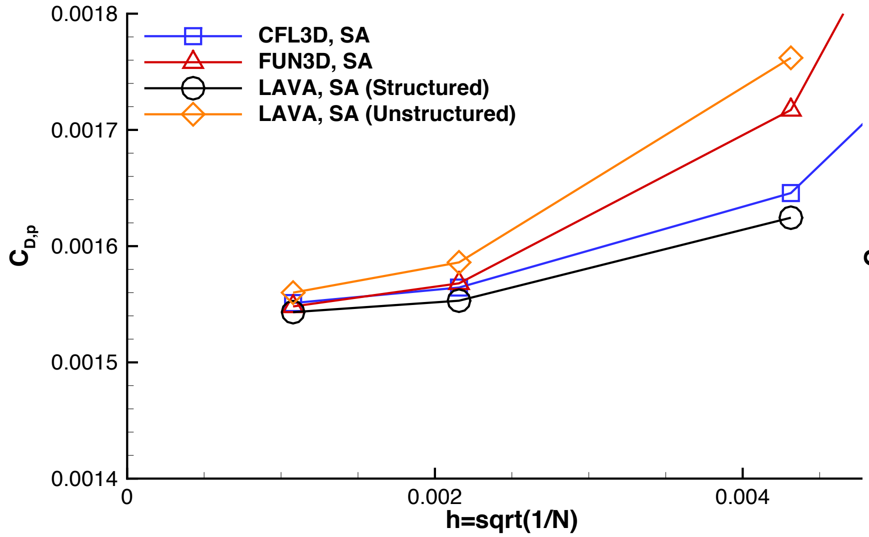
Case 3: Force Comparison

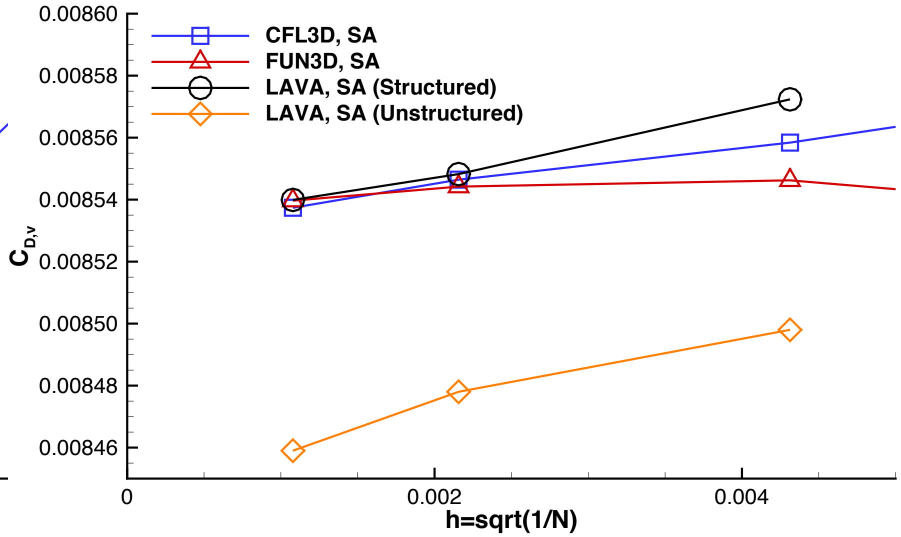




- Lift is converging with mesh refinement for both solvers
- Structured solver is converging to a drag value similar to CFL3D and FUN3D but the unstructured is under predicting the drag by about 1 count

Case 3: Force Comparison Continued





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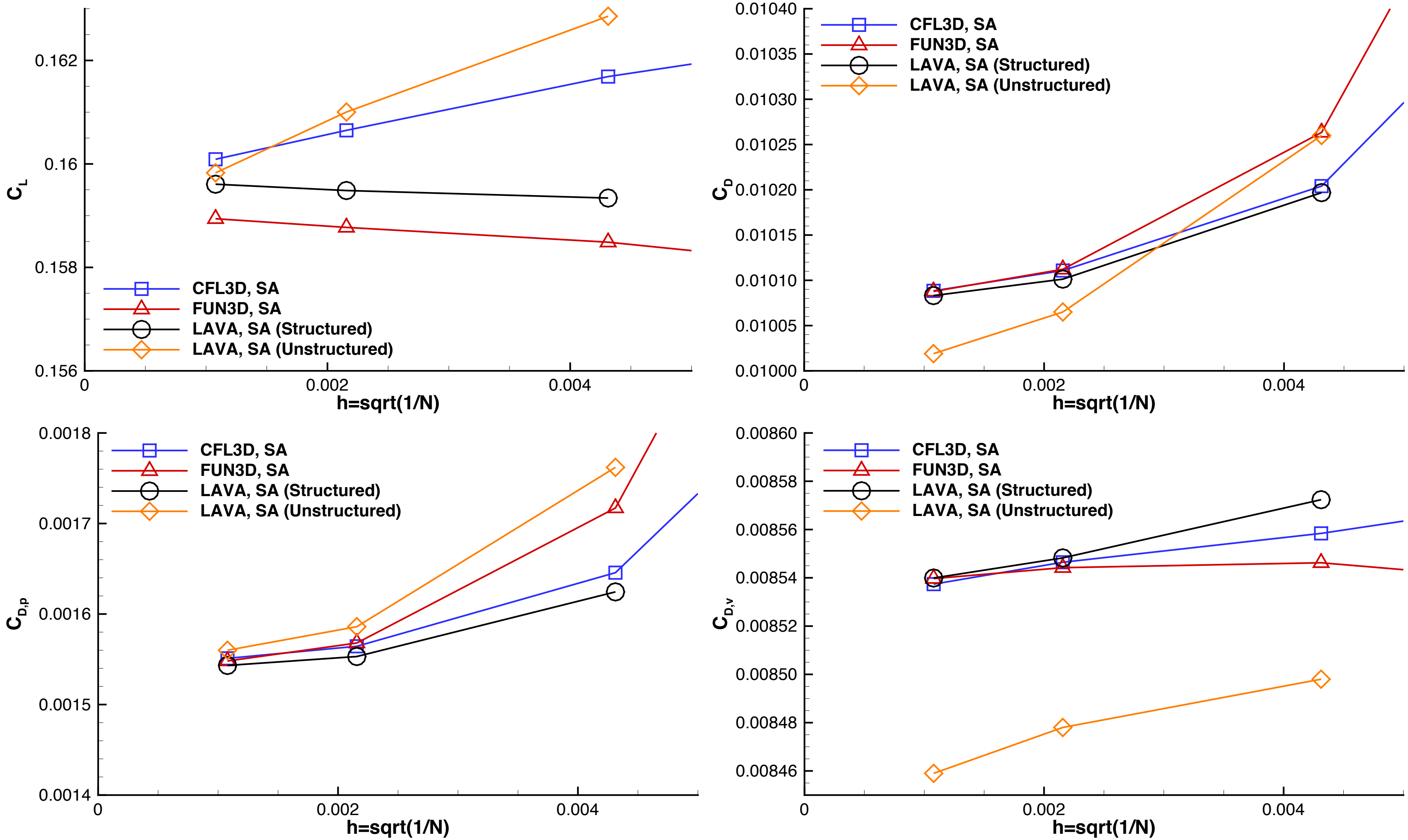
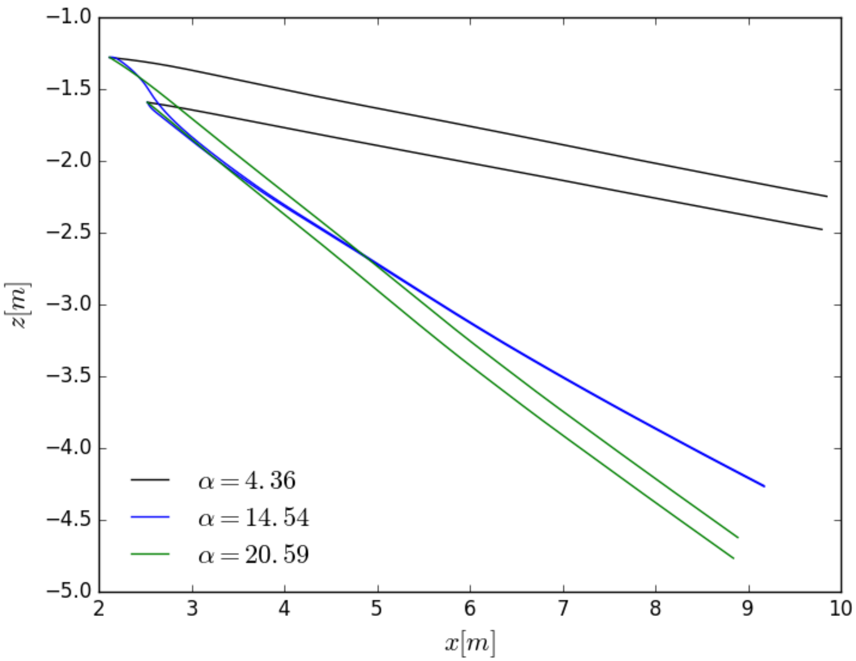
Neil Ashton, Marie Denison, Marian Zastawny, 3rd High-Lift Workshop Summary Paper – OpenFOAM,STAR-CCM+ & LAVA simulations on Unstructured Grids, AIAA-2018-1253

Case 3: Force Comparison Continued

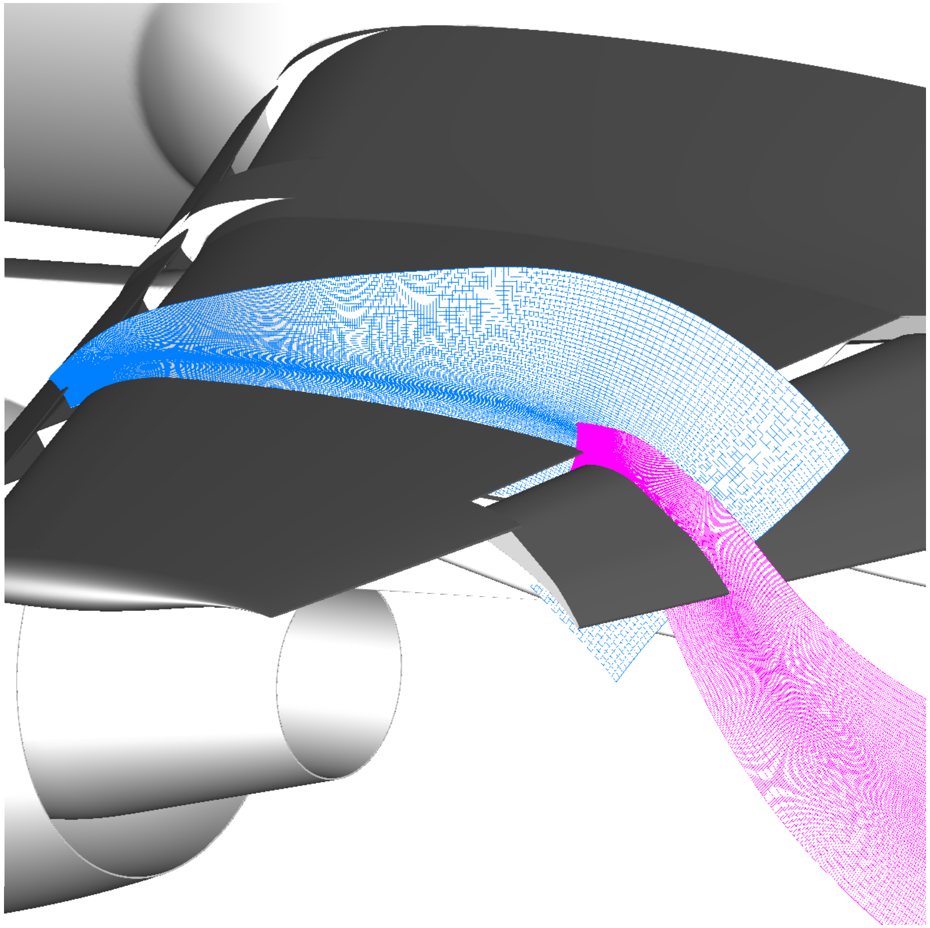


Wake Grids

- Original plan was to generate an wake grid based on the streamlines at "middle" angle (14.54°)
- The streamlines vary greatly with angle of attack so wakes were not general across the whole range of angles
- Decided to use a "geometric" based wake grid



Wake Streamlines



Final "Geometric" Wake Grids