CFD High Lift Prediction Workshop

Overset CFD Results from the 1st CFD High Lift Prediction Workshop

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10th Symposium on Overset Composite Grids and Solution Technology
NASA Ames Research Center
20-23 September 2010

Outline

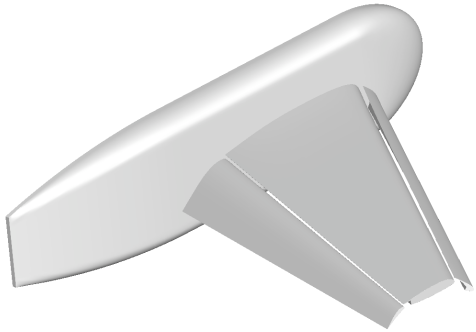
- HiLiftPW-1 Overview
- Overset Grid System
- OVERFLOW Results
  - Grid Convergence
  - Flap Deflection Study
  - Effects of Brackets
  - Issues
- Work in Progress

HiLiftPW-1 Overview

CFD High Lift Prediction Workshop

- Open, two-day workshop focusing on CFD simulation using the NASA Trap Wing high-lift model (http://hiliftpw.larc.nasa.gov)
- Held in Chicago (June 2010) and sponsored by the AIAA Applied Aerodynamics Technical Committee
- Participation from 18 organizations from 8 countries (21 total presentations)
- Technical Objectives:
  - Assess the numerical prediction capability of current-generation CFD technology/codes for swept, medium/ high-aspect ratio wings in landing/take-off (high-lift) configurations
  - Develop practical modeling guidelines for CFD prediction of high-lift flowfields
  - Advance the understanding of high-lift flow physics Enable practical high-lift aerodynamic design and optimization
- Structured (blocked-zonal, overset) and unstructured (tet, hex, hybrid) grid systems provided to participants

NASA Trap Wing "Config 1"



Background

CFD High Lift Prediction Workshop

- **1998-1999** – First series of Trap Wing experiments in NASA LaRC 14x22 WT and NASA ARC 12 Foot PWT
- **2002-2003** – Additional Trap Wing data collected in 14x22 WT
- **2004-2006** – Preliminary discussion of a CFD High-Lift prediction workshop based on Trap Wing datasets
  - External support (e.g. Boeing, etc.) grows during this timeframe
  - Initial thought is to have workshop organized and administered by NASA
- **2006-2007** – Idea of having the workshop organized through AIAA (specifically APA) gains traction, and high-level discussions are held within the APA Vehicle Aerodynamics technical subcommittee
- **Late 2008** – Support for workshop through AIAA is obtained from NASA and key external organizations
- **Orlando 2009** – Official kick-off of workshop and formation of organizing committee
- **Chicago 2010** – HiLiftPW-1

List of Entries (35 Datasets)

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	001	002	003.01	003.02	004	005.01	005.02	006	007	008.01	008.02	008.03	009	010	011	012.01	012.02	013.01	013.02	013.03	014.01	014.02	014.03	015	016	017.01	017.02	017.03	017.04	018	019	020.01	020.02	021.01	021.02
Code	CFX	CFD++	OVER	OVER	HIFUN	FUN3D	NSU3D	FUN3D	TAU	TAU	TAU	TAU	POWER	EDGE	NSU3D	TAS	UPACS	CFD++	CFD++	CFD++	OVER	OVER	OVER	USM3D	FUN3D	FUN3D	CFL3D	CFL3D	CFL3D	ELSA	NSMB	USM3D	USM3D	NSU3D	NSU3D
Type	N	C	N	N	C	N	N	N	N	N	N	N	B	E	N	N	C	C	C	C	C	C	C	C	N	N	C	C	C	C	C	C	C	N	N
Grid	UX9	UH	SX3	SX3	UH	UH6	UH6	UT5	UH8	UH7	UH7	UH7	CB	UH8	UT	UH	SX	UT5	UT5	UX9	SX3	SX3	SX3	UT4	UT5	UH6	SX1	SX1	SX2	SX1	SX	UT4	UT4	UH6	UH6
Turb	SS	KE	SA	SA	SA	SA	SA	SA	SA	SA	SS	RS	VL	SA	SA	SA	SA	SA	KE	KE	SA	SA	SA	SA	SA	SA	SS	SA	SS	SA	SS	KO	KO	SA	SS
Notes			Brackets off on bracket-like grid				Thin											Thin			Roe	HLLC	Central				Thin each direc	Thin each direc	Thin each direc					Thin	Thin

Notes

N=node-centered
C=cell-centered
E=edge-centered
B=Boltzmann

SX=Structured
UX=Unstructured hex
UT=Unstructured tet
UH=Unstructured hybrid
CB=Cartesian based

1=Str point-matched A
2=Str point-matched B
3=Str overset A
4=Unstr tet cell-center A
5=Unstr tet node-center A
6=Unstr hybrid (merged from 5)
7=Unstr hybrid node-center A
8=Unstr hybrid node-center B
9=Unst hex (from 1)

SA=Spalart-Allmaras
SST=Menter Shear Stress Transport
KE=K-Epsilon
VLES=Very Large Eddy Simulation
RSM=Reynolds Stress Model
KO=Wilcox K-Omega
* = modified in some way

OVERFLOW results from Boeing and NASA Ames included in this presentation

Test Cases

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- **Test Case 1 – Grid Convergence Study**
  - Trap Wing "Config 1" (Slat 30, Flap 25)
  - Mach = 0.2, α = 13°, 28°
  - Re = 4.3M (based on MAC)
  - Tinf = 520°R
  - Coarse, Medium, Fine, Extra-Fine grids
- **Test Case 2 – Alpha Sweep, Flap Increments**
  - Trap Wing "Config 1" (Slat 30, Flap 25)
  - Trap Wing "Config 8" (Slat 30, Flap 20)
  - Mach = 0.2, α = 6°, 13°, 21°, 28°, 32°, 34°, 37°
  - Medium Grid
- **Test Case 3 – Slat/Flap Support Effects**
  - Trap Wing "Config 1" (Slat 30, Flap 25)
  - Mach = 0.2, α = 13°, 28°
  - Medium Grid

Optional

Overset Grid System

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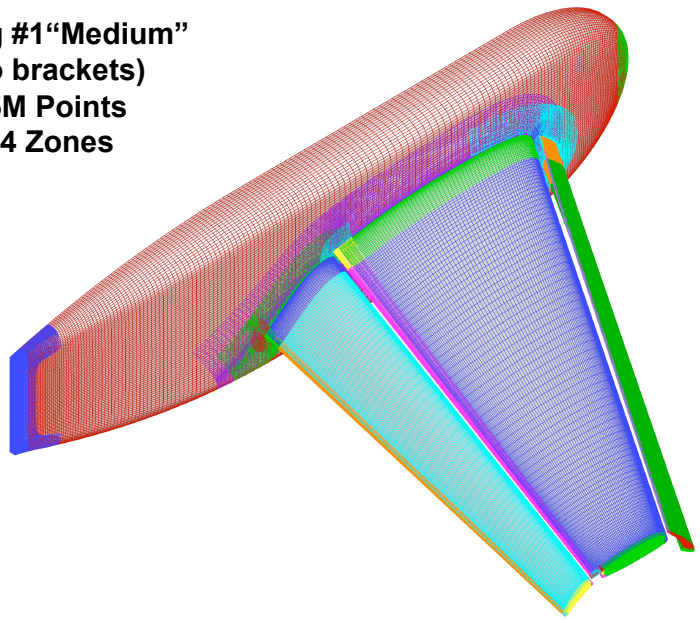
Grid Generation Process (NASA Codes)

CAD → surfaces → volumes → grid connectivity → surface integration

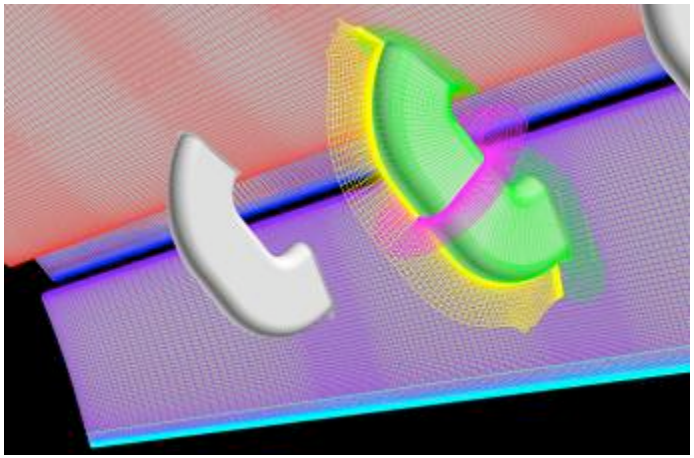
- CAD: MADCAP
- surfaces: MADCAP/SURGRD
- volumes: HYPGEN/LEGRID/BOXGR
- grid connectivity: PEGASUS 5
- surface integration: POLYMIXSUR

CGT Configuration Grid Scripts

Config #1"Medium"
(No brackets)
25M Points
34 Zones



Grids built in accordance with "gridding guidelines" developed for HiLiftPW-1 based on experience with DPW



Overset Grid System (2)

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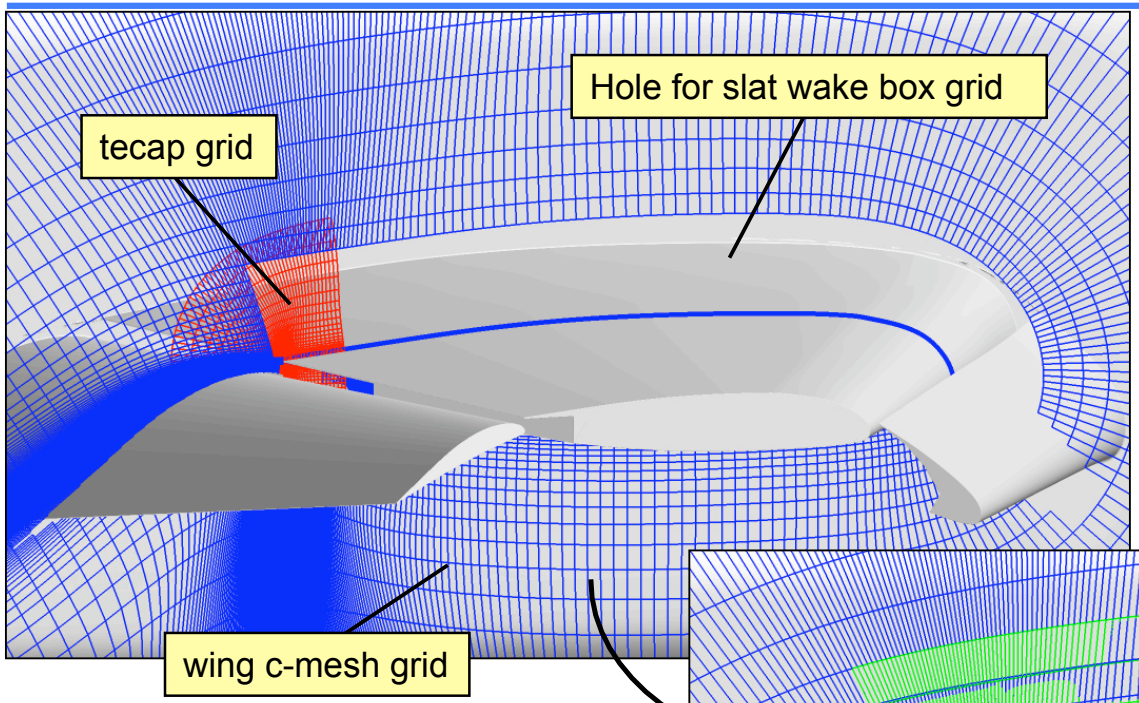
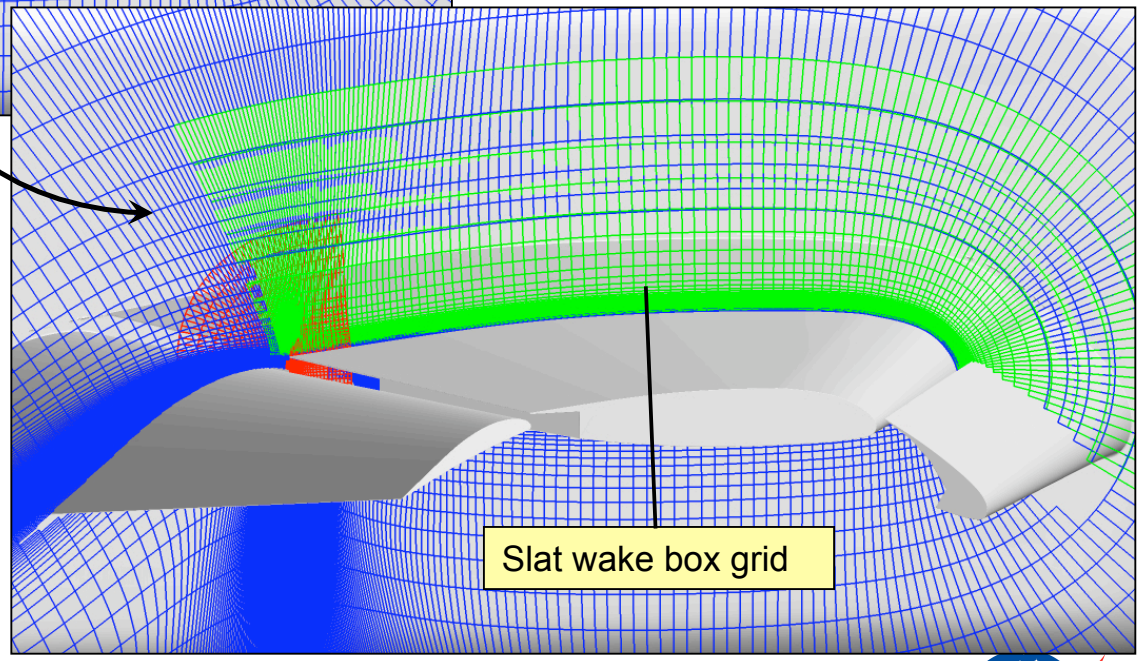


Used variable off-body cell growth rates for wing and flap grids:

- Growth rate in the viscous layer should be < *1.25* for all grids
- To capture the wake from upstream elements, the wing and flap grids should include a region where the growth rate is *1.0*

The slat wake box grid was added to create a region where the off-body growth rate is 1.0. This grid helps transmit the slat wake downstream.

PEGASUS 5 used for domain decomposition



Meshes for Grid Convergence

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Config 1 and Config 8 (body-slat-wing-flap)

Grid	Points	$1/N^{2/3} \times 10^5$	1st Cell Size	y^+	Constant Cells	Growth Rate
Coarse	10,653,004	2.07	.00017 in	.87	2	1.25
Medium	24,965,818	1.17	.00013 in	.66	3	1.18
Fine	83,302,438	0.52	.00009 in	.44	4	1.12
Extra-Fine	281,560,012	0.23	.00006 in	.29	6	1.08

Config 1 (body-slat-wing-flap-brackets)

Grid	Points	$1/N^{2/3} \times 10^5$	1st Cell Size	y^+	Constant Cells	Growth Rate
Medium	58,175,676	0.67	.00013 in	.66	3	1.18

Flow Solver

- OVERFLOW 2.1ad (Boeing) & 2.2 (NASA Ames)
  - 3rd-order Roe upwind, central, HLLC
  - Spalart-Allmaras (SA), SST
  - Full Navier-Stokes viscous terms
  - Low-Mach preconditioning
  - Steady state (with FMG) & time accurate (using dual-time-stepping)
  - Initial conditions from scratch (i.e., freestream) & restarts from previous alpha's

  - Run fully turbulent
  - No wind tunnel walls

Computing

- Boeing
  - PC Cluster: Linux 64bit operating system with 1968 CPUs on 578 nodes
    - 120 2.6GHz Opteron dual core nodes with 8GB of RAM
    - 80 3.0GHz Xeon dual dual-core nodes with 12GB of RAM
    - 112 2.2GHz Opteron dual quad-core nodes with 16GB of RAM
  - Config 1 medium grid (25 million points) run on 24 processors
    - 18.7 seconds per iteration
    - Full convergence reached after 5000 iterations
    - Roughly 26 hours of wall clock time needed per case

- NASA Ames (Pleiades)

Grid	# Pts	# Cases	# CPUS	CPU Hrs
Coarse	10,653,004	192	32	256
Medium	24,965,818	110	64	640
Fine	83,302,438	70	128	1000
X-fine	281,560,012	30	512	8000

500,000 CPU hours over 12 weeks!

Typical Solution Convergence

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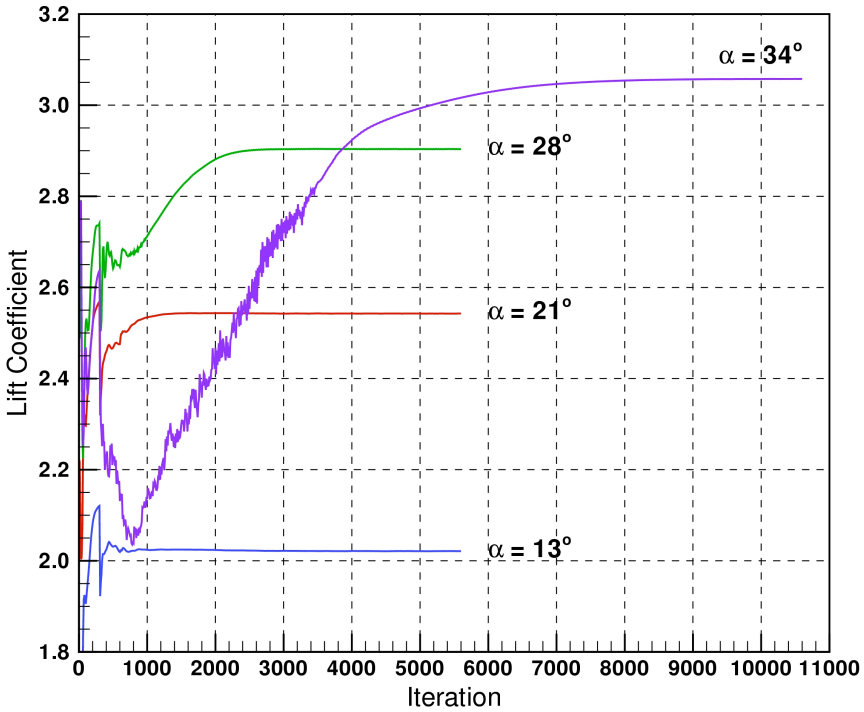
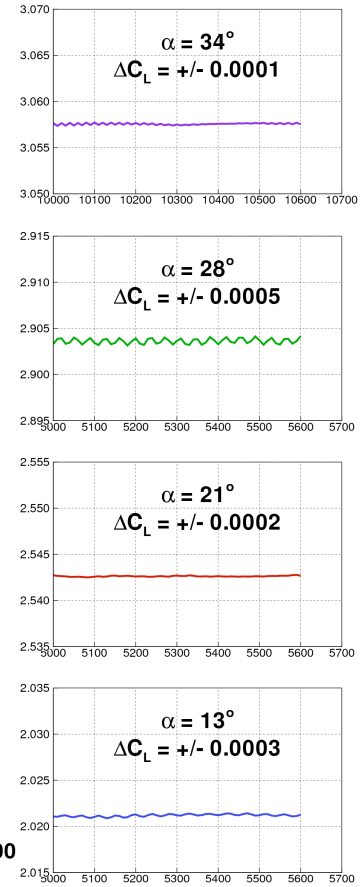
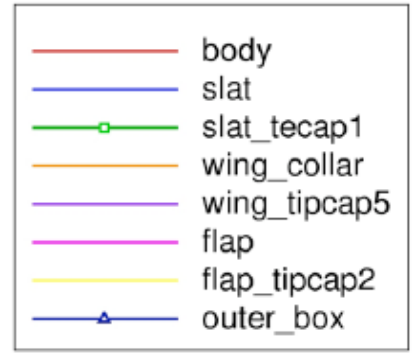
OVERFLOW Convergence Histories - Lift

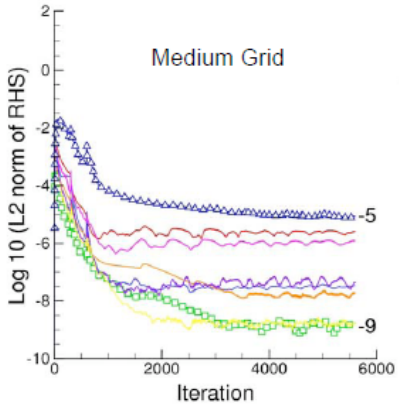
> Config 1 Medium Grid Solutions
> Slat/Flap Brackets Off
> Fully Turbulent, Free Air (Local Time Stepping)
> RN = 4.3 million, Mach = 0.2





Residuals





Higher angles-of-attack required significantly more iterations to converge

Grid Convergence Results

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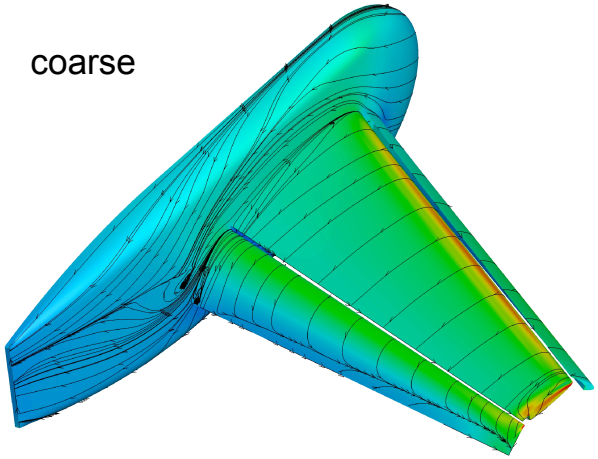
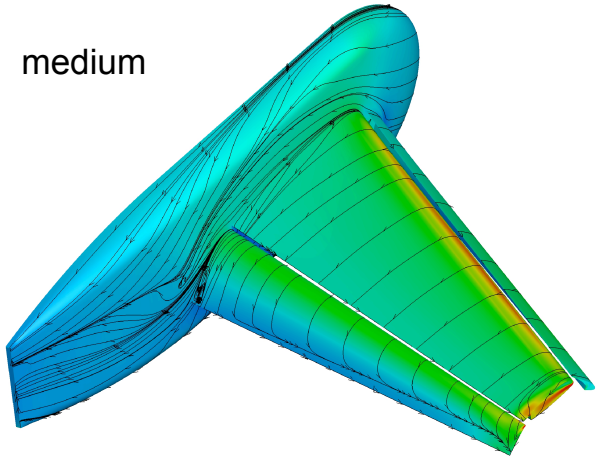
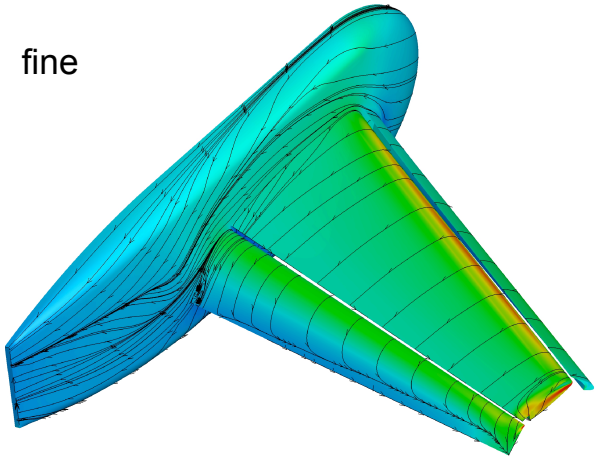
coarse

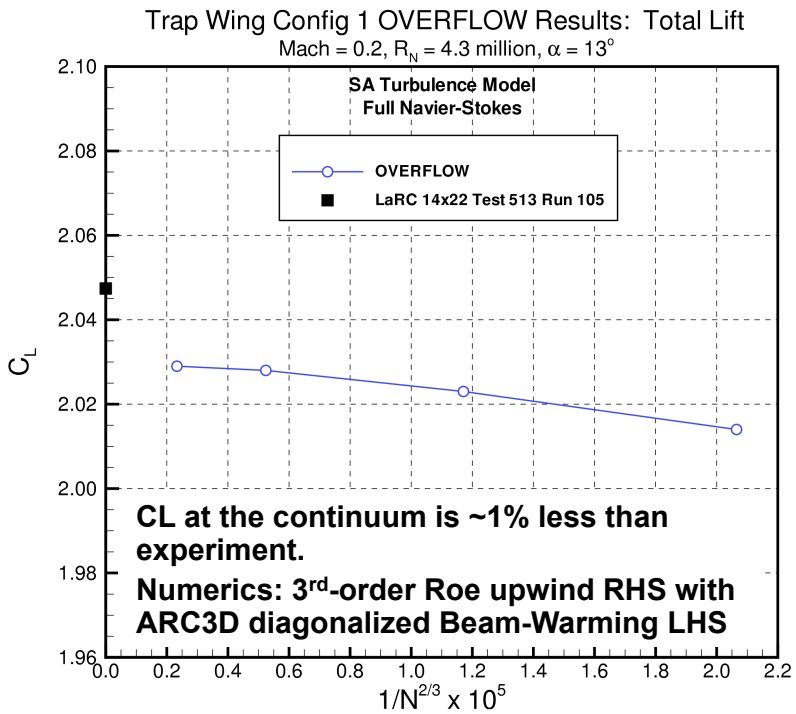


medium



fine





CL at the continuum is ~1% less than experiment.

Numerics: 3rd-order Roe upwind RHS with ARC3D diagonalized Beam-Warming LHS

Flap Deflection Study
Lift & Drag

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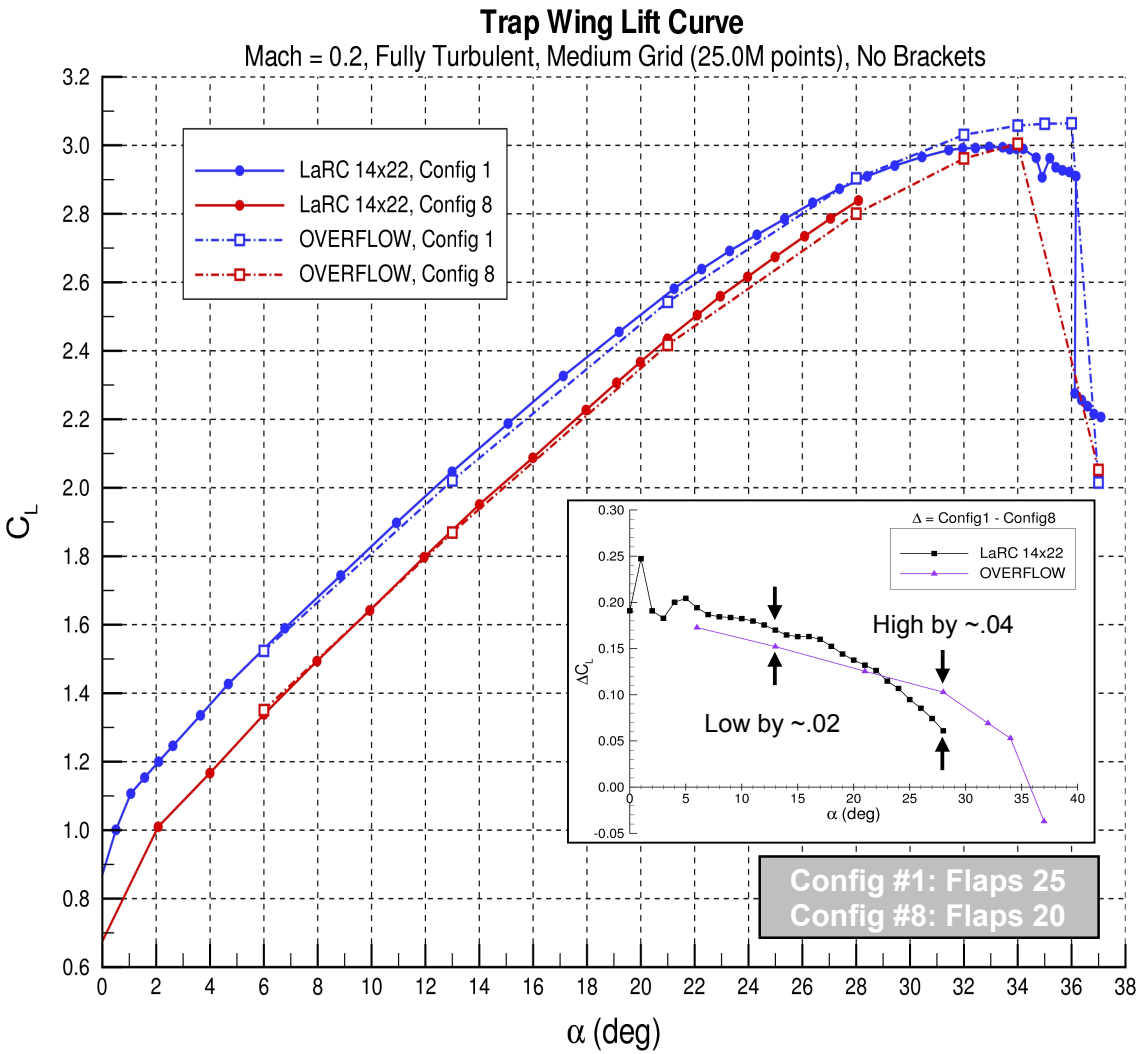

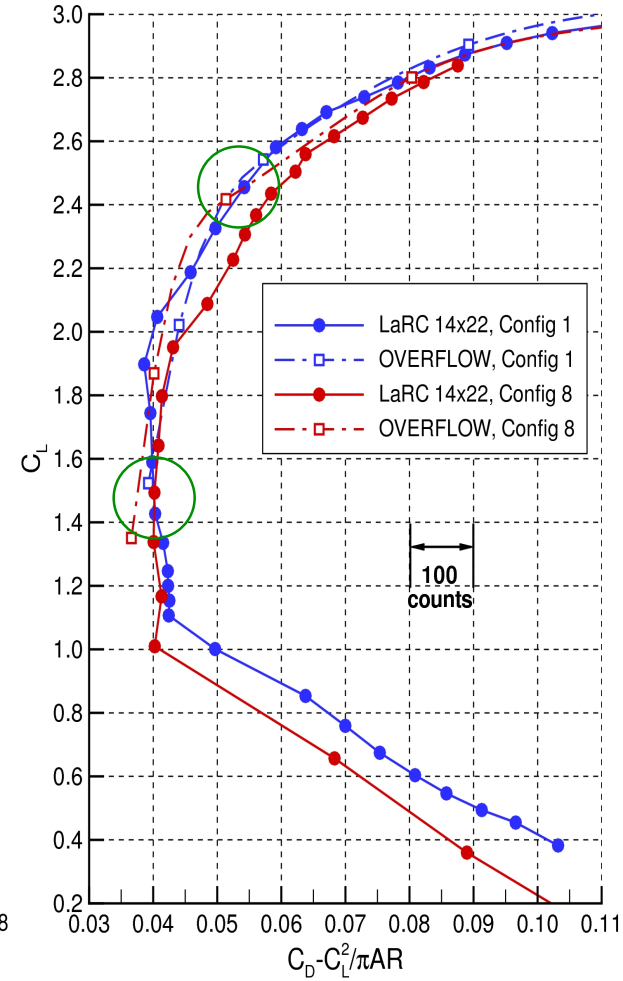

(Idealized Profile Drag)

Flap Deflection Study
Pitching Moment

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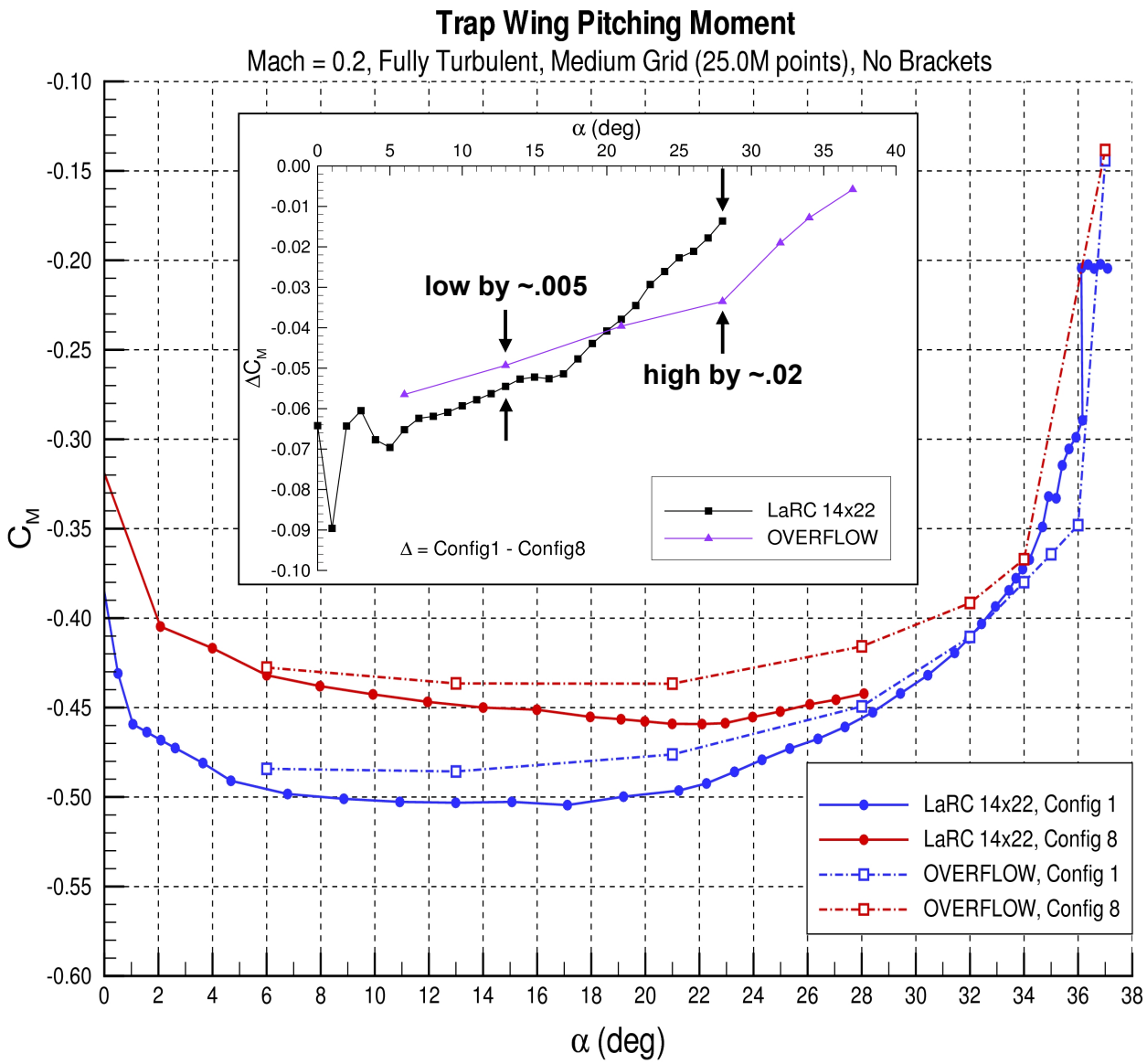

Effects of Brackets

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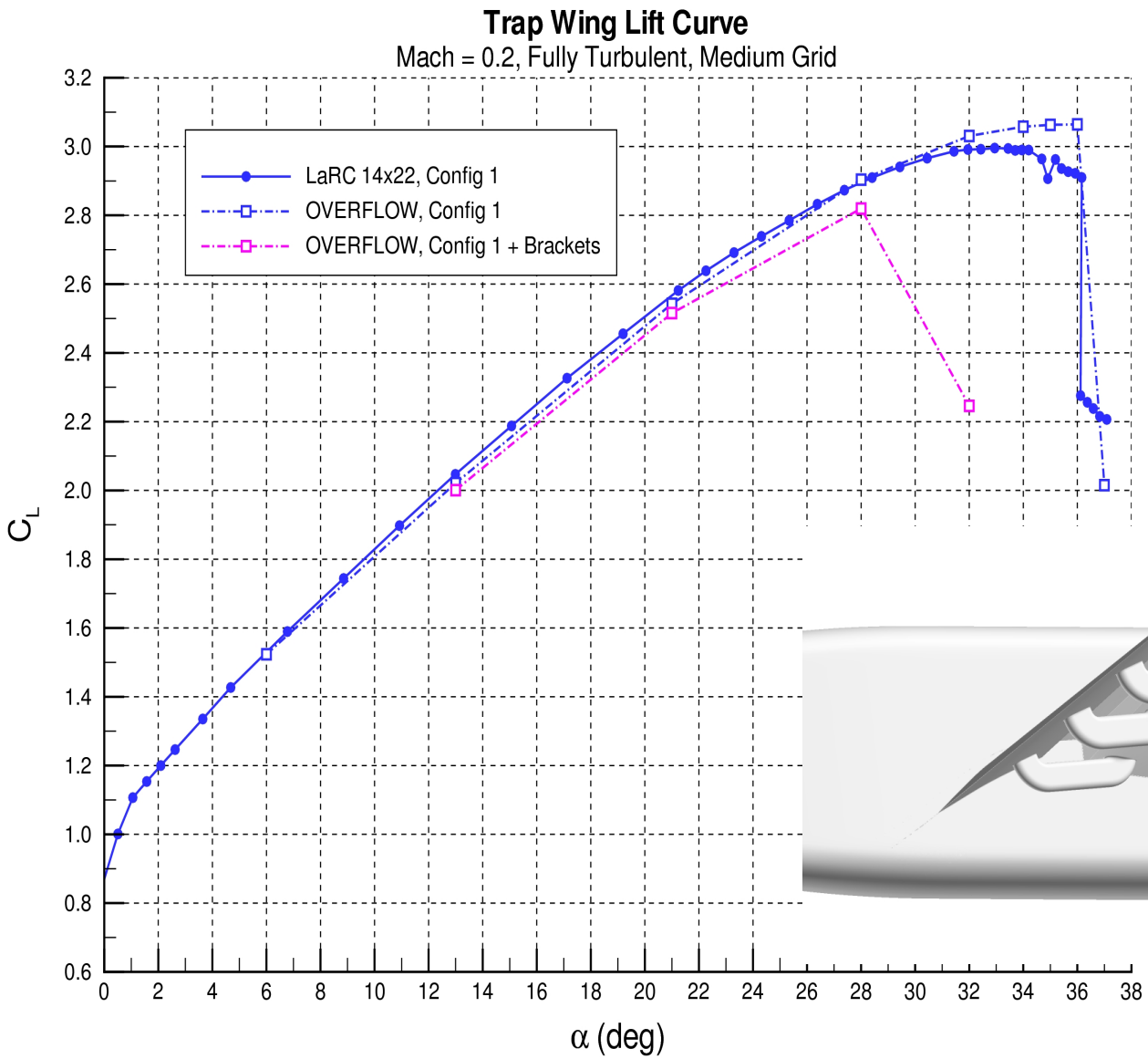

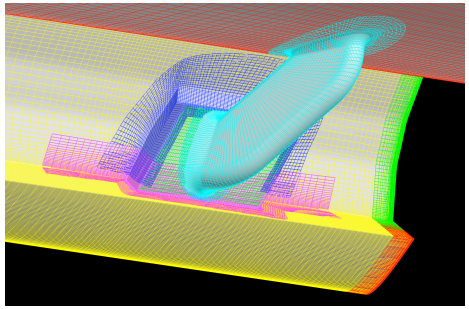

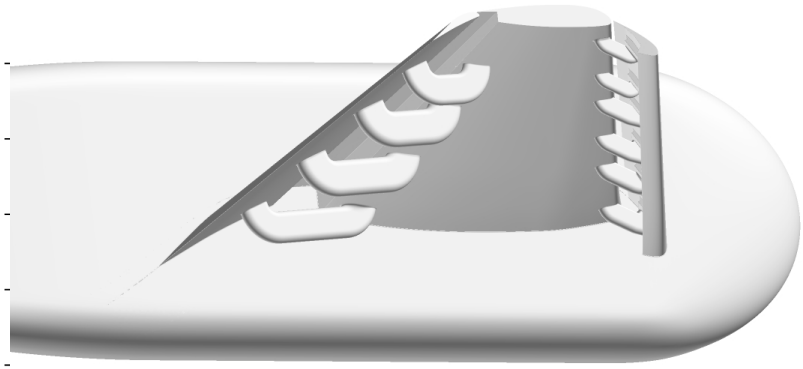

Effect of Brackets

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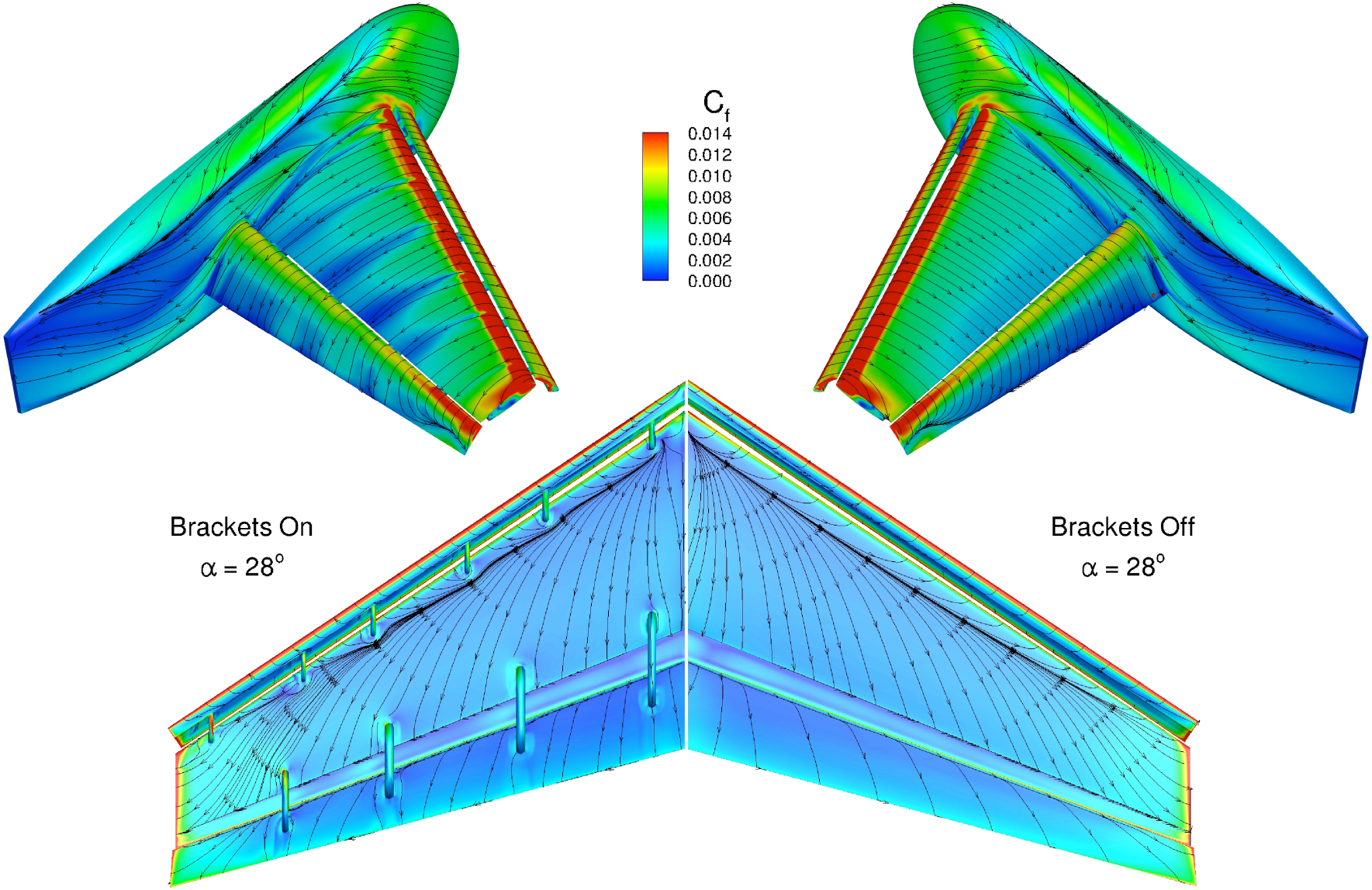

Effect of Brackets

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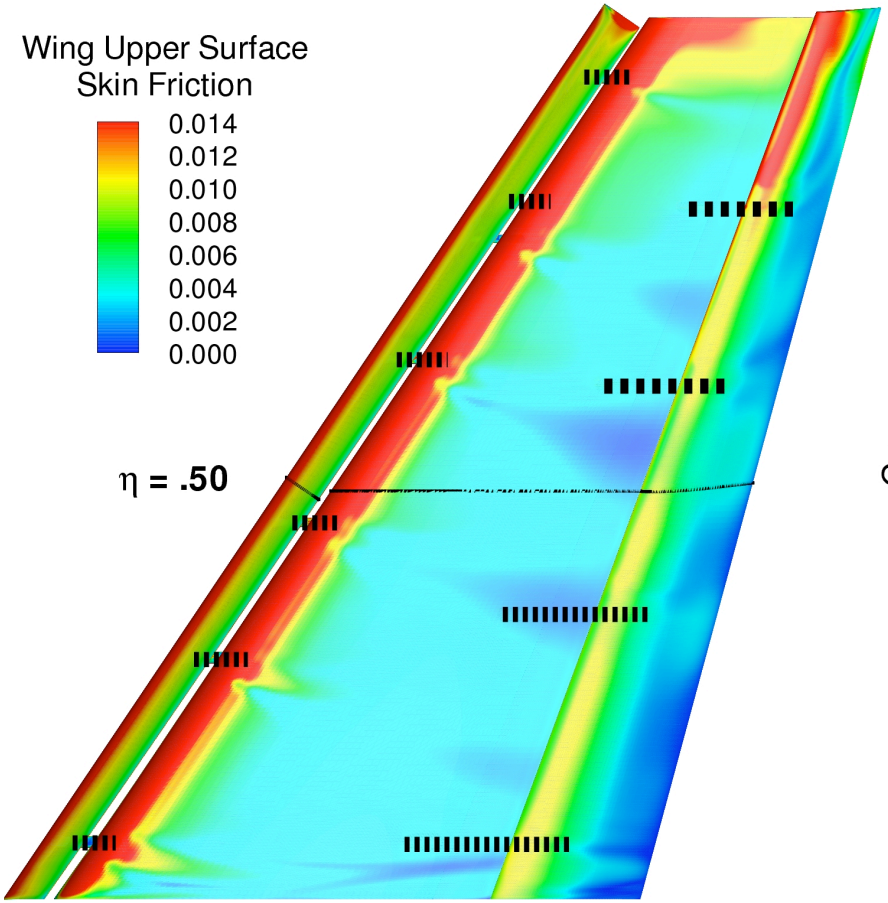
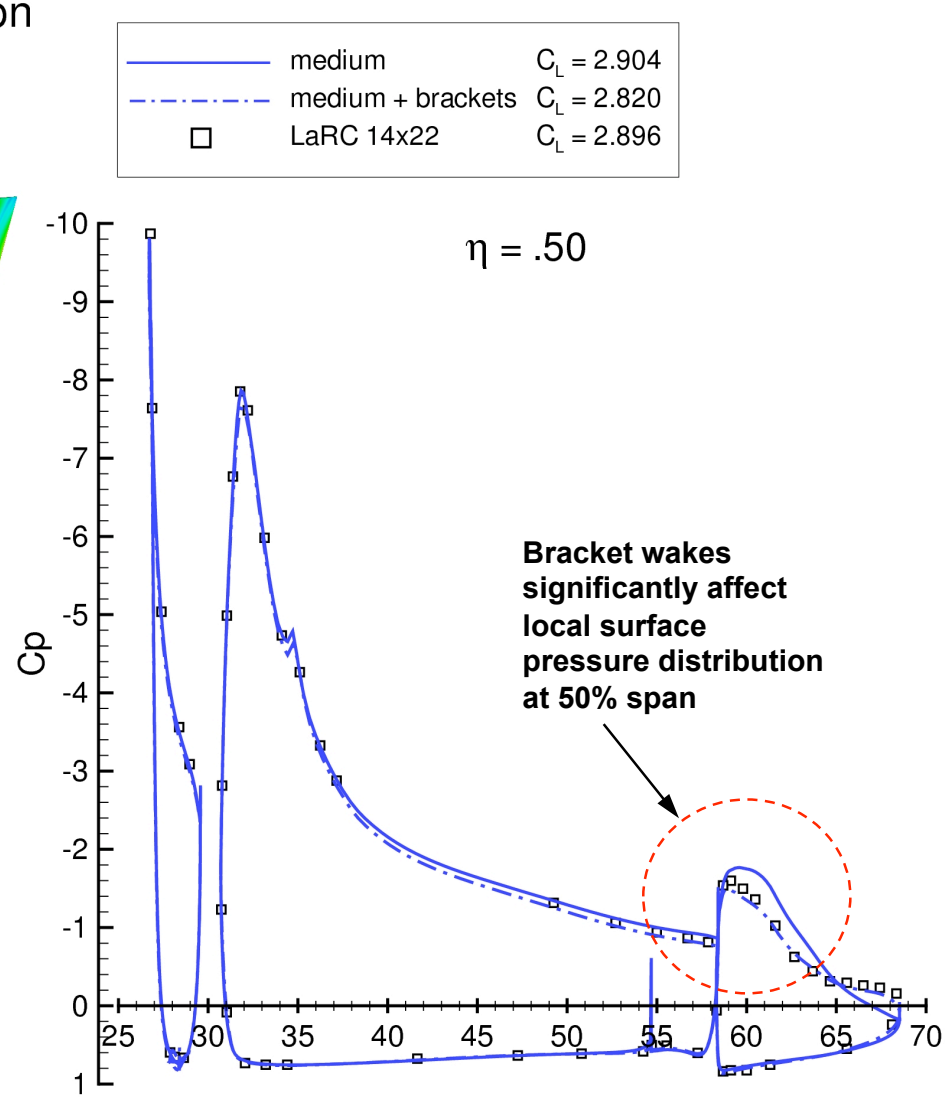
Trap Wing Config1 Pressure Comparison

LaRC 14x22 vs OVERFLOW

RN_{MAC} = 4.3 million, Mach = 0.2, $\alpha = 28^o$





Issues: Different Solution Paths

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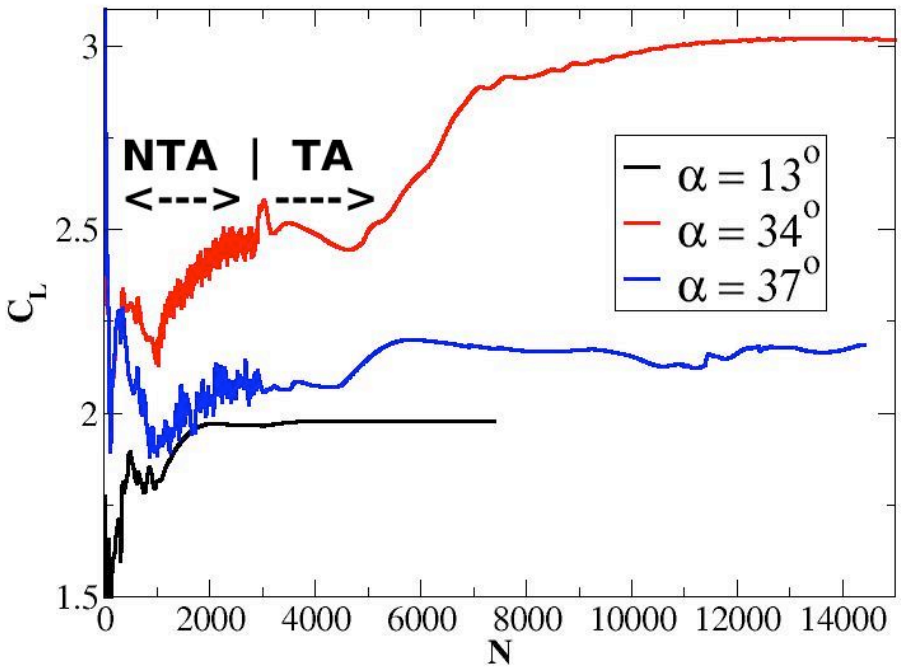
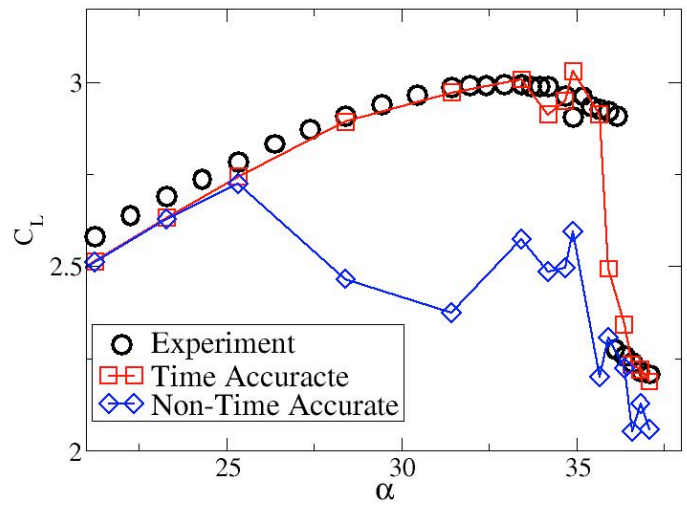
- Time-accurate simulations started from steady-state solutions (central differencing)
- Time-accurate mode extends stall boundary to α=36°



Lift Convergence



Lift Curve

Issues: Solution Hysteresis

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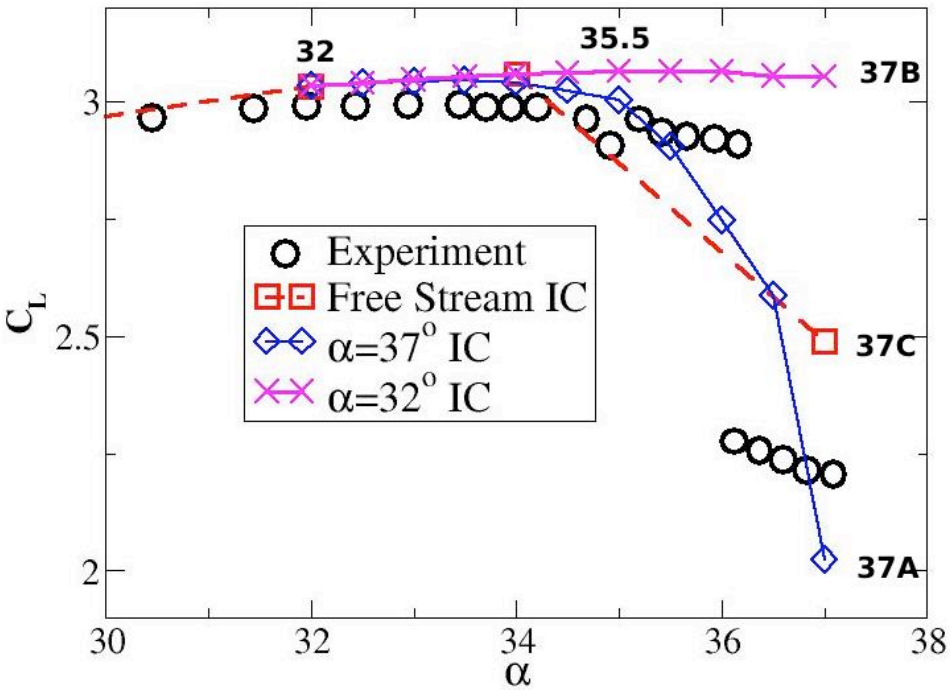
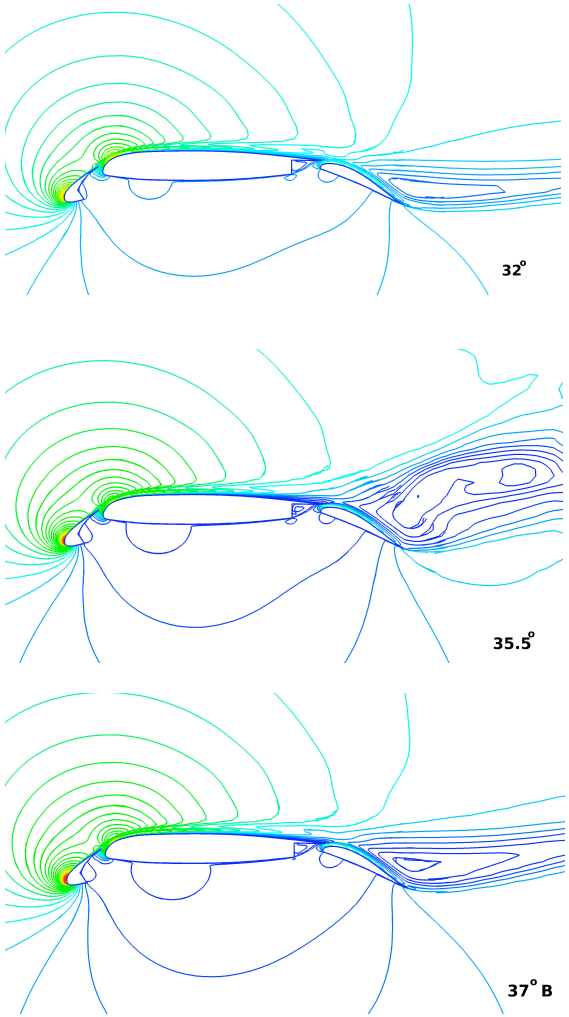
- Using freestream Initial Conditions (IC), late stall at α=37° (37C)
- Using α=32° IC, NO stall at α=37° (37B)
- Using α=37° IC, Stalled case reattaches! (37A)





Work in Progress

- Complete full set of cases with brackets
- Better understand numerics (hysteresis, time/ non-time-accurate solutions)
- Investigate new grid approach: Near-body (NB) / off-body (OB) / grid adaptation framework and process

Grid Approaches

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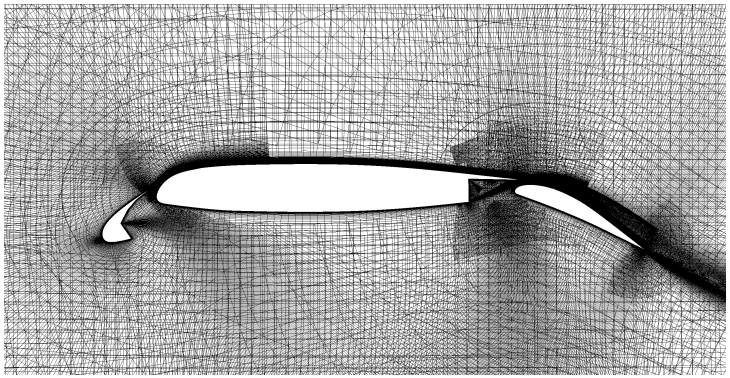
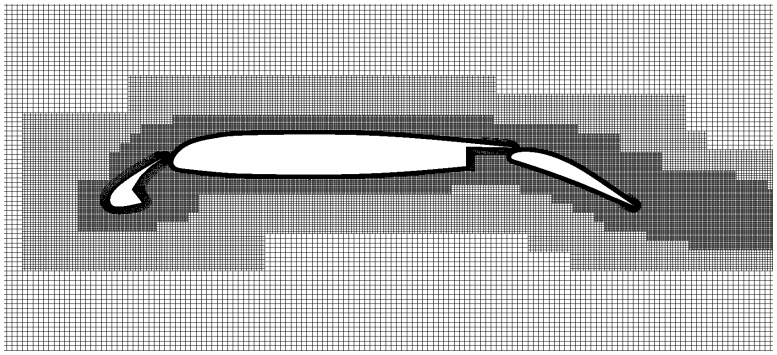
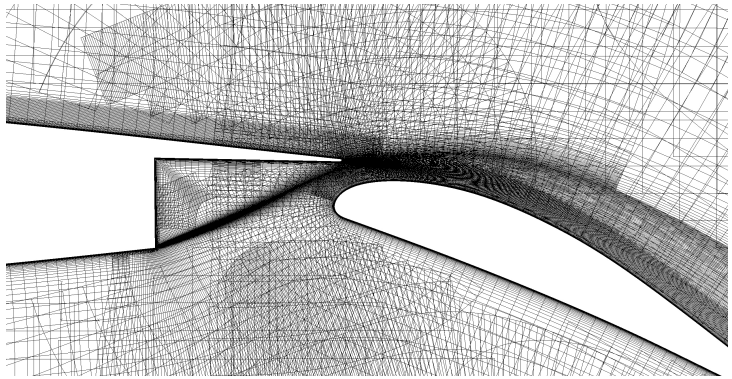
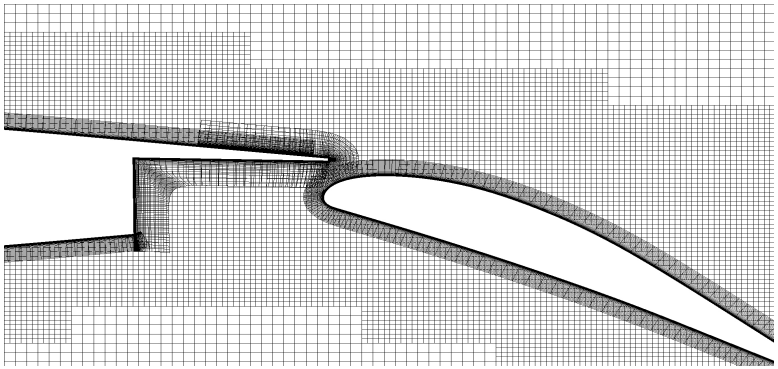
- **Workshop Supplied Overset Grids**
  - C-Mesh Topology for Slat, Wing, Flap, Tips and Collars
  - Pegasus Generated Domain Connectivity
- **Proposed New Grid System**
  - Near Body (NB) O-mesh Topology (Very limited Off-Body Extent)
  - Off-Body (OB) Cartesian
  - DCF/X-Ray Domain Connectivity
  - Off-Body Adaption for Wake and Vortex Capturing









Grid Adaptation

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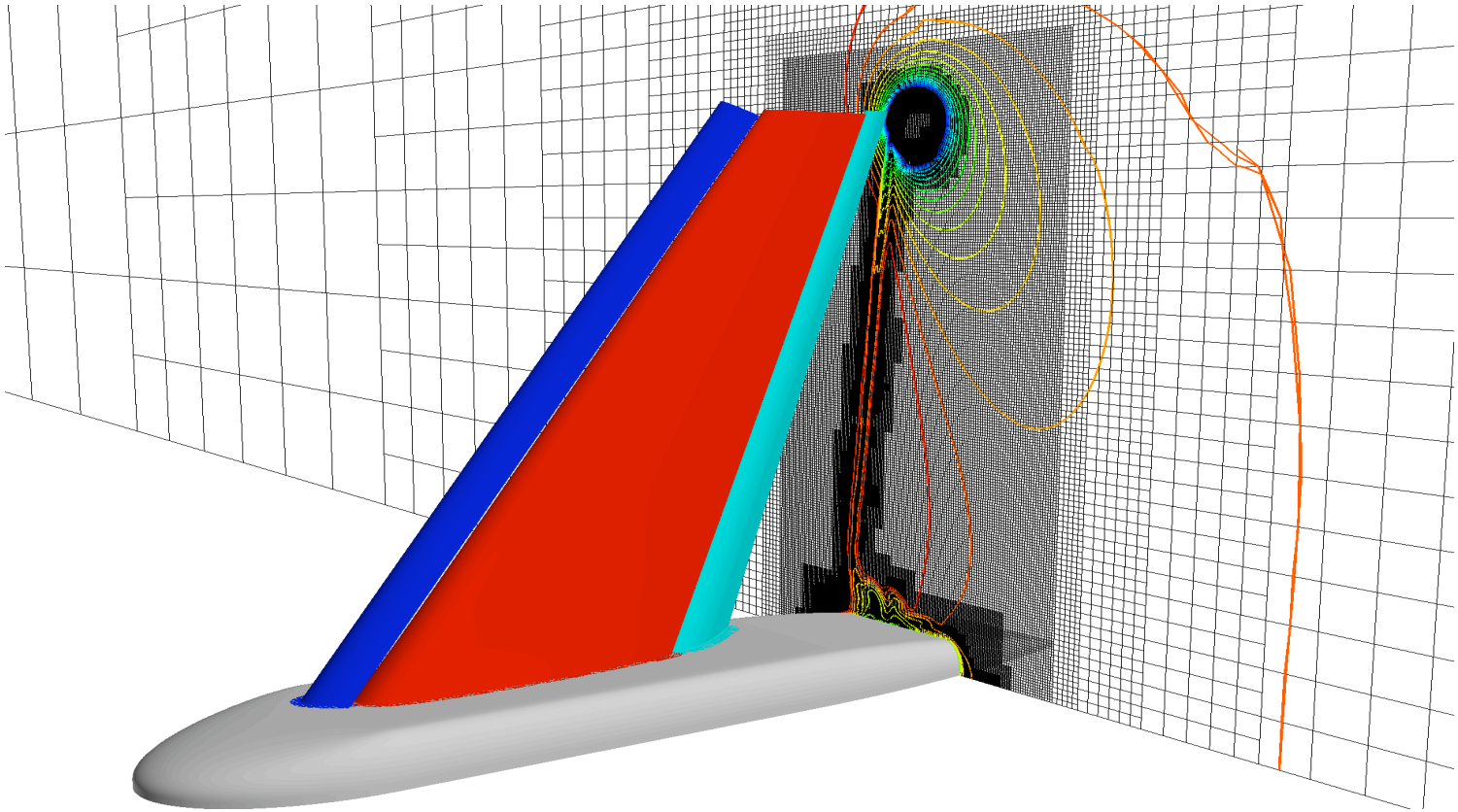
- **Adaption based on**
  - 2nd Undivided Differences Squared ~ O(Dx^4)
  - Off-body adaption for wake and vortex capturing
- **Future enhancements will include**
  - Near-body adaption
  - Adjoint-based adaption criteria