Overview of the First AIAA CFD High Lift Prediction Workshop

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49th AIAA Aerospace Sciences Meeting
Orlando, FL
4-7 January 2011

Organizing Committee

- **Jeffrey Slotnick and Tony Sclafani**
  The Boeing Company
- **Mark Chaffin and David Levy***
  Cessna Aircraft Company
- **Ralf Rudnik**
  DLR – German Aerospace Center
- **Thomas Wayman**
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- **Bob Stuever and Chittur "Venkat" Venkatasubban**
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- **Judi Hannon and Chris Rumsey**
  NASA Langley Research Center
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*** DPW organizing committee member**

Outline

- Special Sessions

- Motivation
- Objectives
- HiLiftPW-1
  - Background
  - Participant Data
  - Test Cases
- Geometry & Experimental Data
  - Data Repeatability
- Grid Systems
  - Gridding Guidelines
  - Grid Sizes & Types
  - Grid Quality
- Acknowledgments

HiLiftPW-1 Special Sessions

CFD High Lift Prediction Workshop

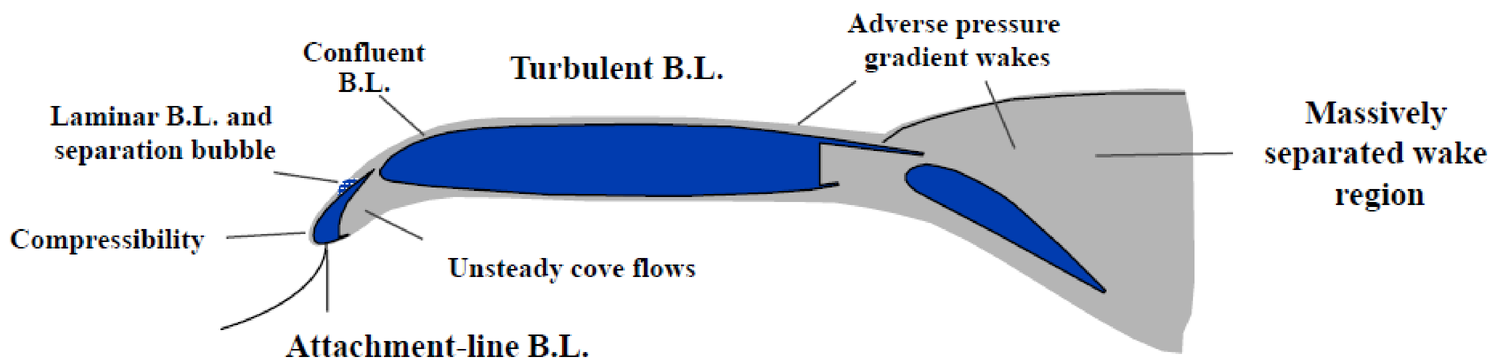
Session 1	
8:00 AM-8:30 AM	AIAA-2011-0862 **Overview of the First AIAA CFD High Lift Prediction Workshop** *J. P. Slotnick; J. A. Hannon; M. Chaffin*
8:30 AM-9:00 AM	AIAA-2011-0863 **NSU3D Results for the First AIAA High-Lift** *M. Long; D. Mavriplis*
9:00 AM-9:30 AM	AIAA-2011-0864 **High Lift CFD Simulations with an SST-Based Predictive Laminar to Turbulent Transition Model** *R. Steed*
9:30 AM-10:00 AM	AIAA-2011-0865 **Computational Assessment of the HiLiftPW-1 Trap-Wing Model Using the elsA CFD Software** *L. Wiart; M. Meunier*
10:00 AM-10:30 AM	AIAA-2011-0866 **OVERFLOW Analysis of the NASA Trap Wing Model from the First High Lift Prediction Workshop** *T. Sclafani; J. P. Slotnick; J. Vassberg; T. Pulliam; H. Lee*
10:30 AM-11:00 AM	AIAA-2011-0867 **Improving the Prediction for the NASA High-Lift Trap Wing Model** *P. Eliasson; S. Peng*
11:00 AM-11:30 AM	AIAA-2011-0868 **Calculations of High-Lift Wing-Body Configuration with k-omega Model Variants** *D. Reyes; S. Girimaji; M. Pandya; K. Abdol-Hamid*
11:30 AM-12:00 PM	AIAA-2011-0869 **Unsteady Flow Simulation of a High-Lift configuration using a Lattice Boltzmann Approach** *E. Fares; S. Noelting*

Session 2	
2:00 PM-2:30 PM	AIAA-2011-0936 **FUN3D and CFL3D Computations for the First High Lift Prediction Workshop** *M. Park; B. Lee-Rausch; C. Rumsey*
2:30 PM-3:00 PM	AIAA-2011-0937 **CFD Comparison Study for Trapezoidal High-Lift Wing Configurations by Structured and Unstructured Mesh Method** *M. Murayama; K. Yamamoto; K. Tanaka*
3:00 PM-3:30 PM	AIAA-2011-0938 **DLR Contribution to the First High Lift Prediction Workshop** *S. Crippa; R. Rudnik; S. Melber-Wilkending*
3:30 PM-4:30 PM	AIAA-2011-0939 **Summary of the First AIAA CFD High Lift Prediction Workshop** *C. Rumsey; M. Long; B. Stuever; T. Wayman*
4:30 PM-5:00 PM	**Open Forum**

Motivation

CFD High Lift Prediction Workshop

- The aerodynamics associated with three-dimensional, swept, medium- to high-aspect ratio wings is extremely complex, and are characterized by:
  - Confluent boundary layers
  - Massive separations
  - Unsteady effects
  - Strong streamline curvature
  - History effects (hysteresis)
  - Flow transition (wall bounded and free shear layers)
- Computational Fluid Dynamics (CFD) is playing an ever-increasing role in predicting these types of flows
- Benchmarking CFD predictive capabilities and enhancing the understanding of the fundamental flow physics of high-lift flows is important to the aerospace community → *High Lift Workshop*



Objectives

CFD High Lift Prediction Workshop

- Assess the numerical prediction capability (meshing, numerics, turbulence modeling, high-performance computing requirements, etc.) 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 to enable development of more accurate prediction methods and tools
- Enhance CFD prediction capability to enable practical high-lift aerodynamic design and optimization

HiLiftPW-1

CFD High Lift Prediction Workshop

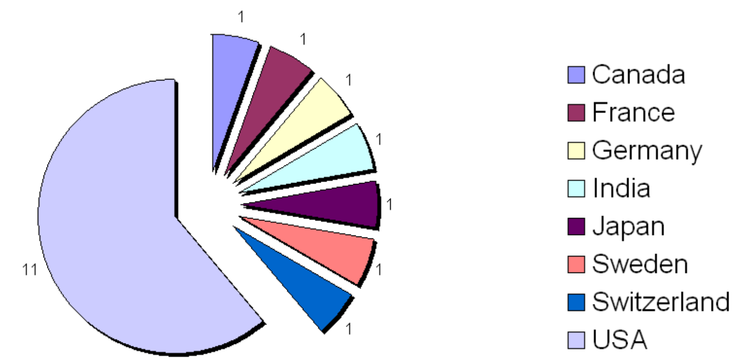
- **Held on June 26-27, 2010 in Chicago, IL prior to the 28th Applied Aerodynamics Conference**
  - Patterned after the successful Drag Prediction Workshop (DPW) series
  - Open, unbiased forums were included in the workshop to discuss the results and promote cross-pollination of best practices
  - Test cases were based on the Trapezoidal (Trap) Wing configuration, which has a significant amount of high-quality data readily available
- **Website: http://hiliftpw.larc.nasa.gov**
  - Geometry files
  - Grid systems
  - Experimental and computational data
  - Workshop presentations
  - Special session technical papers and presentations

Background

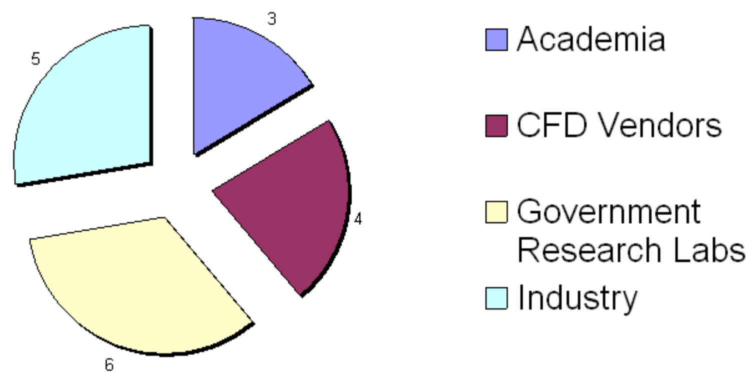
- **1998-1999** – First series of Trap Wing experiments in NASA LaRC 14x22 WT and NASA ARC 12 Foot PWT
- **2002-2003** – Additional Trap Wing data collected in 14x22 WT
- **2004-2006** – Preliminary discussion of a CFD High-Lift prediction workshop based on Trap Wing datasets
  - External support (e.g. 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

Participation

- **21** total presentations (32 initially registered on website)
- **18** individual organizations from **8** countries
- **~40%** non-US participation

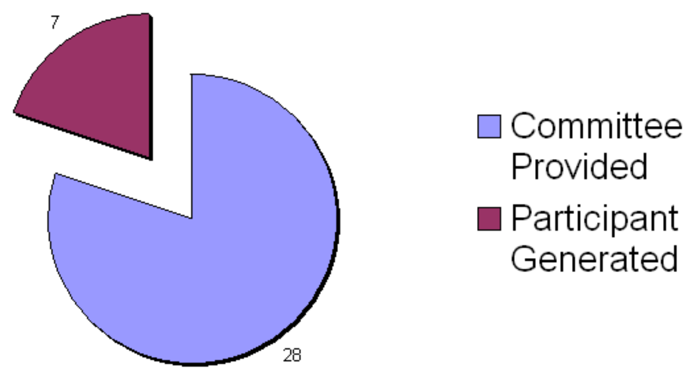


- Broad participation from the aerospace community

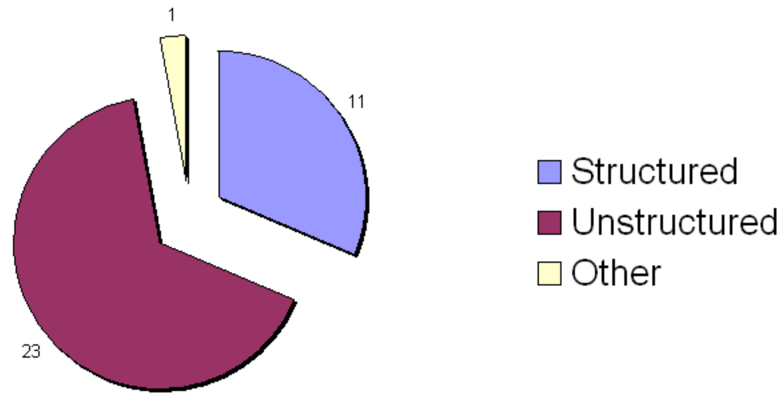


Participation (cont.)

- **35** total datasets
- Most participants used committee-generated grid systems



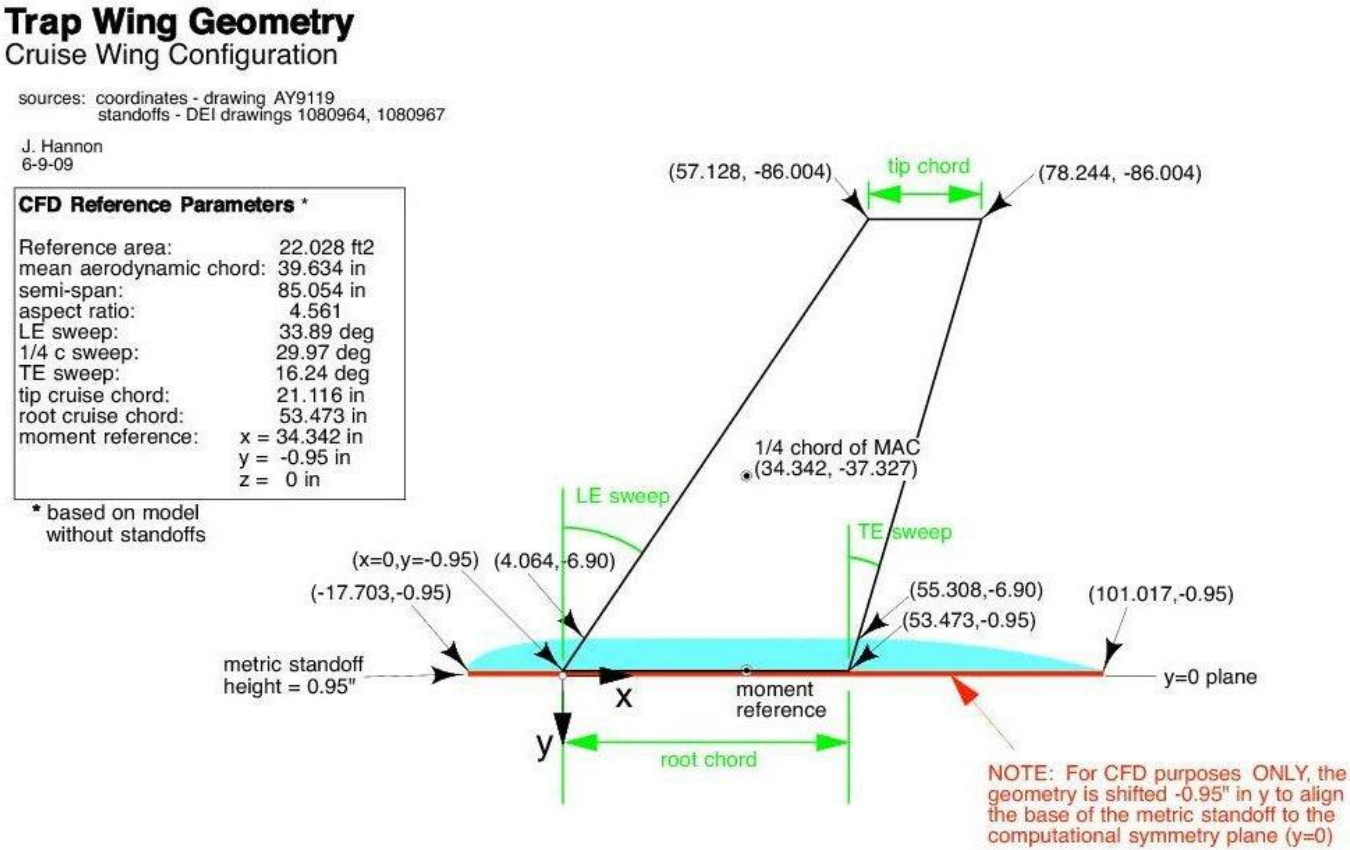
- Most participants used unstructured mesh CFD tools and processes



Test Cases

- **Test Case 1 – Grid Convergence Study** **OPTIONAL**
  - 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

Trap Wing



Trap Wing in 14x22

- 700-800 pressure orifices (tubing run through slat and flap brackets)
- Stand-off with labyrinth seal (geometry shifted 0.95 inch to include stand-off)
- Transition NOT fixed

Experimental Test Campaigns

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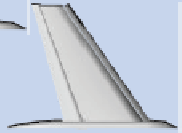
96	97	98	99	00	01	02	03	04	05	06	07	08	09	10

NASA – Ames and Langley,
Boeing – Seattle and Long Beach

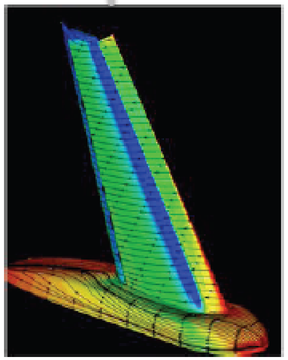
Preliminary Test
14x22 Test 478
1998

High Re Test
ARC 12' Test 60
1999



Acoustic Test
14x22 Test 517
2003

Workshop organizing committee established - 2009



1st AIAA CFD High-Lift Prediction Workshop – June 2010

- 2001 Reno Turbulence Workshop
- 1 configuration
- more flow physics data

Tunnel Flow Survey
14x22 Test 509
2002

Transition Test
14x22 Test 506
2002

Flow-Field Test
14x22 Test 513
2003

Geometry

- Trap Wing geometry model from 1998/1999 re-verified in 2002 (2002 QA) and 2004 (2004 QA)
  - Inconsistencies in flap gap (g/c) and overlap (o/c) exist between all three models for Config #1
- Committee chose 2002 QA geometry definition
  - Measured with deployed elements
  - Accept inconsistencies in flap positioning
    - Focus on CFD code-to-code comparisons using single geometry
    - Use experiment as a reference
- Config #8 based on Config #1 → Config #1 flap transformed to stowed position then set to Config #8 as-designed settings

Experimental Data

	1998 -1999 Tests		2002 Tunnel Flow Survey	2002 Transition Test	2003 Flow Field Test
	12 Foot	*14x22*	*14x22*	*14x22*	*14x22*
Reynolds Number	3.5, 6, 9, 12, 15	4.3	4.3	4.3	4.3
Mach Number	0.15-0.25	0.2	0.2	0.2	0.2
Configurations	10 full-span flap 6 part-span flap	4 full-span flap 4 part-span flap		1 full-span flap (Config 1)	1 full-span flap (Config 1)
Forces/Moments	✓	✓		✓	✓
Surface Pressures	✓	✓		✓	✓
Wall Pressures	✓		✓ (3 walls)	✓ (3 walls)	✓ (3 walls)
Wall BL Profiles			✓ (4 profiles)	✓ (4 profiles)	
Tunnel Flow Angle			✓		
Tunnel Temperature			✓		
Tunnel Pressures			✓		
Turbulence Intensity			✓		
BL Transition	TSP	Limited (Infrared)		**Hot films**	
Velocity Profiles	Limited	**Limited**			PIV
Mini-tuft Images	✓				
Model Deformation				✓	

- HiLiftPW-1 used force/moment, surface pressure, and skin friction data only.
- Limited transition measurement data is available (AIAA 2005-5148)
- Velocity profile data currently being processed

Modeling Differences

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Experiments	CFD
tunnel walls with corrections to free air	free-air
laminar/transitional/turbulent flow	fully turbulent
brackets	no slat or flap brackets (except optional case 3)

Data Repeatability

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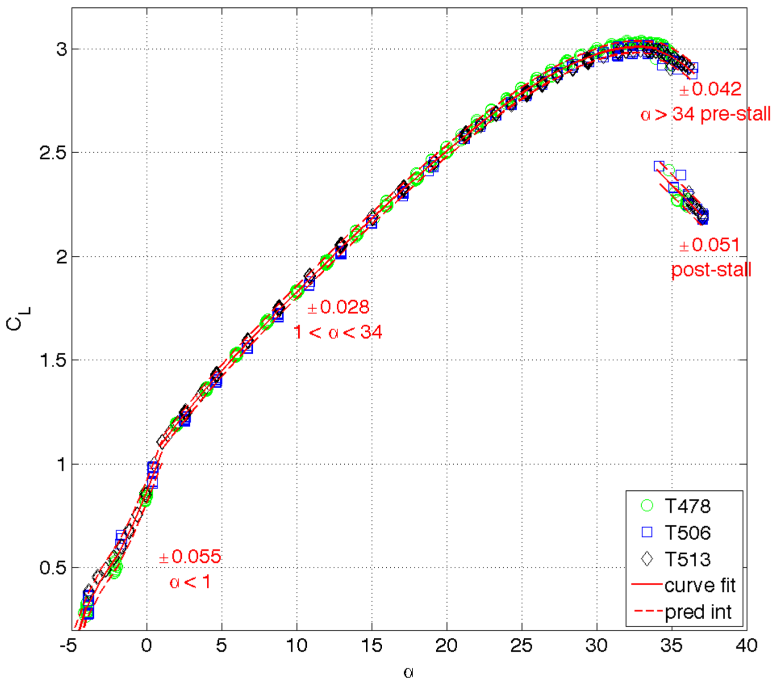
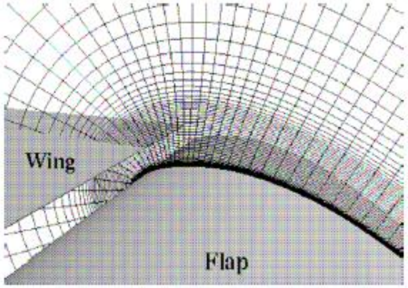
- Using methodology described by Wahls, Adcock, Witkowski, and Wright (NASA TP 3522)
  - Least squares polynomial curve fit based on all the data in a given alpha range for a given configuration
  - Assessing repeatability by amount of scatter about this curve fit
  - Because of biases in the data, this violates statistical principle of “randomness” but is still a useful measure of the data scatter.
- Config #1 repeatability is based on three different tests (1998, 2002, 2003)
  - Prediction intervals are conservative
  - Variations are 2-3x instrumentation uncertainty
- Config #8 repeatability is based on 3 back-to-back polars on one day in 1998



Gridding Guidelines

- Initial spacing normal to all viscous walls (Re = 4.3M based on CREF = 39.6 in)
  - Coarse: y+ ~ 1.0 Dy = 0.00020 in
  - Medium: y+ ~ 2/3 Dy = 0.00013 in
  - Fine: y+ ~ 4/9 Dy = 0.00009 in
  - Extra-Fine: y+ ~ 8/27 Dy = 0.00006 in
- Recommend grids have at least 2 cell layers of constant spacing normal to viscous walls
- Total grid size to grow ~3x between each grid level for grid convergence cases
  - For structured meshes, this growth is ~1.5x in each coordinate direction
- Growth rate of cell sizes in the viscous layer should be < 1.25
  - Include a region with constant cell spacing (growth rate = 1.0) to capture wakes from upstream elements if possible
- Far-field located at a distance of ~100 reference chords for all grid levels
- For the medium baseline grids:
  - Chordwise spacing for leading and trailing edges should be ~0.1% local chord
  - Spanwise spacing at root and tip should be ~0.1% local semi-span
  - Cell size near fuselage nose and after-body should be ~2.0% reference chord
- Trailing Edge Base:
  - Minimum of 4 cells across TE base for the coarse mesh
  - Minimum of 6 cells across TE base for the medium mesh
  - Minimum of 9 cells across TE base for the fine mesh
  - Minimum of 14 cells across TE base for the extra-fine mesh
- Grids should be amenable to multi-grid



Grid Systems (Committee Supplied)

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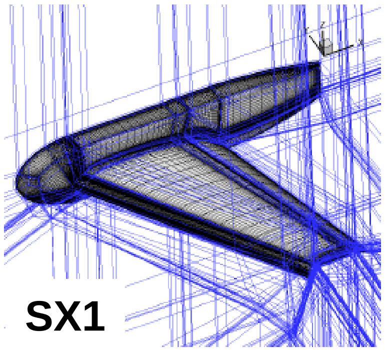
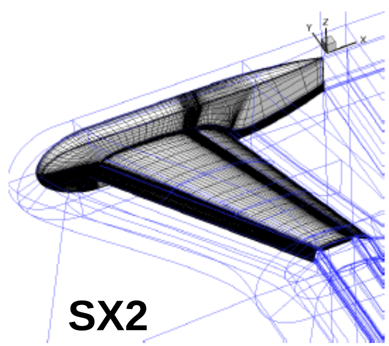
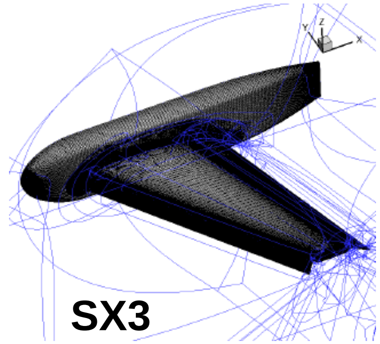
Shorthand Notation	Website Notation	Grid Generation Tool	Grid Type	Notes	Responsible Organization
SX1	Str-OnetoOne-A	ICEM-CFD	Structured Point Matched	1235 zones	Boeing
SX2	Str-OnetoOne-B	GridGen	Structured Point Matched	306-309 zones	Pointwise
SX3	Str-Overset-A	Chimera Grid Tools	Structured Overset	34 zones (Brackets Gridded)	Boeing
UT4	Unst-Tet-Cellcentered-A	VGRID	Unstructured (tet) Cell-Centered	All tetrahedral	NASA
UT5	Unst-Tet-Nodecentered-A	VGRID	Unstructured (tet) Node-Centered	All tetrahedral	Scientific Solutions & Univ of Wyoming
UH6	Unst-Mixed-FromTet-Nodecentered-A	VGRID	Unstructured Mixed Cell Node-Centered	Prisms in boundary layer, tetrahedral in farfield	Scientific Solutions & Univ of Wyoming
UH7	Unst-Mixed-Nodecentered-A	CENTAUR	Unstructured Mixed Cell Node-Centered	Primarily prisms in boundary layer, tetrahedral in farfield	DLR
UH8	Unst-Mixed-Nodecentered-B	SOLAR	Unstructured Mixed Cell Node-Centered	Primarily hexas in boundary layer, tetrahedral in farfield	DLR
UX9	Unst-Hex-FromOnetoOne-A	ICEM-CFD	Unstructured (hex)	Same grid as SX1	Boeing & NASA

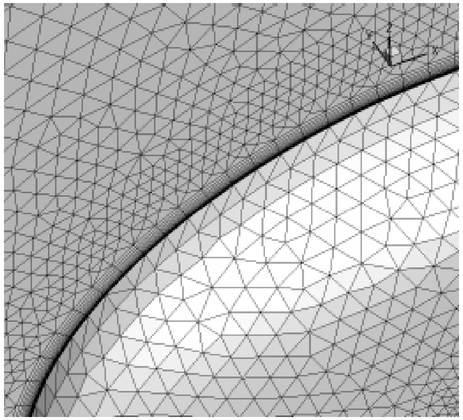
Grid Systems (cont.)

- Examples of committee-supplied grids:

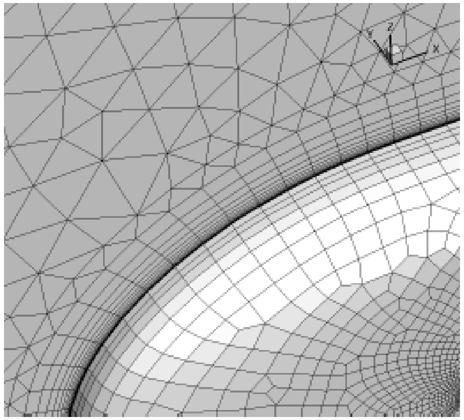




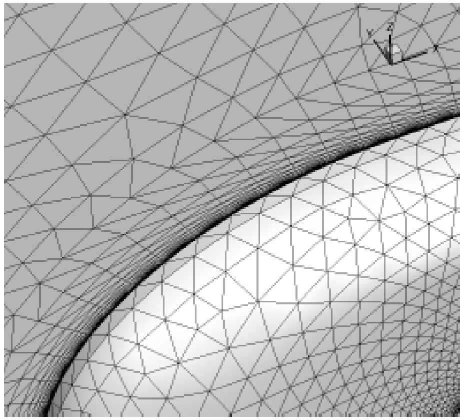




UH7
Centaur



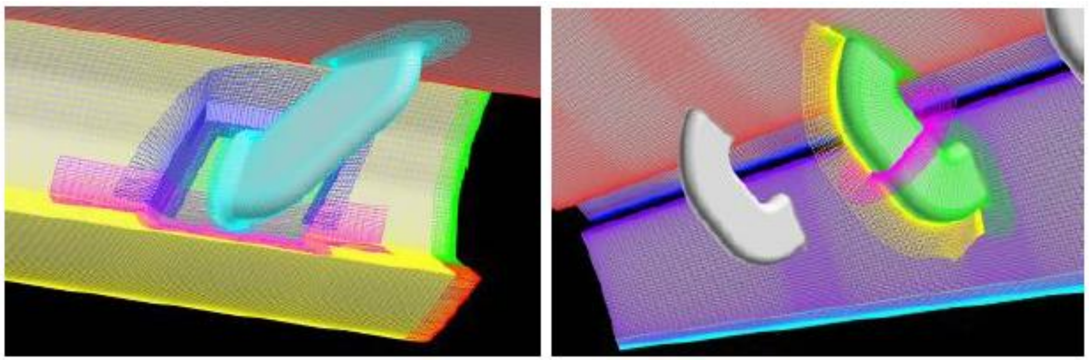
UH8
SOLAR



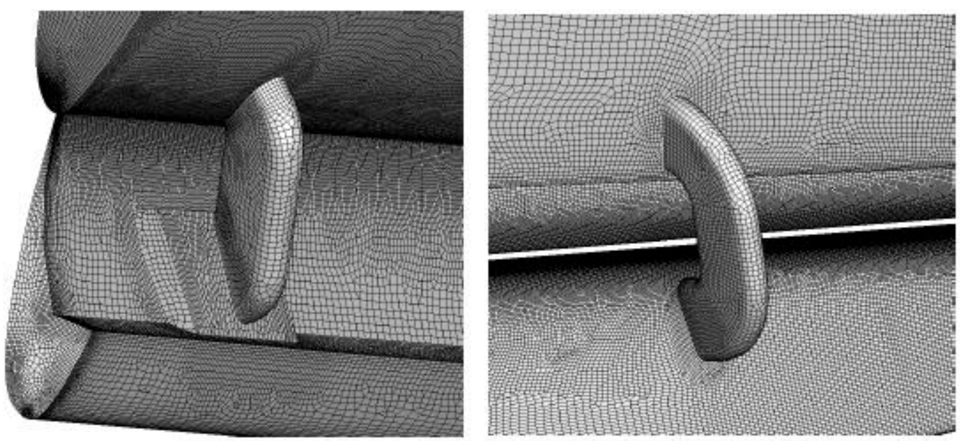
UT6
VGRID

Grid Systems (cont.)

- Two committee grids included versions with the slat and flap brackets



SX3
Structured Overset
(Chimera Grid Tools – Boeing)

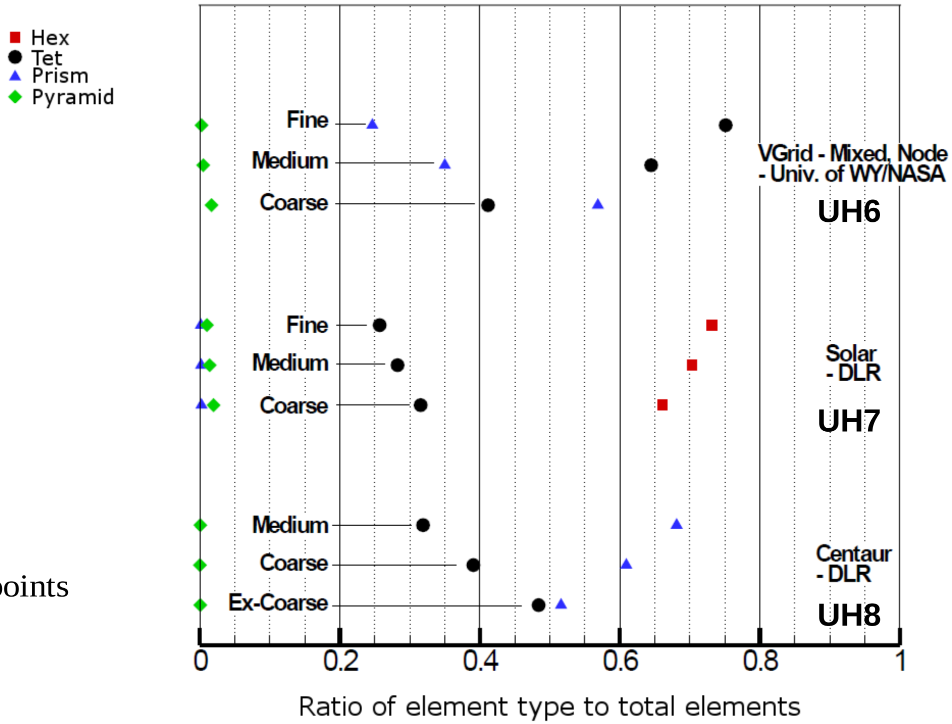


UH8
Unstructured Hybrid
(SOLAR – DLR)

Grid Size and Type

Grid	Extra coarse	Coarse	Medium	Fine	Extra fine
SX1	7.1	22.6	52.1	170.7	
SX2	3.9	11.3	28.5	85.5	
SX3		10.7	25.0	83.3	281.6
UT4*		7.2	21.7	62.7	
UT5		3.7	11.0	32.3	
UH6		3.7	11.0	32.4	
UH7	12.9	16.4	31.5		
UH8		12.3	37.0	110.7	
UX9	6.1	20.4	48.1	161.9	

* UT4 grid sizes indicate number of cells rather than number of points



- Number of points varies dramatically among each refinement level across grid systems
- Distribution of cell types also varies based on grid generation software package used

Grid Quality

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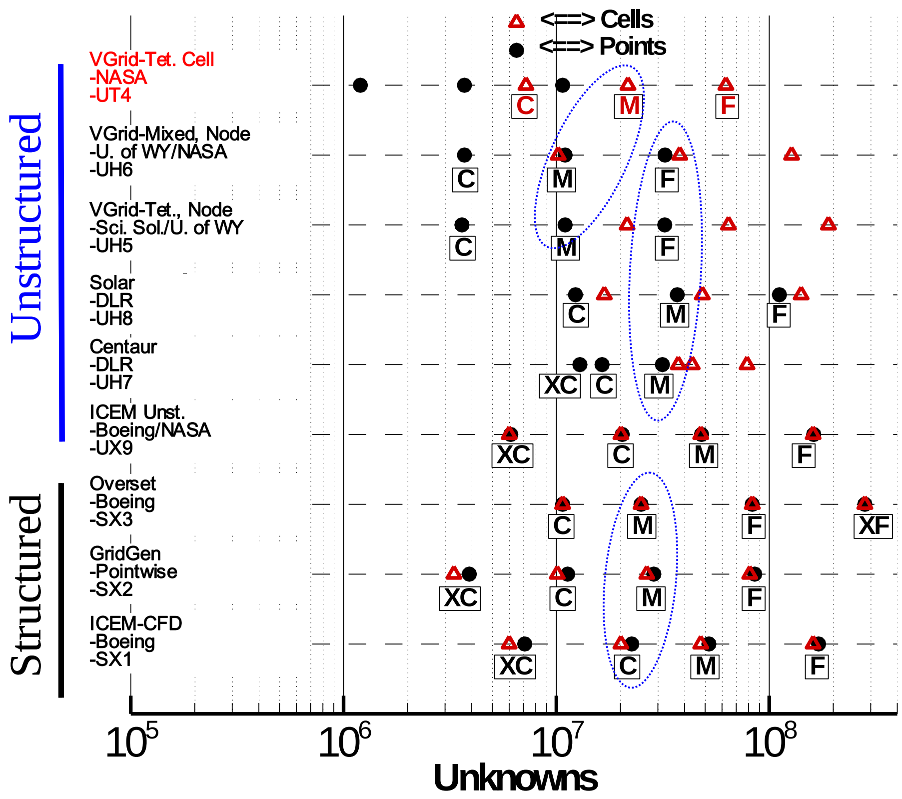
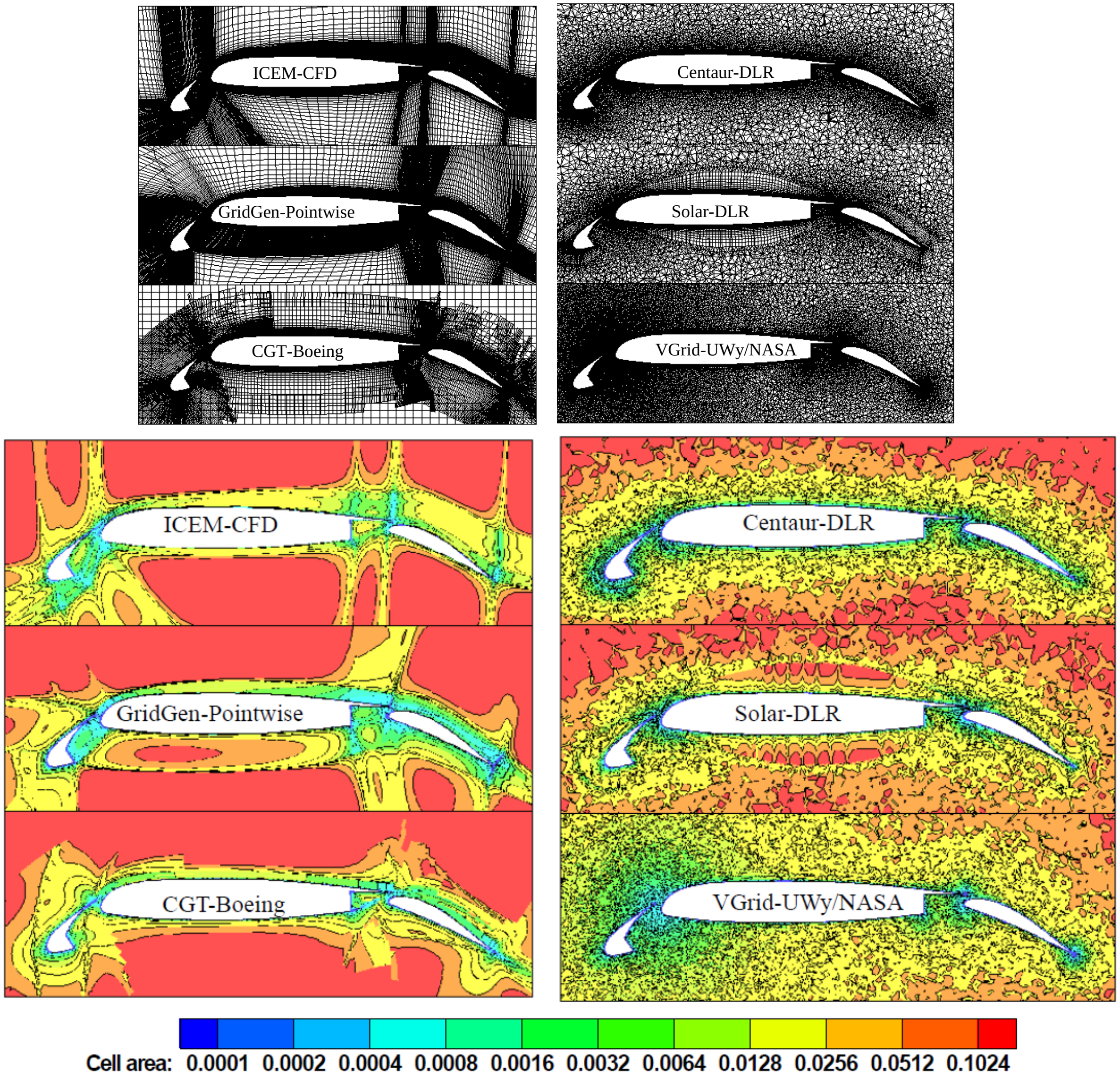
- As part of the broader goal to develop practical modeling guidelines for high-lift CFD, including grid quality, *qualitative* comparisons of a small subset of the grids using cell areas were presented at the workshop
- Comparisons are made based on *cross-sectional cell area* at the Y=50% span cut location
- Comparisons are performed for grid systems of similar unknowns
- No attempt has been made to correlate grid quality to solution accuracy (yet)

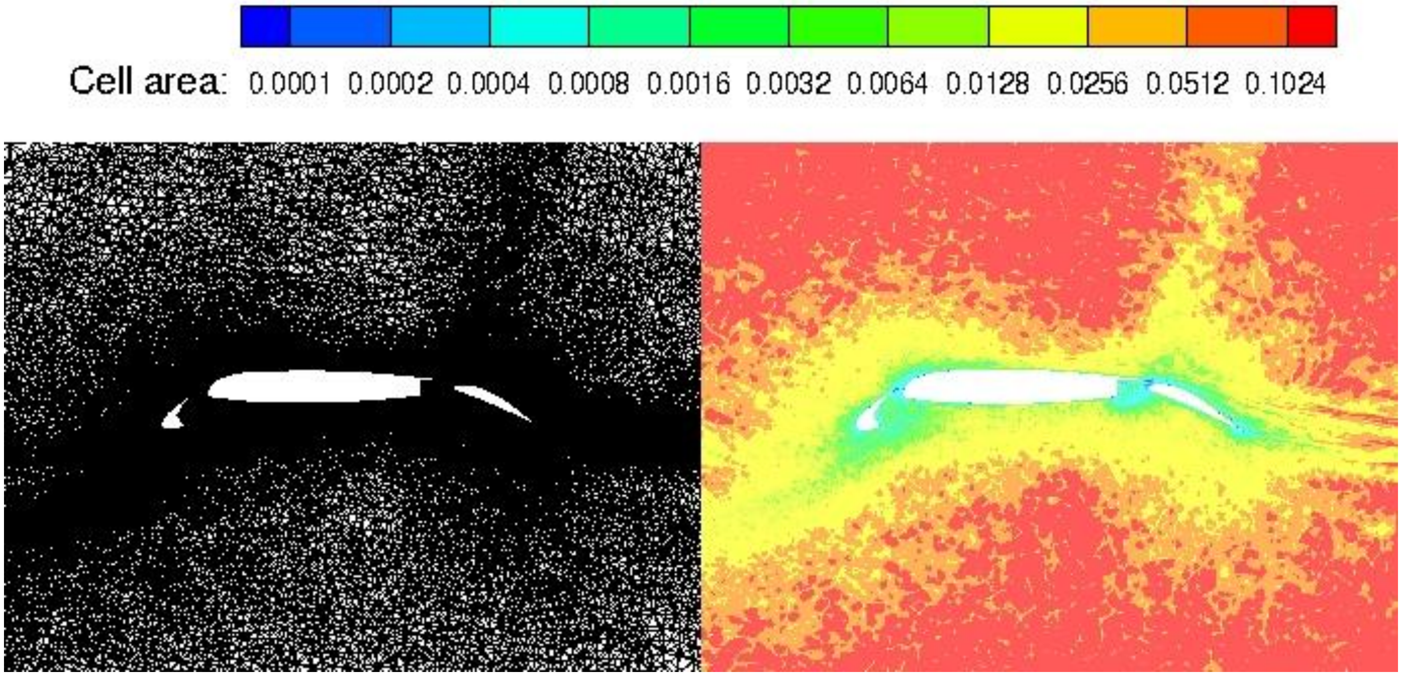


Grid Quality (cont.)

CFD High Lift Prediction Workshop



Grid Quality (cont.)



FUN3D solution on adapted grid.
Adaptation performed using adjoint for reduction of error in drag.

Acknowledgments

- Trap Wing Test/CFD Experts
  Paul Johnson, Paul Meredith, Tony Washburn, Meelan Choudhari, Philippe Spalart, Anutosh Moitra
- Workshop Planning Advisory Board
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  Mike Rogers, Greg Gatlin
- AIAA Applied Aerodynamics Technical Committee
  Jim Guglielmo, Frank Coton, Rob Vermeland, Jim Despirito
- AIAA Conference Planning Staff
  Jean Riley, KC Neidermeyr