Barriers, Challenges & Opportunities for CFD Applications in Aircraft Design

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Invited Presentation

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OUTLINE

• BARRIERS
  – Moore’s Law
  – RANS/URANS

• CHALLENGES
  – Large-Scale Aerodynamic Databases
  – Automated Grid & Solution Checking
  – Non-Unique Solutions

• OPPORTUNITIES
  – Certification By Analysis
  – High-Fidelity MDAO
  – The CFD Stencil
BARRIERS

- **Moore’s Law**
  - Number of Transistors per CPU Chip Doubles Every Two Years
  - Gordon E. Moore, 1965
  "Cramming more Components onto Integrated Circuits", Electronics Magazine

- **Corollary**
  - Computing Speed Doubles Every 18 Months

- **Advancements in CFD Application (50 Years)**
  - Primarily Due to Growth of CPU Power \((10^9X)\)
  - What If These CPU-Growth Trends Stop?
MOORE’S LAW

http://betanews.com/2013/10/15/breaking-moores-law
MOORE’S LAW

http://www.singularity.com/charts/page67.html
The problem is that beyond 2014 shrinkages will no longer cut transistor’s cost.
Benjamin Sutherland
The Economist
November 2013
For planning horizons, I pick 2020 as the earliest date we could call Moore’s law dead. You could talk me into 2022, but whether it will come at 7 or 5nm, it’s a big deal.

Bob Colwell
Intel’s Former Chief Architect
August 2013

http://www.extremetech.com/computing/
MOORE’S LAW

• The End is Near for CMOS Growth!
  – Will this Occur Circa 2020-2025?
  – Will the Limit be 5nm?

• What’s Beyond Silicon?
  – Optical?
  – Biological?
  – Quantum?
  – IBM syNAPSE?
  – Carbon Nanotubes?

• How Do We Plan/Prepare?
  – We’ve Never been Faced with this Situation.
FLIGHT ENVELOPE
BARRIERS

• RANS/URANS Beyond Cruise Point?
  – Juncture-Flow Separations
  – Smooth-Body Separations
  – Buffeting Flows
  – Shock-Induced Separation / Reattachment
  – High-Lift Flows Near $C_{L_{max}}$

• Can Turbulence Models be Developed for RANS/URANS to Handle these Flows?
  – Experimental Data Needed
  – High-Quality, High-Resolution, Turbulence Data
  – Placed into the Public Domain
CHALLENGES

• Large-Scale Aerodynamic Databases
  – Spanning Full Flight Envelope
  – Numerous Altitude, Weight, Fuel Distributions, etc.
  – Cruise & High-Lift Configurations
  – Power Effects w/ Thrust-Drag Bookkeeping
  – Static Trim at Various CG Locations
  – Dynamic Gusts & Manuvers
  – Stability Derivatives; Spoilers, Control Surfaces
  – Coupled Aerodynamic-Structural Simulations
  – Stable Non-Unique Solutions & Hysteresis Loops
  – Automated Grid Generation w/ Checking
  – Automated Flow-Solution Checking
  – Automated Data Mining
  – $O(10^4)$ Cases
OPPORTUNITIES

• Certification By Analysis
  – Reduce Flight Tests (Time & Expense)
  – May Not Require Absolute Accuracy
  – Requires Consistant & Reasonably-Accurate Results
  – Will Better Than Low-Re Wind-Tunnel Data Suffice?
  – Start Where We Can; Expand Further ASAP

• High-Fidelity MDAO
  – Reduced A/C Design Time
  – Improved Designs
  – Higher-Order Methods
  – Remember, Very-Accurate Cruise Performance Matters!
OPPORTUNITIES

• Aerodynamic Databases
  – Simultaneously Solve Matrix \((\alpha, M)\) Sweeps
  – Can a Matrix of 33 \(\alpha\)'s and 9 Mach's be Solved via "Multigrid" for the Cost of \(O(10)\)?
  – Can the Matrix Linkage Provide Additional Information Regarding Non-Unique Solutions or Hysteresis Loops?

• Grid Convergence, Richardson Extrapolation
  – We Already Solve Most of the Basic Information Required.
  – Why Not Automate the Process and Output the Trends?
  – Can This Help Identify Issues?
GRID CONVERGENCE

NACA0012 Airfoil, FLO82 Results, $M = 0.8$, $\alpha = 1.25^\circ$

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<th>ALPHA</th>
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<th>CD</th>
<th>CM</th>
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Vassberg, AIAA Sci-Tech, Kissimmee FL, January 2015
GRID CONVERGENCE

Table IIb: FLO82-HCUSP Transonic Data at $M = 0.8$.

<table>
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<th>Mesh</th>
<th>$\alpha = 0^\circ$</th>
<th>$\alpha = 1.25^\circ$</th>
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Grid Convergence

Metric of Interest

Asymptotic Range

Accuracy Required

$h^p$
• **The CFD Stencil**
  - Compact Stencil & Unstructured Mesh Pushed 25+ Years.
  - Workshops Show ”Slope” Advantage to Structured Meshes.
  - A 100M-Node Overset Mesh Has $O(1M)$ Overlapping Nodes.
  - Why Not Use Expanded Stencils Globally and Compact Stencils Where Needed?
  - Corners of the Flight Envelope Exhibit Strong Shocks and/or Large-Scale Separations.
  - Separations Require Global Refinement (h or p).
  - Shocks Require Local h-Refinement.

• **What Is The Best Approach?**
  - Unstructured, High-Order, w/ both h+p Adaptation?
  - Hybrid Meshes w/ Predominately Expanded Stencils?
SUMMARY

• BARRIERS
  – Are We Prepared for The End of Moore's Law?
  – Can RANS Handle Full Flight Envelope?

• CHALLENGES
  – Large-Scale Aerodynamic Databases, $\mathcal{O}(10^4)$ Cases
  – Automated Grid & Solution Checking
  – Non-Unique Solutions / Hysteresis Loops

• OPPORTUNITIES
  – Certification By Analysis
  – High-Fidelity MDAO
  – Efficient Generation of Aerodynamic Databases
  – The CFD Stencil
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