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

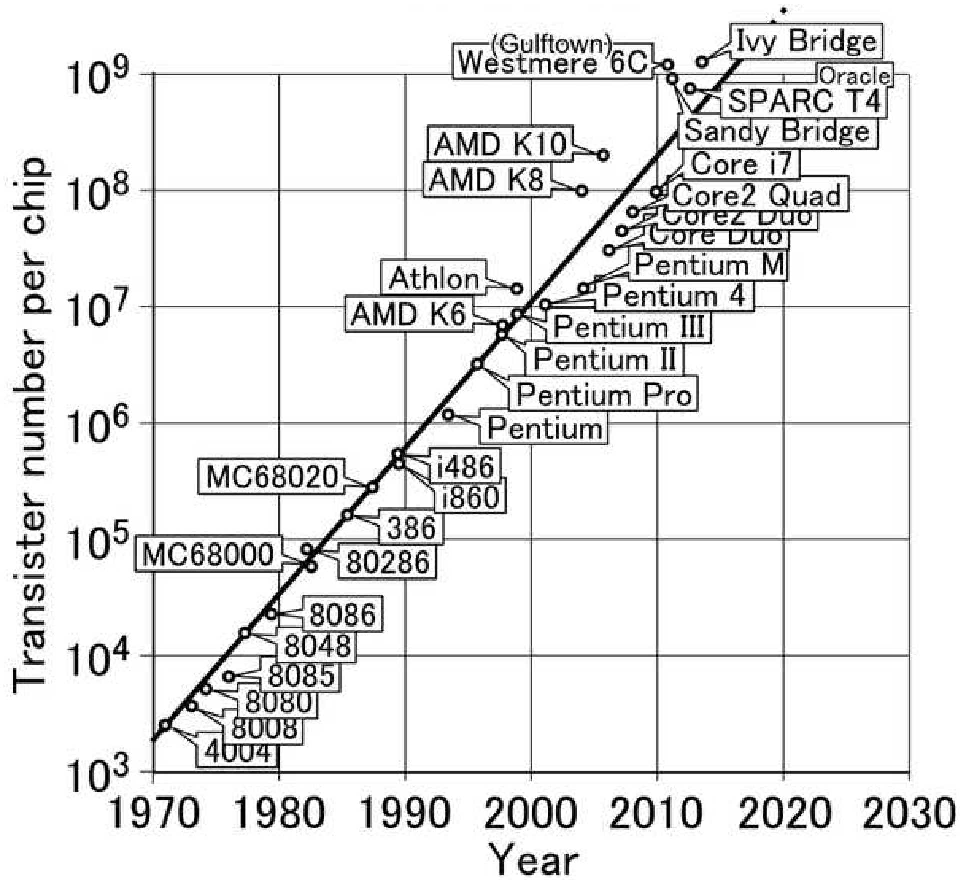
BARRIERS

- **Moore's Law**
  - Number of Transisters 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

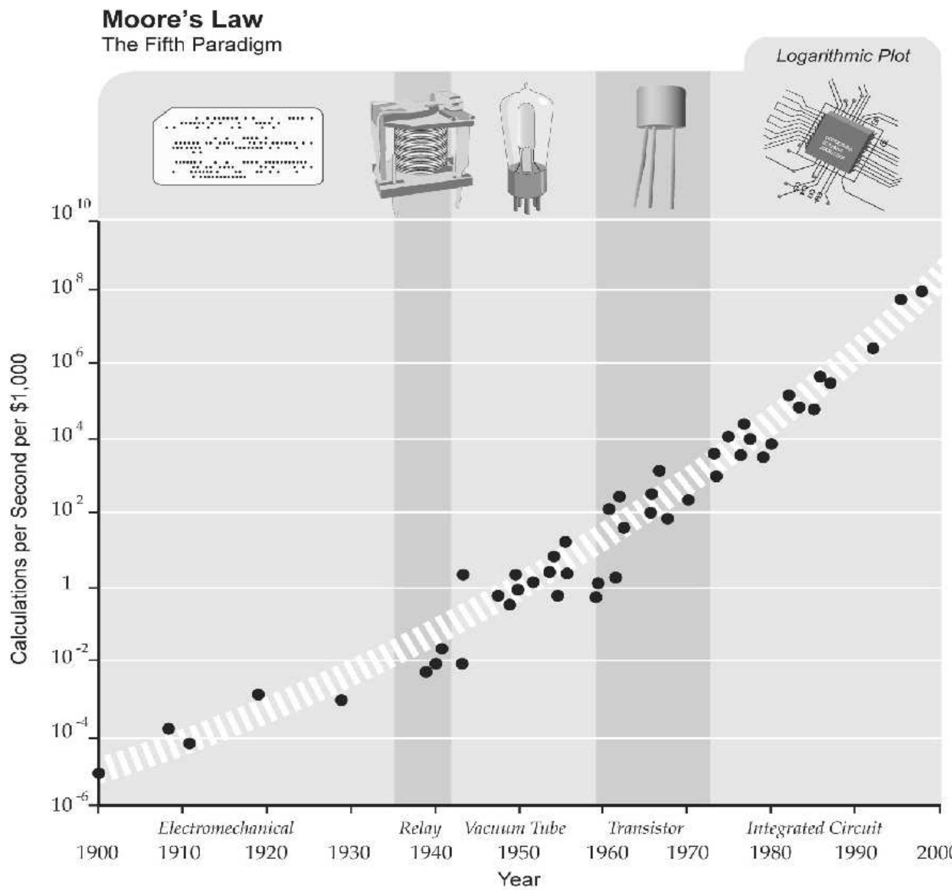
- **Advancements in CFD Application (50 Years)**
  - Primarily Due to Growth of CPU Power (10^9X)
  - What If These CPU-Growth Trends Stop?

MOORE'S LAW



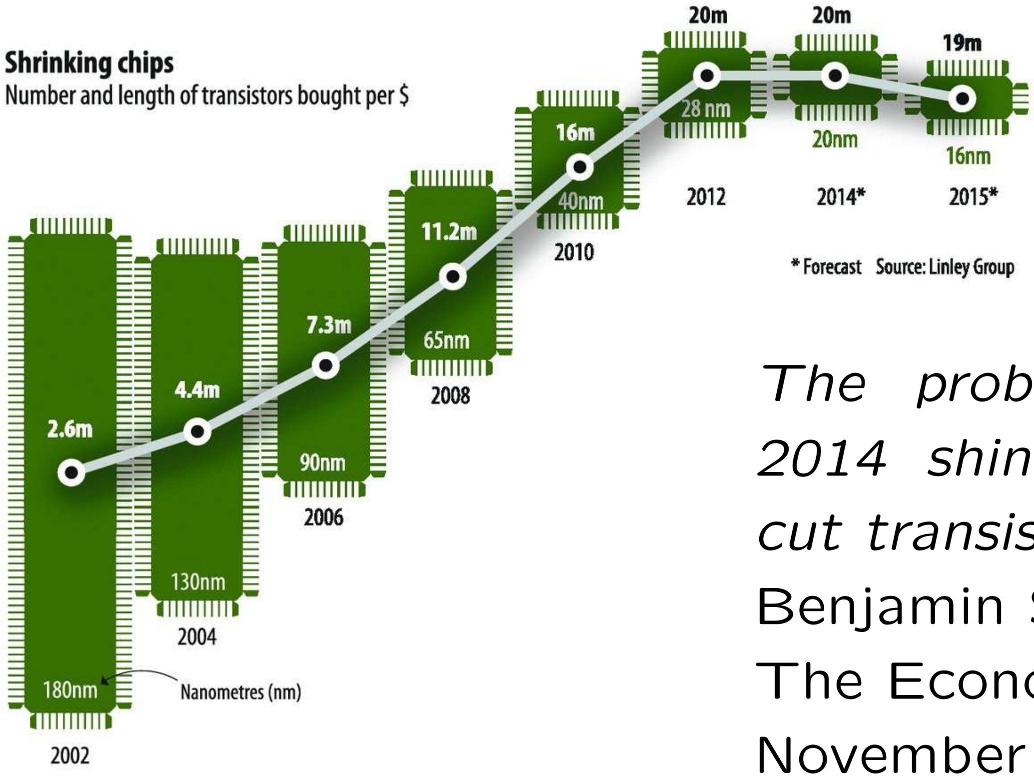
http://betanews.com/2013/10/15/breaking-moores-law

MOORE'S LAW



http://www.singularity.com/charts/page67.html

MOORE'S LAW



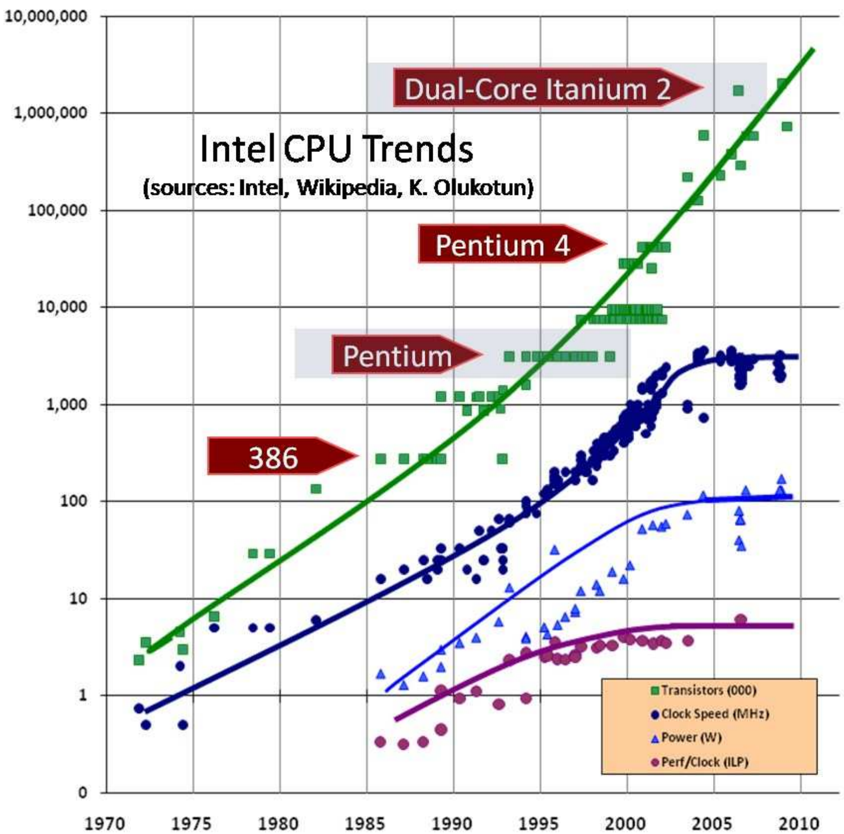
Silicon Atom ~ 0.5nm

The problem is that beyond 2014 shinkages will no longer cut transistor's cost.

Benjamin Sutherland
The Economist
November 2013

http://www.economist.com/news/

MOORE'S LAW



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

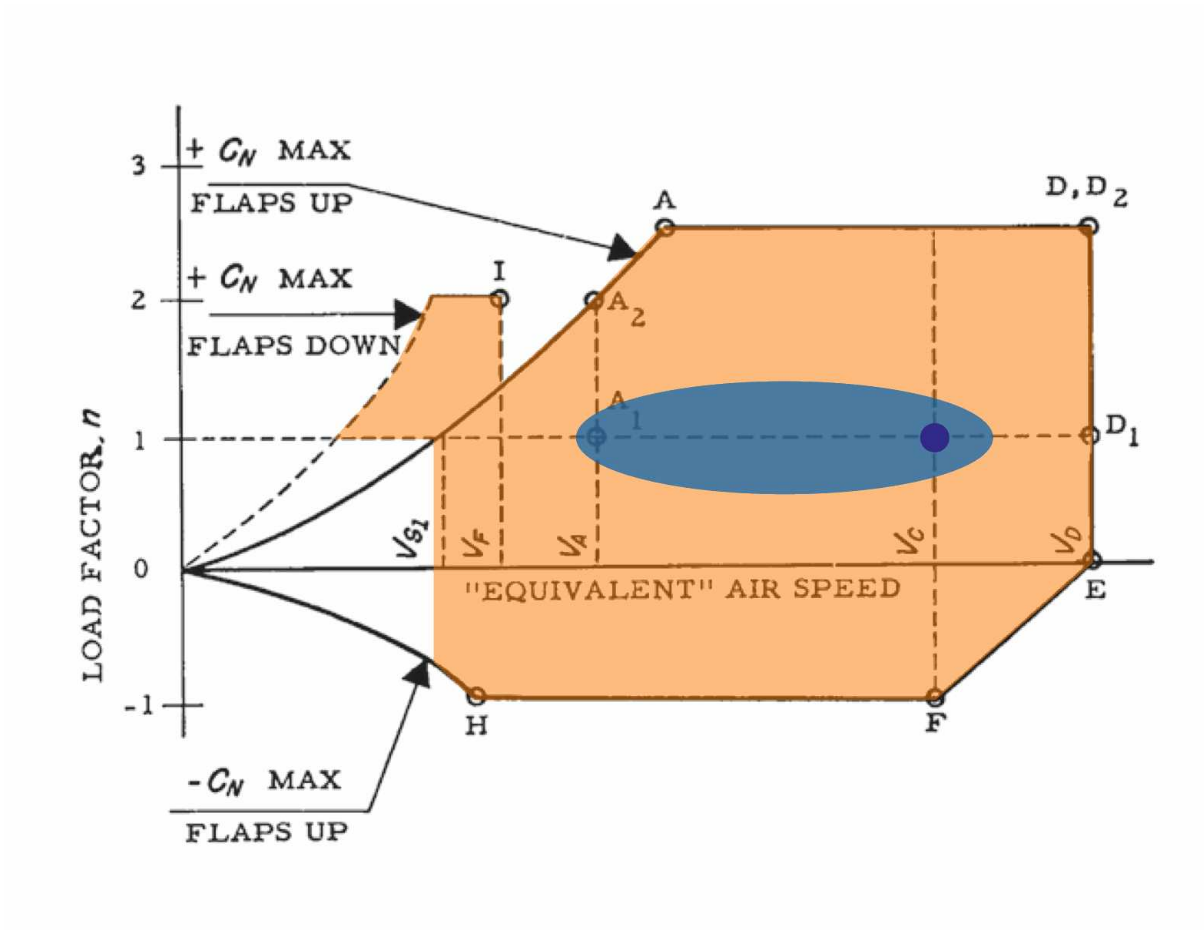
August 2013

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
  - $\mathcal{O}(10^4)$ 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 (α , M) Sweeps
  - Can a Matrix of 33 α's and 9 Mach's be Solved via "Multigrid" for the Cost of $\mathcal{O}(10)$?
  - 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, $M = 0.8$, $\alpha = 1.25^\circ$

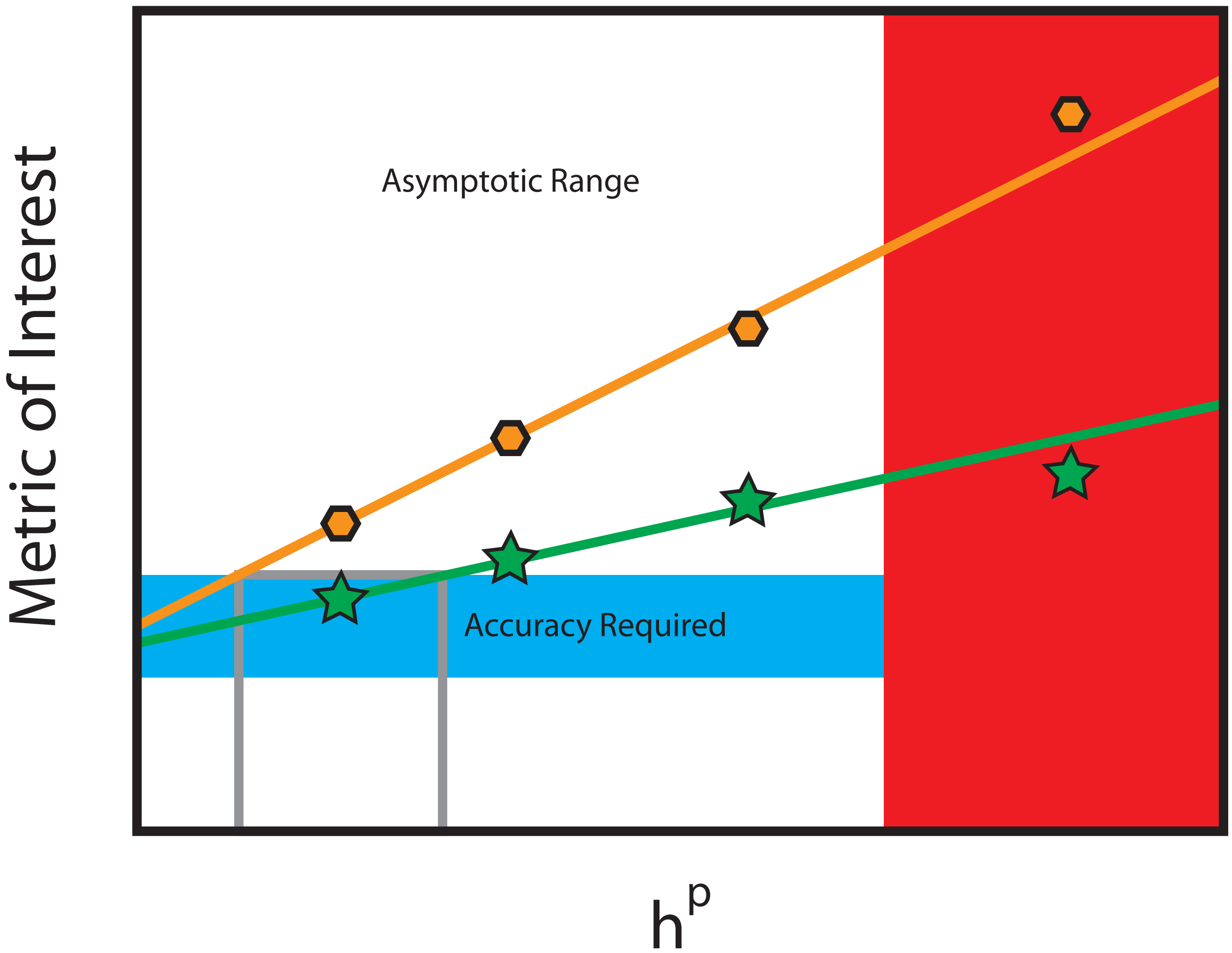
MESH	ALPHA	CL	CD	CM	RED
8-1	1.2500000000	0.2518307612	0.0149882300	-0.0493639569	-14.626
16-2	1.2500000000	0.3062491977	0.0225245242	-0.0270241915	-14.143
32-3	1.2500000000	0.3878427459	0.0278615931	-0.0429474988	-13.856
64-4	1.2500000000	0.3729213799	0.0254877919	-0.0435844268	-13.499
128-5	1.2500000000	0.3734695499	0.0237863714	-0.0438737395	-13.260
256-6	1.2500000000	0.3689802051	0.0233576511	-0.0425529413	-12.847
512-7	1.2500000000	0.3637479004	0.0230847486	-0.0410022279	-12.605
X	1.2500000000	0.0000000000	0.0226067813	0.0000000000	
P	0.0000000000	0.0000000000	0.6516508876	0.0000000000	
R	0.0000000000	1.1654940919	0.6365514857	1.1740730188	

GRID CONVERGENCE

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

Mesh	$\alpha = 0^\circ$	$\alpha = 1.25^\circ$		
NC	C_d	C_l	C_d	C_m
32	+0.011451356	+0.387842746	+0.027861593	-0.042947499
64	+0.010264792	+0.372921380	+0.025487792	-0.043584427
128	+0.008500758	+0.373469550	+0.023786371	-0.043873739
256	+0.008312402	+0.368980205	+0.023357651	-0.042552941
512	+0.008328328	+0.363747900	+0.023084749	-0.041002228
1,024	+0.008338967	+0.360812844	+0.022934404	-0.040136414
2,048	+0.008341760	+0.358281928	+0.022799839	-0.039388829
4,096	+0.008342211	+0.357142338	+0.022737860	-0.039051466
$\star$	+0.008342298	+0.356208937	+0.022684938	-0.038774022
p	2.631	1.151	1.118	1.148

Grid Convergence



OPPORTUNITIES

- **The CFD Stencil**
  - Compact Stencil & Unstructured Mesh Pushed 25+ Years.
  - Workshops Show "Slope" Advantage to Structured Meshes.
  - A 100M-Node Overset Mesh Has $\mathcal{O}(1M)$ 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 Reguire 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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