Recent Applications of CFD to the Design of Boeing Commercial Transports

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High Performance Computing
This is what it's good for . . .

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The 787-8 and 747-8 First Flights

CFD Contributions to 787

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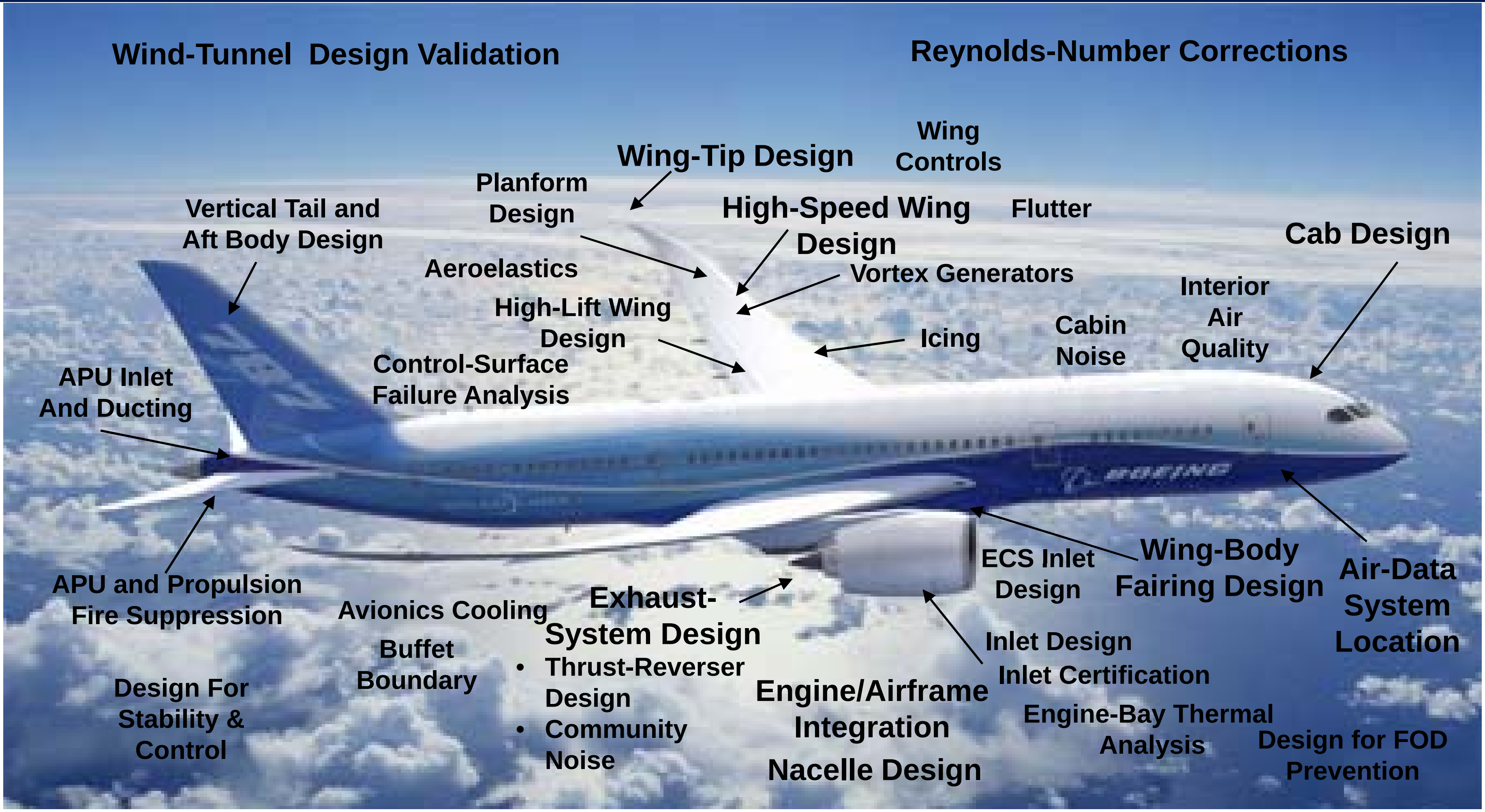

CFD for Full Flight Envelope – High Speed

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Why is this Important?

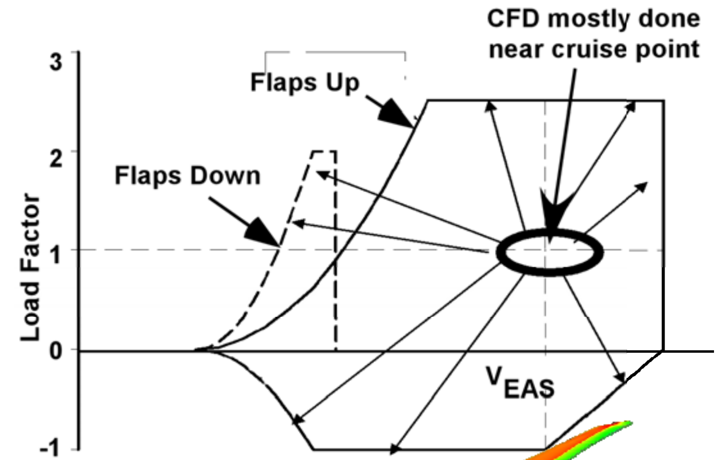
- Reducing Design Cycle Time while increasing data fidelity in the early development phases of a new airplane program is critical to competitiveness
- Creating flight predicted S&C and Loads aero data is very time consuming and requires much wind tunnel testing.

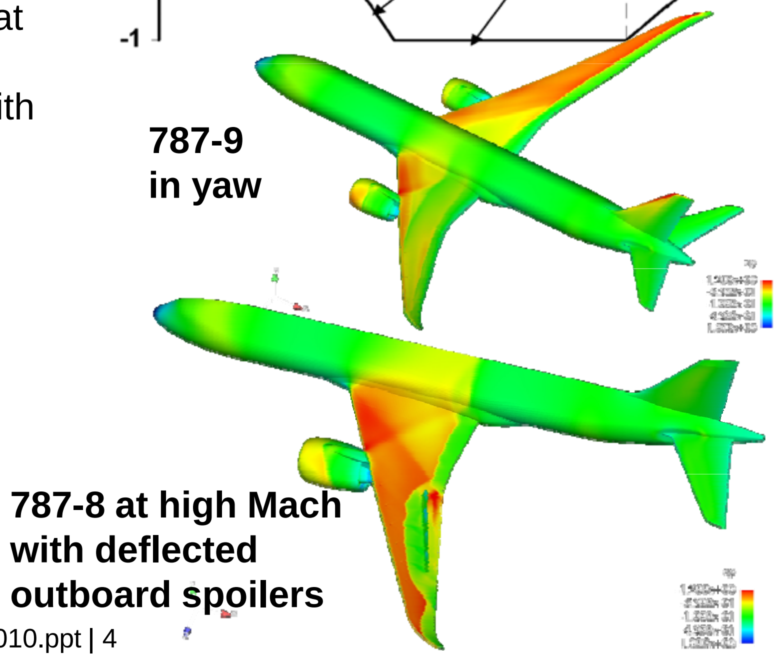
What are the Technical Challenges?

- Accurate CFD prediction of Loads and S&C characteristics at flight conditions with significant flow separation.
- Timely, robust, and repeatable modeling of configurations with control deflections including spoilers, vortex generators, etc.

What are we doing?

- Developing Navier-Stokes CFD processes for accuracy, reliability, and robustness for use by product development engineers for engineering applications.
- Validating/Expanding CFD use in Loads and S&C disciplines
- Integrating wind tunnel and CFD use to reduce cycle time, cost.





CFD at the Edges of the Flight Envelope

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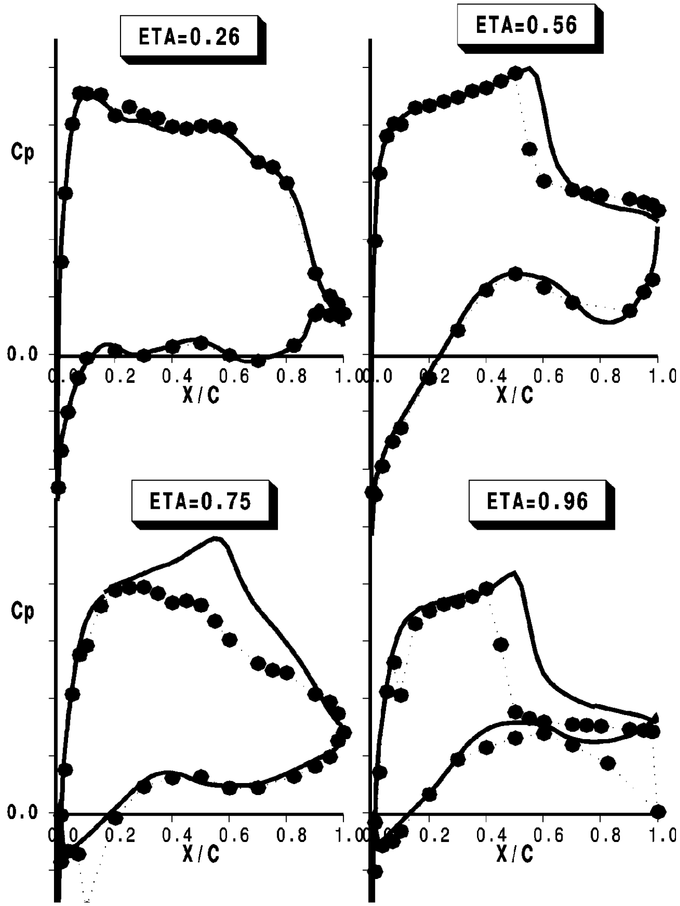
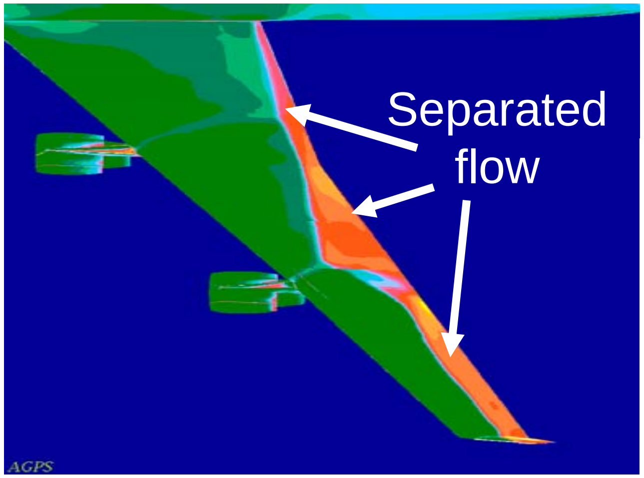
What are the Challenges?

- CFD Issues
  - Large regions of separated flow
  - Turbulence models
  - Need URANS or DES?
- Testing Issues
  - Close to Mach One
  - Model aeroelastics
  - Representative of "Free Air"?

Cp comparison at approximately 2.5g at Mach dive



These CFL3D RANS four-engine transport results are typical of CFD issues at the edge of the envelope



High-Lift CFD

Why is this Important?

- Optimization of high-lift configurations
- Study of simplified/revolutionary high-lift concepts
- Study of large number of geometries, device positions
- Understanding of high-lift flow physics
- Ability to predict maximum lift
- Study of flow-control concepts
- Reduction of wind-tunnel tests
- Eliminate wind-tunnel effects from test data
- Extend test data to full scale Reynolds numbers

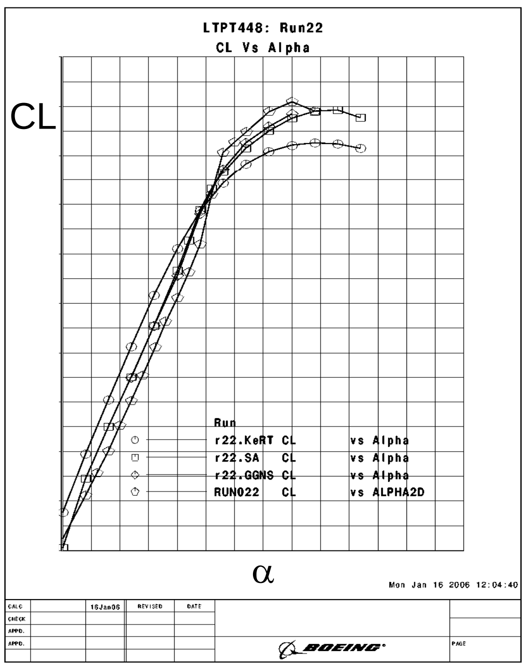
What are the Technical Challenges?

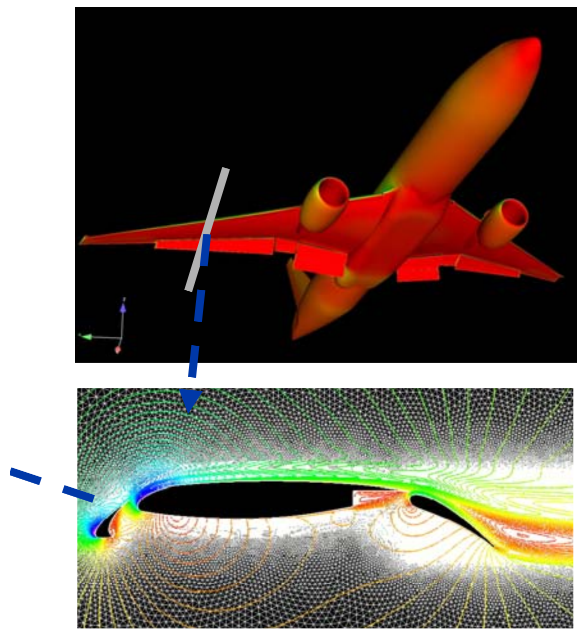
- Understanding highly complex flow phenomena
- Consistent process for prediction of CLmax
- CFD Challenges
  - Lack of robustness
  - Grid resolution requirements are unknown
  - Turbulence modeling effects are unknown
  - Unsteady flow analyses are required but unavailable

2D High-Lift CFD

What Are We Doing?

- Developed Automated Navier-Stokes Two Dimensional Setup Process, ANTS
- Rapid Navier-Stokes analysis of multiple 2-D high-lift wing sections
- Produce accurate and consistent prediction of performance and flow-physics data





3D High-Lift

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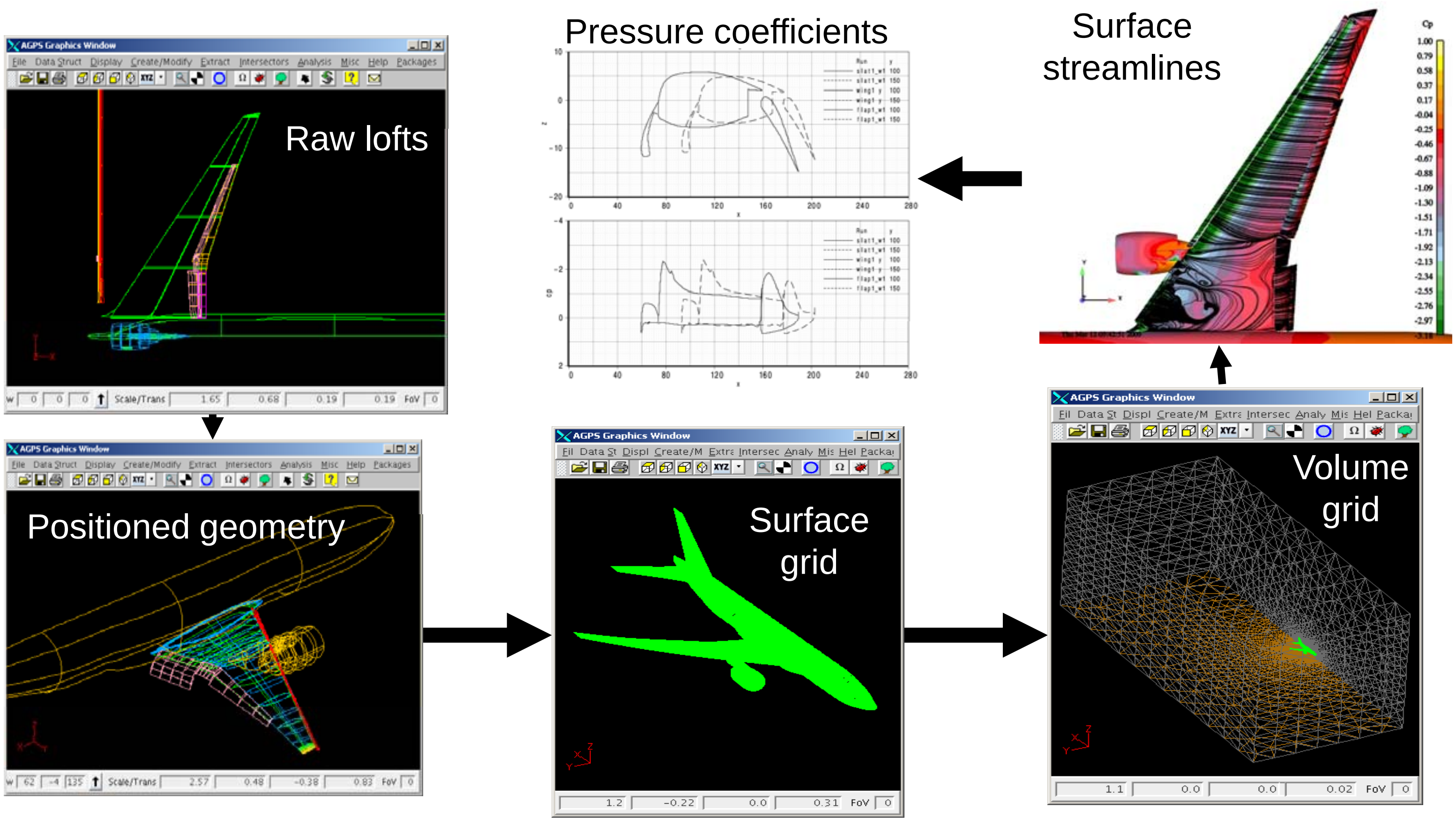
What Are We Doing?

- Developed automated Navier-Stokes 3D system analysis process flow with one day turn around



CFD in Flutter Predictions

Why is this Important?

- Reduce potential flutter risks in new airplane programs
- Enabler to look into non-linear aeroelastic effects earlier in the design cycle
- Minimize impact of design modifications necessary to eliminate potential flutter risks
- Avoid costly design “fixes” to mature airplane design
- Enabler to generate databases for reducing wind-tunnel testing time, cycle time and cost

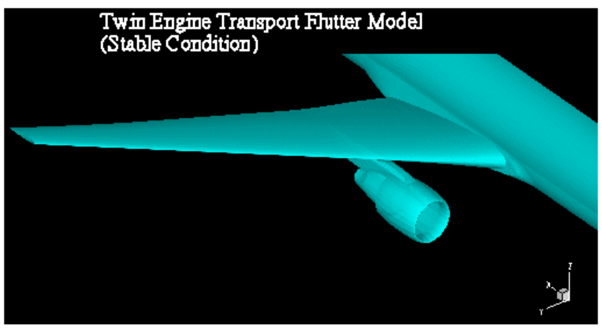
What are the Technical Challenges?

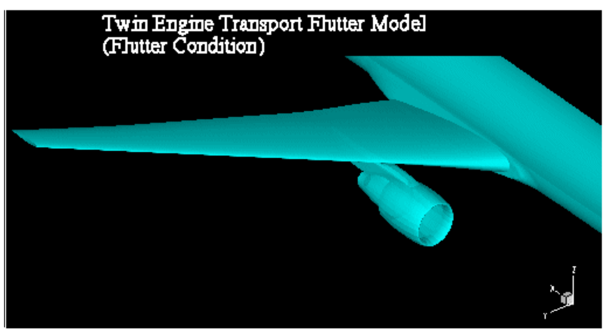
- Highly complex unsteady flow phenomena: coupling of unsteady flow with unsteady structural dynamics
- Existing high speed flutter experimental data are very limited
- High speed flutter tests are costly with long design time and limitations due to wind tunnel, model integrity, subjective engineering calls during tests, etc.
- Computational simulations challenges include: long unsteady cycle time, limited validated methods, mesh deformation robustness for complex geometry, as well as typical steady computational challenges.

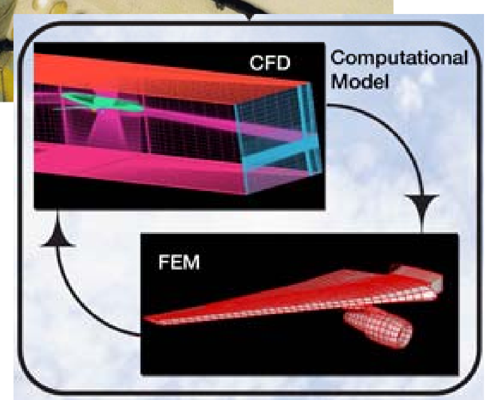
CFD in Flutter Predictions

What Are We Doing

- Create, correlate, and validate both steady and unsteady aeroelastic processes.
- Assure the processes (TRANAIR-based and CFL3D-based) are robust and repeatable.
- Validate process components for each component to assure accurate results:
- Initially validate unsteady code for ‘simple’ wing and isolated nacelle oscillations
- Apply methodology to compute wind-tunnel static aeroelastic deformations and high speed flutter







Wind Tunnel Model
↓
Computational Model
↓
Analysis of Flutter Conditions

CFD in Flutter Predictions

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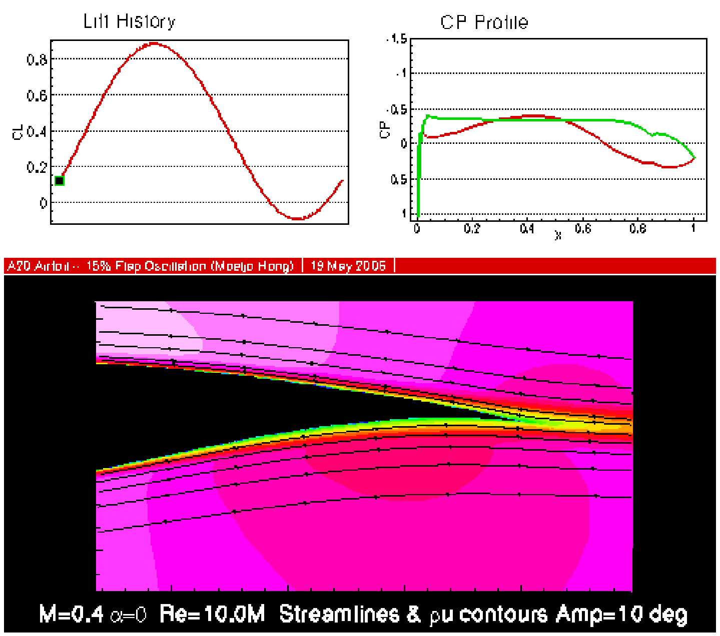
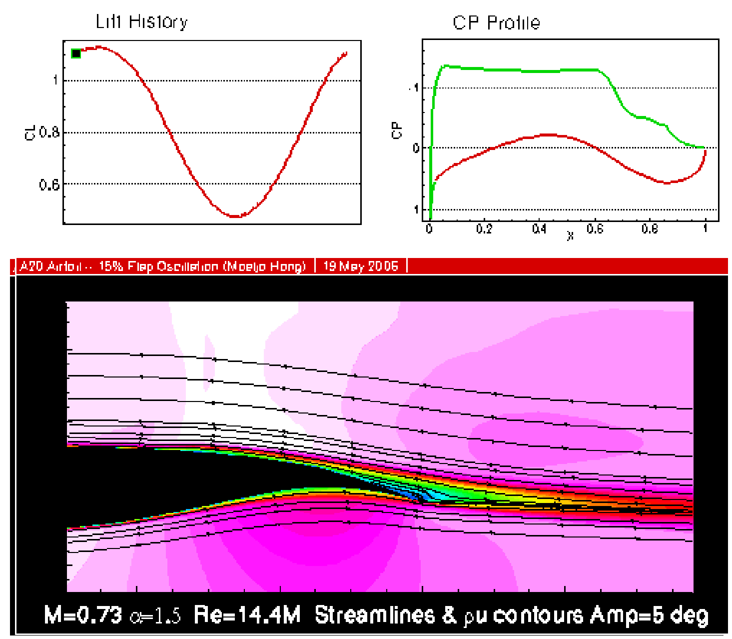
Unsteady Control Surface Modeling with CFL3D

Low Subsonic Speed



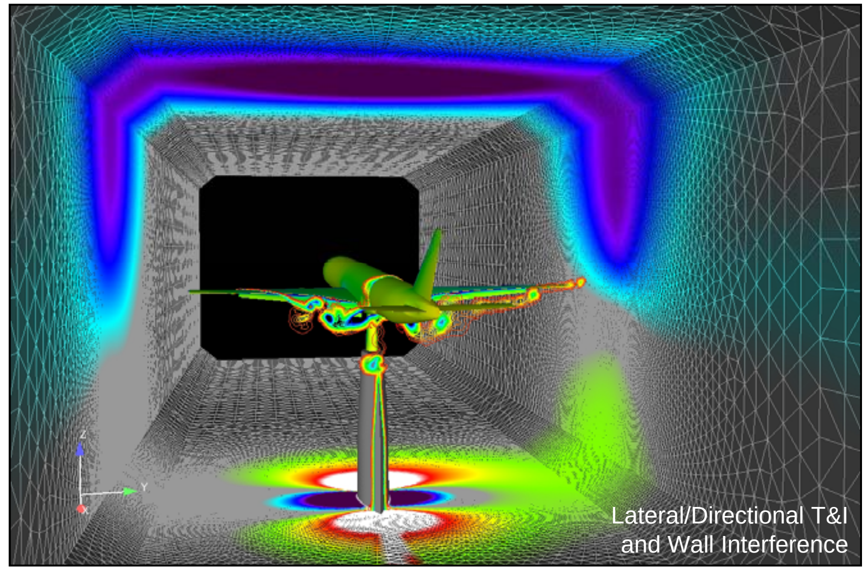
Transonic Speed



Stability & Control Application of CFD

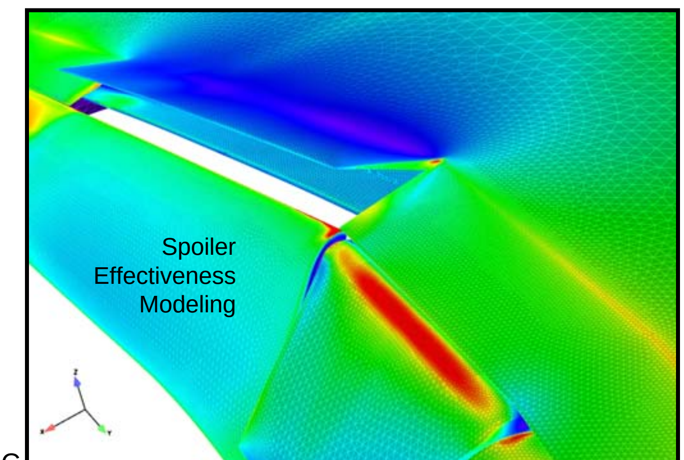
Why is this Important?

- Aircraft weight/performance impacts
- Actuator sizing & system requirements
- Improved simulation fidelity
- Reduced WT testing



What are the Technical Challenges?

- Highly complex geometries
- Increased reliance on augmentation
- Multi-functional controls
- Higher fidelity aero predictions required
- Unsteady flow regimes
- Large matrix of data required
- Asymmetry conditions effects on test data and CFD analyses



Stability & Control Application of CFD

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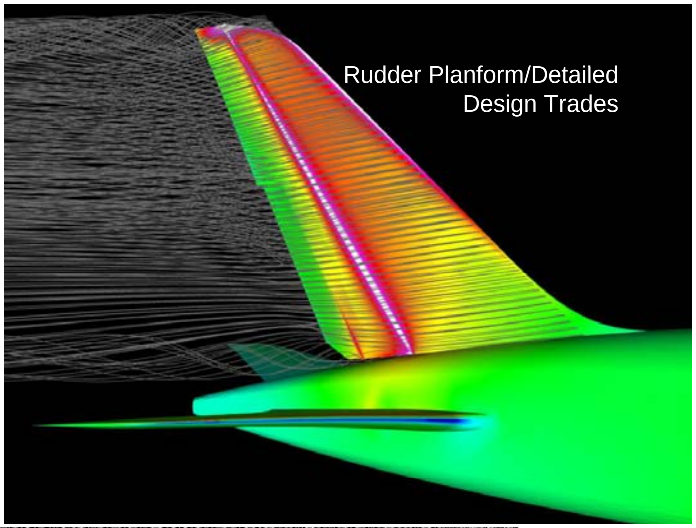
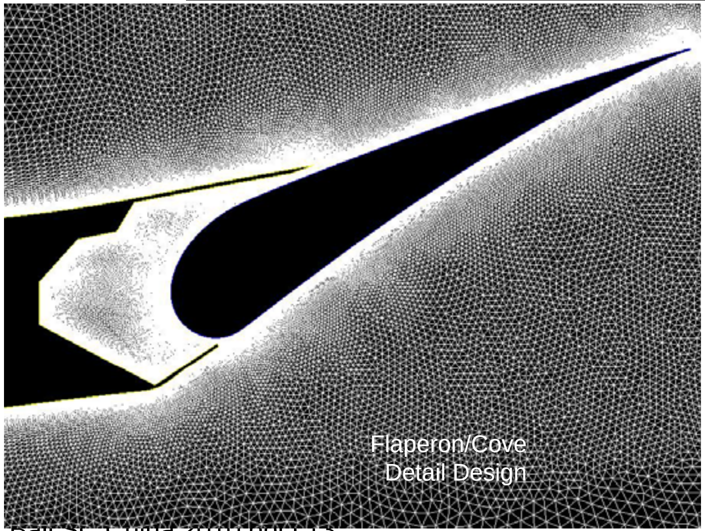
What Are We Doing

- Control surface design
  - Sizing trades
  - Control loads (hinge moments)
  - Design details
- Configuration trade studies
- Wind tunnel-to-flight corrections
  - Tare & Interference
  - Wall effects
  - Reynolds Number effects
- Aerodynamic database development
  - Aeroelastic corrections
  - Dynamic derivatives
  - Supplement WT
- Full Spectrum of Codes
  - A502
  - Tranair
  - CFL3D
  - CFD++ (3D & 2D)





Propulsion Aerodynamics – Thrust Reverser

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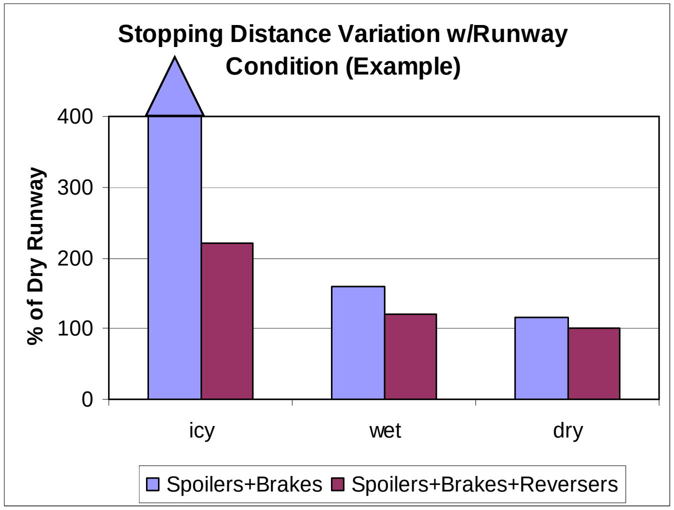
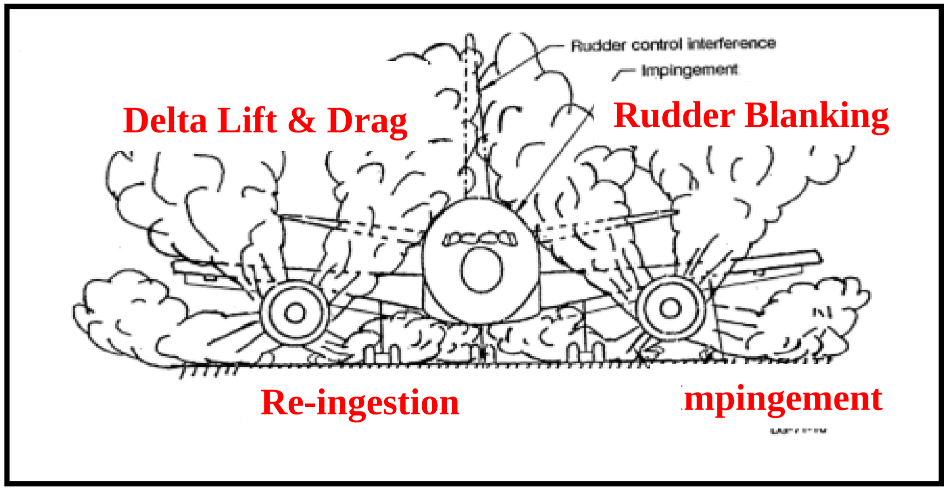


Why is this Important?

- Thrust Reverser (T/R) provides additional deceleration after landing.
- The T/R is essential to meet landing and take off field length requirements, particularly under icy runway conditions.

What are the Technical Challenges?

- Provide required reverse thrust while considering limits imposed by
  - Impingement on A/C surfaces
  - Re-ingestion by A/C engine
  - Rudder blanking
  - Nacelle integration



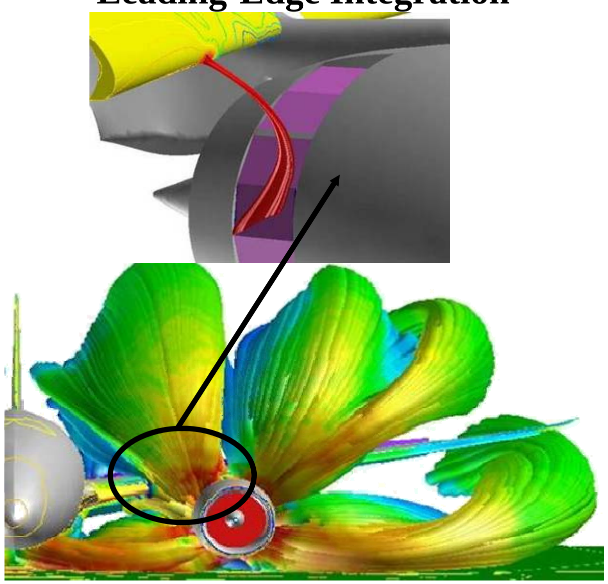
Propulsion Aerodynamics – Thrust Reverser

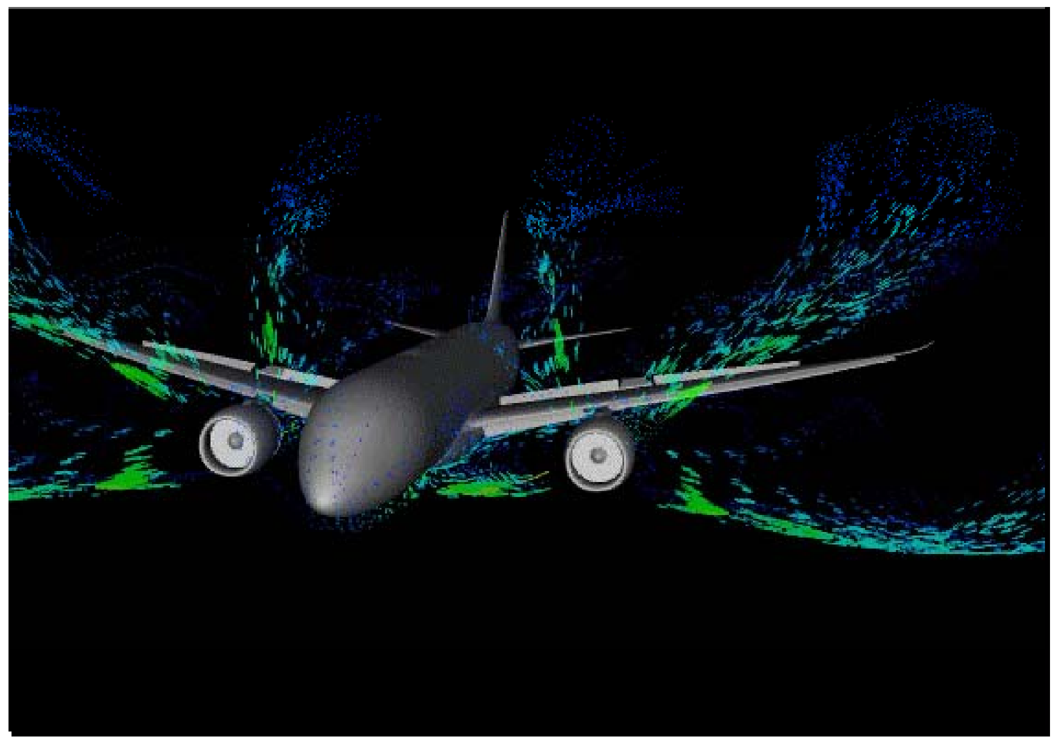
What Are We Doing?

- CFD process developed within Boeing utilized ANSYS/ICEM and CFD++ solver in support of T/R external efflux pattern development and related analysis of re-ingestion, impingement, and controllability concerns.

Reverser/Airframe Compatibility – Installed Analysis

Leading-Edge Integration





Nacelle Thermal Analysis

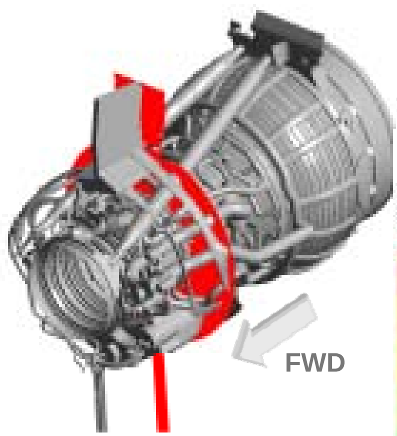
Why is this Important
- Minimizes schedule risk
- Reduce flight test (cost and schedule savings)
- Optimize fuel burn (most efficient use of cooling air)
- Provide basis for combustor case burnthrough certification

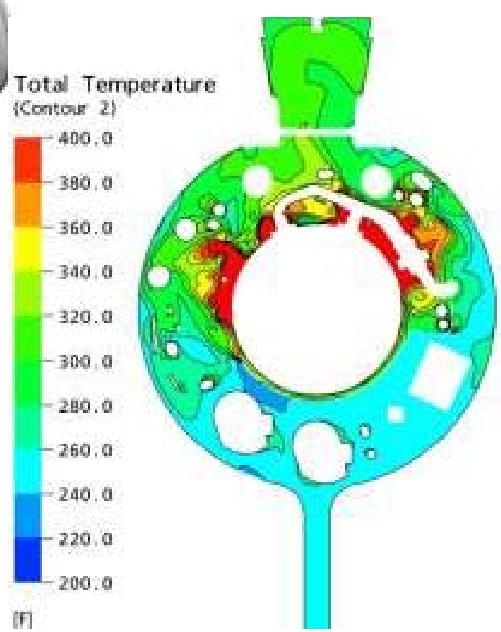
What are the Technical Challenges
- Very complex geometry
- Complex boundary conditions
- Varying flow regimes (low speed to highly under-expanded jets)

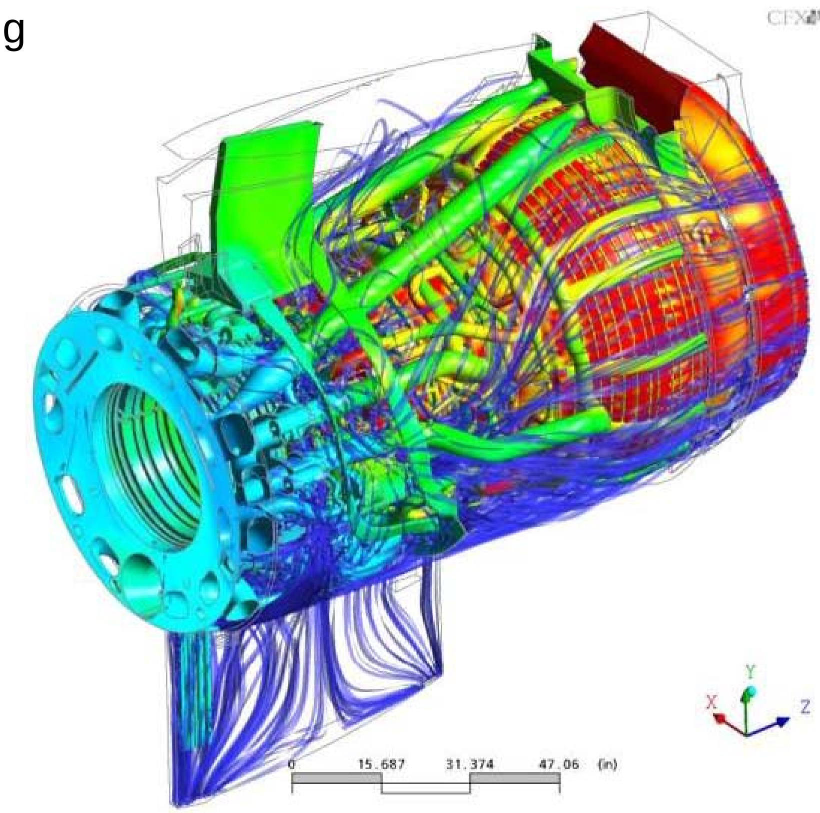
Nacelle Thermal Analysis

What Are We Doing

- Engine Bay CFD Analysis (Primarily done by Engine companies)
- Coupled fluid/thermal analysis of nacelle structure
    - Combustor case burnthrough
    - Auxiliary exhaust thermal mixing







Computational Ice Shape Generation

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Why is this Important?

- Airframe ice shapes corresponding to critical flight conditions were needed for 787 low speed wind tunnel testing to measure the impact on aircraft handling characteristics and maximum lift.
- LEWICE3D, a code developed by NASA, greatly reduced the need to interpolate/extrapolate ice shapes to generate wind tunnel model parts.
- Using LEWICE3D drastically reduced the time needed to generate ice shapes.

What are the Technical Challenges?

- LEWICE3D calculates water droplet trajectories through a converged CFD flow-field to generate a 3D droplet collection efficiency distribution on the airframe. This is a large computation, which had to be parallelized in order to be feasible.
- Finding enough experimental swept wing ice shape data to further refine the ice shape generation model and methodology is problematic.

Computational Ice Shape Generation

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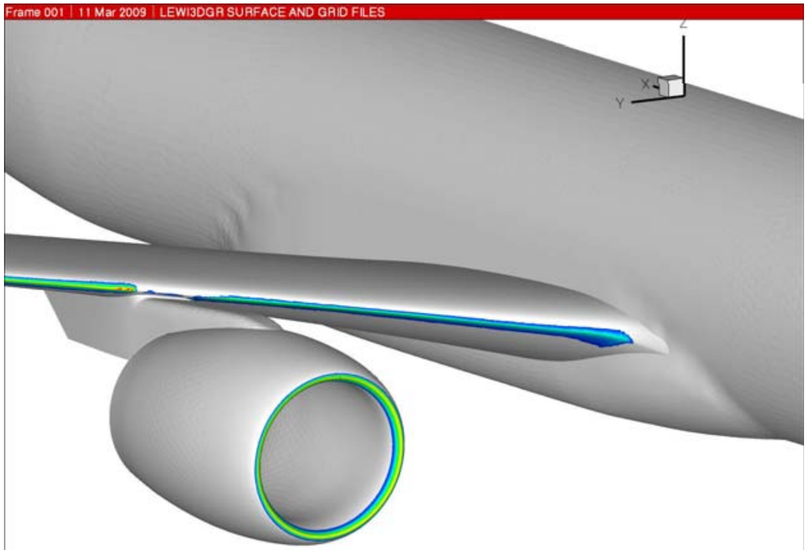
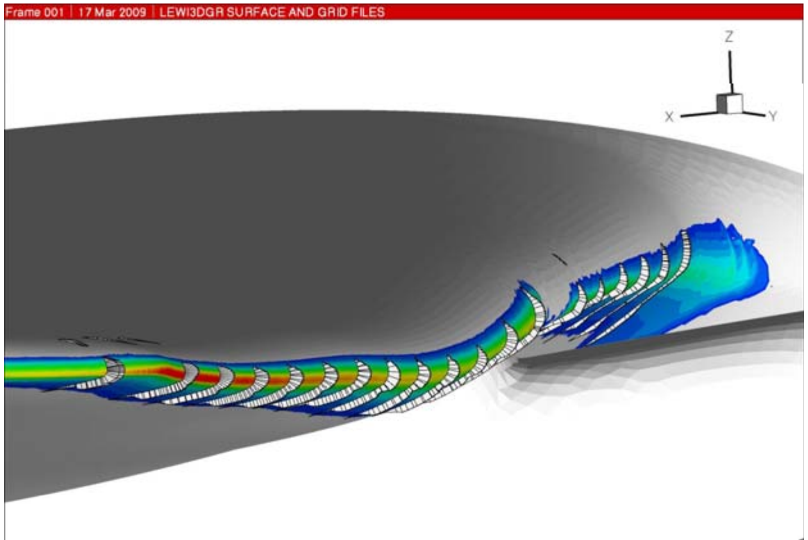
What Are We Doing?

- Flight conditions considered critical for airframe icing were selected.
- Navier-Stokes solvers CFD++ or OVERFLOW were run with these conditions to generate a flow-field for input into LEWICE3D.
- LEWICE3D generated a collection efficiency and ice shape cuts.
- Ice shape cuts were used to produce lofts for stereo lithography production into wind tunnel model parts.



Water Droplet Collection Efficiency



Ice Shape Cuts on Wing Leading Edge

Closing Thoughts

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- CFD exists to enable new solutions to problems, reduce airplane development cost, and reduce time to market
- CFD can allow you to safely explore areas of the flight regime without putting a pilot at risk
- CFD can allow you to analyze conditions for which physical simulation is either very expensive or not possible, such as hypersonic propulsion systems and full flight Reynolds number testing
- Accuracy, robustness and timeliness are the keys to acceptance and use in an industrial environment
- Impediments: applications that do not scale well (to 1000’s of processors) – this is science, resources to run 1000s of flight conditions on 100’s of processors – this is engineering & business