CFD: An Industry Perspective

**Future Directions in CFD Research:
A Modeling and Simulation Conference**

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Hampton, Virginia**

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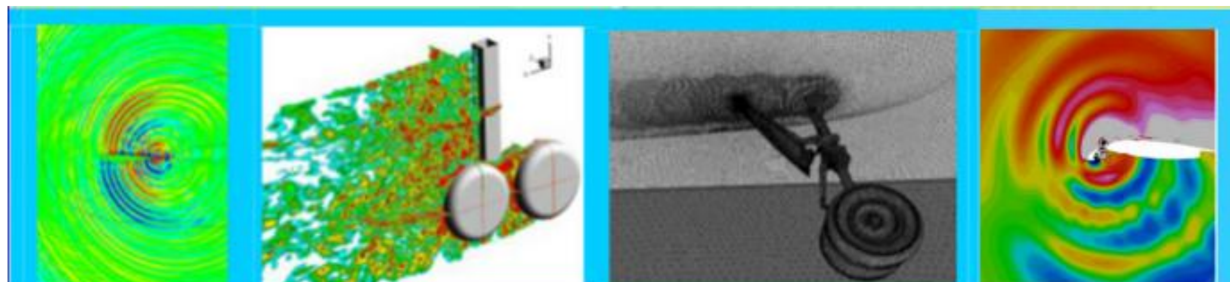
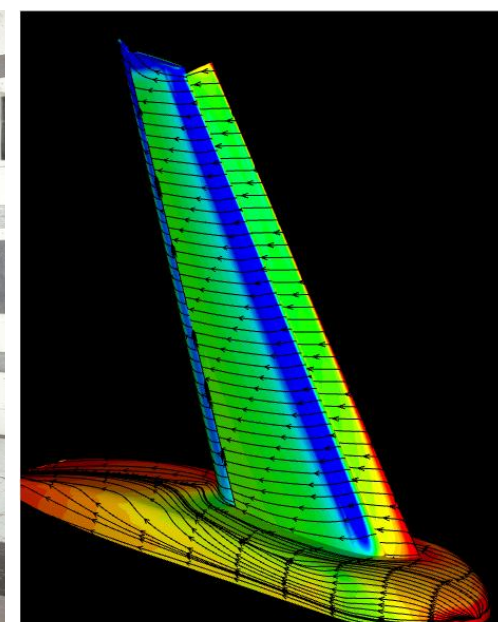
NASA’s Role in Development of CFD

- Technical workshops have been critical in focusing academia, industry, and government resources to enhance understanding of flow physics, evaluation of CFD methods, and development of CFD best practices



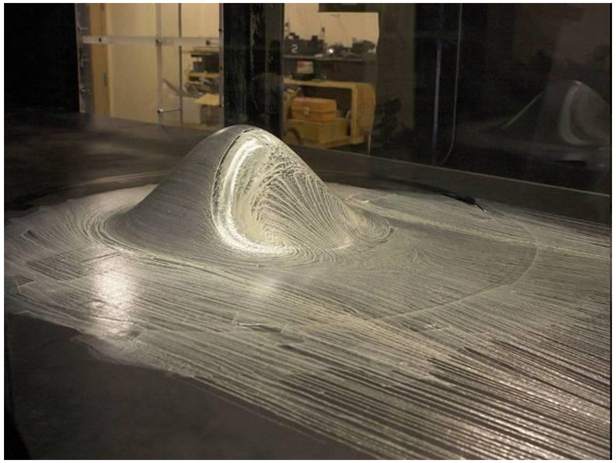
Source: https://info.aiaa.org/tac/ASG/FDTC/DG/BECAN_files_/BANCII.htm

- NASA has been an important organizational member of all international workshops and has provided key expertise in developing workshop CFD validation test cases (DPW, HiLiftPW, Benchmark for Airframe Noise Components, etc.)



NASA's Role in Development of CFD

- **Experimental test data for CFD validation is critical to the understanding of complex flow physics for a wide array of flow environments and aerospace vehicles, and enables the continued development of more accurate and effective CFD methods and tools**
  - NASA has been very active in creating experiments to collect building-block CFD validation data (30p30n slat noise, tandem cylinders, Trap Wing, CRM, FAITH hill, etc.)



FAITH hill

Trap Wing

Common Research Model

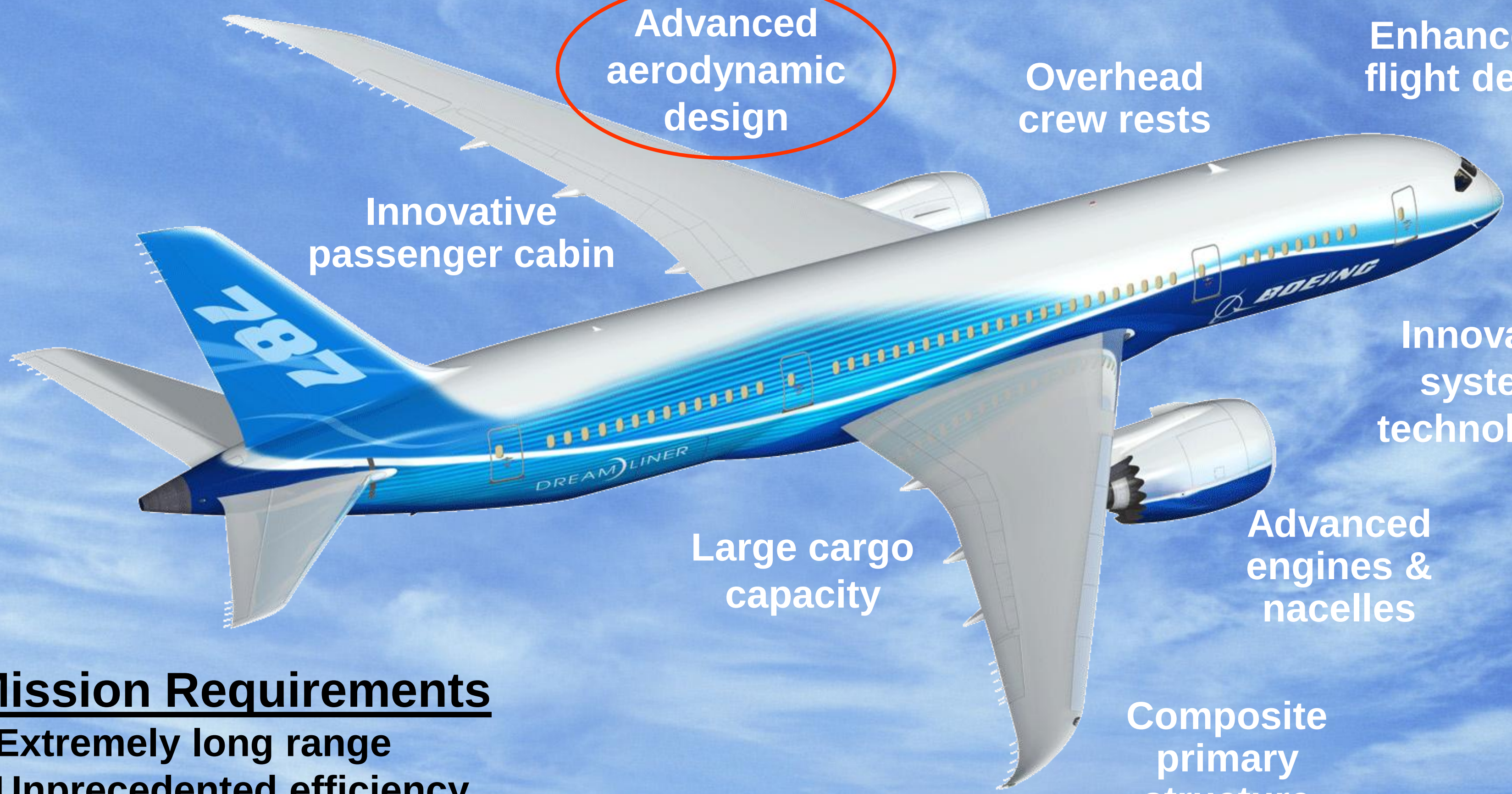
Presentation Outline

- **Role of a prime aerospace manufacturer in use and development of current practice, and emphasis for future direction, in Computational Fluid Dynamics**
- **State of the art, current challenges**
  - Transport aircraft
  - Other configurations
  - MDAO
  - Common Research Model
- **Where we believe CFD should go (Vision 2030)**

Introduction

Role of a Prime Aerospace Manufacturer

787 Design Features



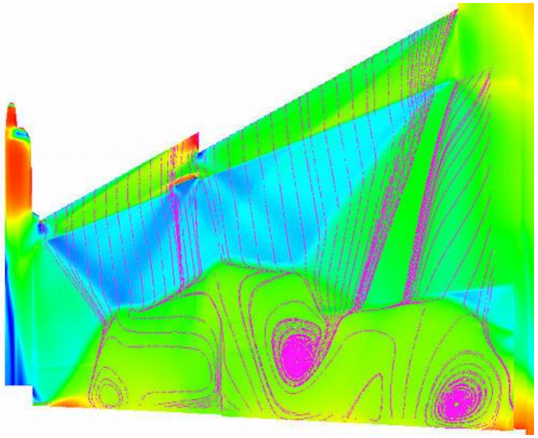
Mission Requirements

- Extremely long range
- Unprecedented efficiency
- Very low community & cabin noise
- Very low emissions

BOEING

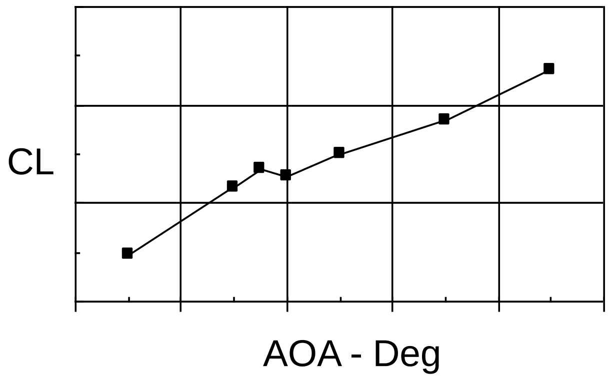
CFD Application In Tactical Aircraft Design

- <u>Background</u>: Initial F/A-18E/F flight testing revealed uncommanded rolling motion while maneuvering at transonic flight due to asymmetric flow separation on the wing upper surface.
- <u>CFD Study</u>: Undertaken to determine whether CFD could predict the lift curve break seen in wind tunnel tests and obtain detailed flowfield description of the phenomena.
- <u>Results</u>: Confirmation that CFD could help identify characteristics associated with cause of abrupt wing stall.



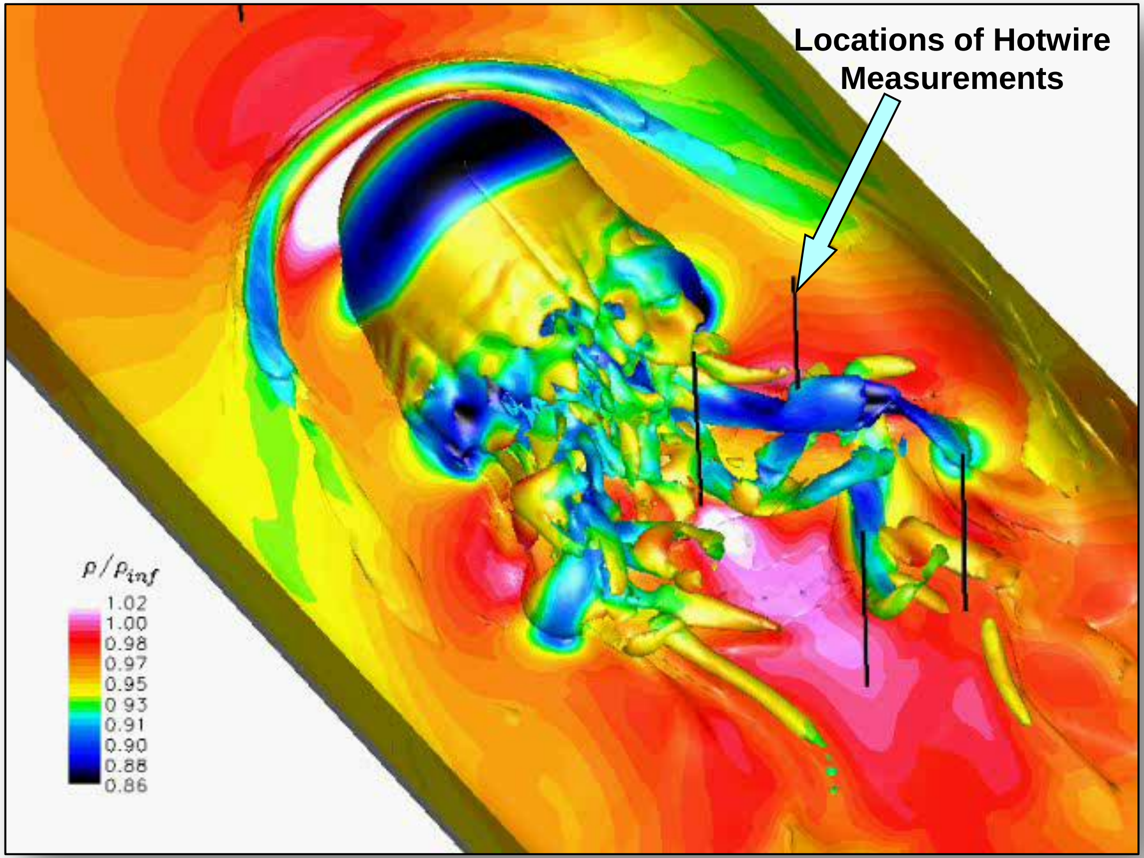
<u>Contours of Surface Pressure and Particle Traces</u>

<u>Lift Curve</u>

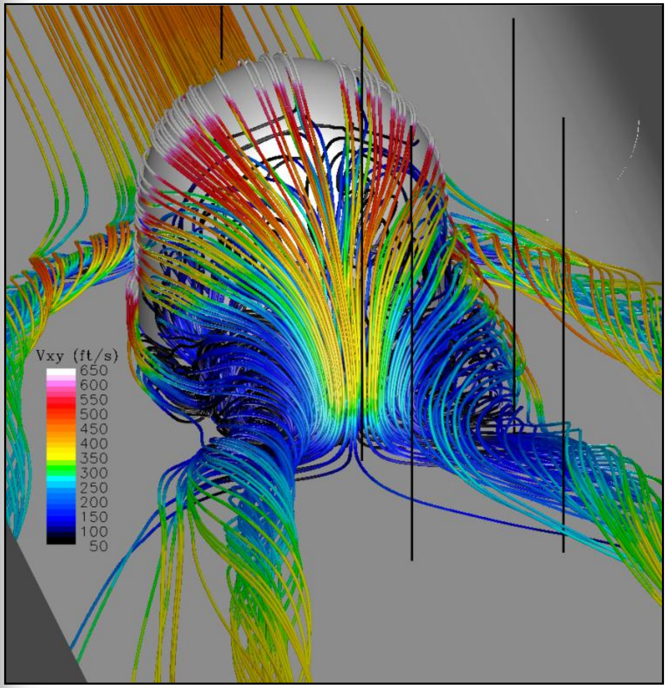


Unsteady Analyses of Hemispherical Turret for Aero-Optic Performance

Animation of Iso-Vorticity Surface



Streamlines in Mean Flow Solution



Unable to discuss details of military applications due to ITAR and Export Control restrictions

Background

State of the Art – Current Challenges

Today's Situation

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Routine

- Steady-State Navier-Stokes in all programs
  - Assess flowfields, conduct trade studies, identify options
  - Diverse applications
- Design confirmation (not design development) through wind tunnel testing

Emerging

- Multi-disciplinary
  - Aeroelasticity
    - Simple modal analysis
    - Coupled to NASTRAN
  - Aero-acoustics
  - Aero-optics
- Automated Optimization
- Unsteady flow
  - Routine for rotary wing applications
  - Use as appropriate for fixed-wing aircraft

CFD Contributions to Aircraft Design

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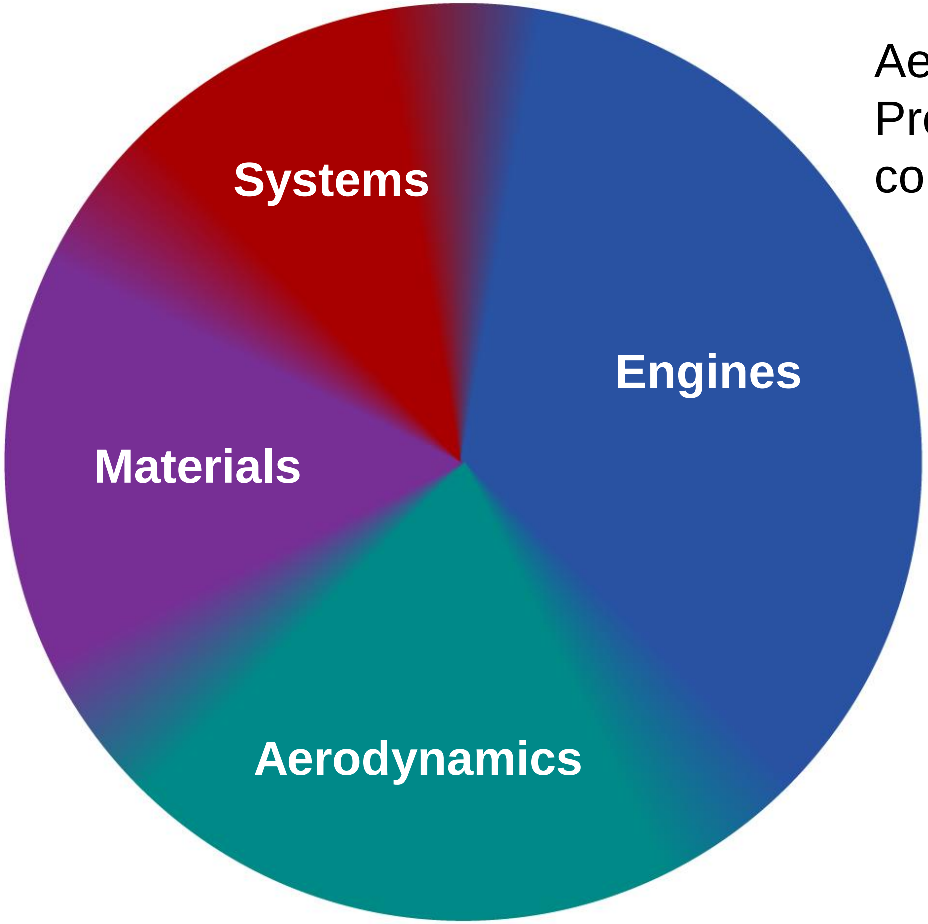
Substantial CFD Utilization **Some CFD Utilization** **Limited CFD Utilization**

Key Enablers Include High Performance Computing and Physics-based Design/Analysis/Optimization

Advanced Technology Contributions to Aircraft Efficiency Improvement

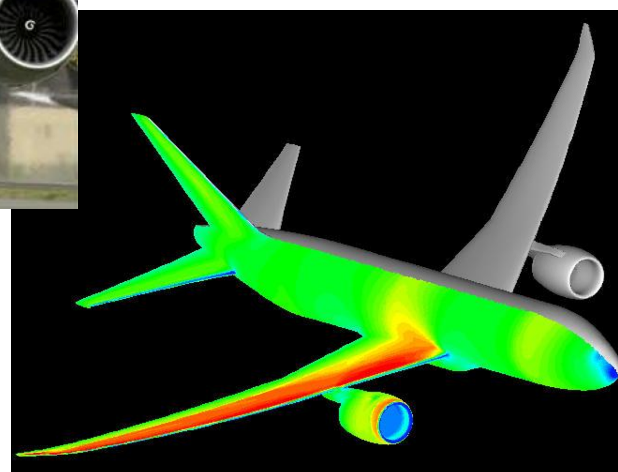


Aerodynamics and Propulsion are main contributors

Improvements relative to 767-300ER

Sources of Aerodynamic Design Expertise

Lessons learned from existing products



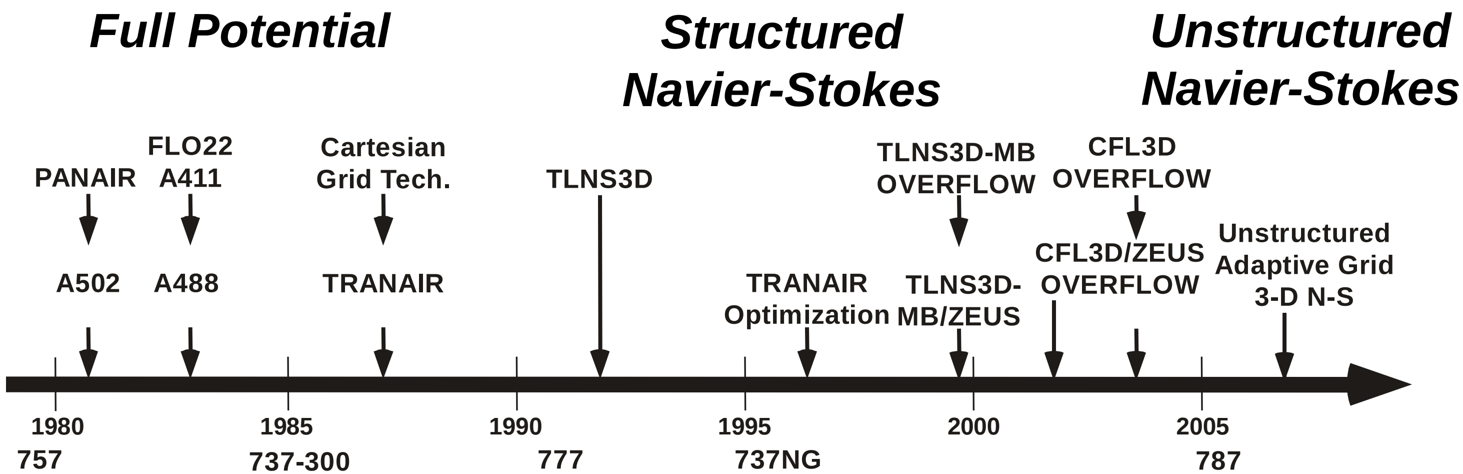
CFD design, analysis, and optimization tools

Extensive wind- tunnel test program

Global Wind Tunnels Used for Development

CFD Maturity and Application Chronology (1980-2010)

CFD Tools



Boeing Products

1980 state of the art

Modern close coupled nacelle installation, 0.02 Mach faster than 737-200

Thicker faster wing than 757, 767 technology

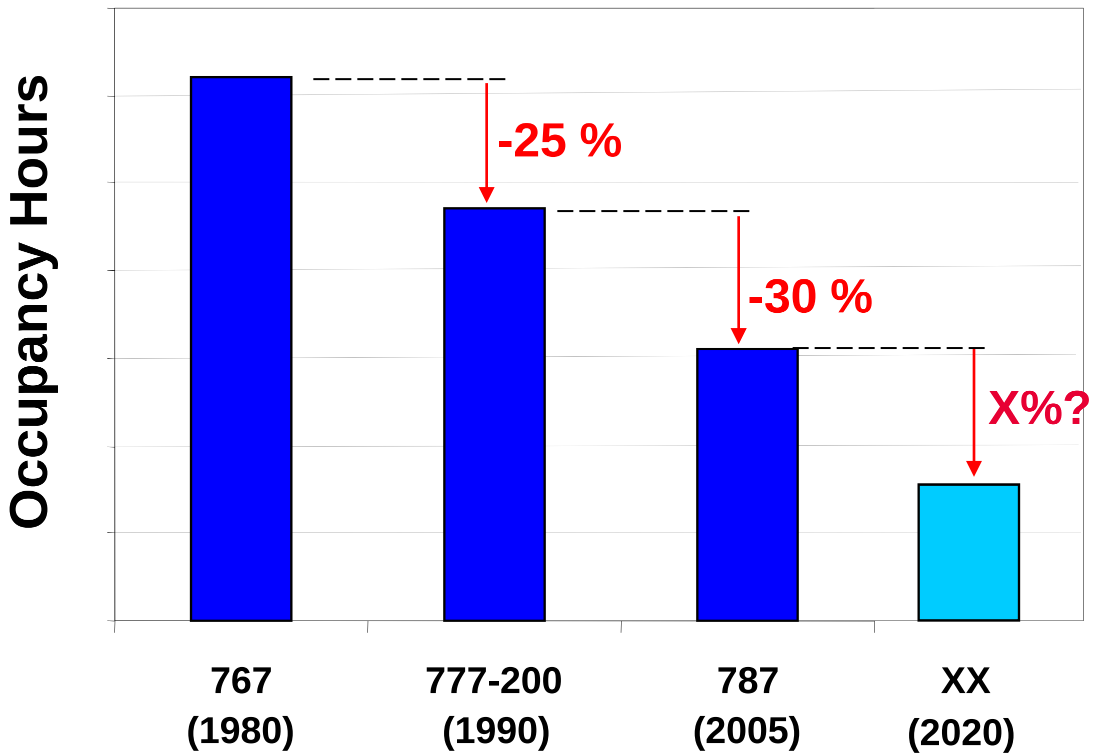
Highly constrained wing design Faster wing than 737-300

Multi-point viscous optimization

CFD for Loads and Stability and Control

Multi-fidelity CFD code are essential for industrial design

Wind Tunnel Test Time Reduction



- **Significant decrease in wind-tunnel testing time since 1980's reduces cost and enables faster market readiness**
- **Reduction in testing time largely enabled by availability of mature and 'calibrated' advanced CFD**
- **How to realize the next major cost reduction?**

Aerodynamic Optimization

- **Navier Stokes based CFD Methods widely used on past and current Aerodynamic Optimization/Design efforts**
  - BCA: Wing body fairing (787), winglets (787), flap support fairings (747), nacelle fan cowl.
  - BR&T: AFRL Joined Wing concept development and optimization, NASA N+2 Supersonic Low Boom effort
- **Developing adjoint capabilities for gradient based optimization using Overflow and internal unstructured grid solver BCFD**
- **Continuing development of MDOPT optimization method**
  - Global surrogate model based optimization using Boeing-developed Design Explorer software
  - Multi-fidelity flow solver option using Boeing-developed Tranair (full potential/integral boundary layer), NASA-developed Overflow (overset structured), Boeing-developed BCFD (unstructured)

Aerodynamic Optimization Tools for AFRL Aerodynamic Efficiency Improvement (AEI)

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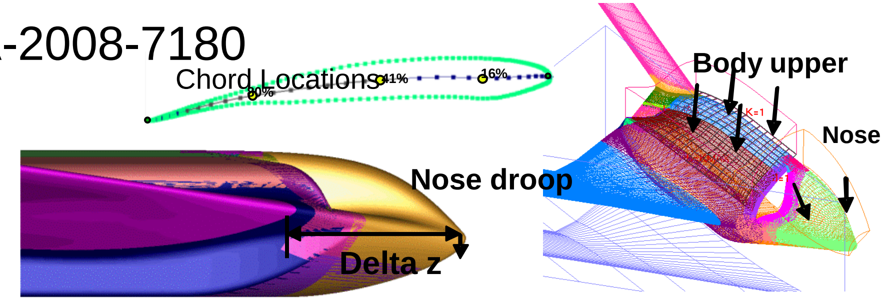
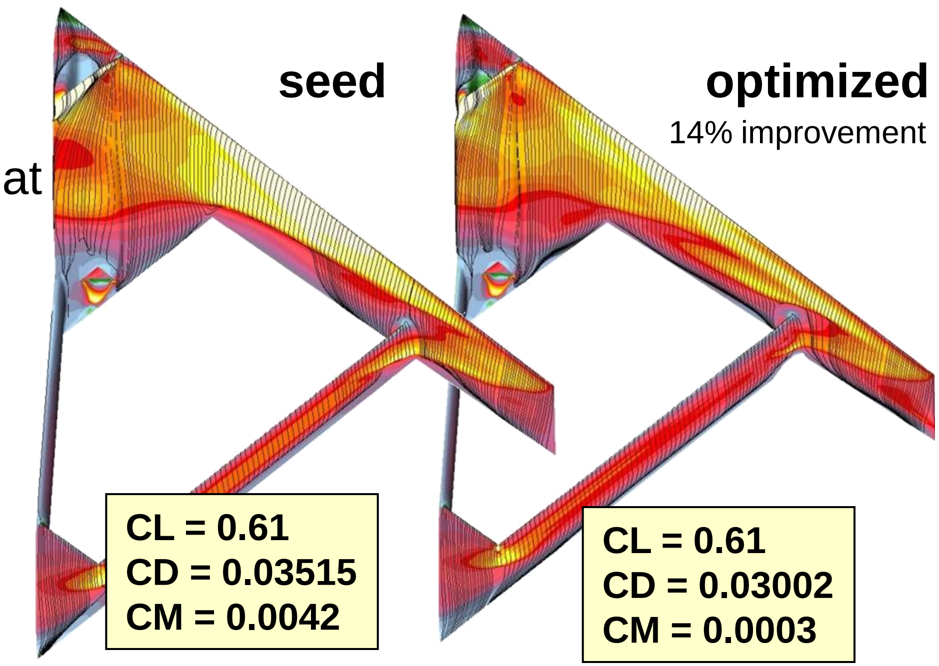
AIAA-2008-7180

- Performed MDOPT Optimization
- Used new Design Explorer tools reducing Drag while trimming configuration
- Used 60 solid design variables shaping wing and aft wing, inlet, and body upper surface
- Constrained CL and CM (trimmed), thickness constraints for antenna
- Optimization concept tested and validated at NASA Ames 11ft Wind Tunnel





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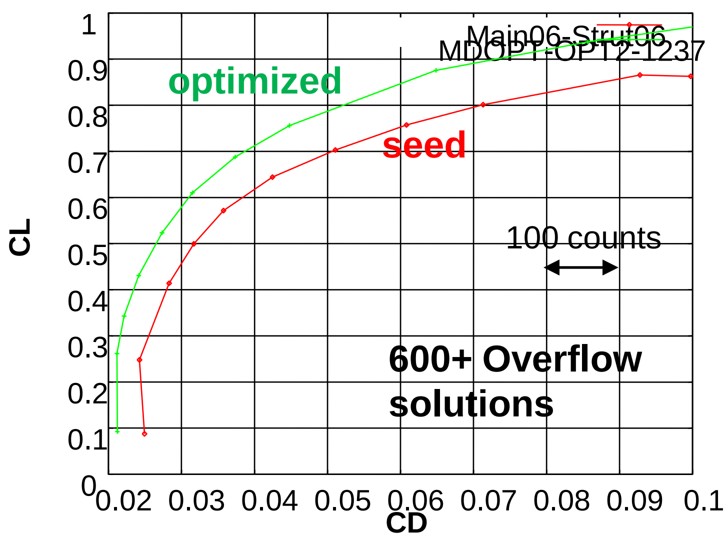

Navier-Stokes Based Winglet Optimization

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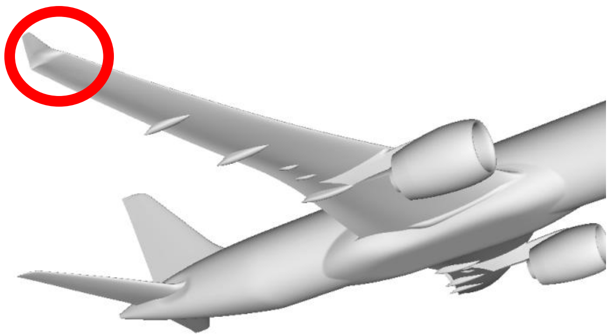
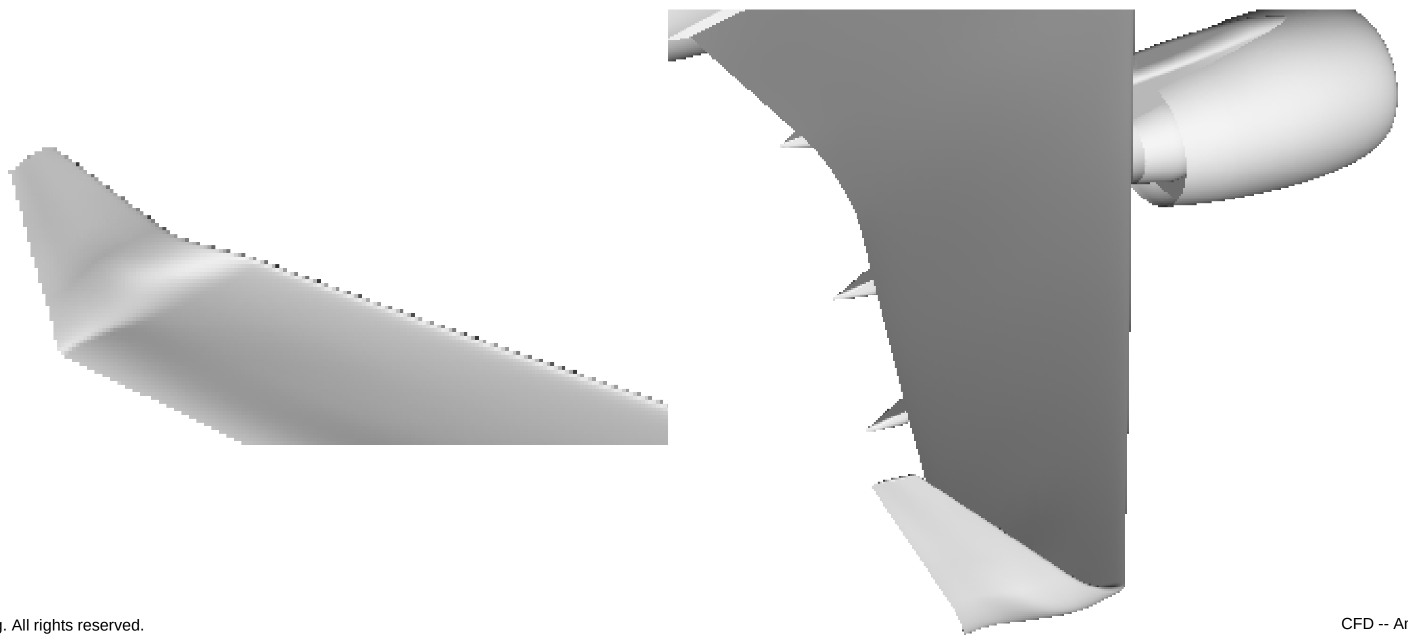
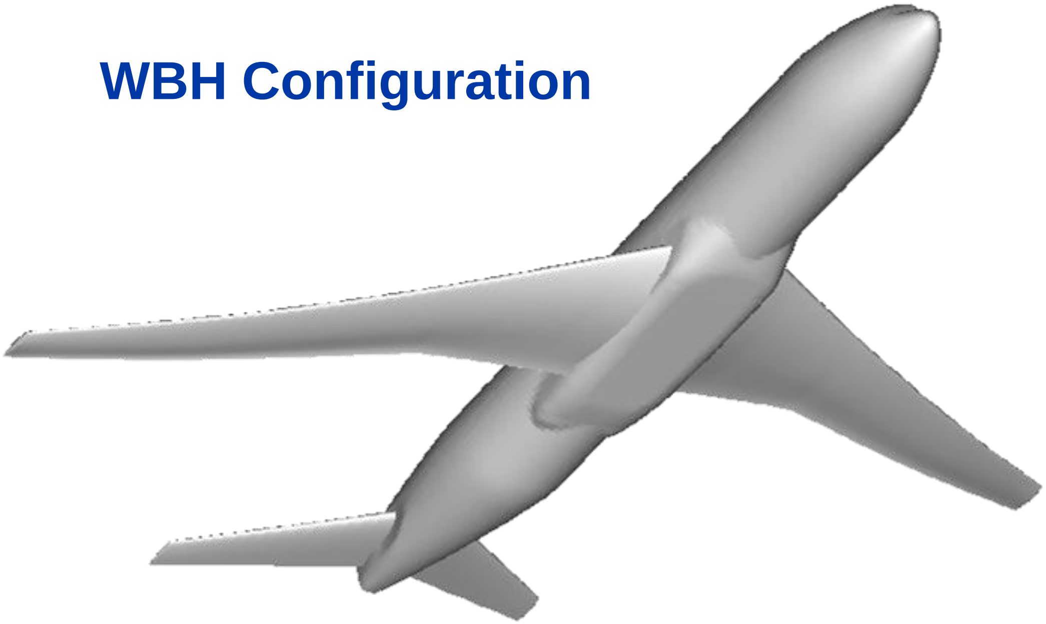


- **Overflow-MDOPT design space with a wide range of junction geometries (56 Design variables)**
- **N-S based design able to approach theoretical aero optimum tight juncture**



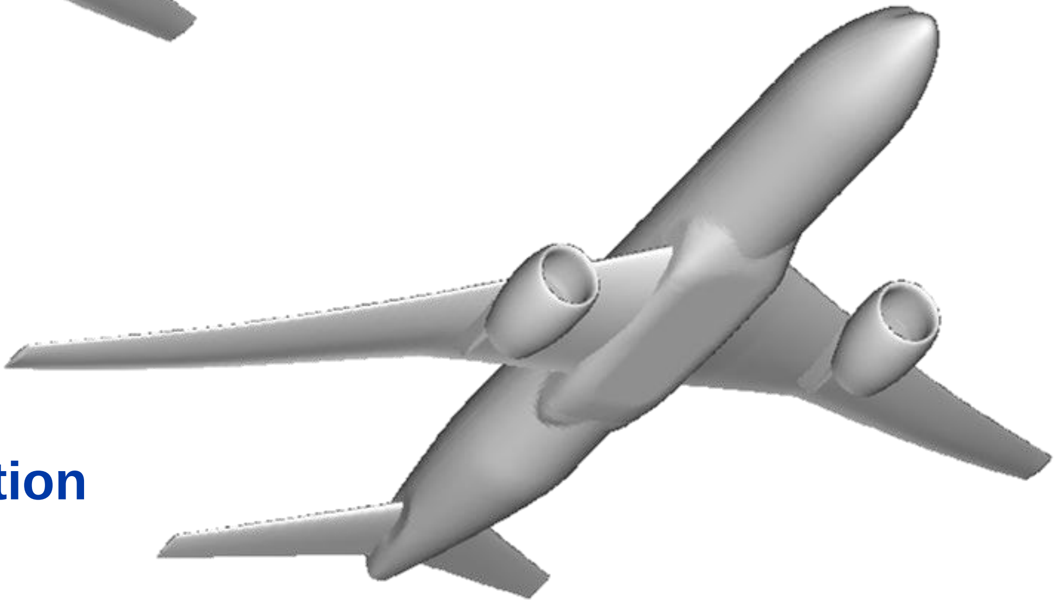
Common Research Model (CRM)

WBH Configuration



- A generic geometry, developed with contributions from Boeing, NASA and other industry

- Representative of modern transport state of the art

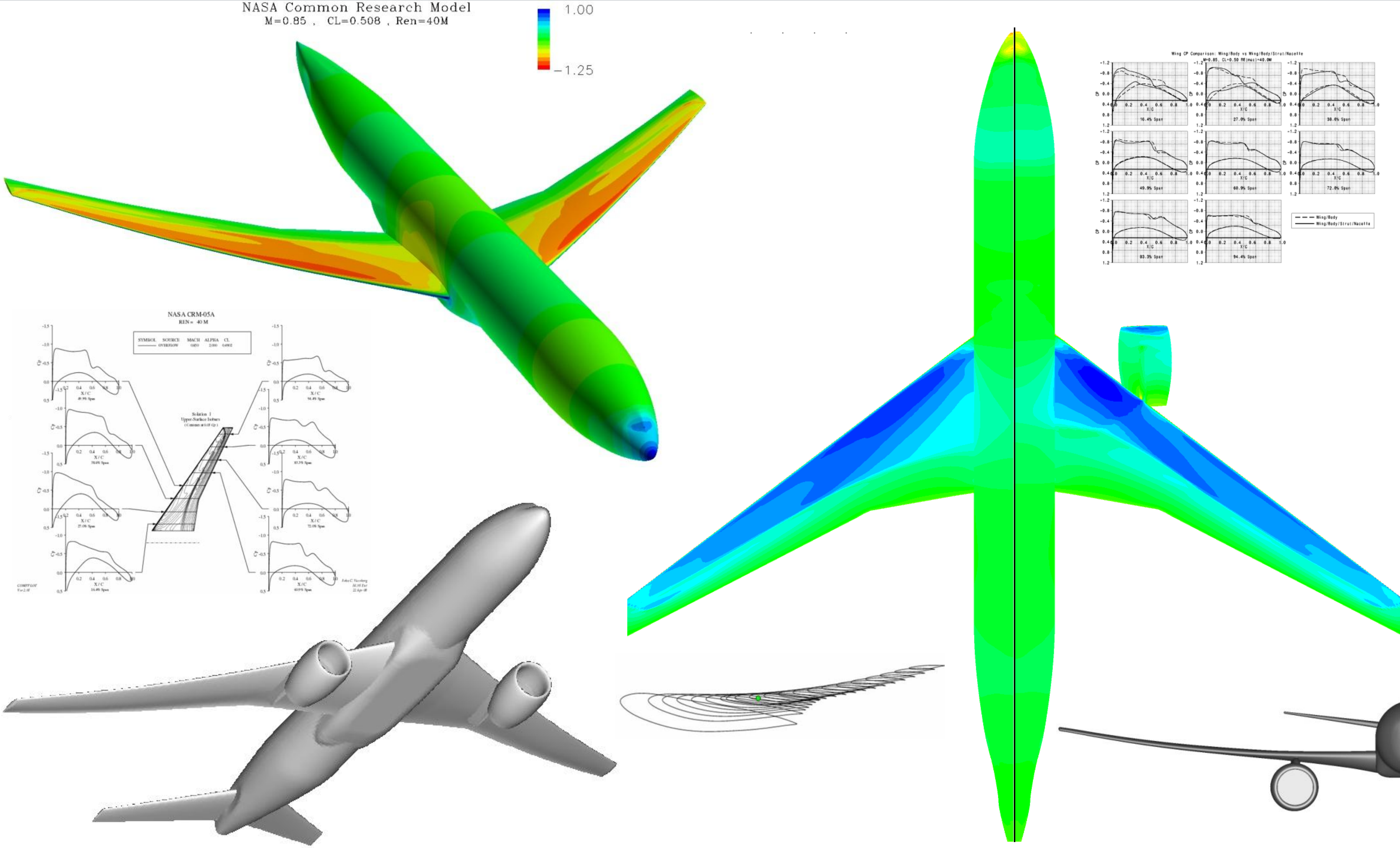


WBNPH Configuration

Common Research Model (CRM) Interest

- **Groups Interested in a CRM**
  - Drag Prediction Workshop
    - Subject Geometry for DPW-IV
  - Computational Methods for Stabilitly and Control (COMSAC)
  - Various Wind Tunnel Facilities
    - NTF
    - Ames 11 Foot
- **Cross-section of Government and Industry**
  - Air Force, Boeing, Cessna, Gulfstream, Hawker-Beechcraft, Lockheed Martin, NASA, Navy, Northrop Grumman, Pratt & Whitney

The CRM has been offered as a generic testbed for validation of emerging prediction methods



Future

Where We Believe CFD Should Go
(Vision 2030)

CFD Challenges

- **Accurate prediction of boundary layer transition**
- **Improved RANS model for efficient complex flow analysis**
- **Accurate prediction recovery, dynamic distortion, and swirl patterns at the Aerodynamic Interface Plane (AIP) for propulsion integration**
- **Accurate prediction of shock-boundary layer in presence of corner flows**
- **An advanced turbulence model within a single framework for accurate unsteady flow phenomena**
- **Efficient and robust mesh adaptation for complex configurations**
- **Error estimation and uncertainty predictions**
- **Multidisciplinary analysis (aeroelasticity, etc.)**

Important Factors for Industry Regarding 2030 CFD

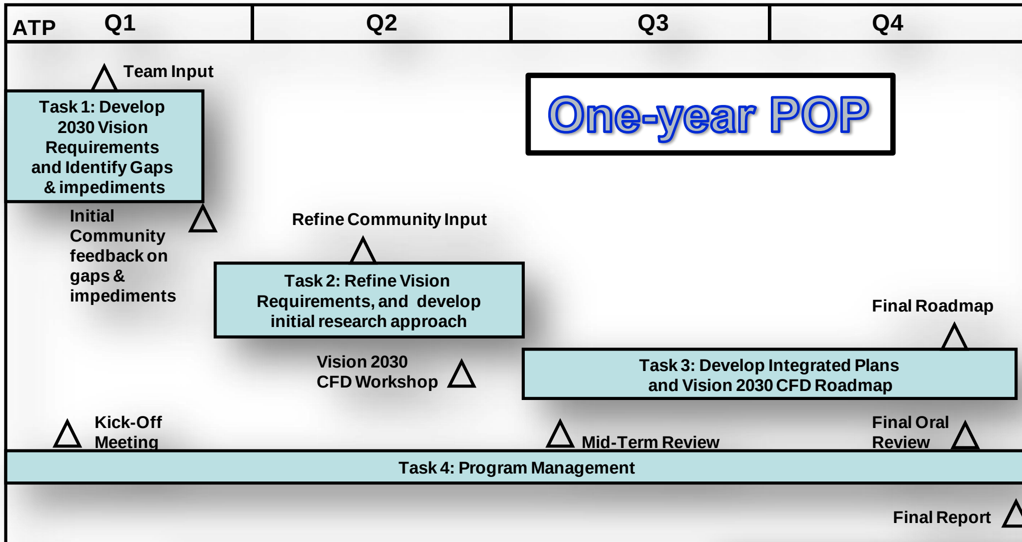
- **Throughput :** End-to-end cycle time must be faster than process based on wind tunnel testing
  - Consistent quick turnaround essential in a schedule-driven development program
  - Engineering development consists of development of large databases for loads, stability and control, and flight simulation
- **Cost:** Database creation using CFD must be cheaper than using wind tunnels
- **Accuracy :** Must be superior to wind-tunnel
- **Error / Uncertainty Quantifications:** Must be able to quantify the error and uncertainty associated with results
- **Expertise :** Must be automated and operational using project engineers, not just CFD experts

'Vision 2030' CFD Code Request for Proposals

- *Many CFD codes are currently available (e.g. NASA / other government labs, external vendors, academia, etc.) based on structured, unstructured and hybrid-grid technology and low fidelity turbulence models, which are adequate for a limited subset of turbulent flow applications of immediate interest. If computations of complex, unsteady, turbulent flows are to become routine, however, it is likely that computational technology will need to evolve to readily embrace new ideas and developments in turbulence modeling, high-order numerical methods, fast solvers, grid adaptation, etc., in addition to exploiting the current and future developments in computer*

- *Answer the following 5 questions:*
  1. *What hardware requirements and software attributes will characterize an advanced 'Vision 2030' CFD code that is used routinely to compute complex turbulent flows, involving flow separation, at subsonic and supersonic/hypersonic speeds, and exhibits greater robustness than current technology?*
  2. *How many orders of magnitude faster (time-to-solution), as compared with current capabilities, will 2030 CFD technology be?*
  3. *What will be the fundamental elements of 2030 turbulence models, and for what classes of problems will they be reliable?*
  4. *What are the principle impediments, both modeling and algorithmic, that must be overcome to achieve the 2030 CFD vision outlined above?*
  5. *What high-risk/high-yield obstacles remain as enduring and daunting challenges that should be the focus of long range efforts by NASA?*

Boeing has assembled a Team to help answer the Vision 2030 CFD code challenge questions



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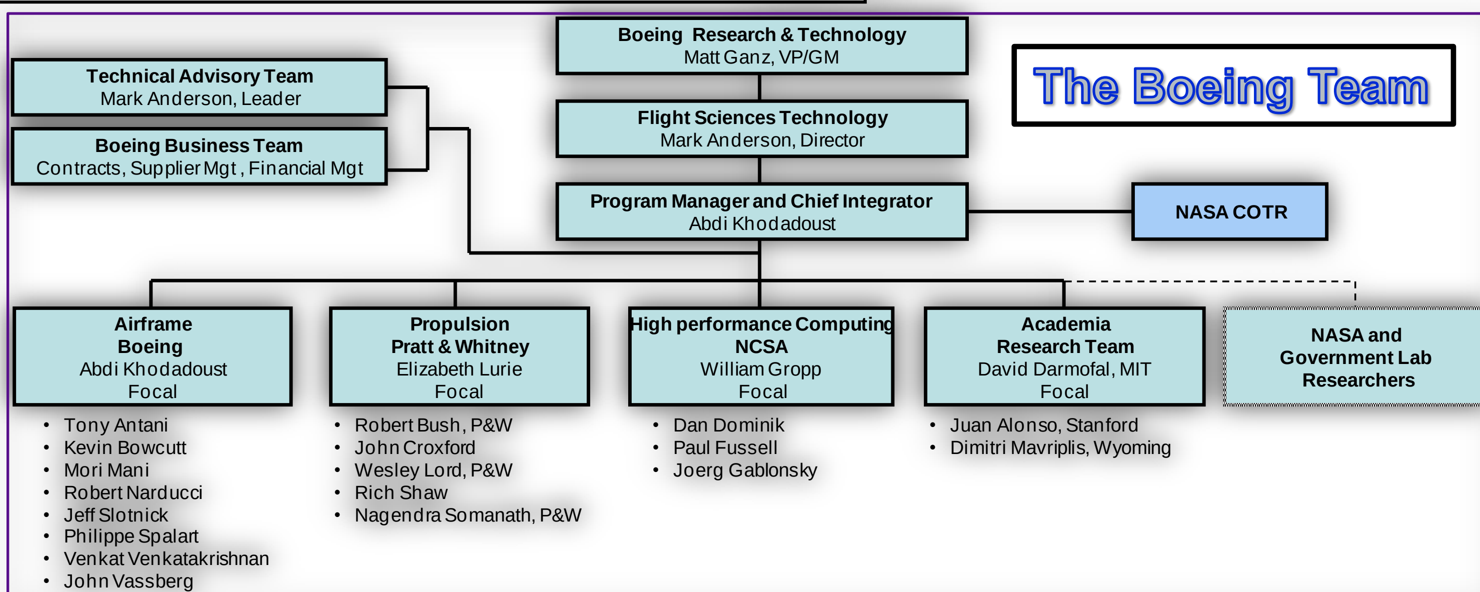


Final Observations

What's Holding Us Back?

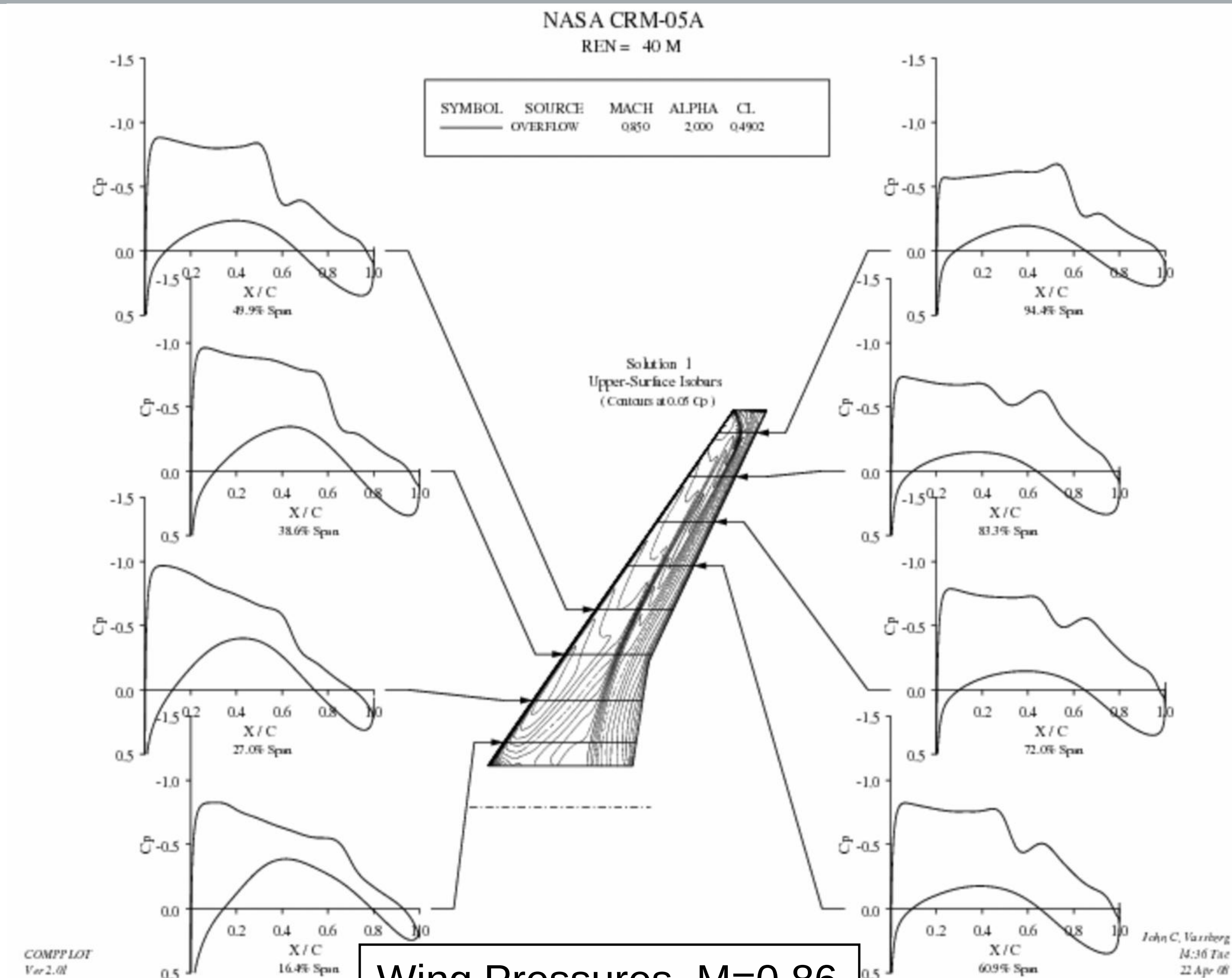
- **Throughput and end-to-end cycle time**
  - Consistent quick turnaround essential in a schedule-driven development program
  - Engineering development culminates in large databases for loads, stability and control, flight simulation
- **Consistency (quality control)**
  - Cannot tolerate intermittent process failures
- **CFD is still a specialist tool to a remarkable degree**
  - User skill is often a key factor in obtaining ***consistent high quality*** results for frontline projects
  - Skill mixes in research groups do not reflect those of frontline project groups

Summary

- **CFD capabilities have brought forth tremendous capabiltiies over 3+ decades of production use**
- **Significant opportunities remain for further advances**
- **Boeing has ideas about appropriate areas for focused effort**
- **Thank you for opportunity to share ideas with you today**

Backup

The CRM Wing is Representative of Modern Transport Aircraft



Wing Pressures, M=0.86

Nacelle/Pylon Effect

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