Contributions of CFD to the 787 - and Future Needs

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Technologies for Performance Efficiency and Environmental Compatibility

- **Introduction**
- **Aerodynamic Efficiency**
- **Weight Efficiency**
- **Propulsion System Efficiency**
- **Future CFD Opportunities**

Many Factors Contribute to Saving Fuel and Avoiding Emissions

High Performance Computing Impacts Many Areas

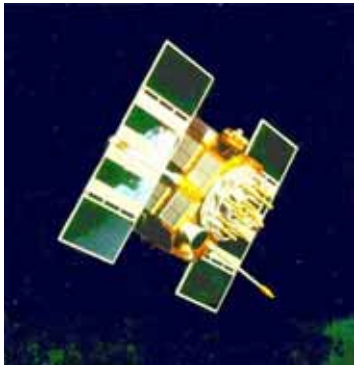
Engine

Aerodynamics

Structures and materials

Systems

Air traffic management



Engine/airframe integration

Design for Performance and Environment

- **Aerodynamic design optimization based on**
  - Evolution from previous Boeing products
  - Extensive advanced CFD
  - Focused wind-tunnel testing, including flight Reynolds number simulation
- **Weight improvements**
  - Materials
  - Load alleviation
- **Engine performance improvements**
  - Higher bypass ratio
  - No-bleed architecture
  - Low aerodynamic interference installation
- **Improved environmental performance**
  - Community noise
  - Cabin noise
  - Emissions
  - Materials impact on the environment

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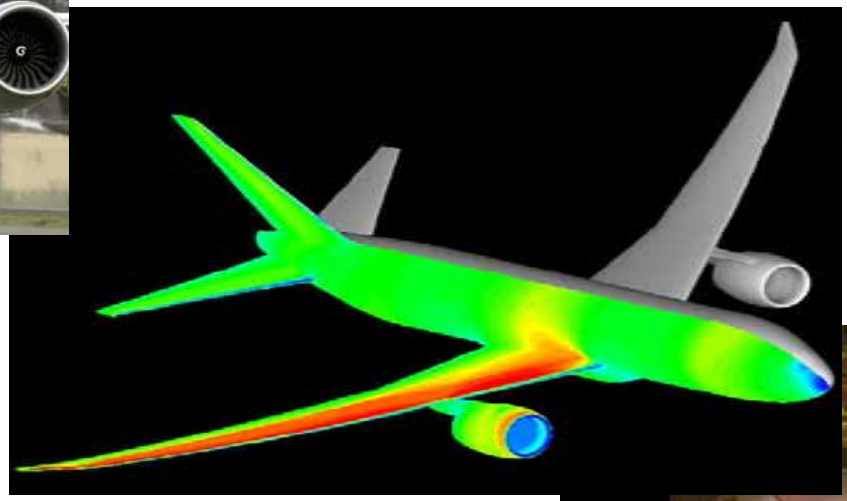
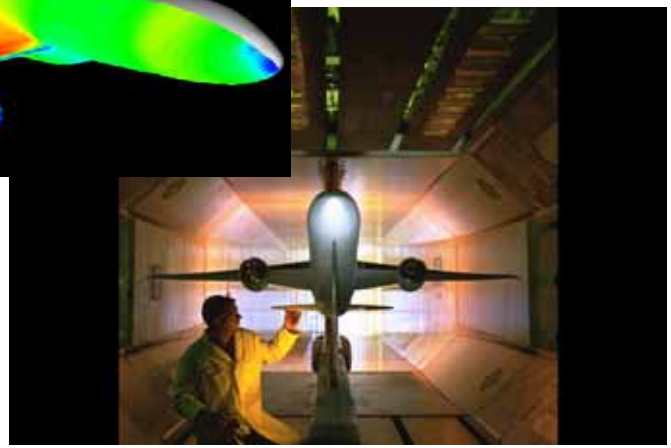
787 Aerodynamic Design

Lessons learned from existing products



CFD design, analysis, and optimization tools

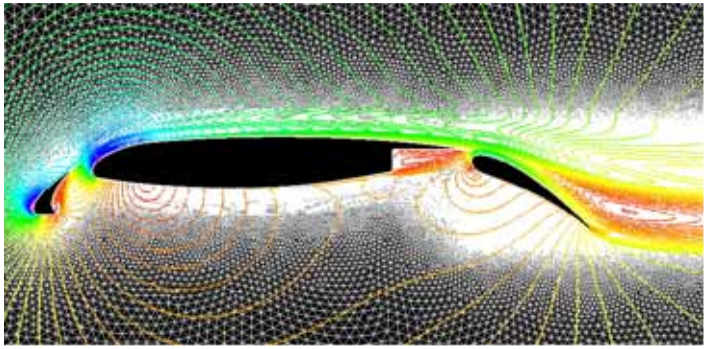


Extensive wind- tunnel test program

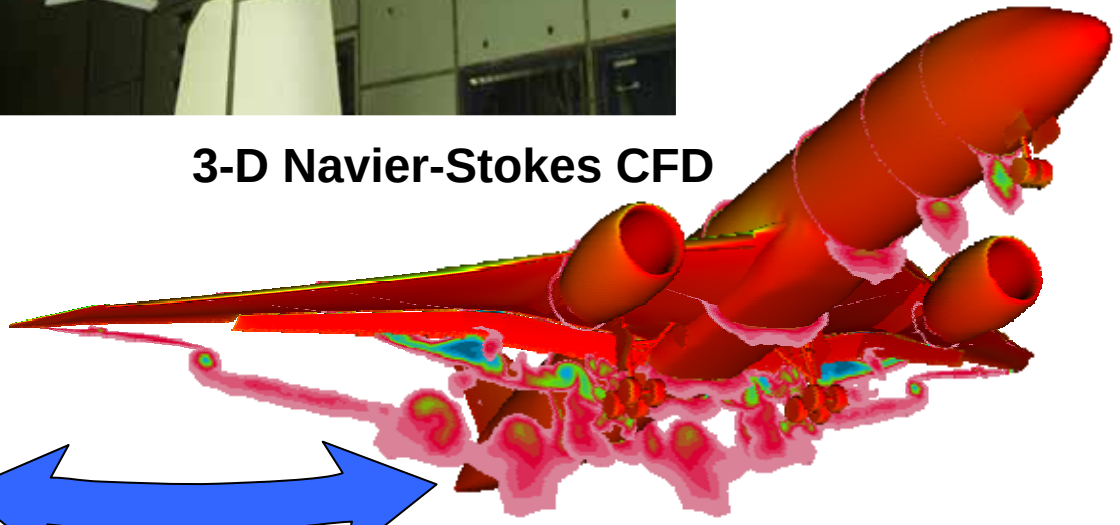
Complementary Use of CFD and Wind Tunnels for High-Lift Design

Wind-Tunnel Testing

2-D Navier-Stokes CFD



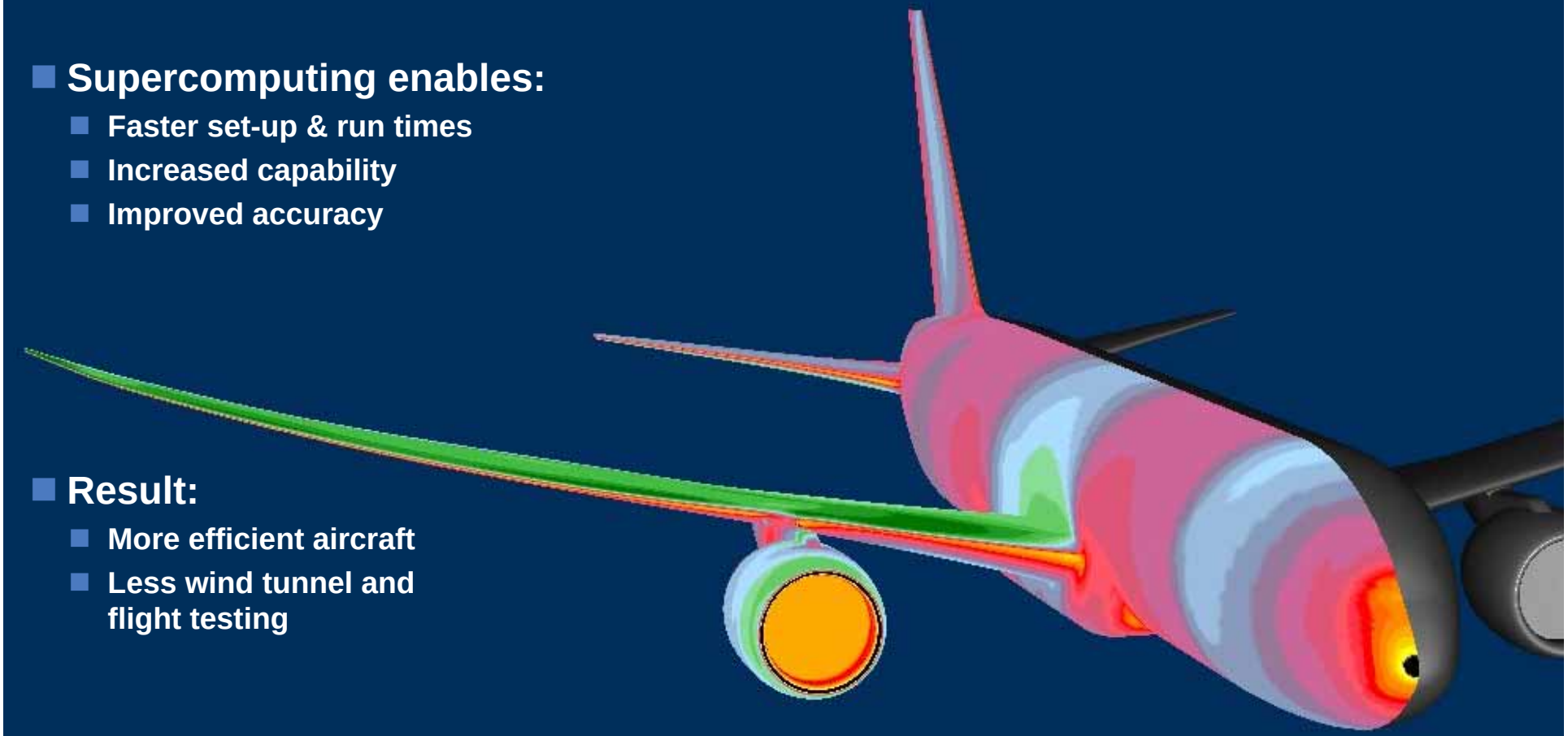
3-D Navier-Stokes CFD



Global Wind Tunnels for Boeing Commercial Airplane Product Development

Modern Computing and CFD Methods Speed Development and Lower Costs

- **Supercomputing enables:**
  - **Faster set-up & run times**
  - **Increased capability**
  - **Improved accuracy**

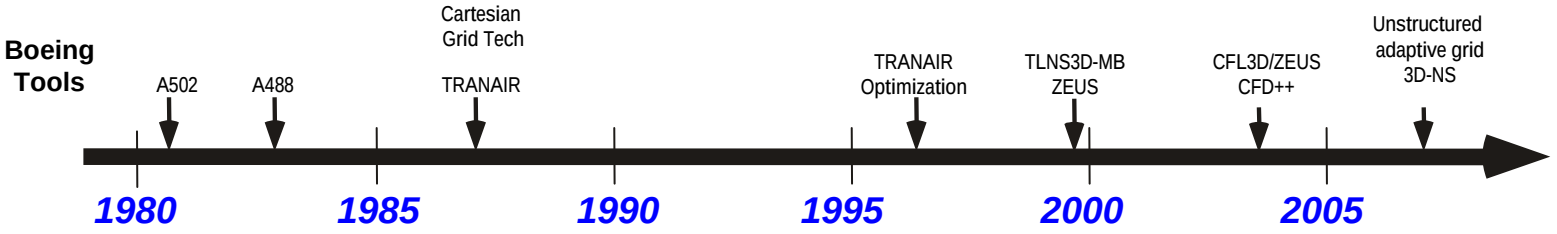


- **Result:**
  - **More efficient aircraft**
  - **Less wind tunnel and flight testing**

CFD Has Significantly Improved the Wing Development Process

Increased computational capability & accuracy

CFD Tools



Boeing Products

1980 state of the art

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

21% thicker faster wing than 757, 767 technology

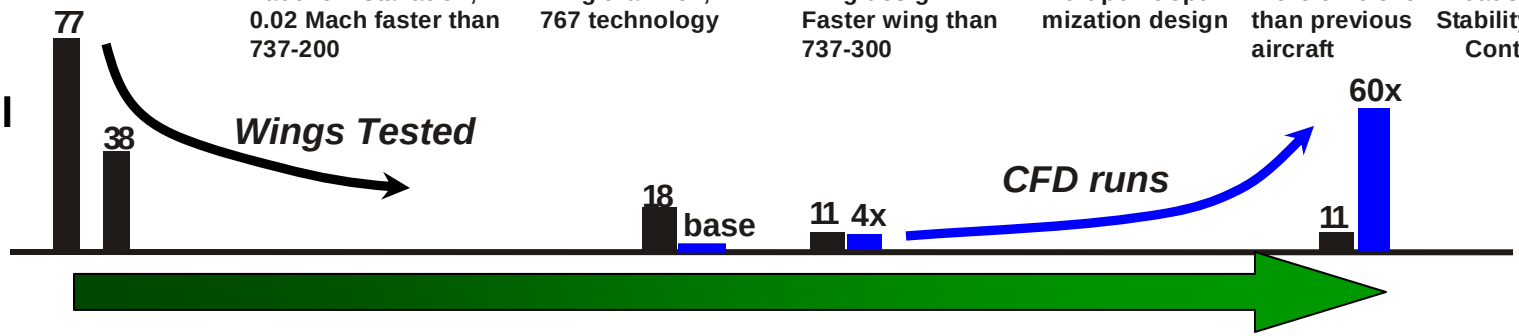
Highly constrained wing design Faster wing than 737-300

Successful multipoint optimization design

Faster and more efficient than previous aircraft

CFD for Loads and Stability and Control

Wind Tunnel vs. CFD



Less testing, lower cost, better products

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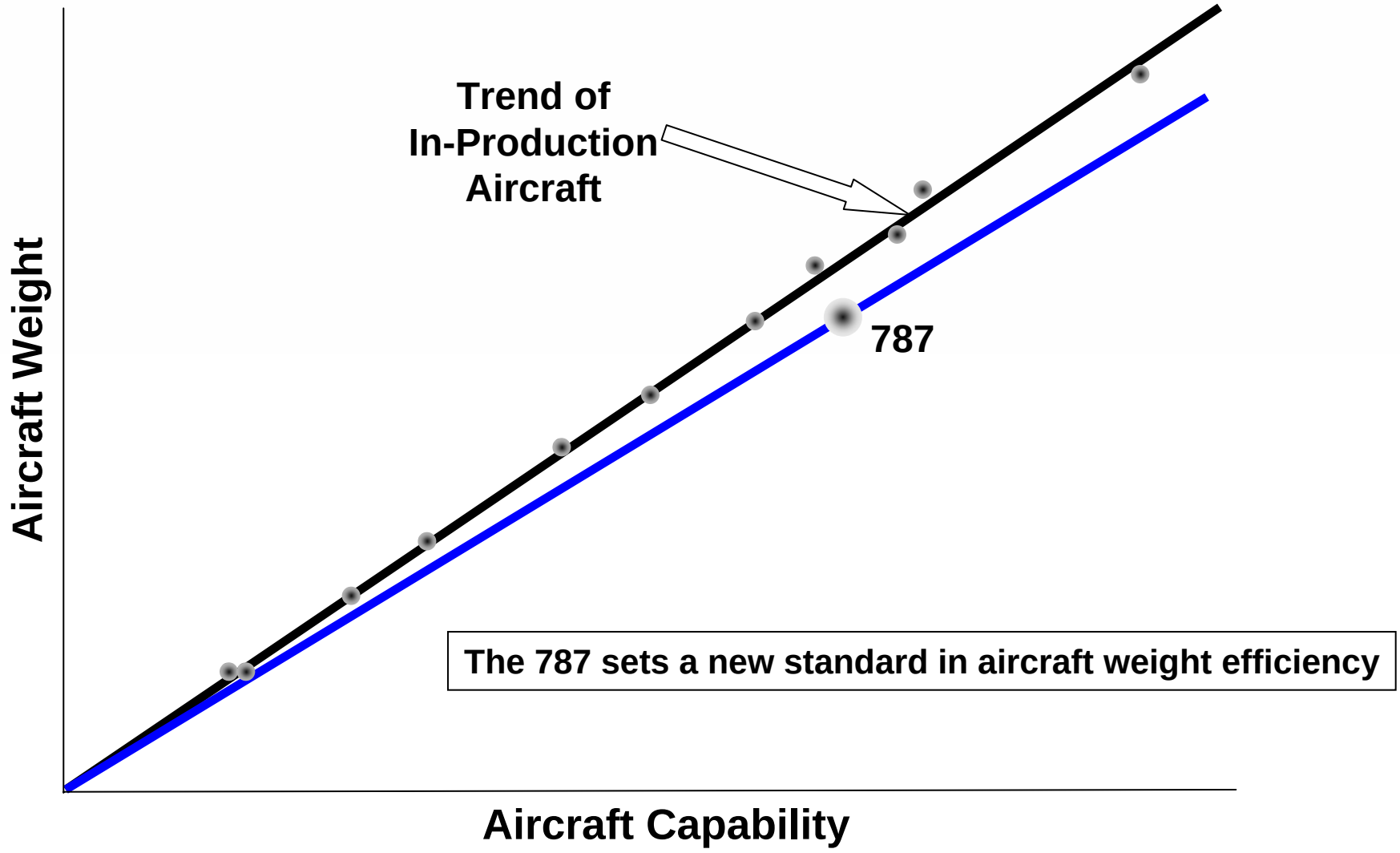
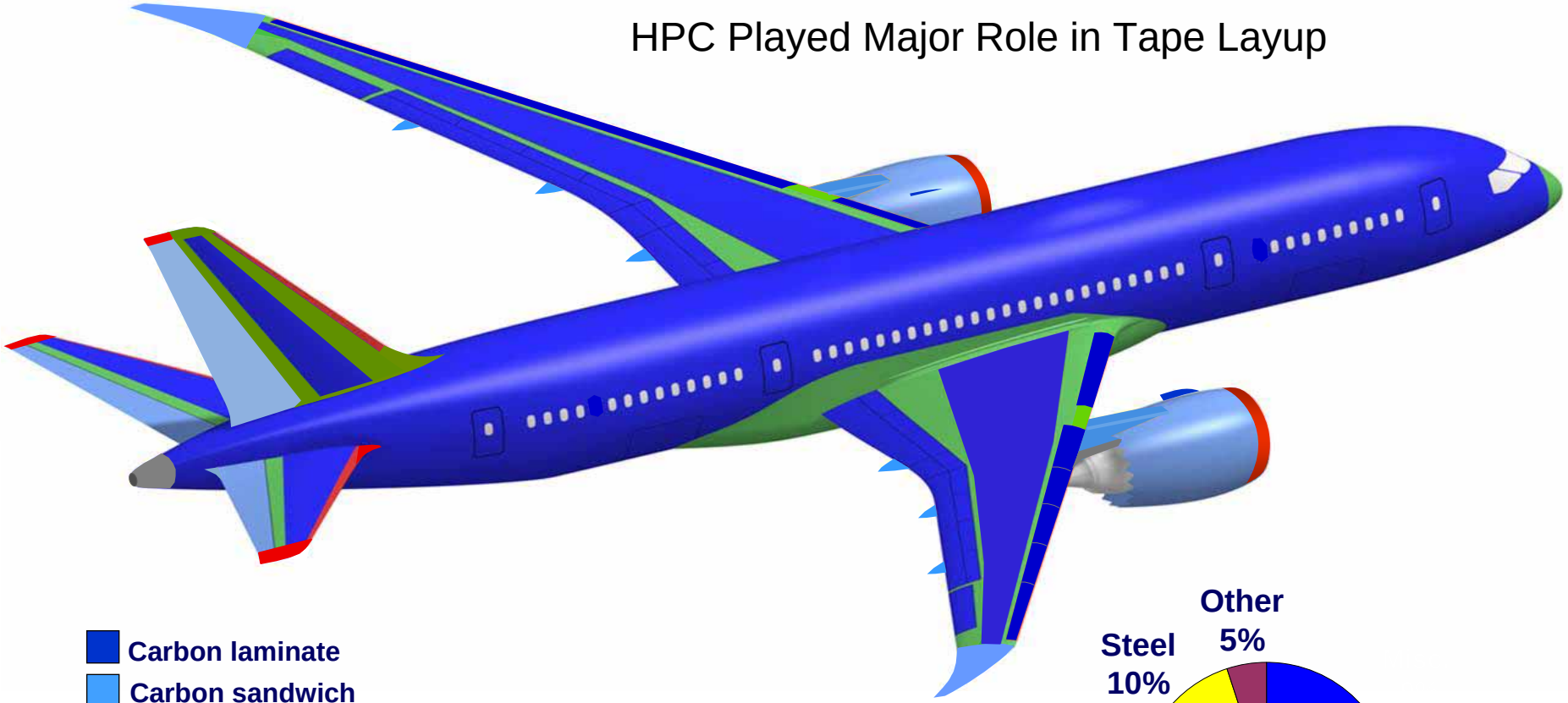
- Future CFD Opportunities

Weight Efficiency

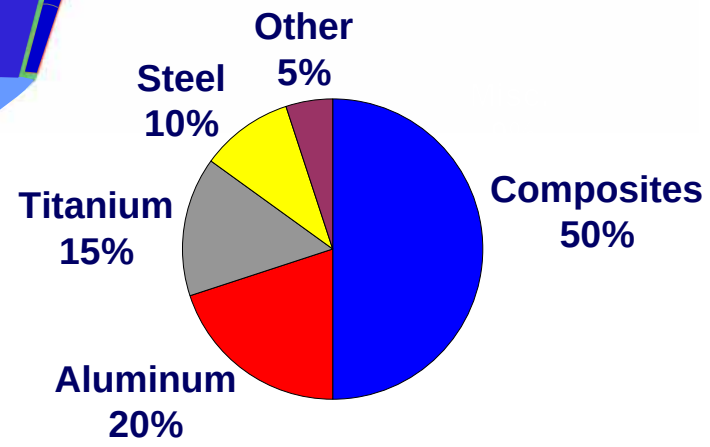


Composites Serve as Primary Structural Material

HPC Played Major Role in Tape Layup



- Carbon laminate
- Carbon sandwich
- Other composites
- Aluminum
- Titanium



Technologies for Performance Efficiency and Environmental Compatibility

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- **Propulsion System Efficiency**
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Propulsion Systems Feature
Key Environmental Technologies

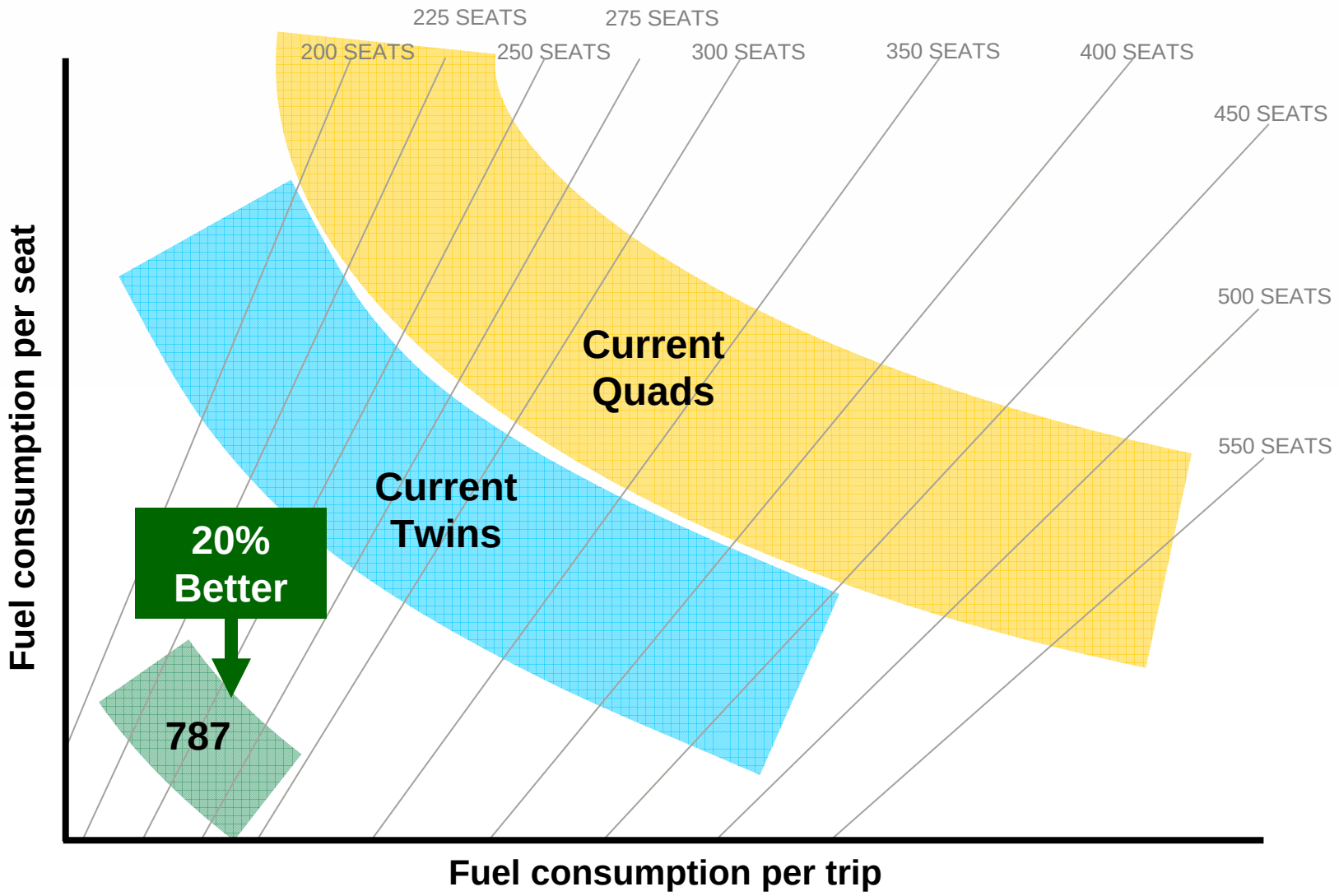
GEnx

Trent 1000

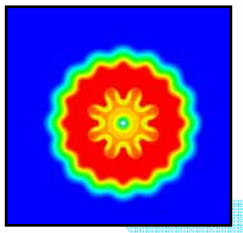
Engine and nacelle features:

- Higher bypass ratio
- No-engine-bleed systems architecture
- Laminar flow nacelles
- Low-noise nacelles with chevrons
- Low emission combustors

Opening a New Era in Fuel Efficiency



Commitment to a Better Future



Analytical studies

Wind-tunnel tests

Static engine tests

2001 QTD 1

Quiet Technology Demonstrator

Boeing
Rolls-Royce
American Airlines

2005 QTD 2

Quiet Technology Demonstrator

Boeing
General Electric
Goodrich
NASA
All Nippon Airlines

747-8

The shape of the future

787

Dreamliner

Efficient Quiet Designs Enabled by High Performance Computing

Reducing noise for communities and passengers with new innovations

Toboggan Fairing reduces Gear Airflow Boise

Quiet for Airport Communities
85 dB Noise Contours at O'Hare

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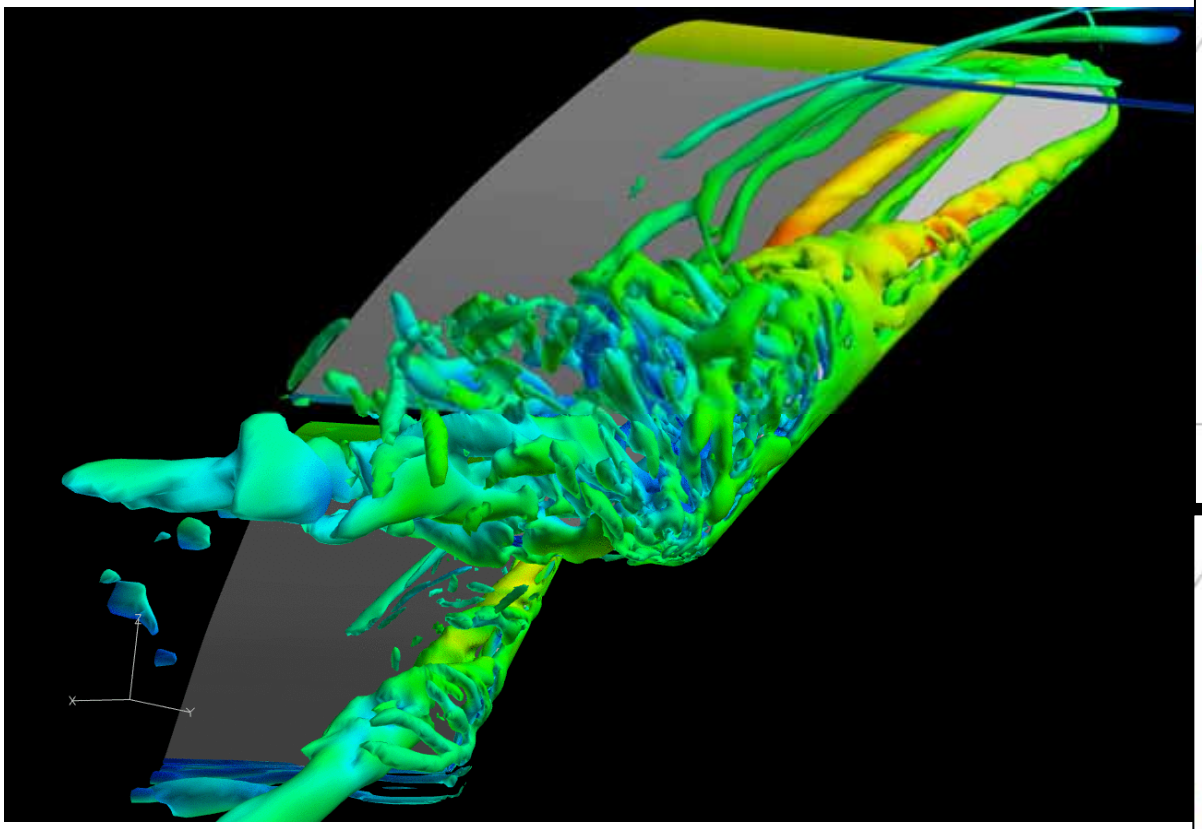
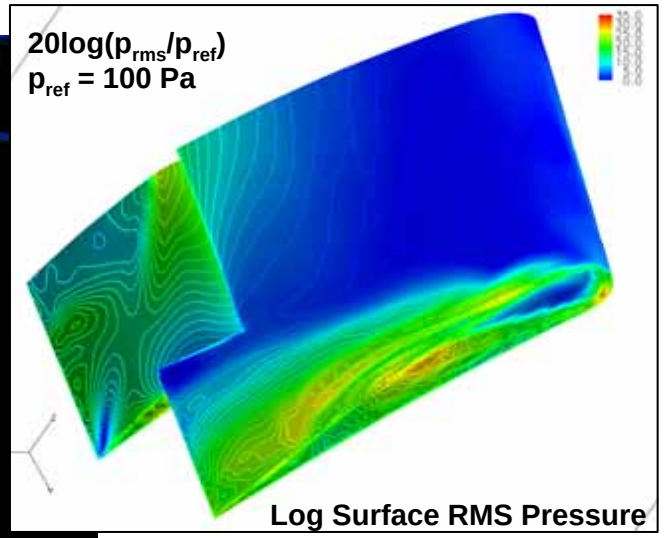
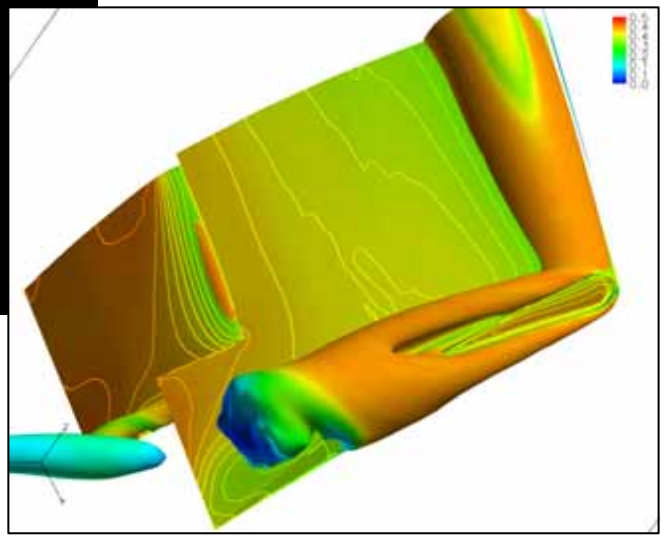
Flap Edge Detached Eddy Simulation

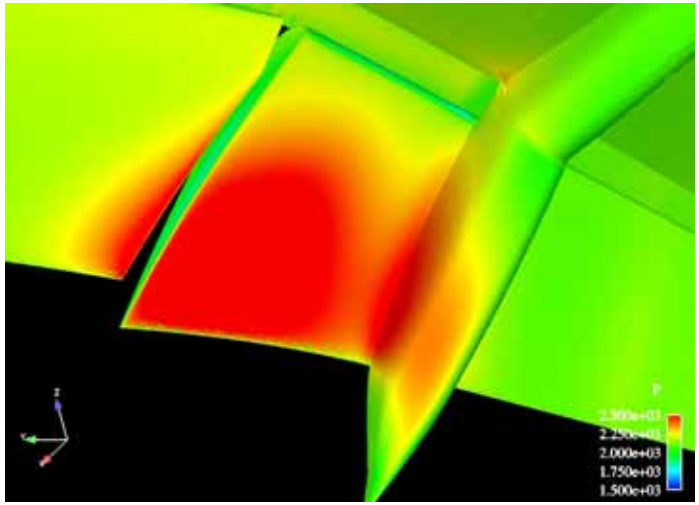


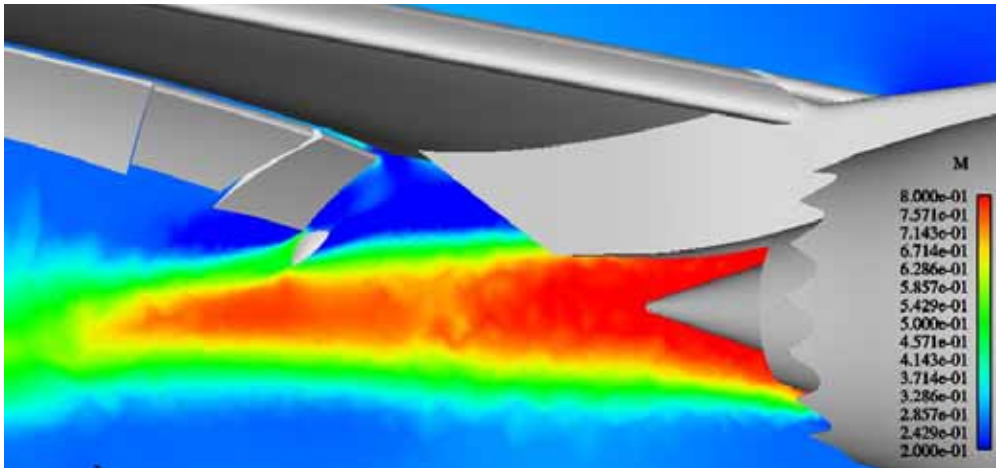
Turbulent Structures
surface of Vorticity^2 – Strain Rate^2
Mach Number (0.2 – 0.5)

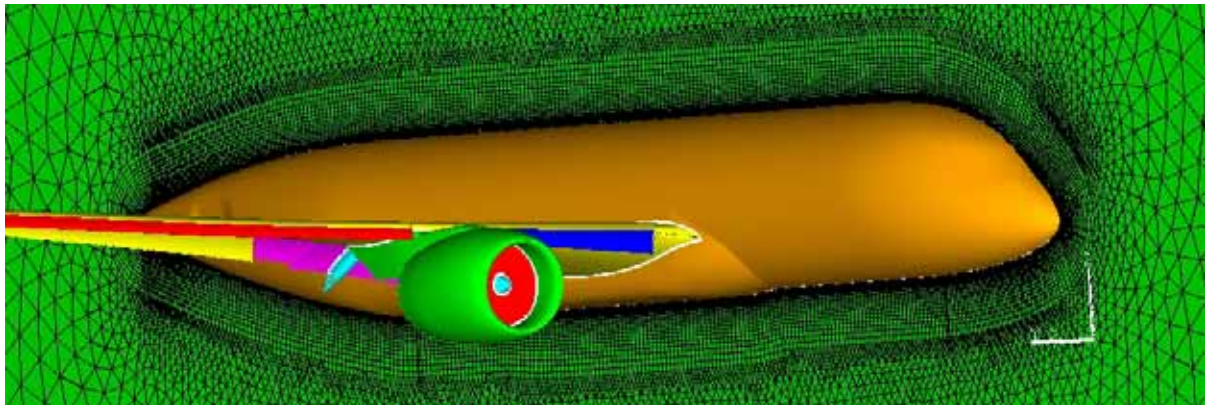




Jet Impingement Loads

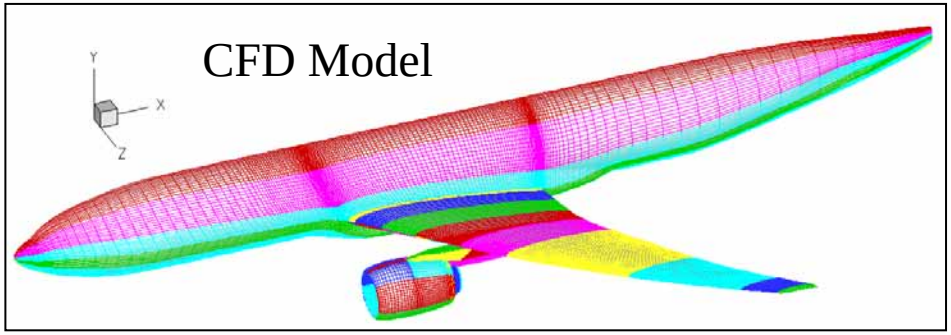


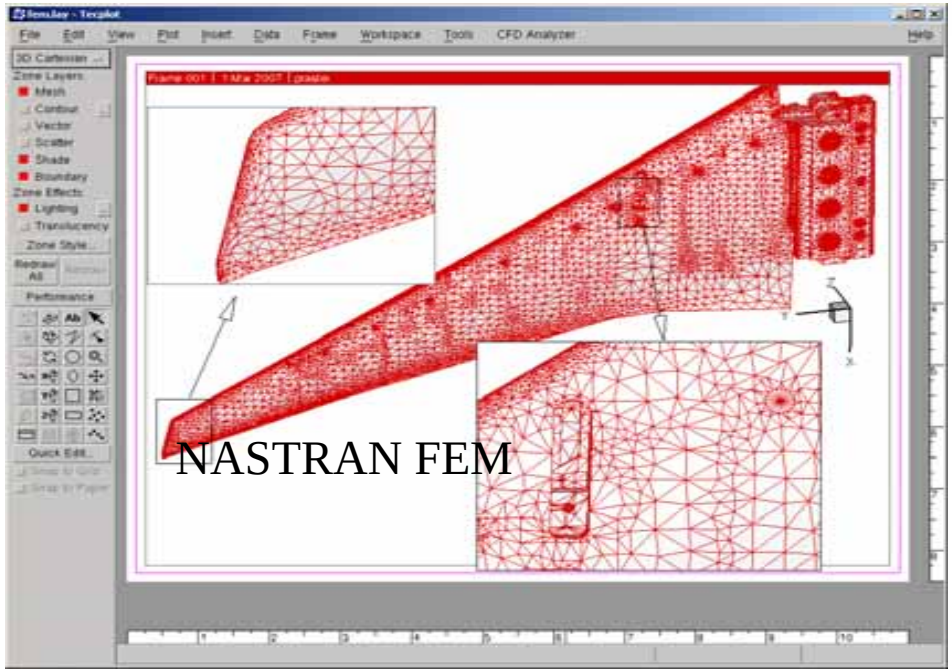




Steady results show the core flow impinging on flap

Aeroelastic Modeling





Aeroservoelastic Modeling

Low Subsonic Speed

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Transonic Speed

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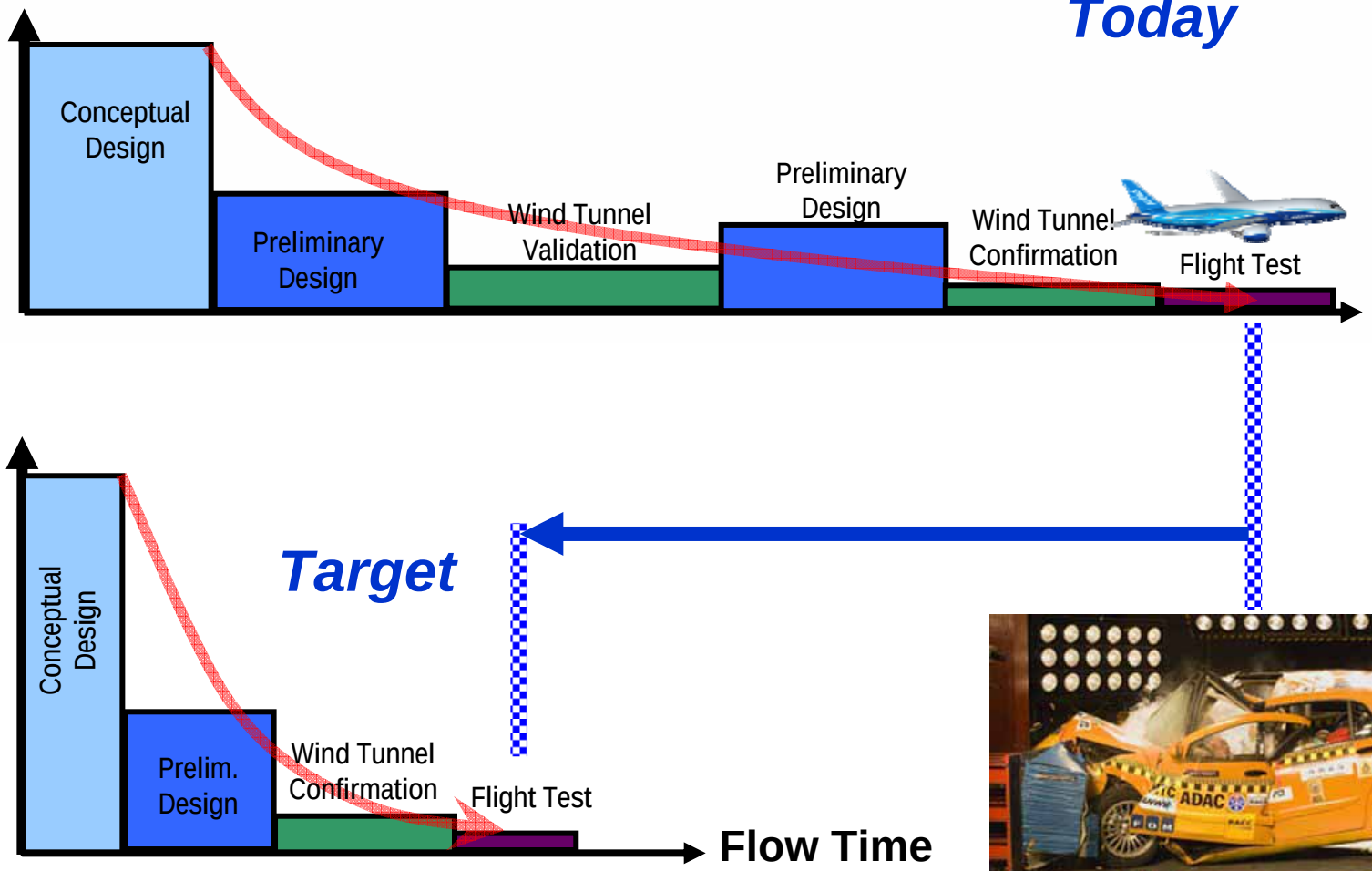
Support development of flight control laws early in the program – impacts structural layout, loads and dynamics, handling qualities assessments and pilot training

Shortened Product Development Cycle Time

Number of Configurations Variations



It's not just aerospace

Challenges and Opportunities

- **Simulation Fidelity**
  - 1980 – had the equations, not the hardware
  - Today – have the improved hardware, but the equations have advanced and we still can't solve all the problems of interest (RANS vs DNS)
- **Compatibility**
  - Hardware options now more diverse
  - Legacy software investment large
  - Need efficient ways to move applications between h/w options
  - Industry needs timely access to new hardware for testing
- **Education**
  - More numerical simulation, less testing – where does 'gut feel' come from? (Rules of thumb)
  - "The computer code said . . . ." (Then it had better be right)
- **Opportunity: Cost and cycle time reduction**
  - Today: Certification by demonstration
  - Tomorrow: Certification by simulation
  - Question: When is tomorrow and what is the path to get there?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747
777
787
767
737
BOEING COMMERCIAL AIRPLANES