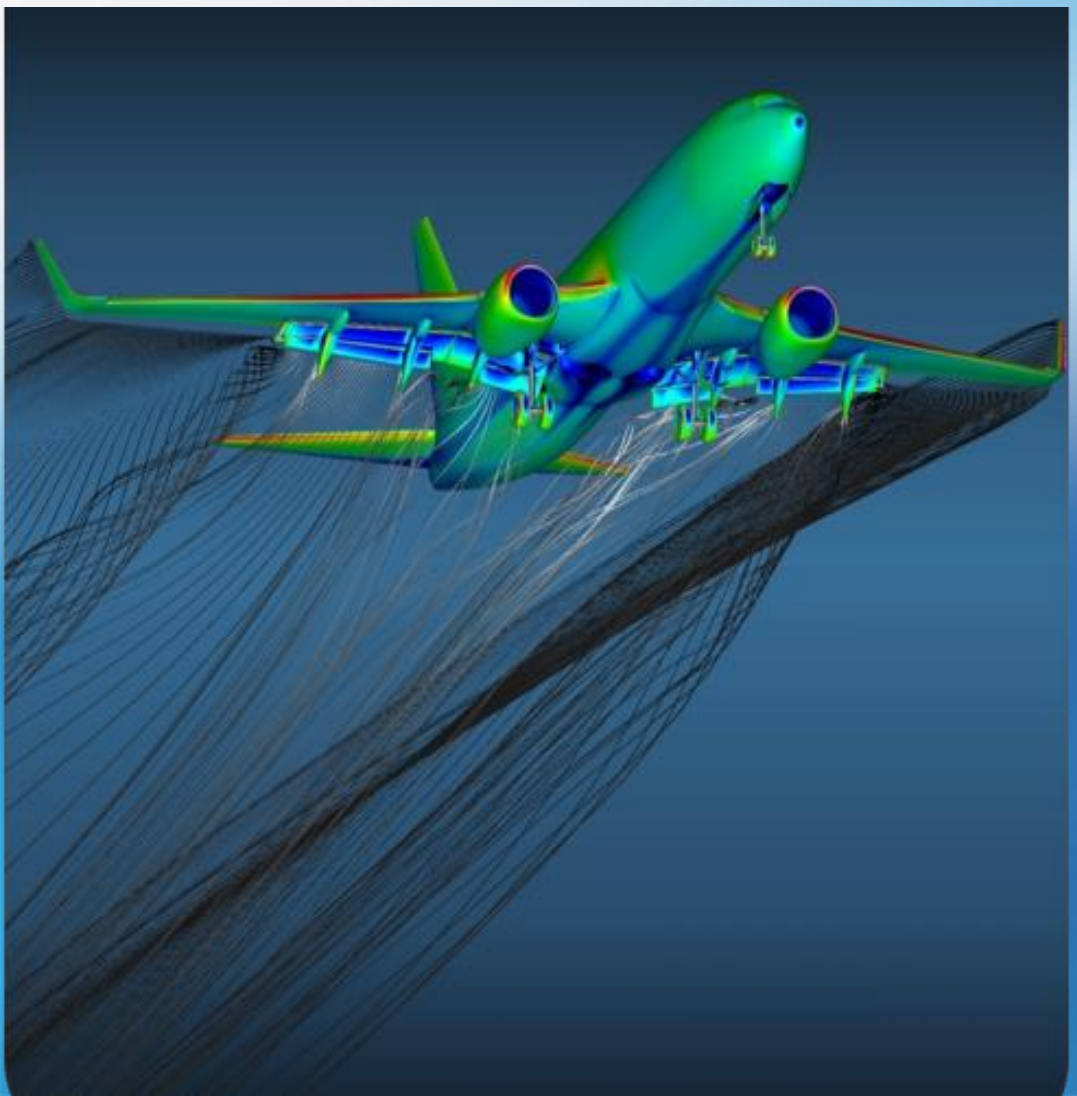

CFD and Aircraft Design

Nov 20, 2014

Robert Gregg
BCA Chief Aerodynamicist

Back when CFD was just starting to be used…

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Setting The Stage

- **PGM-H Transonic Airfoil Analysis Code**
  - **DAC / MDC Enhancements, 1970s**
    - **Coupled Boundary Layer**
    - **TRANEN 2D Inverse Design**
    - **Partial Conservation Parameter**
  - **Supercritical Airfoil Development**
    - **C17, D3300, MD90, etc.**
  - **Divergent Trailing Edge Technology**
    - **Developed by Henne, Gregg & Vassberg, 1982**
    - **D3300, MD11, MD12, MDXX, etc.**
  - **Still Used Today!!!**

In Collaboration w/ Jameson

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Setting The Stage

- **FLO22 Transonic Wing Analysis Code**
  - **John Dahlin Visit / Requested FLO22, Circa 1974**
  - **Pres Henne Enhancements, 1975-1980**
    - **Coupled Boundary Layer**
    - **Pseudo Fuselage Effects (ΔMach, ΔTwist)**
    - **3D Inverse Design**
    - **Henne-Hicks Bump Function Optimizations**
  - **Robb Gregg / John Vassberg Enhancements, 1980s**
    - **Evolution Theory Optimizations**
    - **In-Core Solver, SNGL Mod, Unix Port, etc.**
  - **Supercritical / DTE Wing & Winglet Designs**
    - **C17, MDF100, D3300, MD11, MD12, BWB, etc.**
  - **Still Used Today!!!**

In Collaboration w/ Jameson

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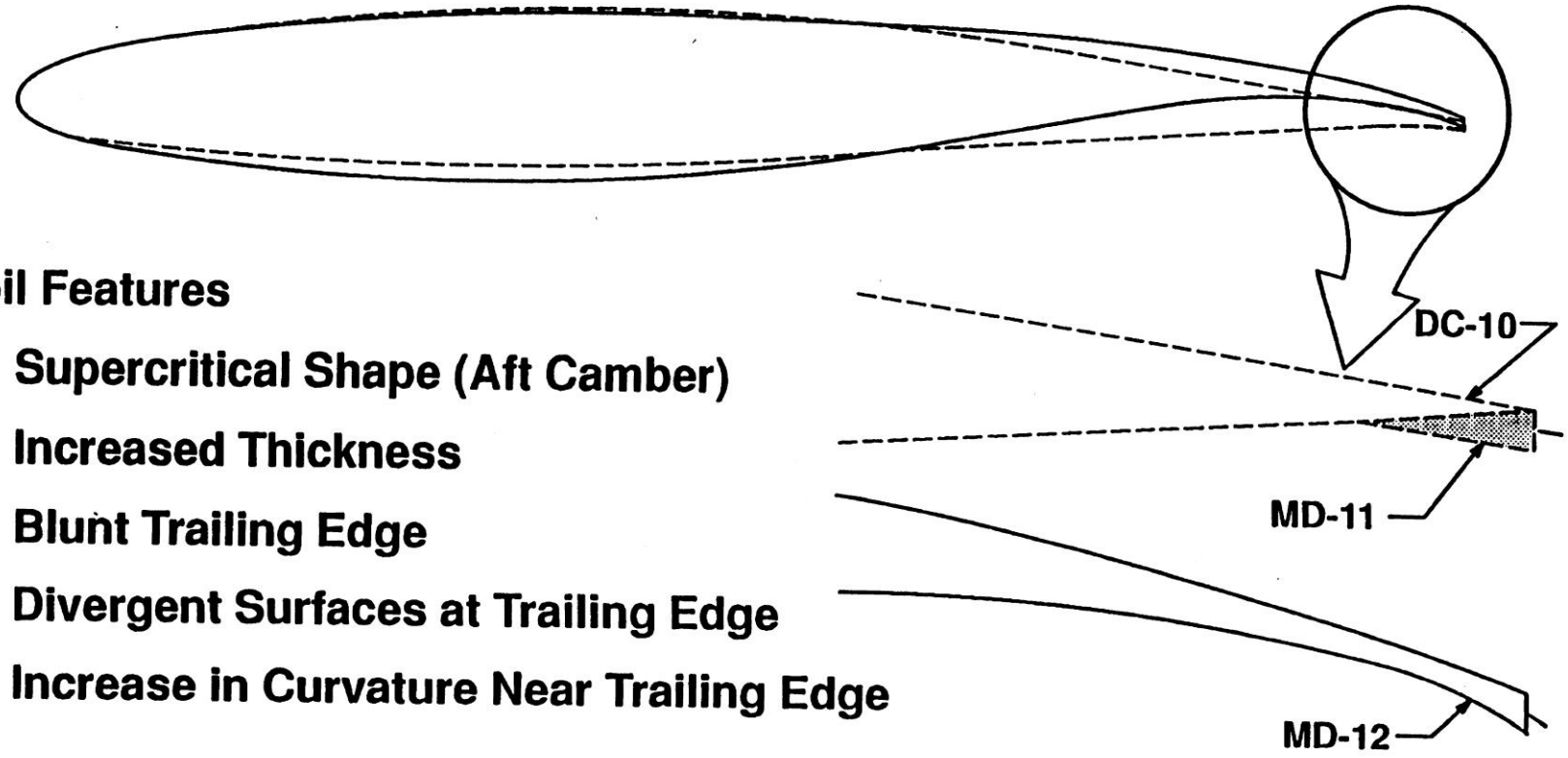
Patented Trailing Edge (DTE) Technology

(U.S. Patent No. 4,858,852)



Airfoil Features

- **Supercritical Shape (Aft Camber)**
- **Increased Thickness**
- **Blunt Trailing Edge**
- **Divergent Surfaces at Trailing Edge**
- **Increase in Curvature Near Trailing Edge**

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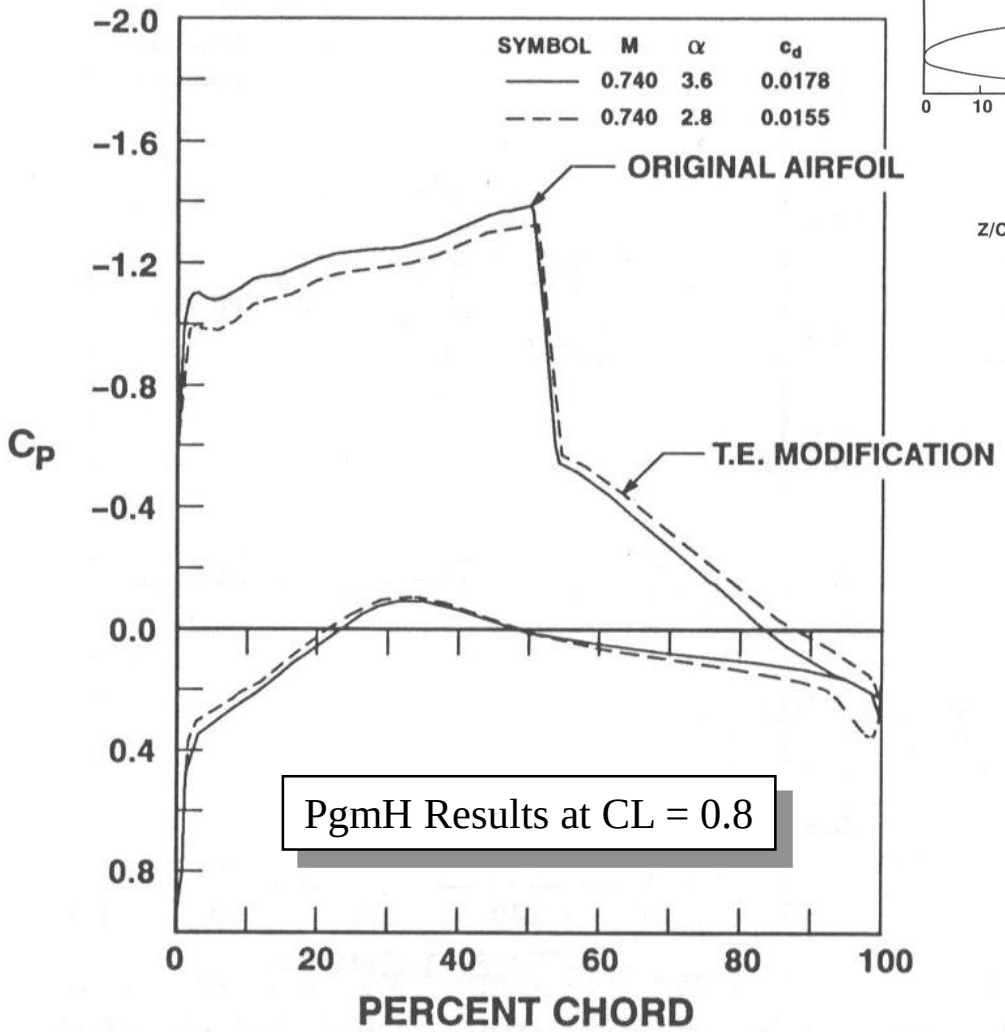
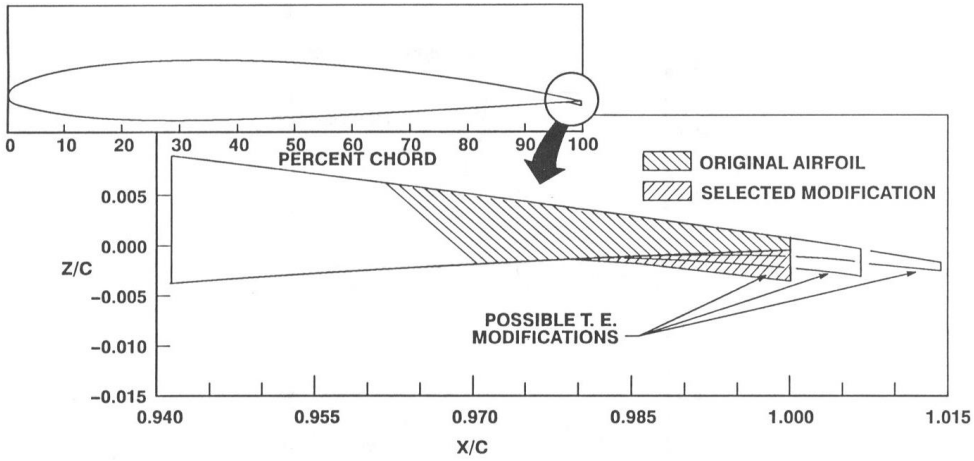
Trailing Edge Wedge Technology



PgmH Results at CL = 0.8



DSMA661 Airfoil TEW Mods

TEW Reduces Shock Strength
At Constant Lifting Condition

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MD-11 Pylon Fairing

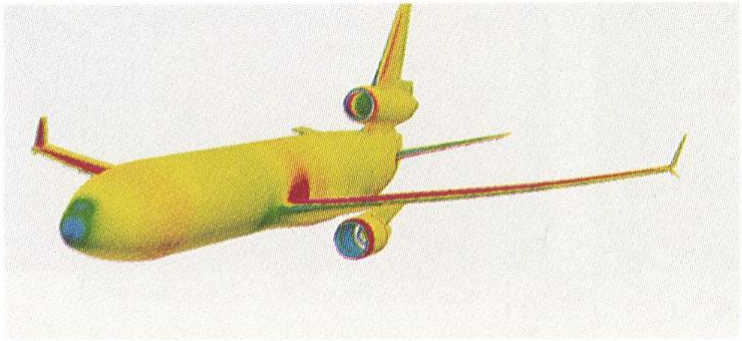

Plate 1 Euler solution for McDonnell Douglas MD-11 transport.

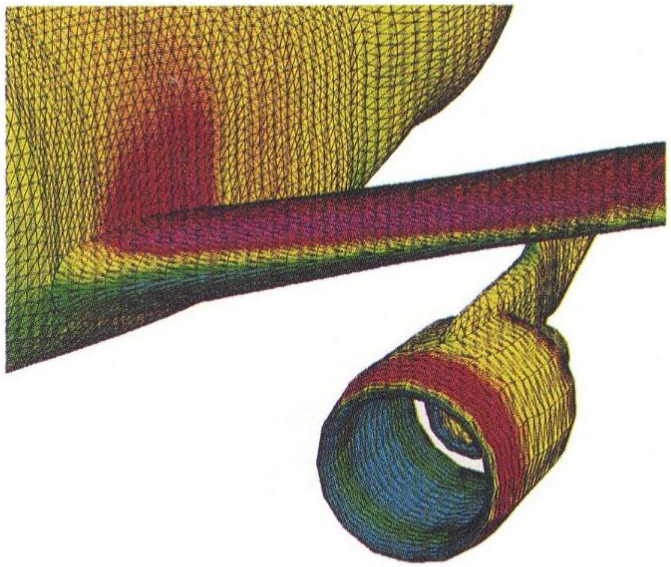

Plate 2 Detailed solution for McDonnell Douglas MD-11 transport fuselage/wing/pylon/nacelle.

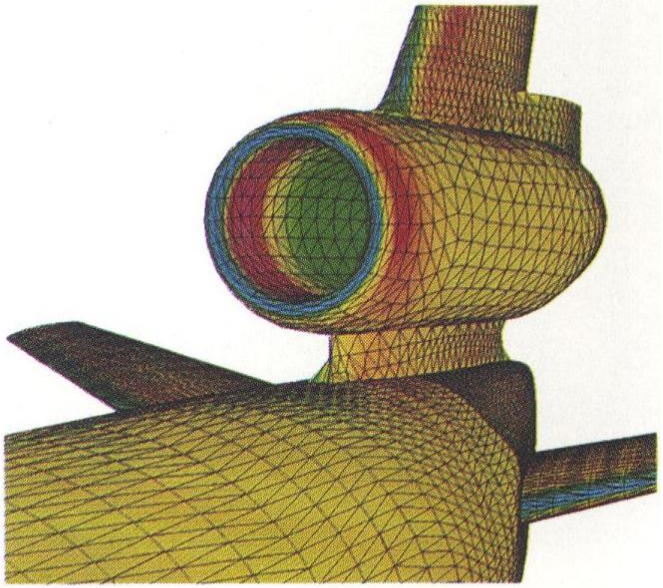

Plate 3 Detailed solution for McDonnell Douglas MD-11 transport empennage/aft nacelle.

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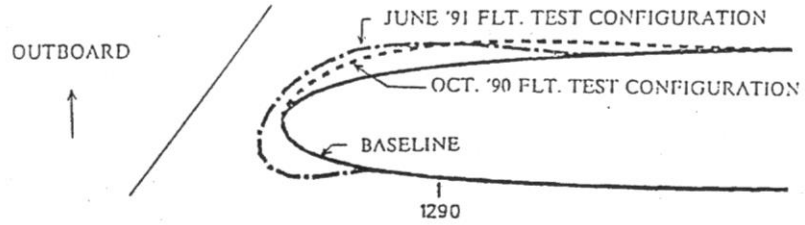
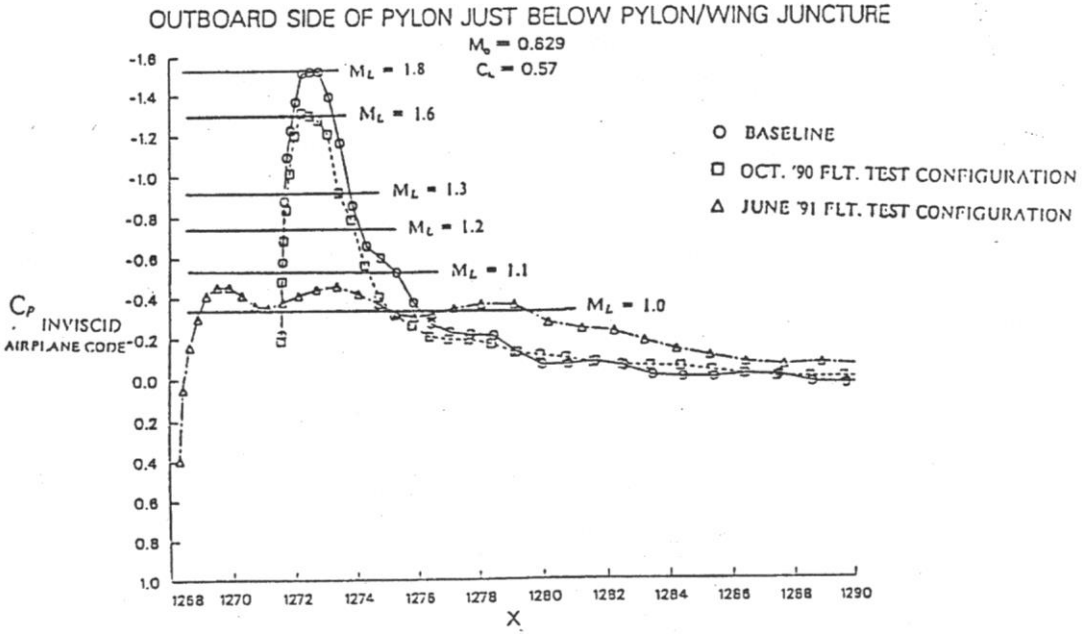
MD-11 PYLON FAIRING





MD-11 Pylon/Wing Intersection Pressure Distributions.

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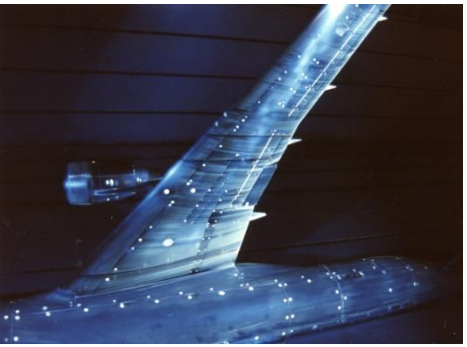
MD-12 High Speed Development

- **High Speed Development and Testing**
  - **First N-S (TLNS) based commercial wing design**
  - **Switched from tri-jet to quad-jet in a period of 1-month**
  - **Completed 1,838 out of 2,438 hrs of transonic testing at program termination**
  - **CFD did a reasonable job predicting cruise characteristics (lift & drag)**
  - **Met all of the requirements but felt it could be better**
    - **N/P Integration**
    - **Off-Design**
  - **CFD predictions of Loads and off-design conditions not as accurate as hoped**



PSP WT Testing

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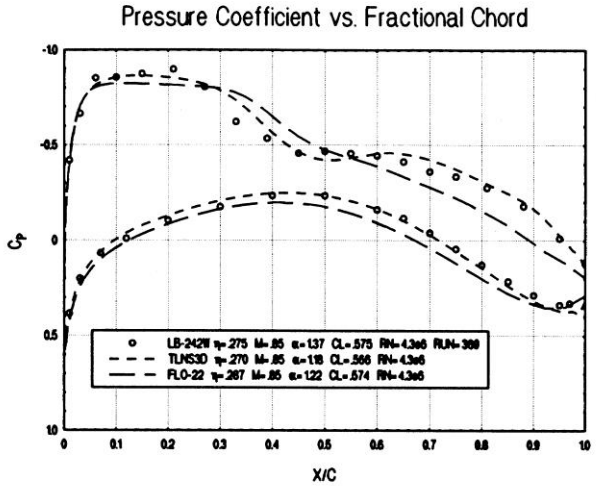
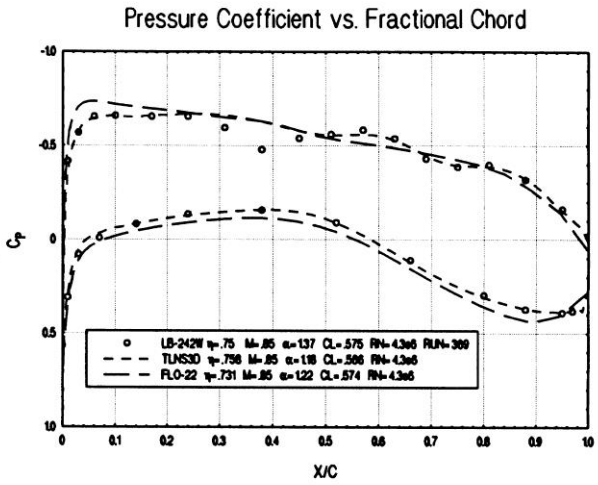
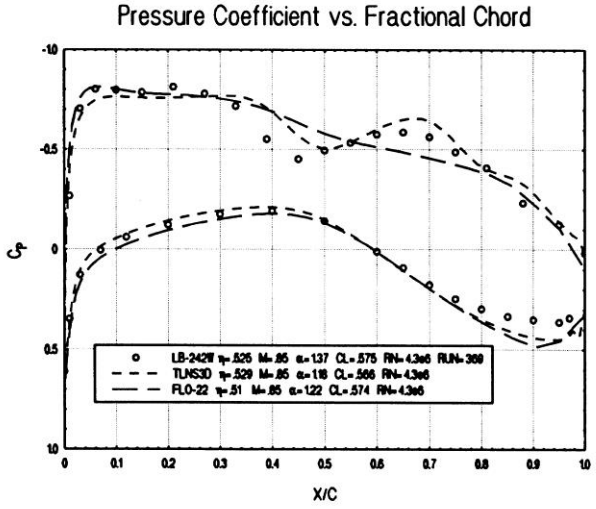
TLNS Comparison to Test Data







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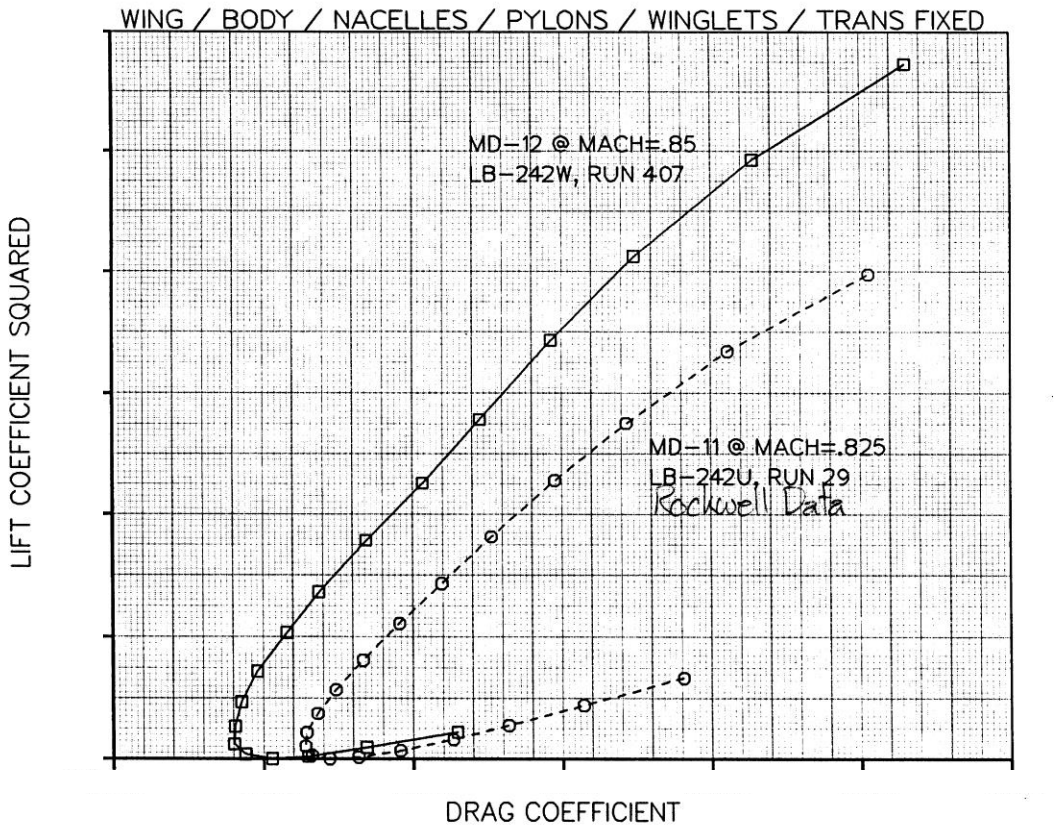
MD-11/MD-12 Test Data Comparison

MD−12 vs. MD−11
DRAG POLAR COMPARISON



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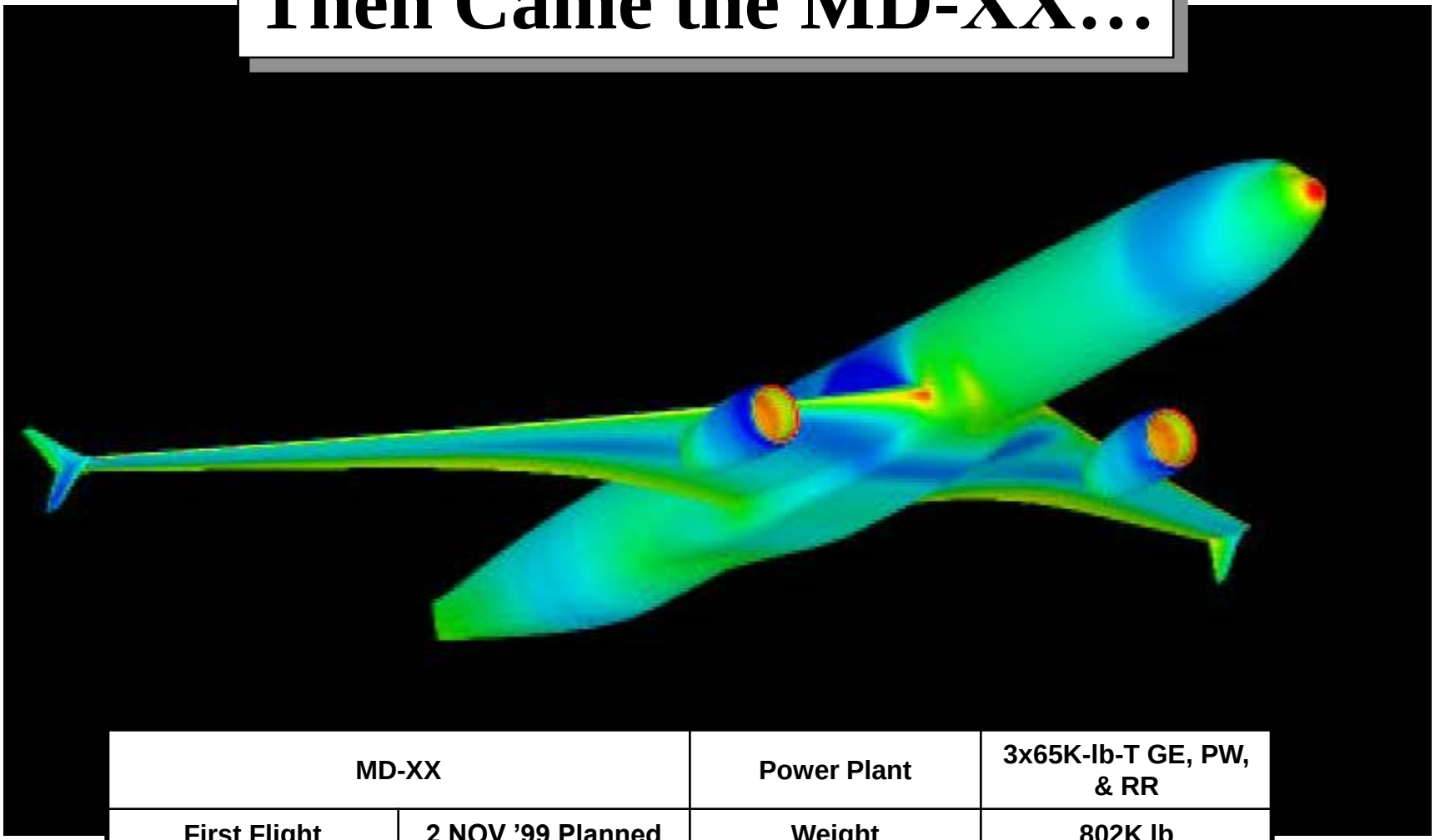
Then Came the MD-XX…



MD-XX		Power Plant	3x65K-lb-T GE, PW, & RR
First Flight	2 NOV ’99 Planned	Weight	802K lb
Wingspan	213’	Ceiling	43K ft
Length	233’ 9” (STR)	Speed	605 mph
Height	64’ 9”	PAX	375 (STR) - 301 (LR)

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Back to the TriJet

- In early 1996, a push to rapidly develop a TriJet based on the MD-12 studies was initiated
- The aerodynamic development was picked up where it was stopped but changed back to the TriJet configuration
- All high and low speed testing required had been completed during the MD-12 to release loft lines and DSO loads
- CFD would be used to “tweak” lines and loads to final configuration - release date: January 1997
  - OVERFLOW / CFL3D-CDISC / OVERDISC
  - SYN107 / SYN88 / FLO107MB

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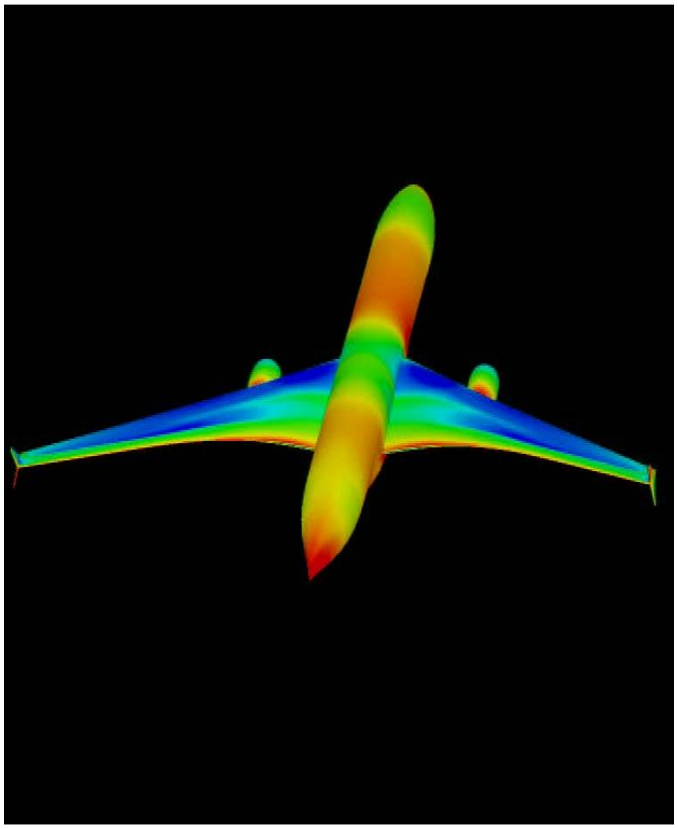
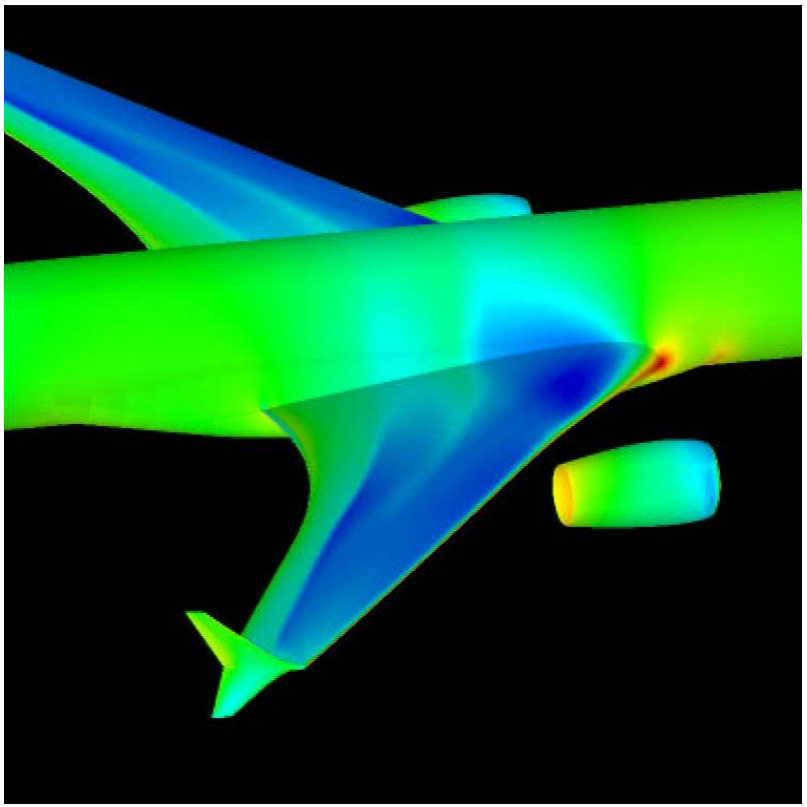
Nacelle/Pylon Integration

MD-XX

In 1996, the W/B could be designed using N-S in the presence of the N/P





FLO107MB Solutions

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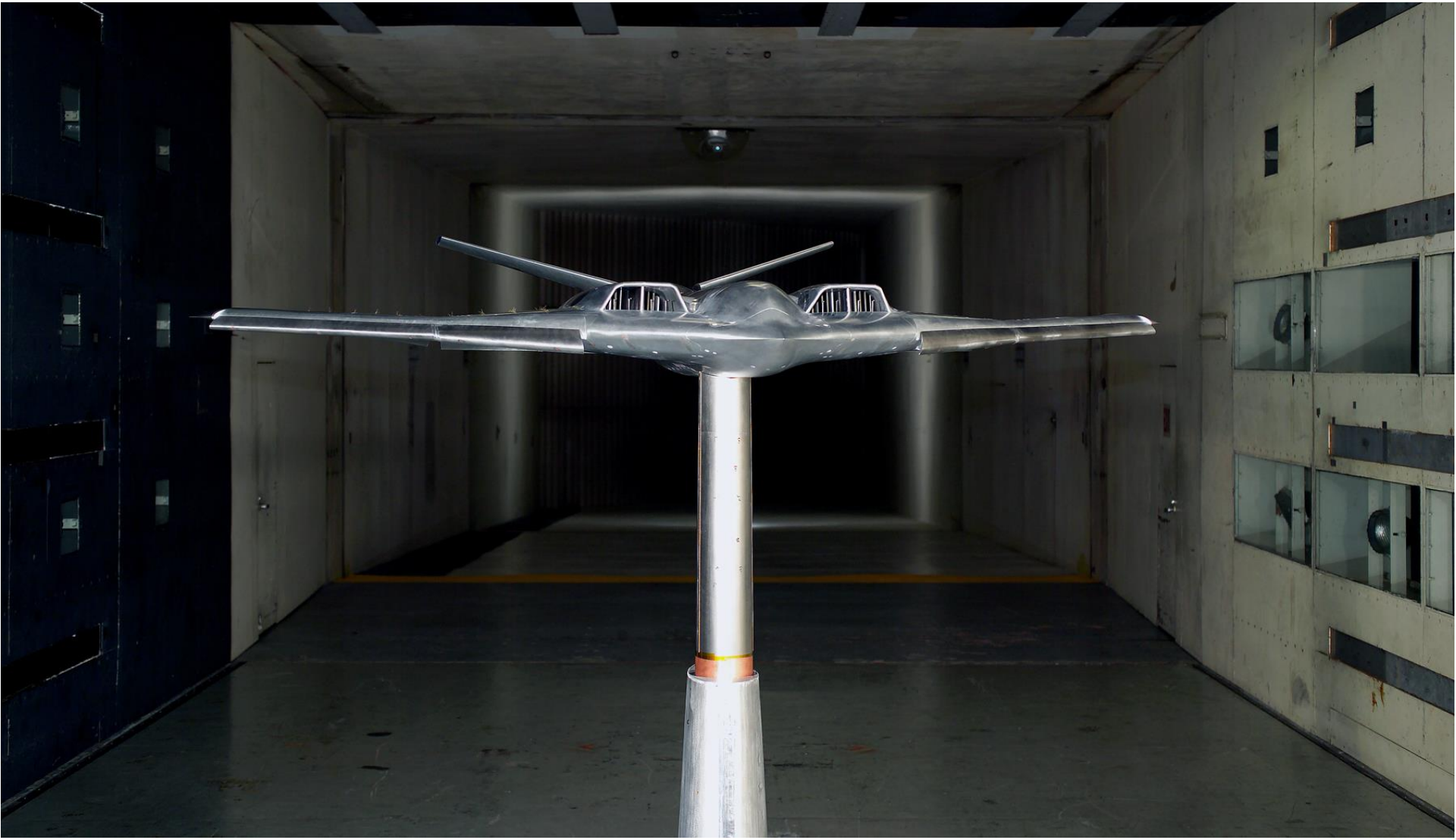
Speed Agile…



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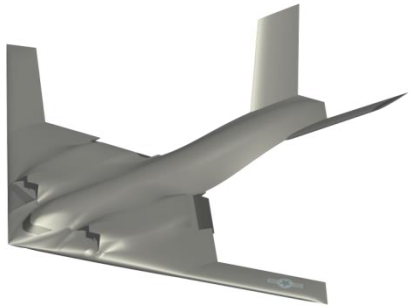
Configuration Evolution and Optimization

Initial Narrow-body Configuration

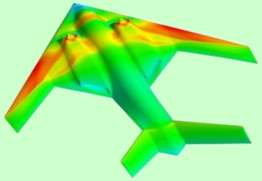


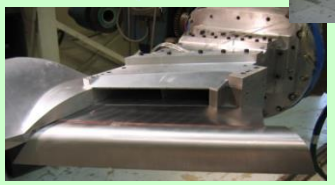
Design challenges:

- Aggressive high speed and low speed performance goals
- USB integration with swept trailing edge, short run
- AFC integration for high lift
- Highly integrated inlet & nozzle
- Shaped design and embedded engines for survivability
- Longitudinally unstable

Speed Agile Development program:

- WT test program
  - 170 hrs USB development
  - 1573 hrs low speed
  - 352 hrs high speed
- CFD optimization for transonic design
- Updated configuration to Speed Agile design and payload requirements





Refined Configuration:

- Optimized high lift system w/ AFC meets 1500-2000 ft takeoff & landing field lengths
- Transonic design meets Mach 0.8 LRC
- USB & nozzle design exceeds 55° thrust turning angle goal
- Acquired high fidelity aero database for flight simulator in cruise, takeoff, landing

Final Wide-body Configuration

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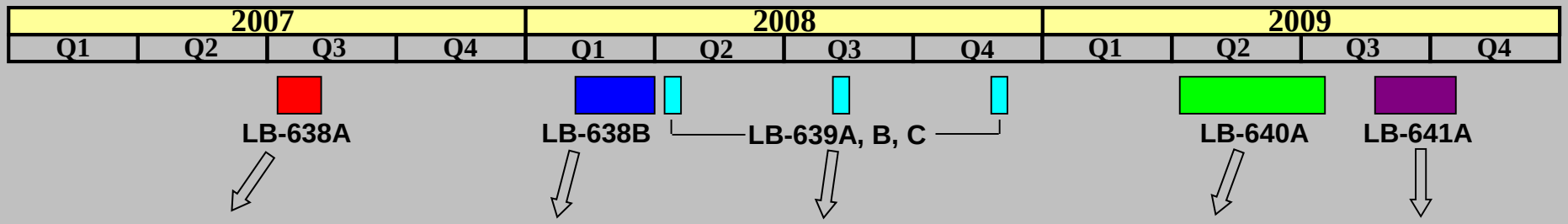
Wind Tunnel Test Program

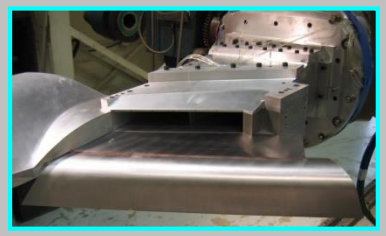


5% Scale AJACS Low Speed Testing
Boeing BVWT 20'x20'
Aug 2007

202 occupancy hrs
- ***Initial low speed performance database***
- ***AFC development***
- ***USB flow turning 30⁰***

5% Scale AJACS Low Speed Testing
NASA LaRC 14'x22'
Apr 2008

256 occupancy hrs
- ***Flow visualization***
- ***Low speed performance enhancements***
- ***Initial sideslip data***



USB Static Development Test
Boeing St. Louis PSTF
Apr, Aug, Nov 2008

170 occupancy hrs
- ***USB development:***
  - ***Nozzle***
  - ***Flap shape***
  - ***VG's***
- ***Achieved goal of 55° flow turning***

5% Scale Speed Agile Low Speed Testing
NASA LaRC 14'x22'
July 2009

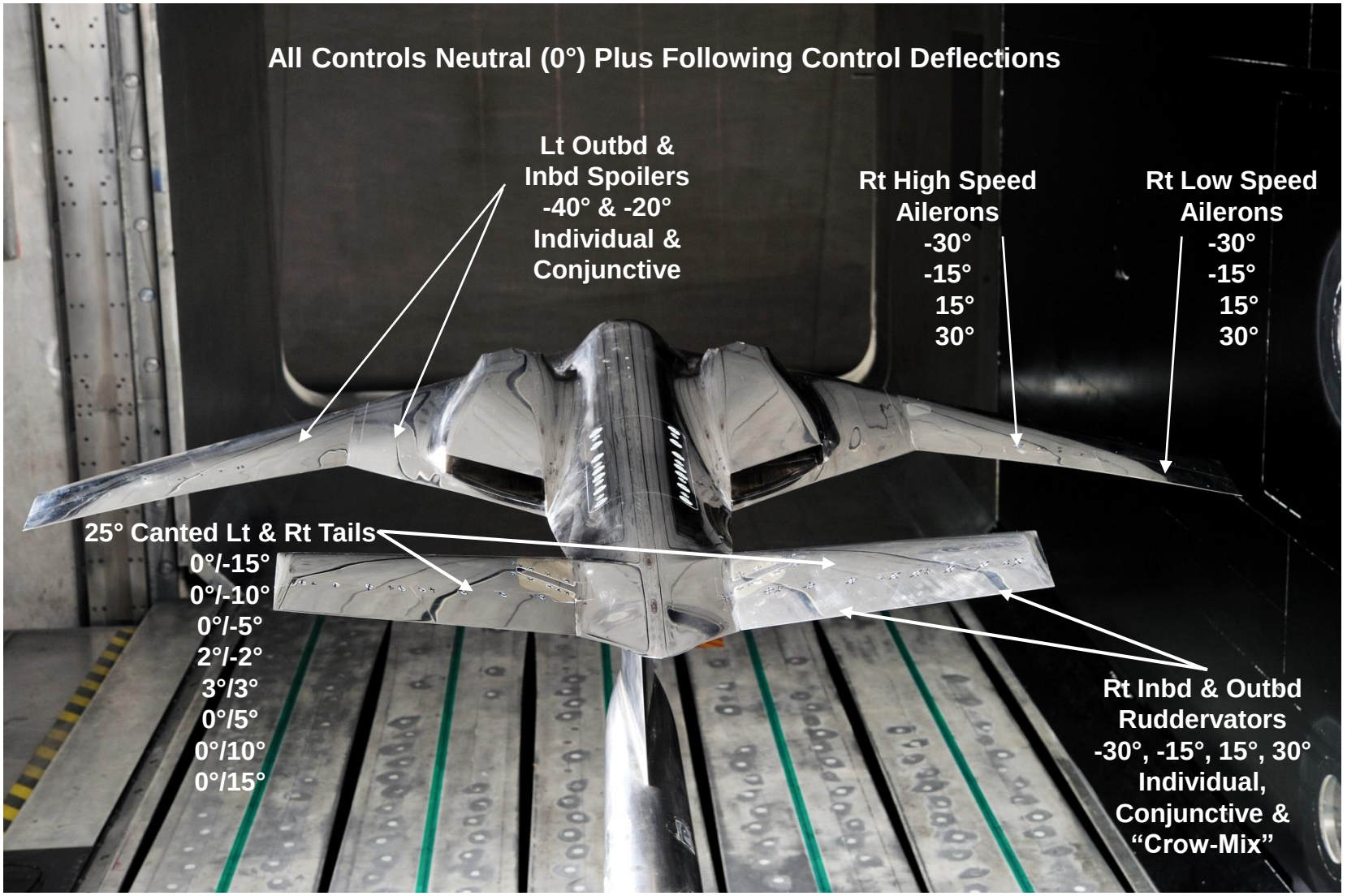
1115 occupancy hrs
- ***OML consistent with high speed model***
- ***TRL validation of high lift performance***
- ***Revised USB nozzle and flap***
- ***Continued AFC development***
- ***Gather database for low speed simulation***

3% Scale Speed Agile High Speed Testing
NASA LaRC NTF
Oct 2009

352 occupancy hrs
- **OML consistent with low speed model**
- **295 air, 34 cyro runs**
- ***TRL validation of high speed design***
- ***Determine Reynolds number effects***
- ***Gather database for high speed simulation***

2095 total hrs development testing

LB-641A Control Deflections



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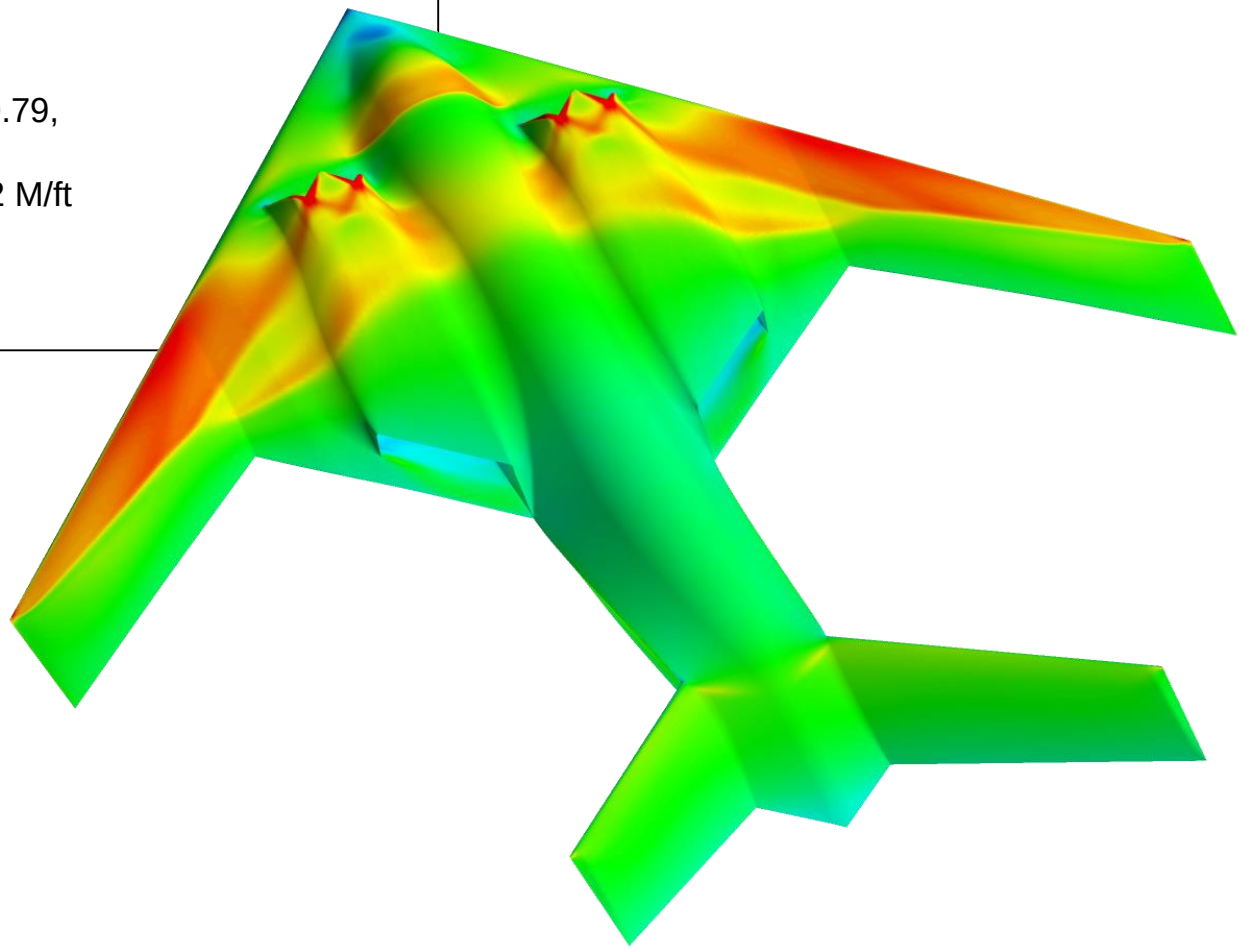
LB-641A CFD Comparison

OVERFLOW Simulation of AJACS in Free-Air

- OVERFLOW Version 2.0Y
- Flow Conditions Analyzed
  Mach = 0.7, 0.75, 0.78, 0.79, 0.80, 0.81, 0.82
  RN = 5.6 M/ft, 30 M/ft, 62 M/ft
- Configurations Analyzed
  iH = 0, 2, 3 degrees



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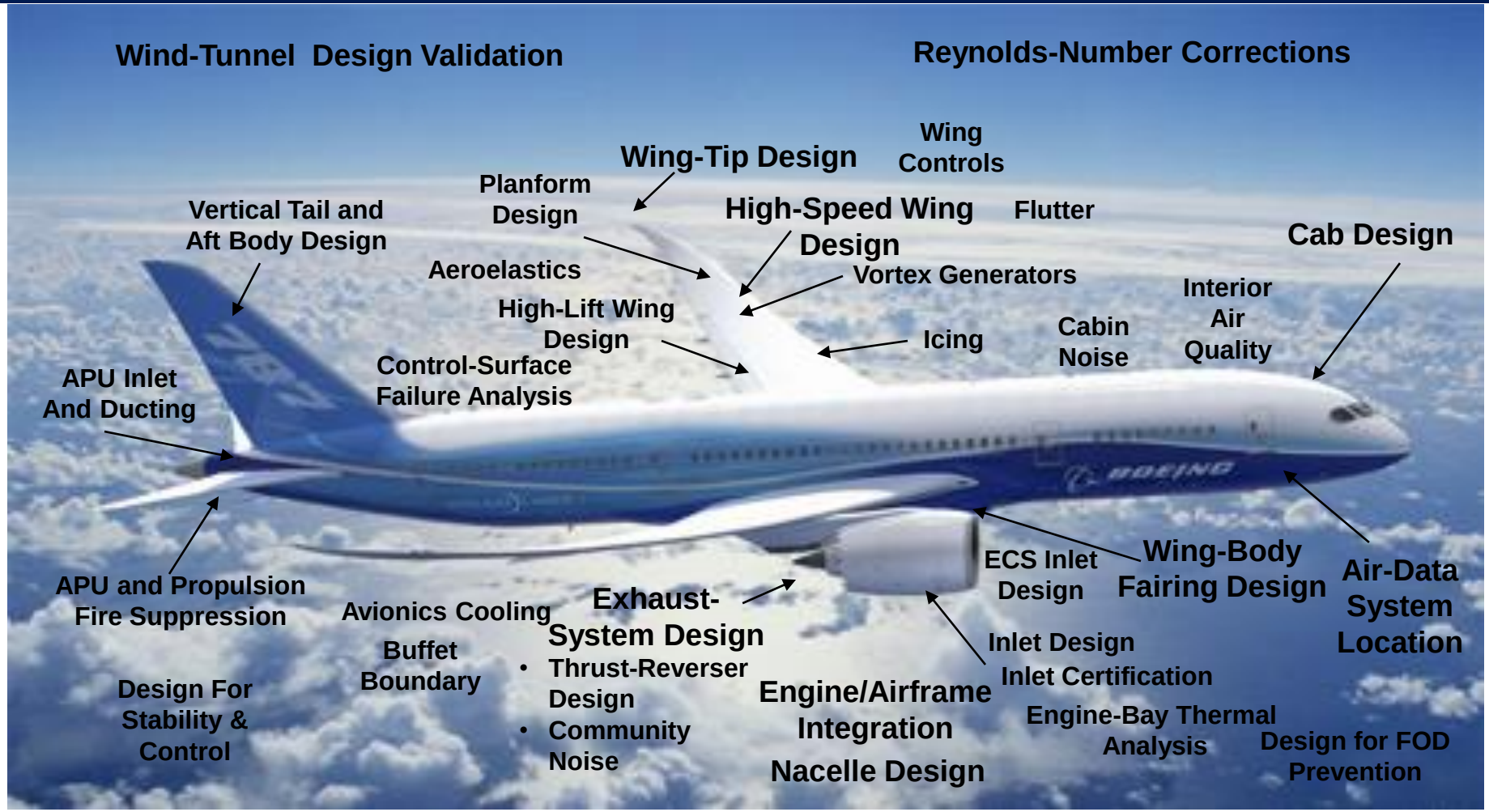
CFD Contributions to 787

BCA Technology | Enabling Technology and Research



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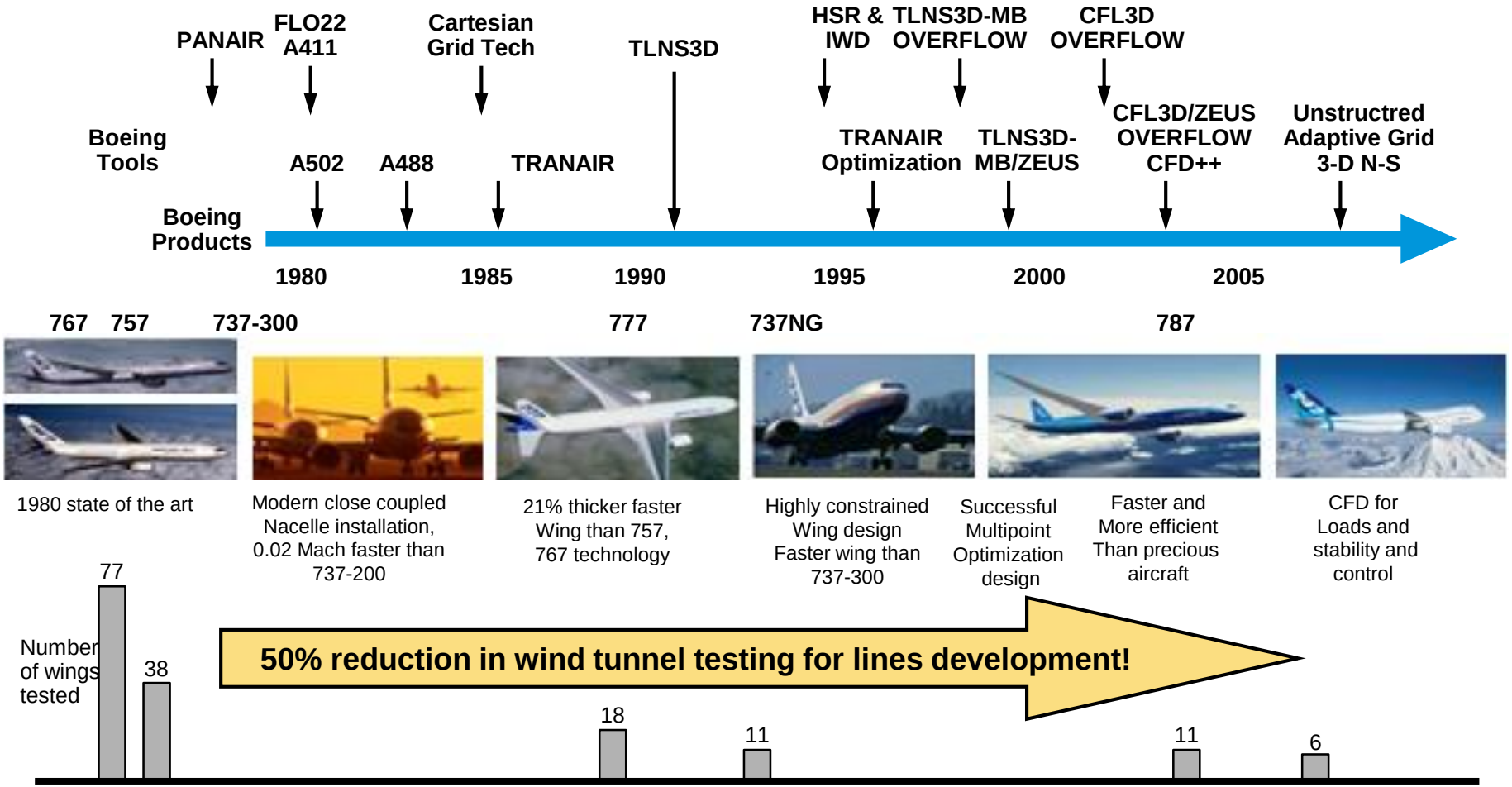
The Impact of CFD on Configuration Development Wind Tunnel Testing

BCA Technology | Enabling Technology and Research



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Happy B-day Antony!

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