Advanced Subsonic Transport Technology

High-Reynolds Number Airfoil/Wing Design

LaRC Program Description

Presented to Code RF

by

Lawrence E. Putnam
Head, Transonic Aerodynamics Branch

May 9, 1990
Advanced Subsonic Transport Technology
High Reynolds Number Airfoil/Wing Design

LaRC Program Description

- OBJECTIVES:
  - To develop and evaluate methodologies for designing advanced high-efficiency cruise wings for the next generation subsonic transport and to develop the methodology for integrating the wing into the complete airplane system
  - Specifically:
    - To develop technology for increasing cruise performance (L/D) by 20 to 100% and cruise Mach number to 0.90
    - To develop CFD methods capable of providing rapid, accurate assessment of performance (lift and drag) of advanced concepts
    - To develop multipoint, multidisciplinary design methodology for integrating wing, propulsion system, and high lift system
Advanced Subsonic Transport Technology
High Reynolds Number Airfoil/Wing Design

LaRC Program Description

- APPROACH:
  - Combine advanced CFD analysis codes, emerging automatic design procedures, and LaRC's unique combination of wind tunnels to develop and assess concepts for revolutionary improvements in transonic transport performance
  - Develop a multidisciplinary approach to airplane design to take advantage of new structures, materials, engine, and active control technology
  - Specifically:
    - Use Navier Stokes methods to design advanced high Reynolds number cruise airfoils
    - Develop 3-D baseline configuration with advanced airfoils and experimentally obtain design sensitivity data
    - Use multipoint design methodology to integrate advanced high lift systems, UHB engines, structures, and materials to develop advanced transport concept
    - Validate methodology by ground testing
    - Transfer technology to industry through cooperative programs and contacts
Advanced Subsonic Transport Technology

High Reynolds Number Airfoil/Wing Design

Key LaRC Wind Tunnel Facilities

- National Transonic Facility
- 0.3-Meter Transonic Cryogenic Tunnel
- 8-foot Transonic Pressure Tunnel
- 16-foot Transonic Tunnel
- 14x22 foot Subsonic Tunnel
- Low Turbulence Pressure Tunnel

- High Reynolds number concept validation
- High Reynolds number airfoil validation
- Wing development, configuration development, and cruise airfoil performance validation
- Airframe propulsion system installation effects
- High lift system development
- High lift airfoil development
Advanced Subsonic Transport Technology
High Reynolds Number Airfoil/Wing Design

Capability of 2-D Navier Stokes Methods

- Experiment, Cook
- Navier Stokes, Swanson

RAE 2822 airfoil
$M_\infty = 0.73$
$\alpha = 2.79^\circ$
$Re = 6.5 \times 10^6$
MULTIPOINT WING DESIGN

Point Design Airfoils

Cruise

Climb

Landing

Take off

"Best" global match

Tailored span load distribution by using leading-edge and trailing-edge flaps
Advanced Subsonic Transport Technology
High Reynolds Number Airfoil/Wing Design

Conceptional Multipoint Design Approach

- Develop point design optimum airfoils for cruise, climb, take-off, and landing
- Develop compromise airfoils with fixed center section, leading edge flaps (slats) and trailing edge flaps
- Vary leading edge and trailing edge flap deflection/chords to find “best” global match to point design optimums
- Integrate “best” flapped airfoils into 3-D wing design
- Use leading and trailing edge flaps to “simulate” optimum twist/camber distribution for 3-D wing at each design condition
- Assess performance and determine sensitivities
- Iterate design
Advanced Subsonic Transport Technology
High Reynolds Number Airfoil/Wing Design
Conceptional Multipoint Design Benefits

\[ \frac{M_{\infty}}{\sqrt{D}} \]

Conventional
Multipoint design

1.0

\[ M_{\infty} \]
Subsonic Transport Technology

Current R&T Base Program

- **FY 90**
  - Development of DISC (Direct Interactive Surface Curvature) design method
  - Applications of design method to improve cruise drag
  - Development of unstructured CFD methods
  - Fundamental studies of induced drag
  - Initiation of multipoint design method development

- **FY 91 (Funded)**
  - Assess Navier Stokes codes
  - Application and improvement of unstructured CFD methods
  - Continue multipoint design method development
  - Design, fab, and test transport configuration to provide data for defining design criteria
    - Leading edge sweep
    - Trailing edge thickness
    - Camber/twist distribution
    - Cruise flaps
  - Continued induced drag reduction studies
  - Install DISC design method in 2-D Navier Stokes code
DESIGN APPROACH

TARGET PRESSURES FROM WING/BODY ANALYSIS

DISC DESIGN METHOD

NEW AIRFOIL GEOMETRY FOR WING/BODY/NACELLE

INITIAL AIRFOIL GEOMETRY
Direct Iterative Surface Curvature (Disc)

Aerodynamic Design Method

- Method modifies geometry based on curvature-pressure relationships to obtain a specified pressure distribution
- Design module couples with any direct analysis code
- Current implementation applies to any aerodynamic surface with attach flow (i.e. wings, nacelles, fuselages, winglets, etc.)
- Recent extensions allow design at subsonic through supersonic speeds
- Boeing using method in axisymmetric nacelle design code modified by LaRC developer
- Boeing implementing method in 3-D Euler wing code
- Method being used to design supersonic laminar flow glove for F-16XL
Elimination of Nacelle Interference Using DISC Design Method

\[ M = 0.8 \]

\[ \eta = 0.33 \]

\[ \eta = 0.44 \]

\[ \begin{align*}
C_\eta & \quad 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \\
\end{align*} \]

\[ \begin{align*}
Z/c & \quad 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \\
\end{align*} \]

WB  WBN  DISC WBN
B-747 Surface Mesh

4450 boundary points
3790 triangles

19700 points
105370 tetrahedrons
Pressure Contours on a B-747

M=0.84, α = 0
INDUCED - DRAG RESEARCH

Planar sheared/crescent wing tips

Turbines

Winglets on transport wing

Wing tip blowing

Tip jet exhaust path

Tip flow entrained into jet

Wing tip vortex
Advanced Subsonic Transport Technology
High-Reynolds Number Airfoil/Wing Design

INDUSTRY

ESTABLISH
DESIGN
CRITERIA

EXPERIMENTAL
STUDIES

DEVELOP
ADVANCED
AIRFOILS

MULTIPOINT
WING
DESIGN

WING
DESIGN
VERIFICATION

MULTIDISCIPLINE
MULTIPOINT
TRANSPORT
CONFIGURATION

EXPERIMENTAL
DESIGN
VALIDATION

DESIGN METHODOLOGY

ADVANCED CONCEPTS
Advanced Subsonic Transport Technology
High-Reynolds Number Airfoil/Wing Design
Multidisiciplinary Design

range, block fuel

flex polars

PERFORMANCE
gross weight

wing struct. wt.

fuel wt., gross wt.

AERODYNAMICS
shape, thickness
deflections
loadings

WING STRUCTURE
skin thickness
spar/rib caps

strains, stresses
## Advanced Subsonic Transport Technology

### High-Reynolds Number Airfoil/Wing Design

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Criteria Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design High-Reynolds Number Airfoils</td>
<td>△</td>
<td>△</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Multi-Point Design Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Improved 2-D &amp; 3-D Drag Prediction Methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Optimization Methodology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop High-Reynolds Number CFD Methods</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Design Capability for Non-Planar Interacting Surfaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Multidisciplinary Expert Design System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Experiments for Method Calibration/Validation</td>
<td></td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Design High-Aspect-Ratio/High-Reynolds Number Wing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-Aspect-Ratio, High-Reynolds Number Wing Validation</td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td></td>
</tr>
<tr>
<td>Design Integrated UHBE, High-AR, High-Lift Configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Design Validation</td>
<td></td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Develop/Evaluate Advanced Concepts</td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td><strong>FUNDING, $M</strong></td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Advanced Subsonic Transport Technology
High-Reynolds Number Airfoil/Wing Design

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Criteria Development</td>
<td>350</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design High-Reynolds Number Airfoils</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Multi-Point Design Method</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Improved 2-D &amp; 3-D Drag Prediction Methods</td>
<td>75</td>
<td>300</td>
<td>300</td>
<td>165</td>
<td></td>
</tr>
<tr>
<td>Develop Optimization Methodology</td>
<td>200</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Develop High-Reynolds Number CFD Methods</td>
<td>300</td>
<td>355</td>
<td>395</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Develop Design Capability for Non-Planar Interacting Surfaces</td>
<td>25</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Multidisciplinary Expert Design System</td>
<td>350</td>
<td>660</td>
<td>660</td>
<td>775</td>
<td></td>
</tr>
<tr>
<td>Baseline Experiments for Method Calibration/Validation</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design High-Aspect-Ratio/High-Reynolds Number Wing</td>
<td>75</td>
<td>75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High-Aspect-Ratio, High-Reynolds Number Wing Validation</td>
<td>150</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Integrated UHBE, High-AR, High-Lift Configuration</td>
<td>75</td>
<td>150</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integrated Design Validation</td>
<td>500</td>
<td>850</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop/Evaluate Advanced Concepts</td>
<td>75</td>
<td>170</td>
<td>220</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>250</td>
<td>250</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>ADP</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>NET</td>
<td>1500</td>
<td>2250</td>
<td>3000</td>
<td>3000</td>
<td>3000</td>
</tr>
<tr>
<td>Program Support</td>
<td>500</td>
<td>750</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>2000</td>
<td>3000</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
</tr>
</tbody>
</table>
### Advanced Transport Technology Program
**High Reynolds Number Airfoil/Wing Design**

#### LaRC Program Description

<table>
<thead>
<tr>
<th>Contracts/Grants</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Criteria - Boeing</td>
<td>175</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Douglas</td>
<td>175</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-D/3-D Drag Prediction - Grant</td>
<td>-</td>
<td>75</td>
<td>75</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>- Contract</td>
<td>-</td>
<td>150</td>
<td>150</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hi Rn CFD Methods</td>
<td></td>
<td>75</td>
<td>75</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>- Contract</td>
<td>150</td>
<td>200</td>
<td>215</td>
<td>215</td>
<td>210</td>
</tr>
<tr>
<td>Optimization Methodology - Boeing</td>
<td>-</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>- Douglas</td>
<td>-</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>Multidisciplinary Design - Boeing</td>
<td>-</td>
<td>100</td>
<td>250</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>- Douglas</td>
<td>-</td>
<td>100</td>
<td>250</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Advanced Concept Develop. - Grant</td>
<td>75</td>
<td>120</td>
<td>120</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### In-House

<table>
<thead>
<tr>
<th>Models</th>
<th>300</th>
<th>350</th>
<th>400</th>
<th>650</th>
<th>950</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-D Airfoils</td>
<td>(100)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline Transport</td>
<td>(200)</td>
<td>(150)</td>
<td>(100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Wing</td>
<td>(150)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Integrated Config.</td>
<td>(500)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Concepts</td>
<td>(50)</td>
<td>(100)</td>
<td>(150)</td>
<td>(100)</td>
<td></td>
</tr>
<tr>
<td>Instrumentation</td>
<td>250</td>
<td>250</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>ADP</td>
<td>100</td>
<td>200</td>
<td>200</td>
<td>200</td>
<td>25</td>
</tr>
</tbody>
</table>

#### Support Service Contracts

<table>
<thead>
<tr>
<th>Support Service Contracts</th>
<th>200</th>
<th>430</th>
<th>540</th>
<th>545</th>
<th>415</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multipoint design</td>
<td>(50)</td>
<td>(50)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-planar design</td>
<td></td>
<td></td>
<td>(25)</td>
<td></td>
<td>(75)</td>
</tr>
<tr>
<td>2-D/3-D Drag Prediction</td>
<td>(75)</td>
<td>(75)</td>
<td>(75)</td>
<td>(75)</td>
<td></td>
</tr>
<tr>
<td>Hi Rn CFD Methods</td>
<td>(75)</td>
<td>(80)</td>
<td>(80)</td>
<td>(85)</td>
<td>(90)</td>
</tr>
<tr>
<td>Multidisciplinary Methodology</td>
<td>(150)</td>
<td>(160)</td>
<td>(160)</td>
<td></td>
<td>(175)</td>
</tr>
<tr>
<td>Wing/Integrated Config. Design</td>
<td>(75)</td>
<td>(150)</td>
<td>(150)</td>
<td>(150)</td>
<td></td>
</tr>
</tbody>
</table>

#### Program Support

<table>
<thead>
<tr>
<th>Program Support</th>
<th>500</th>
<th>750</th>
<th>1000</th>
<th>1000</th>
<th>1000</th>
</tr>
</thead>
</table>

#### TOTAL

| TOTAL                     | 2000| 3000| 4000| 4000| 4000|