HSR Supersonic Laminar Flow Control

High-Speed Research Project

4.3 Aerodynamic Performance

4.3.4 Supersonic Laminar Flow Control
An Overview

NASA Langley Research Center
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MDA
LaRC
LaRC
ARC
BCAG
SLFC Mission Statement

Develop and validate technologies for Supersonic Laminar Flow Control (SLFC) and perform the SLFC aerodynamic design for the HSCT with an assessment of the net benefit and risks.

SLFC Benefits
HLFC Application to HSCT

Aerodynamic Benefit: 8 to 10% increase in Cruise L/D

Implementation Penalties: Systems and Structural Weight Increment, Fuel Displacement, TSFC, Suction Air Momentum Drag

Performance Benefits: $\Delta$MTOW=-6 to -8%, $\Delta$Block Fuel=-10 to -12%
$\Delta$Engine Airflow=-8 to -12%

Thermal Benefits: Reduced Skin Temperatures
- Reduced Fuel Heating rate
- Increased Materials Options

Benefits would be larger for a heavier/longer-range configuration and for HLFC scheme with wall cooling

**HSR Supersonic Laminar Flow Control**

**Benefits of SLFC**

- 8% increase in cruise L/D (9.3=>10)
- 11% reduction in fuel burn (390,000lbs=>347,100lbs)
- 7% reduction in MTOW (740,000lbs=>688,200lbs)
- 50-100 degree(F) reduction in local skin temperatures
Laminar and Turbulent Surface Temperatures

(M = 2.4)

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<tr>
<th>Material</th>
<th>Polyimide</th>
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<th>Epoxy</th>
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L-Laminar (M=2.4)
T-Turbulent (M=2.4)
HSR Supersonic Laminar Flow Control

SLFC Major Issues

• BL Suction - Where? How much?
• Impact on Inviscid Drag

• Weight of Suction System
• Compatible High Lift System
• Leading Edge Protection - Insects, Ice
• Complexity & Cost of Systems and Structure
• Durability & Maintainability

HSR Supersonic Laminar Flow Control

CY

| 37 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 |

SYSTEM STUDIES

FLIGHT TEST FEASIBILITY STUDIES

PDR CDR

F-16XL SLFC FLIGHT EXPT 4/96

FY 94

PCD-1

PCD-2

SLFC BASELINE DECISION 3/97

Potential Benefits from SLFC Very High
- Improved L/D 8-11%
- Reduced T/O weight 5-8%
- Smaller engine 5-12%
- Less fuel needed 10-14%
- Improved economics ~4%
- Lower emissions
- Lower skin temp.

$\Delta T - 100^\circ F$

Use Modified F-16XL2 for SLFC Flight Exps

- 3D Euler Inverse Design
- 3D BL Stability Analysis
- Careful Selection of Instrumentation
- Critical SLFC database
- SLFC wing design feasible
- HLFC appears promising
- Optimization decreases suction requirements
- Work on implementation issues suspended
- Calibrate existing analysis/design codes
- Improve prediction/design methods
- 3D wing design & suction/cooling requirements
- Update integration study
- Develop plans for improving Tech Readiness Level

F-16XL FLIGHT TEST COMPLETE

4/96
## 4.3 AERODYNAMIC PERFORMANCE

### 4.3.4 Supersonic Laminar Flow Control

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<td>Quiet Tunnel Data &amp; Analysis</td>
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<td>Improved Wing Design</td>
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**HSR Supersonic Laminar Flow Control**

### 4.3.4.1 F-16XL-2 Flight Test

( Hardware Demonstration )
OBJECTIVES:

- Demonstrate achievement of laminar flow to 50-60% chord on a highly swept wing at supersonic speeds

- Obtain flight data for CFD code validation and development of design methodology

- Establish initial SLFC design criteria to provide a more realistic assessment of SLFC benefits for the HSCT
F-16XL Supersonic Laminar Flow Control Experiment
F-16XL2 SLFC WING INSTRUMENTATION

Notes:
1) Circled instrumentation did not pass SCAG QA.
2) Only the two inboard suction panel leading edge pressure taps shown (113 total in I.E.)

NASA
VER 11-21-95
AERODYNAMIC AND SUCTION REQUIREMENTS

Attachment Line Suction
\[ R_e = 140 \ (C_q \text{ max}) \]
\[ R_e = 200 \ (C_q \text{ min}) \]

Suction Downstream of Attachment Line
- \( C_q \text{ max} \): \( N \leq 6 \) (Envelope)
- \( C_q \text{ min} \):
  - \( N \leq 4, \quad f = 0 \)
  - \( N \geq 10 \) (\( \lambda = \text{Constant}, \quad f = 0 \))
  - \( N \geq 12 \) (\( \psi = \text{Constant}, \quad f = 0 \))

Detected by Attachment Line Stability

Suction Ramp Determined by Crossflow Stability Requirement

Constant Suction Over Rooftop

F-16XL-2 SLFC Flight Experiment
Comparison of Measured and Predicted Surface Pressures

Flight Data
- \( M = 1.92 \)
- \( \alpha = 3.92 \)

TNLS3D Euler
- \( M = 1.90 \)
- \( \alpha = 3.10 \)
4.3.4.2 SLFC Tool Development

a. Tool calibration
b. Quiet tunnel database

Tool Calibration from F-16XL database

Flight Data: Cp, Tw, Suction flute meas.

**Douglas Approach**

FT2SA

- Produces smooth CP, Ct data on a fine surface grid

INTWNG-SE (surface Euler)

- Edge velocities for BL3D by solving the surf. Euler equations based on the input CP and attachment line location

**Boeing Approach**

BOEING POST-PROCESSOR

- Similar to FT2SA but no smooth interpolation to fine grid

CDISC+EULER

- Inverse design of surface to match the input CP at measured locations with Euler solution at these locations

INTWNG-INT or BL3D interface

- Produces edge velocities for BL3D by interpolation of Euler velocities and location of attachment line using Euler velocities

BL3D

EVALK3D

Correlation with measurement of transition location
Predicted N-factors on the F16XL Suction Glove at Design Point
(assuming a representative suction distribution \(C_s\) achieved by the suction patches)
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Sketch of Attachment-Line Region

N-factor Correlation

Parallel Method

2D-Eigenvalue Approach
Constant N-valued Curves for Transition Correlation

\[ R_e = 0.3582 \bar{R} \]

Embryonic "Next generation" tools

Receptivity Module | Linear PSE (or OS) Module | Nonlinear PSE Module
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Significance of Quiet Tunnels

![Diagram showing the transition and radiated noise in a tunnel.](image)

#### Table 1: Noise Levels

<table>
<thead>
<tr>
<th>Distance (m)</th>
<th>Noise Level (dB)</th>
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<tbody>
<tr>
<td>0</td>
<td>50</td>
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<tr>
<td>1</td>
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<td>2</td>
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<td>10</td>
</tr>
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<td>9</td>
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</table>

(c) Bleed valve closed, T = 0.

(a) Bleed valve open, T = 0.
Fig. 1 Transition location correlates well with $N=13$ over a wide range of unit Reynolds numbers.

Fig. 2 Transition location also correlates well with $N=13$ over a wide range of angles of attack.

Fig. 3 Transition location on 1 in. diam. 76 deg. swept-cylinder model vs. $Re_D$ using TSP.
Swept Wing Model Test in FML
Laminar Flow Supersonic Wind Tunnel

RESEARCH OBJECTIVE: Obtain pressure and transition data on a full-size segment of the F-16XL passive glove for comparison with flight data and CFD validation

APPROACH: The M1.6 Quiet Tunnel was designed to operate in the same Reynolds number range as the F-16XL laminar flow test vehicle. A pressure model was tested in FY95. The next entry will employ thermally sensitive paint to determine transition location. Transition is expected to occur due to attachment line contamination and by crossflow instability mechanisms.

APPLICATION: These tests are in support of laminar flow control for the next generation supersonic transport.

STATUS/PLANS: Pressures were measured during the first entry. A comparison with flight data is shown here (angles of attack were adjusted for best match). The next entry, expected in Feb-Mar. 1996, will investigate transition in the leading edge region.
4.3.4.3 SLFC Aerodynamic Design

- Design wing contour
- Suction & cooling requirements
- Step/gap/waviness requirements
- Compute skin friction reductions
- Calculate BLC suction requirements

Summary

SLFC Impact on HSCT:
Aerodynamic & Economic Benefits
- Drag reduction, Increased L/D,
- Reduced MTOW, Lower skin temps, etc.

PCD 2:
4.3.4.1 F-16XL-2 SLFC Flight Experiment
4.3.4.2 SLFC Design Tool Methodology
4.3.4.3 SLFC Aerodynamic Design