LFC/HLFC PEER REVIEW
MARCH 23, 1989

BASIC RESULTS
SLOTTED AND PERFORATED LFC MODELS

CHARLES D. HARRIS
AIRFOIL DESIGN PARAMETERS

Free-stream design conditions

\[ M_{\infty} = 0.82 \]
\[ \Lambda = 23^\circ \]
\[ c = 7.07 \text{ ft} \]
\[ R_c = 20 \times 10^6 \]
\[ c_t = 0.47 \]

Design conditions normal to leading edge

\[ M_N = 0.755 \]
\[ c_N = 6.508 \text{ ft} \]
\[ R_{c,N} = 16.9 \times 10^6 \]
\[ (t/c)_N = 13.0 \text{ percent} \]
\[ c_{t,N} = 0.55 \]
PANEL ARRANGEMENT

UPPER PANELS

Forward 0 - 26.6 %c
Center 26.6 - 58.7 %c
Aft 58.7 - 89.1 %c

Wingbox

LOWER PANELS

Forward 0 - 24.4 %c
Center 24.4 - 55.6 %c
Aft 55.6 - 89.1 %c

Flap
MEASURED AND PREDICTED PRESSURE DISTRIBUTIONS FOR SLOTTED LFC MODEL

<table>
<thead>
<tr>
<th>$R_c \times 10^6$</th>
<th>$\alpha$, deg</th>
<th>$M_\infty$</th>
<th>$C_{L,\infty}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.51</td>
<td>0.8216</td>
<td>0.53</td>
</tr>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8200</td>
<td>0.47</td>
</tr>
</tbody>
</table>

$C_p$, sonic

$M_{wall, above} = 0.995$

$M_{wall, below} = 0.887$
SPANWISE PRESSURE DISTRIBUTIONS, $M_\infty = 0.82$

$R_C = 10 \times 10^6$

Ceiling

$C_P$

$2Z/B = 0$

$X/C$

$0, 0.2, 0.4, 0.6, 0.8, 1.0$
TRANSITION PATTERN ON UPPER SURFACE - SLOTTED MODEL

\[ R_c = 10 \times 10^6 \]

- Thin film
- Edge of turbulent wedge
- Transition zone
- Fully laminar
- Fully turbulent
- Edge of turbulent wedge
- Airflow
COMPARISON OF MEASURED AND PREDICTED SUCTION DISTRIBUTIONS

$M_\infty = 0.82, R_C = 10 \times 10^6$

Graph showing $C_Q$ vs $x/c$ with data points and a line representing theory.
TRANSITION PATTERN ON UPPER SURFACE - SLOTTED MODEL

\[ R_c = 20 \times 10^6 \]
MEASURED AND PREDICTED PRESSURE DISTRIBUTIONS FOR SLOTTED LFC MODEL

<table>
<thead>
<tr>
<th>$R_c \times 10^6$</th>
<th>$\alpha, \text{deg}$</th>
<th>$M_\infty$</th>
<th>$C_{L\infty}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8226</td>
<td>0.49</td>
</tr>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8200</td>
<td>0.47</td>
</tr>
</tbody>
</table>

$C_p$, sonic

$X/C$
SPANWISE PRESSURE DISTRIBUTIONS, $M_\infty = 0.82$

$R_C = 20 \times 10^6$

Ceiling

$C_P$

$22/B = 0$

X/C
EFFECT OF REYNOLDS NUMBER ON EXPERIMENTAL PRESSURE DISTRIBUTION, SLOTTED MODEL

\[ \begin{array}{cc}
R_e \times 10^6 & M_{\infty} \\
10 & 0.8216 \\
20 & 0.8226 \\
\end{array} \]

Design
WHY DIDN’T THEY?

- DECREASE MACH NUMBER?
- DECREASE ANGLE OF ATTACK?
- CHANGE FLAP SETTINGS?
- CHANGE SUCTION DISTRIBUTION?
- CHANGE AIRFOIL CONTOURS?
- CHANGE LINER CONTOURS?
SKETCH OF FLOW REGION
BETWEEN MODEL UPPER SURFACE AND LINER

LINER WALL
SUPersonic CHANNEL
THROAT
SENSITIVITY OF FLOW TO SMALL VARIATIONS
IN MACH NUMBER NEAR THE DESIGN MACH NUMBER

(a) $M = 0.8225$

(b) $M = 0.8221$
(c) $M = 0.8220$

(d) $M = 0.8217$
PRESSURE DISTRIBUTIONS AT OFF DESIGN MACH NUMBERS

(a) $M = 0.80$  
(b) $M = 0.78$
(c) $M = 0.76$

(d) $M = 0.74$
(e) $M = 0.72$

(f) $M = 0.70$
TRANSITION LOCATION
UPPER SURFACE OF SLOTTED MODEL

Transition location, percent chord

Reynolds number

Most forward turbulent film

Transition zone

Most rearward laminar film
TRANSITION LOCATION
LOWER SURFACE OF SLOTTED MODEL

Transition location, percent chord

Most forward turbulent film

Transition zone

Most rearward laminar film

Reynolds number
MEASURED VARIATION OF DRAG WITH $R_c$/SWEPT LFC AIRFOIL

Slotted suction surface, $M_\infty = 0.82$
VARIATION OF TRANSITION FOR SIMULATED HLFC SWEPT LFC AIRFOIL SLOTTED UPPER SURFACE

Lower surface suction, $0 \leq x/c \leq 0.25$

Transition location, % chord

Upper surface suction, % chord

Data

\begin{tabular}{c|c}
\hline
$R_c \times 10^{-6}$ & 20 & 10 \\
\hline
\end{tabular}
PERFORATED LAMINAR FLOW CONTROL MODEL

STA 0

STA 18.035

STA 19.035

Note: Section is normal to the leading-edge
FORWARD LOWER SURFACE

\[ Z/C \]

- Slotted Panel
- Porous Panel

\[ X/C \]
COMPARISON OF DESIGN PRESSURE DISTRIBUTION

--- Slotted Model
--- Porous Model

\[ C_p \]

\[ X/C \]
TRANSITION PATTERN ON UPPER SURFACE - PERFORATED MODEL

\[ R_C = 9.2 \times 10^6 \]
COMPARISON OF THEORETICAL AND EXPERIMENTAL SUCTION DISTRIBUTION, 10 MILLION REYNOLDS NUMBER

Suction Coefficient $\times 10^{-4}$

- Slotted (Exp)
- Theory (slotted)
- Theory (porous)
- Porous (Exp)

$x/c$
MODIFICATIONS TO PERFORATED PANELS
TO INCREASE SUCTION CAPACITY

- Enlarged all metering holes in first two panels
- Added second suction nozzle to each laminar duct in first panel
- Enlarged laminar nozzle extensions in first two panels
- Installed metering holes in first two suction flutes
- Replaced forward nonsuction panel with original slotted panel
- Installed two new vacuum pumps
EFFECTS OF MODIFICATION OF SUCTION SYSTEM ON PERFORATED MODEL, 10 MILLION REYNOLDS NUMBER
TRANSITION PATTERN ON UPPER SURFACE - PERFORATED MODEL

\( R_e = 9.5 \times 10^6 \)
COMPARISON OF PRESSURE DISTRIBUTIONS
SLOTTED AND MODIFIED PERFORATED MODELS

<table>
<thead>
<tr>
<th>$R_c \times 10^6$</th>
<th>$\alpha$ deg.</th>
<th>$M_\infty$</th>
<th>Panels</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.51</td>
<td>0.8216</td>
<td>Slotted</td>
</tr>
<tr>
<td>10</td>
<td>0.89</td>
<td>0.8139</td>
<td>Perforated</td>
</tr>
</tbody>
</table>

$C_p$ vs. $x/c$

Perforated model

$M_{wall, above} = 1.015$

$M_{wall, below} = 0.853$
COMPARISON OF MEASURED AND PREDICTED PRESSURE DISTRIBUTIONS FOR SLOTTED AND PERFORATED LFC MODELS

<table>
<thead>
<tr>
<th>$R_C \times 10^6$</th>
<th>$\alpha, \text{deg}$</th>
<th>$M_\infty$</th>
<th>Panels</th>
<th>$C_{L\infty}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.51</td>
<td>0.8216</td>
<td>Slotted</td>
<td>0.53</td>
</tr>
<tr>
<td>10</td>
<td>0.71</td>
<td>0.8213</td>
<td>Perforated</td>
<td>0.56</td>
</tr>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8200</td>
<td>Theory</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Upper surface

C$_p$, sonic

Lower surface

Perforated model

$M_{\text{wall, above}} = 0.992$

$M_{\text{wall, below}} = 0.886$
SPANWISE PRESSURE DISTRIBUTION
PERFORATED MODEL, \( M = 0.82, R = 10 \times 10 \text{ cm} \)
TRANSITION PATTERN ON UPPER SURFACE - PERFORATED MODEL

\[ R_e = 10 \times 10^6 \]
TRANSITION PATTERN ON UPPER SURFACE - PERFORATED MODEL

\[ R_{c} = 20 \times 10^6 \]
COMPARISON OF MEASURED AND PREDICTED PRESSURE DISTRIBUTIONS FOR SLOTTED AND PERFORATED LFC MODELS

<table>
<thead>
<tr>
<th>$R_{c} \times 10^6$</th>
<th>$\alpha$, deg</th>
<th>$M_{\infty}$</th>
<th>Panels</th>
<th>$C_{L_{\infty}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8226</td>
<td>Slotted</td>
<td>0.49</td>
</tr>
<tr>
<td>20</td>
<td>0.71</td>
<td>0.8238</td>
<td>Perforated</td>
<td>0.50</td>
</tr>
<tr>
<td>20</td>
<td>0.51</td>
<td>0.8200</td>
<td>Theory</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Upper surface

Cp, sonic

Perforated model

$M_{wall, above} = 0.998$

$M_{wall, below} = 0.925$
SPANWISE PRESSURE DISTRIBUTION

PERFORATED MODEL, $M = 0.82$, $R = 20 \times 10^6$

Diagram showing spanwise pressure distribution with various stations labeled and thin films indicated.
TRANSITION LOCATION
UPPER SURFACE OF PERFORATED MODEL

Transition location, percent chord

Most forward turbulent film

Transition zone

Most rearward laminar film

Reynolds number
COMPARISON OF SUCTION DISTRIBUTIONS
Final Configurations, 10 Million Reynolds Number, M_∞ = 0.82

<table>
<thead>
<tr>
<th>Theory</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>○</td>
</tr>
<tr>
<td></td>
<td>○</td>
</tr>
</tbody>
</table>

Slotted
Perforated

Suction coefficient \( \times 10^4 \)

\( x/c \)
VARIATION OF TRANSITION WITH REYNOLDS NUMBER

LFC Airfoil Upper Surface, $M_\infty = 0.82$

Transition location, % chord

Reynolds number

Transition zone

Surface

Slotted

Perforated
COMPARISON OF UPPER SURFACE DRAG

$M_\infty = 0.82$

Note: Max suction system capability

$C_{d,s}$

$C_{d,w}$

$C_{d,t}$

Reynolds number, $R_C \times 10^6$

○ Slotted
□ Perforated
CONCLUDING REMARKS

- Successful in achieving design pressure distribution
- Full chord laminar flow maintained through large supersonic zone at 10 million Reynolds number
- Substantial reduction in drag achieved
- No significant difference between the slotted and perforated configurations when all factors considered