ABSTRACT

Tests are planned in the 15cm x 15cm supersonic wind tunnel at NASA Glenn to demonstrate the applicability of micro-ramp flow control to the management of shock wave boundary layer interactions. These tests will be used as a database for computational fluid dynamics (CFD) validation and Design of Experiments (DoE) design information. Micro-ramps show potential for mechanically simple and fail-safe boundary layer control.
Application of Microramp Flow Control Devices to an Oblique Shock Interaction

Stefanie Hirt
Bernhard Anderson
Boundary Layer Management

Bleed
- Removes low energy fluid
- Complex System
- Drag penalties

Microramps
- Boundary layer mixing
- Mechanically simple
- Fail-safe
Test Goals and Objectives

Research Goal:

To demonstrate the applicability of micro-ramp flow control for management of shock wave boundary layer (SWBL) interactions.

Research Objectives:

1. To develop an experimental data base of CFD validation and Design of Experiments (DOE) design information.
2. To evaluate DOE designs for accuracy and cost effectiveness based on experimental data base.
3. To validate CFD analysis of micro-ramp actuators based on experimental data base.

Types of Experiments:

1. Oblique shock wave boundary layer interactions.
2. Normal shock wave boundary layer interactions.
15x15cm Microramp Flow Control Tests

Oblique SWBL Experiments

No Flow Control

Micro- Ramp Flow Control

Normal SWBL Experiments

No Flow Control

Micro- Ramp Flow Control
Facility Information

15x15 cm Supersonic Wind Tunnel

- Mach Number: 2.0
- Reynolds Number: $1.5 \times 10^6 - 5 \times 10^6$ /ft
- Inflow: 40 psig pressure at ambient temperature
- Exhaust: ~ 2.0 psia
- Boundary Layer Thickness: ~ 0.5 in (1.3 cm)
- Microramp x-location: -5.12 in (-13.0 cm)
Microramp Parameters

Top View

Side View
Parameter Values

Spacing, s (mm): 25 30 35
Height, h (mm): 3.0 4.0 5.0
Chord, c (mm): 12 18 24

Central Composite DOE: 15 Cases
Every Combination: 27 Cases
DOE Designs

Main Effects Design - 4 cases
D-Optimal Design - 6 cases
Full Factorial Design - 8 cases
Central Composite Design - 15 cases
# Response Variables

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Layer Pitot Pressure Recovery</td>
<td>PTAVE</td>
</tr>
<tr>
<td>Boundary Layer Total Pressure Recovery</td>
<td>PFAVE</td>
</tr>
<tr>
<td>Compressible Displacement Thickness</td>
<td>$\delta^*$</td>
</tr>
<tr>
<td>Compressible Momentum Thickness</td>
<td>$\theta$</td>
</tr>
<tr>
<td>Incompressible Shape Factor</td>
<td>$H_i$</td>
</tr>
</tbody>
</table>
Oblique Shock / Microramp Interaction
CFD Calculation

Reference Plane
Reference Plane Profiles

Upwash

Downwash

Upwash Region
Downwash Region

Normal Distance, Y/δ

Velocity Ratio, U/Uedge

Pitot Pressure Recovery, Pt/Po
## Microramp Optimization

<table>
<thead>
<tr>
<th>DOE Design</th>
<th>s (mm)</th>
<th>h (mm)</th>
<th>c (mm)</th>
<th>PREF</th>
<th>δ* (cm)</th>
<th>θ (cm)</th>
<th>Htr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effects (4 points)</td>
<td>25.0</td>
<td>5.0</td>
<td>24.0</td>
<td>0.829</td>
<td>0.427</td>
<td>0.247</td>
<td>1.237</td>
</tr>
<tr>
<td>D-Optimal (6 points)</td>
<td>25.0</td>
<td>5.0</td>
<td>24.0</td>
<td>0.801</td>
<td>0.433</td>
<td>0.242</td>
<td>1.237</td>
</tr>
<tr>
<td>Full Factorial (8 points)</td>
<td>25.0</td>
<td>5.0</td>
<td>24.0</td>
<td>0.793</td>
<td>0.428</td>
<td>0.239</td>
<td>1.254</td>
</tr>
<tr>
<td>Central Composite (15 points)</td>
<td>25.0</td>
<td>5.0</td>
<td>24.0</td>
<td>0.813</td>
<td>0.440</td>
<td>0.239</td>
<td>1.239</td>
</tr>
</tbody>
</table>

- Optimal design obtained by minimizing Htr
- Based on CFD results
Experimental Grid Resolution Study

13 x 25 (Test)

51 x 50 (Reference)
# Test Schedule

<table>
<thead>
<tr>
<th></th>
<th>FY07</th>
<th>FY08</th>
<th>FY09</th>
<th>FY10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
<td><strong>15x15 cm Wind Tunnel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Cell Prep</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microramps - Oblique</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isolator Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microramps - Normal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildup Shutdown</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inlet Wind Tunnel Test</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Microramp Inlet Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Aero Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Design and Fab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Final Remarks

- CFD for the Oblique Shock Interaction is complete. Experimental testing will begin soon.

- Issues affecting the experimental data were resolved.
  - Data resolution
  - Static pressure gradient
  - Boundary layer edge selection

- Normal Shock Interaction test conditions are being finalized.

- Future Plans:
  - Fail-Safe Hybrid Flow Control
  - Multiple Shock Interaction with Microramps
  - Large Scale Inlet Test with Microramp Flow Control
Backup
Advanced Inlet Flow Control
Central Composite Face Centered Design
Total Pressure Contours

Config. rvg400

Config. rvg401

Config. rvg402

Config. rvg403

Config. rvg404

Config. rvg405

Config. rvg406

Config. rvg407

Config. rvg408
Advanced Inlet Flow Control
Central Composite Face Centered Design
Total Pressure Contours

Config. rvg407

Config. rvg408

Config. rvg410

Config. rvg411

Config. rvg412

Config. rvg413

Config. rvg414

Config. rvg415