Application of Microramp Flow Control Devices to an Oblique Shock Interaction

Stefanie Hirt
Bernhard Anderson

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.
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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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spacing, $s$ (mm)</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Height, $h$ (mm)</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Chord, $c$ (mm)</td>
<td>12</td>
<td>18</td>
<td>24</td>
</tr>
</tbody>
</table>

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

Central Composite Design - 15 cases
## Response Variables

<table>
<thead>
<tr>
<th>Response Variable</th>
<th>Symbol</th>
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<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>
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<tr>
<td>Incompressible Shape Factor</td>
<td>$H_i$</td>
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</table>
### Microramp Optimization

- Optimal design obtained by minimizing Htr
- Based on CFD results

<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>
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<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>
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<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>
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<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>
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<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>
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</table>
Experimental Grid Resolution Study

13 x 25 (Test)

51 x 50 (Reference)

![Graph showing correlation coefficient and regression analysis.](image)
## Test Schedule

<table>
<thead>
<tr>
<th>Test Item</th>
<th>FY07</th>
<th>FY08</th>
<th>FY09</th>
<th>FY10</th>
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<tbody>
<tr>
<td>15x15 cm Wind Tunnel</td>
<td>Q1-Q2</td>
<td>Q1-Q2</td>
<td>Q1-Q2</td>
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<td>Microramps - Oblique</td>
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<td>Isolator Test</td>
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<td>Inlet Wind Tunnel Test</td>
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<td>Microramp Inlet Test</td>
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<tr>
<td>-Aero Design</td>
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<td>FY08</td>
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<td>-Design and Fab</td>
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<tr>
<td>-Testing</td>
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<td>FY10</td>
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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. 409
Config. rvg410
Config. rvg411
Config. rvg412
Config. rvg413
Config. rvg414
Config. rvg415