Subsonic Round and Rectangular Twin Jet Flow Effects

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Rick Bozak and Mark Wernet
NASA Glenn Research Center

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Outline

• Twin jet configurations
• Twin jet conditions
• PIV configurations
• Results
  – Single Jet Comparison
  – Twin Round Jets
  – Twin Rectangular Jets
• Summary
Twin Jet Configurations

- Jet spacing in center-to-center distance ($s$) over nozzle diameter ($D$)
- 2-inch diameter convergent round nozzles (TCON)
- 2.13-inch area equivalent diameter rectangular nozzles:
  - 2:1 aspect ratio (A2Z0)
  - 8:1 aspect ratio (A8Z0)

<table>
<thead>
<tr>
<th>Twin Spacings</th>
<th>Round $s/D$</th>
<th>TCON</th>
<th>Rectangular $s/D$</th>
<th>A2Z0</th>
<th>A8Z0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>2.63</td>
<td>♦</td>
<td>2.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z4</td>
<td>3.55</td>
<td>♦</td>
<td>3.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z9</td>
<td>5.63</td>
<td>♦</td>
<td>5.26</td>
<td></td>
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</tr>
</tbody>
</table>
Twin Jet Conditions

- **Jet Conditions**
  - Acoustic Mach Number $M_a$ from 0.7 to 1.33
  - Nozzle Static Temperature Ratio $T_{sr}$ from 0.84 to 2.27
  - Forward Flight Mach Number $M_f$ from 0.05 to 0.25

<table>
<thead>
<tr>
<th>Jet Conditions</th>
<th>TCON</th>
<th>A2Z0</th>
<th>A8Z0</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M_a$</td>
<td>$T_{sr}$</td>
<td>$M_f$</td>
<td>Single</td>
</tr>
<tr>
<td>0.90</td>
<td>0.84</td>
<td>0.05</td>
<td>✓</td>
</tr>
<tr>
<td>1.33</td>
<td>2.27</td>
<td>0.05</td>
<td>✓</td>
</tr>
<tr>
<td>1.33</td>
<td>1.76</td>
<td>0.05</td>
<td>✓</td>
</tr>
<tr>
<td>1.33</td>
<td>1.76</td>
<td>0.10</td>
<td>✓</td>
</tr>
<tr>
<td>1.33</td>
<td>1.76</td>
<td>0.20</td>
<td>✓</td>
</tr>
<tr>
<td>1.33</td>
<td>1.76</td>
<td>0.25</td>
<td>✓</td>
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</table>
Particle Image Velocimetry (PIV) Configurations

- Coordinate system

- Streamwise (x-z plane)
  - 22” x 14” field of view
  - x/D of 0 to 30

- Cross-stream (y-z plane)
  - 10.5” x 22” field of view
  - x/D of 1, 2, 5, 10, 15, and 20
Single Jet Comparison

$M_a = 0.9$, Unheated

Single Jet: Cross-stream PIV

$M_a = 0.9$, Unheated
Twin Round Jets: Streamwise PIV

$M_a = 1.33, \ T_{sr} = 1.76, \ M_f = 0.05$
Twin Round Jets: Streamwise PIV

\[ M_a = 1.33, \quad T_{sr} = 1.76, \quad M_f = 0.25 \]
Twin Round Jets: Cross-stream PIV
$s/D = 2.63$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$
Twin Round Jets: Cross-stream PIV
\[ s/D = 2.63, \quad M_a = 1.33, \quad T_{sr} = 1.76, \quad M_f = 0.25 \]
Twin Round Jets: Cross-stream PIV

\( s/D = 3.55, \ M_a = 1.33, \ T_{sr} = 1.76, \ M_f = 0.05 \)
Twin Round Jets: Cross-stream PIV
$s/D = 5.63$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$
Twin 2:1 Rectangular Jets: Streamwise PIV

\[ \frac{s}{D} = 2.45, \quad M_a = 1.33, \quad T_{sr} = 1.76 \]

\[ M_f = 0.05 \quad M_f = 0.25 \]
Twin 2:1 Rectangular Jets: Cross-stream PIV

\( s/D = 2.45, \ M_a = 1.33, \ T_{sr} = 1.76, \ M_f = 0.05 \)
Twin 8:1 Rectangular Jets: Streamwise PIV

$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$

$M_f = 0.05 \quad M_f = 0.25$
Twin 8:1 Rectangular Jets: Cross-stream PIV

\( s/D = 3.55, \quad M_a = 1.33, \quad T_{sr} = 1.76, \quad M_f = 0.05 \)
Twin 8:1 Rectangular Jets: Cross-stream PIV

$s/D = 3.55$, $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.25$
Streamwise PIV at $M_a = 1.33$, $T_{sr} = 1.76$, $M_f = 0.05$

Reductions in Peak Turbulence ($\text{TKE}/U_j^2$)

| Twin Spacing | Round $(s/D)$ | TCON  | Rectangular $(s/D)$ | A2Z0* | A8Z0* *
<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Z1</td>
<td>2.63</td>
<td>13%</td>
<td>2.45</td>
<td>12%</td>
<td>X</td>
</tr>
<tr>
<td>Z4</td>
<td>3.55</td>
<td>0</td>
<td>3.32</td>
<td>X</td>
<td>10%</td>
</tr>
<tr>
<td>Z9</td>
<td>5.63</td>
<td>0</td>
<td>5.26</td>
<td>X</td>
<td>9%</td>
</tr>
</tbody>
</table>

*For the rectangular nozzles, the peak turbulence does not coincide with the streamwise measurement plane.
Summary

• Cross-stream and streamwise round and rectangular twin jet flow field PIV measurements were obtained at a few twin jet spacings and jet conditions.
• A decrease in turbulent kinetic energy levels relative to a single jet between the two jets at close spacings could be the result of enhanced mixing. This change in TKE levels is only evident in streamwise PIV measurements at the closest jet spacings obtained for each set of nozzles.
• When forward flight is increased, a velocity deficit between nozzles was measured. This appears to be due to the twin jet model blockage.
• The velocity deficit causes increased turbulence levels between the nozzles. The increased turbulence levels could be causing increased noise levels, relative to a single jet, found with far-field acoustic measurements.
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