Near-Wall Velocity Field Measurements of a Very Low Momentum Flux Transverse Jet

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50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference
Cleveland, OH

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Edward Coy, AFRL/RQRC

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Outline

• Research Motivation
• Experimental Setup
• Results
• Conclusion
Optical Diagnostics

Light Source

Combustion products

Cooling fluid

Detector

Window

Optical path length

Cooling fluid

Window
Jet and Crossflow Interaction

Light Source

Crossflow

$D_j$

$y_p$ (jet penetration length)
Experimental Facility

Flow straightener

Perforated plate

Air conditioning plenum

Jet fluid

Light source

Sheet forming optics

Flow conditioning plenum
Important Parameters

- **Momentum flux ratio**
  \[ J = \frac{\rho_j u_j^2}{\rho_o u_o^2} \]

- **Blowing ratio**
  \[ M = J^{1/2} = \frac{\rho_j^{1/2} u_j}{\rho_o^{1/2} u_o} \]
Initial Conditions

Crossflow

Jet

\[
\frac{U_0}{U_{0,\text{mean}}} \quad \frac{U_j}{U_{j,\text{mean}}}
\]

\[(y - h)/h \quad x/D_j\]
Instantaneous Velocity Field

\[ J = 0.075 \]
Mean Velocity Field – Streamlines

\[ J = 0.014 \]
Mean Velocity Field – Streamlines

\[ J = 0.0013 \]
Maximum Jet Penetration

\[ x/D_j = 0.05 \]
\[ x/D_j = 0.0 \]

1.8% difference
Jet Exit – Velocity Profile

\[ \frac{U_j}{U_{j\text{mean}}} \]

- \( J = 0.075 \)
- \( J = 0.034 \)
- \( J = 0.014 \)
- \( J = 0.0050 \)
- \( J = 0.0013 \)

\[ x/D_j \]
Jet Exit – RMS Profile

$U'_{\text{rms}}/U_{\text{mean}}$ vs $x/D_j$

- $J = 0.075$
- $J = 0.034$
- $J = 0.014$
- $J = 0.0050$
- $J = 0.0013$
Reynolds Shear Stress, $u'v'$
Reynolds Shear Stress, $u'v'$

![Graph of Reynolds Shear Stress with $J = 0.0013$.]
Reynolds Shear Stress, $u'v'$

$x/D_j = 1$

$x/D_j = 2$

$x/D_j = 3$
Reynolds Shear Stress, $u'v'$

$J = 0.075$

$J = 0.0013$

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$J = 0.0013$

$J = 0.075$

$J = 0.0013$
Time Dependent Jet Behavior

Time domain

Frequency domain

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Time Dependent Jet Behavior

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Time Resolved Jet Behavior

\[ J = 0.0050 \]

\[ \frac{v}{u_j} \]

\[ \frac{y}{D_j} \]

\[ \frac{x}{D_j} \]
Time Resolved Jet Behavior

\[ J = 0.075 \]
PIV Precision Uncertainty

Jet Crossflow
Precision Uncertainty – Jet

<table>
<thead>
<tr>
<th>$J$</th>
<th>$u'^2$</th>
<th>$v'^2$</th>
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<td>0.0844</td>
<td>0.0009</td>
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\[ u_{\text{prec}} = 2S_i / N^{1/2} \]

$S_i$ = standard deviation of $i^{th}$ parameter

$N$ = number of samples (3,000)
Conclusion

• Confirmed jet and crossflow interaction for $M = 0.275$ ($J = 0.075$)
• $J = 0.0013$ minimizes crossflow penetration
• $J = 0.0013$ is most unstable value of those studied
• PIV data provides evidence for highly 3-dimensional jet and crossflow interaction
• Reduced Reynolds shear stress values indicate potential improved performance of low momentum jets for use in film cooling applications
• Ingestion of crossflow fluid creates pulse-like jet behavior
Questions?
Backup
### Precision Uncertainty – Jet

<table>
<thead>
<tr>
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<th>$u'$</th>
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<th>$\sqrt{u'^2}$</th>
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## Precision Uncertainty - Crossflow

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Experimental Conditions

• Particle Image Velocimetry (PIV) Parameters
  – 527 nm light source
  – 100 ns pulses
  – 0.5 mJ/pulse
  – Image-pair time separation = 120 μs
  – Image-pair capture rate = 3348 Hz
  – Particle diameter = 1 μm
  – 20 particle per 32 x 32 pixel interrogation region

• Crossflow
  – Re_o = 14,000
  – u_o = 2.71 m/s

• Jet
  – 62 < Re_j < 472
  – u_j = 0.731 m/s