Aerodynamics and Heat Transfer for Airfoil-Endwall Junctures in Gas Turbine Engines

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This talk evaluates endwall heat transfer and shear stress with filleted vanes in gas turbine engines.

Motivation, past studies, and research objectives

Experimental facilities and techniques

Discussion of results
Secondary flows augment wall heat transfer and increase aerodynamic losses for a gas turbine

Secondary flow model presented by Langston (1980)

Experimental measurements, Kang, et al. (1999)

Horseshoe vortex
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Horseshoe vortex

Passage vortex
Various leading edge/endwall junction geometries have been investigated with promising results.

Sauer, Müller, and Vogeler (2000)

Zess and Thole (2001)

Shih and Lin (2002)
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Various leading edge/endwall junction geometries have been investigated with promising results.

Sauer, Müller, and Vogeler (2000)

Zess and Thole (2001)

Shih and Lin (2002)


Han and Goldstein (2004)

Mahmood, Gustafson, and Acharya (2005)
The goal was to find how fillet reduce aerodynamic losses and heat transfer for gas turbine vanes

Project Objectives
1) Evaluate endwall heat transfer and shear stress with an unfilleted vane
2) Evaluate endwall heat transfer and shear stress with a filleted vane
We conducted this research in a closed-loop, low speed wind tunnel

Axial fan

Primary heat exchanger

<table>
<thead>
<tr>
<th>Scale</th>
<th>9X engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chord (C):</td>
<td>59.4 cm (23.4”)</td>
</tr>
<tr>
<td>Pitch (P):</td>
<td>45.7 cm (18.0”)</td>
</tr>
<tr>
<td>Span (S):</td>
<td>55.0 cm (21.7”)</td>
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To measure temperatures on a constant heat flux surface, we used infrared thermography.

Spatial transformation of fillet surface
Oil film interferometry (OFI) can provide measurements of wall shear stress.
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- Interference between light rays (out of phase)
- Reflective surface (nickel foil, 0.05 mm thick)
- Dow Corning 200 silicone oil
- Airflow direction
- Low-pressure sodium vapor lamp (monochromatic)
- Interference between light rays (out of phase)
- $\Delta x$, $\varphi = 2\pi$
- Reflective surface (nickel foil, 0.05 mm thick)
OFI was benchmarked for channel flow and implemented in the vane cascade
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\[ f = \frac{\tau_w}{\frac{1}{2} \rho U_m^2} \]

Colebrook Correlation

Oil Film Interferometry
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\[ \text{Colebrook Correlation} \quad \Box \quad \text{Oil Film Interferometry} \]
Adding a fillet to the airfoil-endwall junction changes the endwall heat transfer

\[ \text{St}_\infty = \frac{h}{\rho C_p U_\infty} \]

- 0.018
- 0.016
- 0.014
- 0.012
- 0.010
- 0.008
- 0.006
- 0.004
Heat transfer coefficients are lowered on the pressure side of the passage

\[ \text{St}_\infty = \frac{h}{\rho C_p U_\infty} \]
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\[ St_\infty = \frac{h}{\rho \cdot C_p \cdot U_\infty} \]
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\[ St_\infty = \frac{h}{\rho C_p U_\infty} \]

The graph shows the variation of heat transfer coefficients with s (m) for both No fillet and Linear fillet conditions.
The OFI method shows unique endwall flow patterns caused by secondary flow.
Adding a linear fillet increases skin friction, but reduces flow turning at the passage exit.

\[ C_f = 0.020 \]
Adding a linear fillet increases skin friction, but reduces flow turning at the passage exit.
The linear fillet increases wall shear stress through the center of the passage.

\[ C_f = \frac{\tau_w}{\frac{1}{2} \rho U^2_\infty} \]
Wall shear stress and heat transfer coefficients do not appear to be related for a turbine vane.

\[ St_{\infty} = \frac{h}{\rho C_p U_{\infty}} \]

\[ C_f = \frac{\tau_w}{\frac{1}{2} \rho U_{\infty}^2} \]
The Reynolds analogy is not valid along the center of the passage
In conclusion, adding a linear fillet reduces endwall surface area.

Adding a linear fillet marginally changes the heat transfer distribution.

Wall shear increases with the fillet, but endwall flow turning is reduced.

Wall shear stress and heat transfer coefficients do not appear to be related in the vane passage.

Questions?