UTSR Fellowship Final Presentation

Dale Fox
Heat Transfer / Secondary Flow
Supervisor: Mike Fox
Mentors: Hongzhou Xu, Kevin Liu
Caterpillar: Confidential Green

EMERGENCY NUMBERS
HD – 5555
KM – 7500

CPR TRAINED
AED
FIRE EXTINGUISHER

If access to assigned assembly area is unsafe, use closest alternate area.
1. Personal Background
2. Heat Transfer Projects
3. Deliverables
4. Summer Experience
5. Questions
1. Personal Background
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Personal Background

• Hometown: West Jordan, UT

• University of Kansas
  - B.S. in Mechanical Engineering, 2016

• University of Texas
  - Advisor is Dr. David Bogard
  - M.S. in M.E., thermal fluid systems, 2018
  - Ph.D. in M.E., 2020???

• UTSR Fellowship – Solar Turbines
AGENDA

1. Personal Background

2. Heat Transfer Projects
   • PSP Scaled Cascade – IR Thermography Investigation
   • Engine Scale PSP Rig – Preliminary Feasibility
   • TLC Rig – Broken Trip Strips Assembly Design

3. Deliverables

4. Summer Experience

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IR Thermography Investigation

PSP Scaled Cascade Rig
IR Thermography Investigation

• Proposed modifications of scaled linear cascade with:
  - IR camera
  - IR window

• Assess differences between PSP and IR
  - Useful for evaluating literature done with IR

• Investigate effects of elevated density ratio

• External heat transfer coefficient measurements
Pressure Sensitive Paint
• Currently in use at Solar
• Sensitive to $O_2$ concentration
• Track location of

Infrared Thermography
• Directly measures surface temperatures (requires coolant temperature difference)
• Can measure HTC on surface by forced heat flux
• Subject to thermal conductivity problems
Literature Comparisons of IR & PSP

Wright, L. M., Gao, Z., Varvel, T. A., Han, J. C., “Assessment of Steady State PSP, TSP, and IR Measurement Techniques for Flat Plate Film Cooling”

Preliminary Cost Breakdown:

• IR Camera: A655sc
  - $19,950
  - 25° Lens
  - Software included

• IR Windows:
  - 2x $995 3” Germanium windows
Engine Scale PSP Rig

Preliminary Feasibility & Objectives

Caterpillar: Confidential Green
Engine Scale PSP Rig Analysis

• Film cooling effectiveness on as-manufactured engine hardware
  Purpose: validation of new manufacturing techniques for film cooling holes & quality control for production components
• Dynamic similarity (Reynolds & Mach numbers)
• PSP Measurement Requirement: Isothermal Primary & Secondary Flow
• Flexibility – reconfigurable to work for different stages / turbines
Proposed Rig Outline
Proposed Test Section

- 3 Passage Test Section
- 3D Printed nozzle, diffuser
- Printed / Machined test section
1x Engine Scale (T250 IV Stg. 1 Nozzle)
Nozzle Inlet:
• \( \text{Re} = \frac{\rho U C}{\mu} = 500,000 \)
• \( \text{Ma} = \frac{U}{\sqrt{\gamma R T}} = 0.1 \)
• \( T_o \)
• \( P_o \)
• \( U_\infty \)

1x Rig Scale
Nozzle Inlet:
• \( \text{Re} = \frac{\rho U C}{\mu} = 500,000 \)
• \( \text{Ma} = \frac{U}{\sqrt{\gamma R T}} = 0.1 \)
• \( \frac{1}{5} T_o \)
• \( \frac{1}{7} P_o \)
• \( \frac{1}{2} U_\infty \)
Summary of Annular Rig Design Objectives

• Non-destructive installation and sealing of components to be tested, with reasonable interchangeability to test multiple parts in a single experimental block
• Mechanical strength and sealing for moderate pressure on interior walls of test section during operation, at approximately ambient temperature
• Low-distortion optical access to vane surfaces for viewing by PSP camera; borescope, embedded windows, clear test section walls or other solutions could be viable.
• Test rig internal walls matched to vane profiles for correct aerodynamic loading on the test component
• Modular components: test rig should accommodate replacement of the passages for testing of different nozzles in the future
• Measured and controlled mass flowrate for both primary and secondary flow passages – Has been found to be feasible with current Solar facilities
Broken Trip Strips Assembly Design

TLC Flow Test & CFD Simulation
Broken Trip Strip Project

• Developmental investigation of varying trip strip configurations
  - Continuous/staggered rib arrangement
  - Varying width of gap at LE

• Simplified leading edge geometry
  - Literature review
  - Semi-circular passage w/ trip strip
  - Triangular passage

• Designed for TLC experimental flow bench
TLC Heat Transfer Models

- Thermochromic liquid crystal paint
- Measures HTC through transient technique
- Frequently used at Solar for validating passage heat transfer design
Planned Experimental Test Rig

• Design in progress on test article - soon to be sent for quote

• Experimental work to include other passage geometries as well – tests are expected to be sensitive to passage geometry
CFD Test Cases

- No trip strip
- Continuous trip strip
- Trip strip gap 1
- Trip strip gap 2
- Trip strip gap 3
- Staggered trip strip
- Stg. trip strip gap 1
- Stg. trip strip gap 2
- Stg. trip strip gap 3
Continuous Rib Heat Transfer Results

- Significant separation behind continuous rib
- Rib gap makes average Nusselt number more consistent
- On average, heat transfer is enhanced by trip strip gap
Staggered Rib Heat Transfer Results
Detailed Look at Decrease in HTC

- Central “jet” rises over the course of several ribs
- Peak in HTC aligns with max velocity
- Subsequently jet is dispersed / brought down by ribs
Summary of Nusselt Number Results, Re = 90,000

Simulation Results for Re = 90,000

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</table>
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Deliverables

Engineering Design Memos:
• IR Thermography Measurement Proposal
• Annular Rig Feasibility & Scope Definition
• Broken Trip Strip Literature Review
• Broken Trip Strip Preliminary Design & CFD
Takeaways

• Engineering in academia ≠ engineering in industry
• Communication is critical between departments
• Engineering documentation & organization
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Internship Experiences

Turbo Expo 2019
Turbomachinery Technical Conference & Exposition
Presented by the ASME International Gas Turbine Institute
Phoenix Convention Center, Phoenix, AZ
THANK YOU

• Heat Transfer
  • Hongzhou Xu, Kevin Liu
  • Mike Fox
• Dev. Test
  • Jeremy Lo, Tony Bianchi, Bill Walsh, Tristan Clark
• Nancy Guardado
• Summer Interns