DOE FACT SHEETS
FOR
UTSR PROJECTS

Aero Losses, Heat Transfer, Discharge Coefficients for Different Vane Trailing Edge Cooling Technologies for Syngas-Fired Gas Turbines

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II. PROJECT DESCRIPTION

A. Project Objectives

The objective of this proposed study is to comprehensively investigate alternative trailing edge cooling technologies for gas turbines fueled with syngas. Syngas fuels are expected to cause deposition onto and corrosion of turbine surfaces. These surface effects can be expected to cause blockage of coolant discharge exits, increase aerodynamic losses, decrease turbine flow area, increase external heat transfer rates, and reduce trailing edge film cooling effectiveness levels. Trailing edge designs are often a focal point of a design team due to competing demands of aerodynamics, heat transfer, stress, and manufacturing.

Within this context, the project will investigate aerodynamic losses, surface heat transfer coefficient distributions, surface film cooling effectiveness distributions, and discharge coefficients for different vane trailing edge cooling configurations. Surface heat transfer coefficients will be measured on external vane surfaces and on the surfaces of internal trailing edge cooling passages, also modeled to match operating vanes, with different pin fin arrangements. The vane configurations which will be investigated (Figures 1-4) include:

(i) baseline condition (solid airfoil),
(ii) covered trailing edge,
(iii) letterbox ejection,
(iv) gill slot, and
(v) pressure-side holes.

B. Background/Relevance

Background. One of the most difficult regions of a gas turbine to cool is the trailing edge of a vane or blade. Aerodynamic considerations require the trailing edge to smoothly narrow to a small radius, while controlling the diffusion of boundary layers. Heat transfer challenges include cooling a surface with a high heat load far downstream from where film cooling protection is optimum in a region with little area for the flow of cooling air. At the same time strong market forces are pushing the power industry toward the use of coal derived syngas in gas turbine systems. However, even the cleanest syngas will contain small amounts of sulfur and particulate contamination, which can be expected to roughen turbine surfaces due to deposition and corrosion. Surfaces roughened from deposition and corrosion will produce higher surface heat transfer coefficients, higher aerodynamic losses, reduced film coverage, and reduced effective throat area. Turbine systems fueled by syngas will need designs tolerant of these affects. Consequently, the trailing edge region of vane and blades will be even more difficult to cool.

Relevancy. The present project is planned so tasks and activities are closely aligned with UTSR goals in the heat transfer and aero area, emphasizing the effects of turbine service resulting from the use of **synthetic gas and alternative fuels**. (1) Measured distributions of surface temperature and film effectiveness with the different trailing edge configurations are going to provide information on the potential of different designs to produce: (a) equivalent cooling and (b) better airfoil trailing edge life, with less trailing edge cooling flow. (2) Information on these different trialing edge configurations are also needed because of the greater susceptibility of some designs for clogging from the deposition and contaminants which are associated with many alternate fuels. Data will allow industrial designers to assess the relative performance of four different trailing edge arrangements, with different levels of particulate clogging susceptibility, over a range of flow parameters both for low-Mach number flows and for high Mach number flows. (3) Hole discharge coefficients, and aerodynamic losses and wake characteristics downstream of the airfoils will also aid assessments of the relative performance and benefits of the arrangements studied. (4) The uses of different fuels (fuel flexibility) also often require the use require different combustion systems. Different combustion systems produce different amounts of mixing, different turbulence levels, and different magnitudes and distributions of turbulence length scales in the mainstream flow.

The present program is planned to develop the understanding and database necessary to successfully apply these competing trailing edge cooling schemes. These trailing edge designs include the common gill slot, a covered trailing edge, a configuration where the vane core exhausts to pressure side holes, and a design called the letterbox where the core extends through rectangular slots in the trailing edge. In order for designers to make knowledgeable decisions about trailing edge geometries, they need to understand the tradeoffs between aerodynamic loss, flow blockage, discharge coefficient, and heat transfer issues.

C. Period of Performance. 8/1/2005 – 7/31/2008

D. Project Summary/Modification

Under the University Turbine Research (UTSR) program, the University of North Dakota and the University of Utah are investigating alternative trailing edge cooling technologies for gas turbines fueled with syngas. With the departure of Dr. Phil Ligrani from the University of Utah to Oxford University, the program will be modified to eliminate further work from the University of Utah. The following project summary has been modified to reflect this change.

The University of North Dakota (UND) is currently using it's 11 times scale low speed cascade facility to investigate the aerodynamics and heat transfer associated with different trailing end configurations with and without syngas roughened surfaces. The vanes used in this facility are based on an incompressible version of a fully loaded nozzle guide vane for a medium sized engine. This large scale facility will allow the acquisition of full exit surveys and internal heat transfer measurements. The University of Utah (UoU) has begun and has now terminated measurements in a transonic cascade facility for the aerodynamic and heat transfer investigation. This high speed facility uses a transonic version of the same nozzle guide vane to investigate the impact of Mach number on the aerodynamics of different trailing edge configurations and allow a substantial extension of the Reynolds number range.

Tasks

1. UND will use a simulated syngas roughened surface generated by Brigham Young University's accelerated deposition rig. This surface will be applied to the vanes with various trailing edge configurations to study the influence of deposition on vane heat transfer and aerodynamics. The level of roughness generated by Brigham Young's deposition rig has been found to be consistent with the levels of roughness characterized by Dr. Jeffrey Bons of the Brigham Young University for in service industrial airfoils.

2. Finalize the geometry of the conventionally loaded vane and trailing edge cooling arrangements, based on discussions with industrial affiliates. (UND-largely complete)

3. Measurement and analysis of vane surface static pressure distributions, Mach number distributions, and trailing-edge hole discharge coefficients. (UND-currently underway)

4. Investigation of trailing edge aerodynamic losses and turbulence parameters for competing trailing edge designs. (UND-currently underway)

5. Investigation of the impact of the trailing edge configurations on external heat transfer coefficient distributions. (UND-currently underway)

6. Investigation of internal heat transfer coefficients for competing trailing edge designs. (UND-currently underway)

7. Characterization of the adiabatic effectiveness of exit discharge air on any downstream gas path surfaces. (UND-currently underway)

8. Identify how knowledge will support UTSR-NETL goals, meeting UTSR Program objectives, coal syngas and hydrogen fuels. (UND)

III. PROJECT COSTS

UTSR Project Cost: $342,552 (Revised cost: $246,242)

IV. MAJOR ACCOMPLISHMENTS SINCE BEGINNING OF PROJECT

- Developed final external and internal geometries for gill slot, letterbox, and ***pressure-side hole*** configurations.

- Designed and fabricated mold for gill slot and letterbox vane configuration. ***Fabricated gill slot aerodynamic and heat transfer vanes. Currently, developing letterbox aerodynamic and heat transfer vanes.***

- Designed and fabricated internal heat transfer geometry for ***pressure-side hole,*** gill slot and letterbox configurations. ***Acquired internal heat transfer and pressure drop data for conventional pin fin array used in gill slot and pressure-side hole vanes.***

- Acquired pressure distribution and exit surveys for baseline vane for gill slot and letterbox designs. (ASME Paper No. GT2006-90168.)

- Acquired pressure distributions and full exit surveys for gill slot vane over a range of Reynolds numbers, turbulence conditions, and flow rates. (Plan to offer ASME Paper No. GT2007-27399 for presentation at Turbo Expo 2007, subject to approval of IRB.)

- Acquired external heat transfer and film cooling effectiveness distributions downstream from gill slot over a range of Reynolds numbers, turbulence conditions, and flow rates. (Plan to offer ASME Paper No. GT2007-27397 for presentation at Turbo Expo 2007, subject to approval of IRB.)

- Graduated 2nd Lt. (USAF) Jake Johnson with Master of Science (August 2006)

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

- Obtain simulated syngas roughened surface from Brigham Young University

- Characterize heat transfer and pressure drop in converging channel high solidity pin fin array.

- Finish construction of letterbox vanes and characterize heat transfer, adiabatic effectiveness, and aero-losses for letterbox trailing edge configuration.

- Build prototype roughened surface using UND's 3-D printer to generate a negative mold.

- Graduate Nathan Fiala with Master of Science (Dec 2006)

VI. MAJOR ACCOMPLISHMENTS PLANNED IN OUTYEARS (6-18 MONTHS)

- Apply simulated syngas roughened surface to base vane and characterize aerodynamics and heat transfer.

- Construct pressure-side holes vane and characterize aerodynamics and heat transfer

- Design and build mold insert for fabrication of covered trailing edge vane

- Design, fabricate, and test low pressure drop high solidity pedestal array for covered trailing edge vane

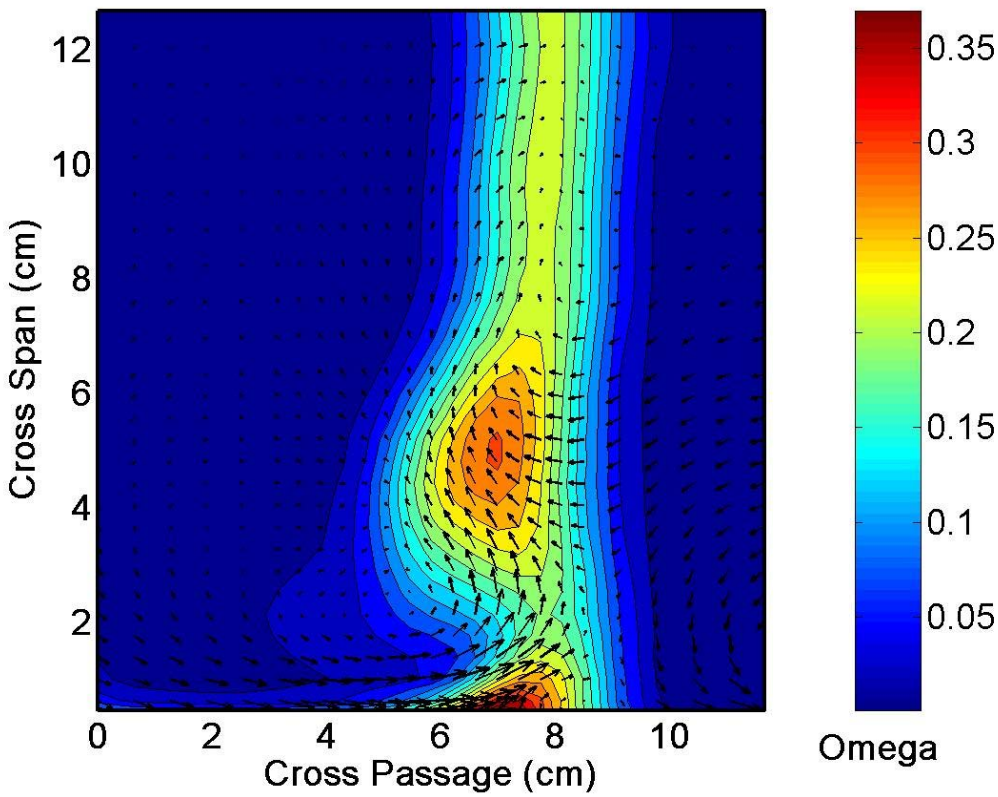
- Fabricate covered trailing edge heat transfer and aerodynamic vanes and begin testing.

VII. ISSUES

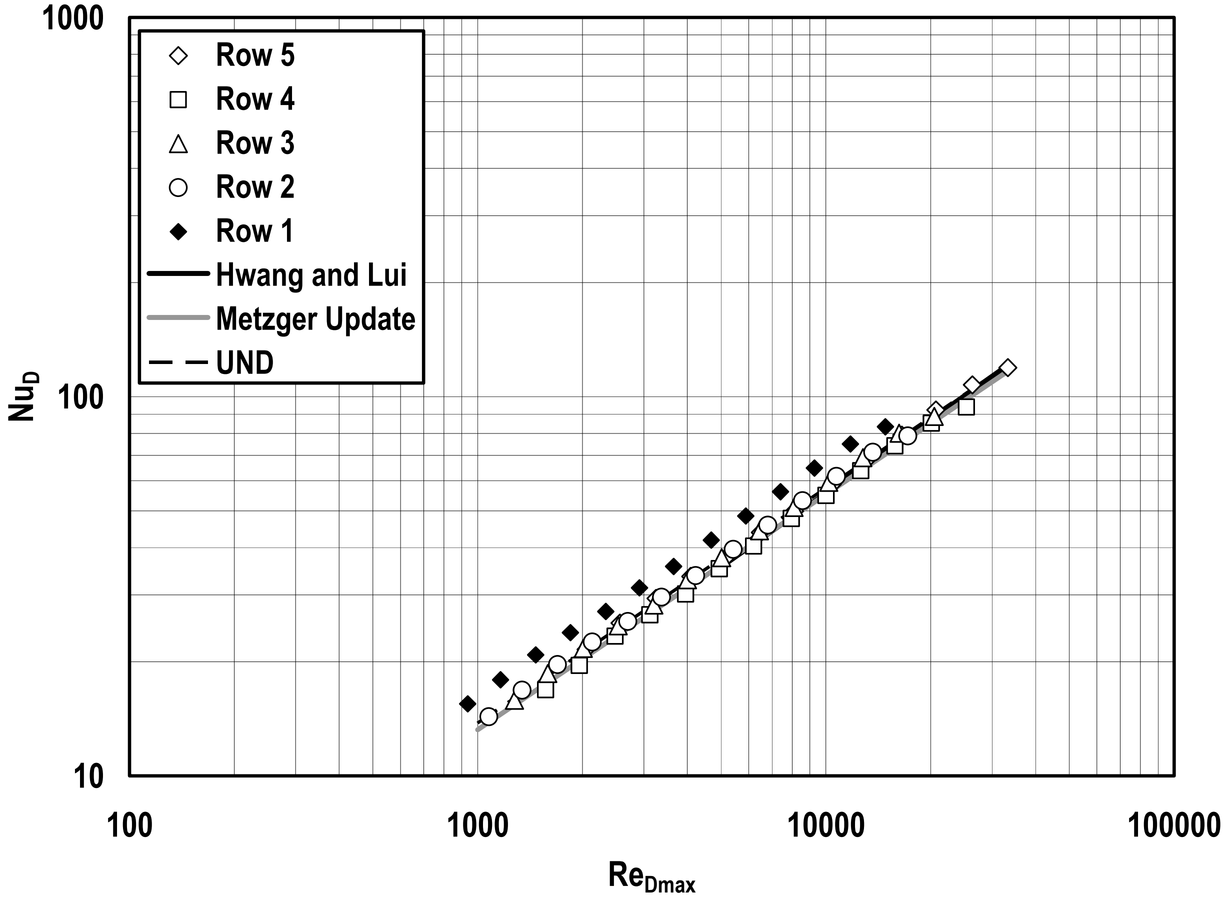
Dr. Phil Ligrani has left the University of Utah for Oxford University and will no longer be a participant on the project.

VIII. ATTACHMENTS

Exit Loss Survey for Gill Slot Vane with Grid Generated Turbulence, $Re_C = 10^6$, Design Flow



Comparison between UND Converging Pin Fin Array Heat Transfer and Literature Correlations



Heat Transfer Distributions Downstream from Gill Slot Ejection for Aero Combustor with Varying Discharge Rates and Chord Reynolds Numbers.