Improved Film Cooling Performance for Turbine Vanes and Endwalls with Realistic Surface Conditions

FACT SHEET

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II. PROJECT DESCRIPTION

A. Objectives

The objectives of this work are to evaluate the effects of roughness and film-cooling hole blockages on a turbine airfoil and its associated endwall. Roughness and cooling hole blockage arise from combinations of particle deposition, erosion, and repeated thermal barrier coating applications. Also being investigated are potential changes to cooling hole designs that would improve film-cooling performance by alleviating the degradation of film cooling performance when the surface becomes contaminated by these depositions through the use of synfuels.

B. Background/Relevancy

Background.

This research program addresses the important issues that are relevant to engine service and that are directly linked to the part life for the first vane of the turbine, particularly when using synfuels to power the turbine. The focus of the study is to evaluate film cooling performance on the vane and endwall under realistic operating conditions including roughness on the vane platform and cooling hole blockages, which is due to particle deposition, and erosion of thermal barrier coatings. In addition, we are evaluating a potential solution for alleviating these effects by combining a film cooling hole with a trench.

It is particularly important to address these realistic conditions in a laboratory environment to assess their relative importance in predicting turbine service life. Moreover, it is important to evaluate potential solutions for these effects. With regards to evaluating potential solutions, we are evaluating the use of trenches for two primary purposes: (i) to improve cooling performance for holes that have been blocked by particle deposition and (ii) to direct the leakage flow at the combustor-turbine interface and vane-to-vane interface to further reduce endwall temperatures.

Relevancy.
The benefits of this project will be twofold. First, the data provided from these large scale experiments will characterize the effects of foreign deposits on heat transfer to airfoils and their associated endwalls in industrial gas turbines. This data is needed to provide accurate models for predicting the life of turbine airfoils in operating environments. Second, this study will investigate potential methods for alleviating the detrimental effects of dirt deposits in blocked film cooling holes. Shallow transverse slots will be combined with film cooling holes to better disperse the available coolant. Both of these benefits will lead to reduced costs for the user as a result of longer component life.

C. **Period of Performance.** 7/1/2003 – 6/30/2006 (with a no cost extension through December 2006).

D. **Project Summary**

Under the University Turbine Research (UTSR) program, Virginia Tech and the University of Texas are identifying ways to mitigate effects of using synfuels in gas turbines where issues such as particle deposition, hole blockage, and erosion can lead to reduced component life.

Two existing large-scale turbine vane cascades are being used for the proposed research. Studies on the vane endwall are conducted at Virginia Tech and studies on the vane itself are conducted at the University of Texas. In these studies, particular emphasis is placed on detailed velocity field and thermal field measurements. Infrared imaging of these surface temperatures is the primary means of quantifying effects on the surface heat load and film cooling performance on the vane and endwall.

Joint Tasks with Virginia Tech and University of Texas

1. Hold an initial planning meeting with industrial partners to discuss the proposed coolant hole configurations.
2. Conduct a survey of actual coolant holes that are distorted due to the manufacturing process or due to contamination by deposited material during extended operations.

Various distortions of the coolant hole will be reduced to relatively few basic categories so that a systematic study of the distorted hole configurations will be viable.

Endwall Investigation (Virginia Tech Tasks)

3. Measure cooling effectiveness levels on a film cooled endwall and an endwall with coolant leakage from a slot within the vane passage, representing where the two airfoil platforms meet, another slot, representing the combustor-turbine interface.
4. Measure cooling effectiveness levels on a film cooled endwall with roughness that represents a range of dirt deposits.
5. Measure cooling effectiveness levels on a film cooled endwall with distorted film holes and roughness on the endwall surface.
6. Measure cooling effectiveness levels on a film cooled rough endwall with clean film cooling holes placed in the transverse slots at the combustor turbine interface and vane-to-vane interface.
7. Measure cooling effectiveness levels on a film cooled endwall with roughness whereby partially blocked film cooling holes will be placed in the transverse slots at the combustor-turbine interface and vane-to-vane interface.

Vane Investigation (University of Texas)

8. Test roughness effects on film cooling performance on a vane. This will involve multiple rows of holes on the pressure and suction side of the vane.
9. Evaluate the performance of coolant holes that have been designed to simulate realistic distorted holes due to deposition. The various categories of hole distortions defined in Task 2 will be tested, and tests will include effects of surface roughness and high mainstream turbulence levels.
10. Evaluate the performance of a shallow transverse slot overlaying the coolant holes on the vane. The slot is expected to protect the hole exits from contamination, and improve performance of contaminated holes.
11. Conduct tests with the slot configuration listed in Task 10, but with the slot altered to simulate contamination by deposited foreign material.

III. PROJECT COSTS

$572,385

IV. MAJOR ACCOMPLISHMENTS SINCE BEGINNING OF PROJECT

- Improved the spreading of the coolant by decreasing the upstream slot width between the combustor and the turbine thereby indicating that the slot design is important in improving vane endwall film cooling
- Modeled and evaluated the effects of depositions, spallation, and hole blockages on endwall film cooling performance
- Showed a severe reduction in film cooling effectiveness levels with blocked film cooling holes at the leading edge while small amounts of deposition at the same location improved the cooling effectiveness
- Measured a significant increase in film cooling effectiveness levels with film cooling holes placed in a trench at the leading edge of the vane endwall

- Effects of surface roughness on film cooling performance measured on the pressure and suction sides of the simulated vane. A range of roughness levels has been examined from low levels of roughness to roughness grit size of 0.12*d* where *d* is the hole diameter. Roughness was found to have only small effects on the pressure side, but cause as much as 50% reduction in adiabatic effectiveness on the suction side.
- The influence of near-hole obstructions was tested using coolant holes on the suction side of the vane. Obstructions were found to cause significant reduction in adiabatic effectiveness if position immediately upstream of the coolant holes, but would cause a slight improvement in performance if positioned downstream of the coolant holes. These effects were not sensitive to the shape of the obstructions, but were sensitive to the size of the obstruction.
- Various transverse shallow trench configurations were tested to determine whether the shallow trench would mitigate the effects of surface roughness and/or obstructions. A narrow trench configuration was found to significantly improved adiabatic effective as shown in Figures 3 and 4. Maximum adiabatic effectiveness was increased by more than 30%, and high levels of adiabatic effectiveness were maintained for large blowing ratios.

V. MAJOR ACTIVITIES PLANNED DURING THE NEXT 6 MONTHS

For Virginia Tech, the major planned activity involves measuring the flow field and thermal field with deposits and trench placed at the leading edge of the vane endwall. These measurements will be carried out to better understand the effect of deposits and trenches on the leading edge film cooling performance. The major activity for the University of Texas will be to measure the effects of transverse trench on the heat transfer coefficients for a range of blowing ratios.

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

Project will end in December 2006.

VII. ISSUES

None

VIII. ATTACHMENTS

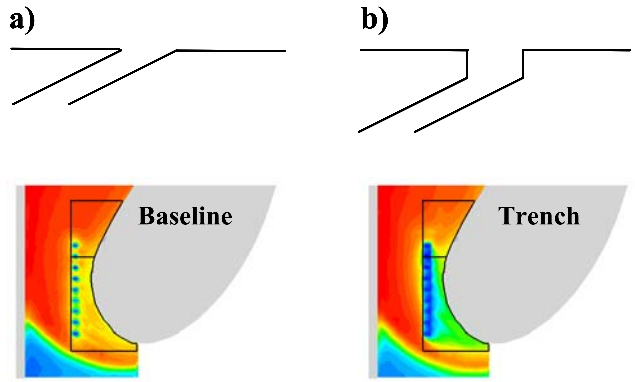
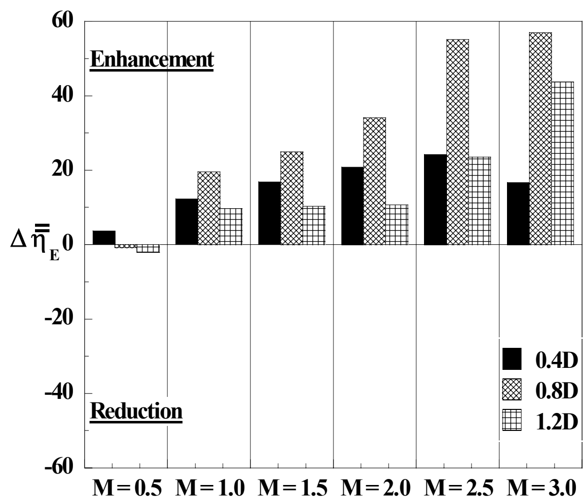


Figure 1. Compares the contours of adiabatic effectiveness between a) the baseline study and b) a trench at the leading edge of a vane endwall.



$$\Delta\overline{\overline{\eta}}_E = [(\overline{\overline{\eta}}_{trench} - \overline{\overline{\eta}}_{baseline}) / \overline{\overline{\eta}}_{baseline}] \times 100$$

$\overline{\overline{\eta}}_{baseline}$ - effectiveness without a trench

Figure 2. Comparison of percent enhancement on area-averaged adiabatic effectiveness as a result of placing trenches of varying depths at the leading edge of a vane endwall.

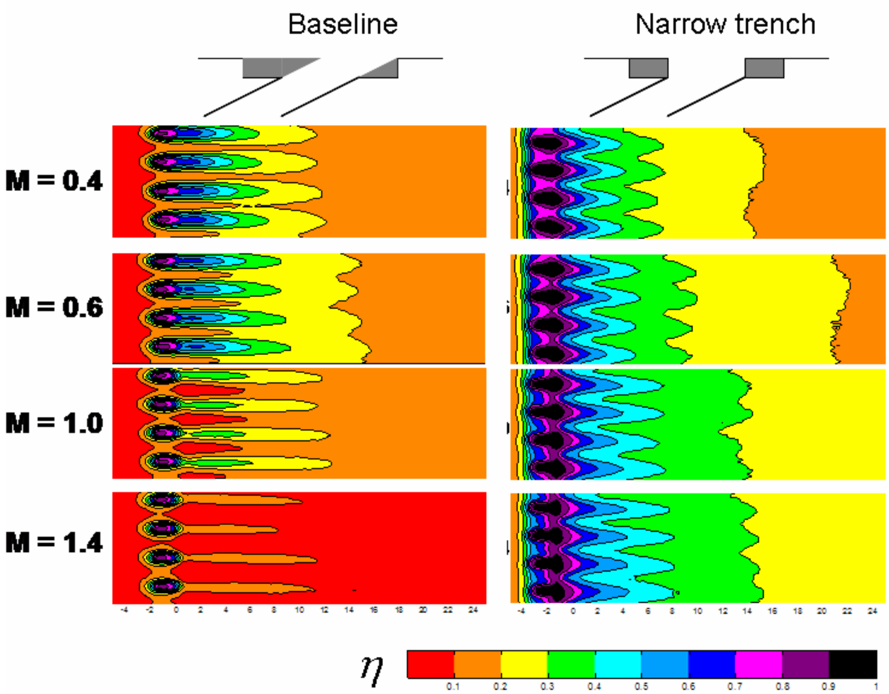


Figure 3. Comparison of the spatial distribution of film effectiveness with baseline cylindrical holes and with holes embedded in a shallow, transverse trench.

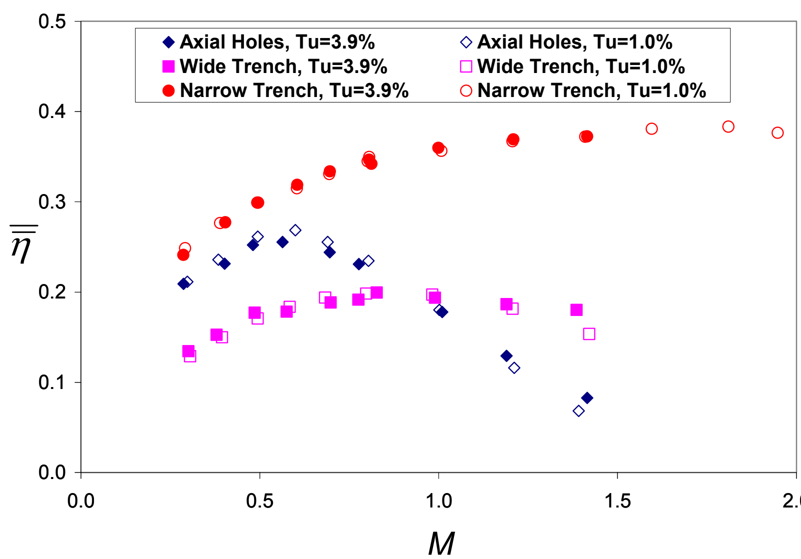


Figure 4. Spatially averaged adiabatic effectiveness for axially inclined cylindrical holes compared to wide and narrow trench configurations.