EFFECTS OF COATING BLOCKAGE AND DEPOSITS ON FILM COOLING EFFECTIVENESS AND HEAT TRANSFER

FACT SHEET

I. PROJET PARTICIPANTS

Minking K. Chyu, Department of Mechanical Engineering, University of Pittsburgh, Pittsburgh, PA 15261
(412) 624-9784
mkchyu@engr.pitt.edu

Tom I-P. Shih, Department of Aerospace Engineering, Iowa State University, 2271 Howe Hall, Rm 1200, Ames, IA 50011-2271,
(515) 294-6241
tomshih@iastate.edu

Tom George, National Energy Technology Laboratory, P O Box 880, 3610 Fort Collins Ferry Rd., Morgantown, WV 26507-0880
(304) 285-4825
tgeorge@netl.doe.gov

Richard Wenglarz, South Carolina Institute for Energy Studies, 386-2 College Ave., Clemson, SC 29634
(864) 656-2267
rwnglrz@clemson.edu

II. PROJET DESCRIPTION

A. Objectives

The main objective of this University Turbine System Research (UTSR) project is a combined experimental and computational effort to systematically explore the transport processes associated with film-hole partial blockage and surface deposits on the film cooling performance for various film-hole geometry. Information gained from this research will provide the turbine manufacturers with fundamental insight that can impact the future design of turbine airfoil cooling.

B. Background/Relevancy

Film cooling is one of the most effective cooling techniques for protecting turbine blade from thermal degradation imposed by the hot gas stream. However, film holes may be partially blocked due to either metallic-bond coating (MBC) or thermal barrier coating (TBC). Associated with these coating processes, surface non-uniformities may be created. In realistic turbine operation, film hole blockages are formed due to oxidation, deposits, corrosion, erosion, and foreign object damage. These effects combined roughen the airfoil surface overall, which, in turn, bring substantially higher heat load relative to the standard cases with smooth surfaces. While there have been recent studies concerning roughness on turbine surfaces, it is rather inconclusive if the deposit buildups, especially within the influencing domain of a film hole, are, in fact, detrimental or beneficial to the film cooling performance. With a coordinated experimental and computational approach, this project is to systematically explore the transport processes associated with film-hole partial blockage and surface deposits on the film cooling performance for various film-hole shapes. In addition, special focused will be directed to explore advanced concepts in transforming these surface phenomena into cooling enhancement effects. Spatially-resolved film effectiveness and heat transfer coefficient will be acquired using a state-of-the-art infrared imaging system. Knowledge gained from this research is expected to further advance the cooling technology for existing and future power generation turbine systems.

C. Period of Performance
August 1, 2004 – July 31, 2007

D. Project Summary
Under the University Turbine System Research (UTSR) program, the University of Pittsburgh (PITT) and Iowa State University (ISU) are jointly examine the effects of film-hole blockage and surface deposits on film cooling. The research team at the PITT will perform detailed film cooling measurements to quantify these effects. Computational researchers at ISU will develop optimal practice guidelines for CFD simulations of film cooling affected by partial blockage and realistic surface conditions. The experimental database will serve as a reference for validating the CFD simulation. The CFD efforts will complementarily provide important transport insight that is otherwise unattainable by experiments. The collective information gained from this research could further provide guidelines for advanced film cooling strategies, which includes modifying and optimizing hole shapes, better fuel filtration, and improved maintenance scheduling as well as specific clean-up procedures for future turbine engines.

PROJECT COSTS
$399,706

MAJOR ACCOMPLISHMENTS SINCE BEGINNING OF PROJECT

Experimental

- Studied the new film cooling concept of upstream-ramp
    - ✓ Single film cooling hole case
    - ✓ Mulitple-hole-row case
- Studied the new film cooling concept of flow-aligned-blocker
    - ✓ Single film cooling hole case

- ✓ Multiple-hole-row case
- Studied the film cooling concept of film cooling holes embedded in a trench or cavity. Multiple-hole-row case with both local film cooling effectiveness and heat transfer coefficient revealed by employing transient IR technique
- Comparison with corresponding computational results and exploring significant insight for further advances of the concept

Computational

- Performed 2-D and 3-D CFD simulations to examine the effects of TBC blockage and TBC roughness on film cooling effectiveness. Results of study was presented at the 2006 AIAA Aerospace Sciences Meeting, and the paper reference is as follows: Na, S., Cunha, F.J., Chyu, M.K., and Shih, T.I-P., "Effects of Coating Blockage and Deposit on Film Cooling Effectiveness and Surface Heat Transfer," AIAA Paper 2006-0024, January 2006.
- Performed CFD simulations to explore design paradigms to improve film-cooling effectiveness. Three new design concepts were developed and CFD simulations were performed to evaluate their usefulness. The three designs are (1) flow-aligned blockers placed downstream of film cooling holes to minimize the entrainment of hot gases underneath of film-cooling jets, (2) a ramp placed upstream of a row of film-cooling holes to modify approaching boundary-layer/film-cooling jet interaction in a way that enhances film-cooling effectiveness, and (3) a new shape-hole concepts that increases lateral spreading as well as penetration downstream of the hole. CFD results for the first two design concepts were presented at the 2006 IGTI conference, and the paper references are as follows: (a) Shih, T.I-P., Na, S., and Chyu, M.K., "Prevent Hot-Gas Entrainment by Film-Cooling Jets via Flow-Aligned Blockers," ASME Paper GT-2006-91161, IGTI Conference and Expo, Barcelona, Spain, May 8-11, 2006. and (b) Na, S. and Shih, T.I-P., "Increasing Film-Cooling Adiabatic Effectiveness by Using an Upstream Ramp," ASME Paper GT-2006-91163, IGTI Conference and Expo, Barcelona, Spain, May 8-11, 2006.

MAJOR ACTIVITIES PLANNED DURING THE NEXT SIX MONTHS

- Examine detailed film effectiveness and heat transfer with presence of surface deposits and advanced cooling concepts
- CFD simulation of film cooling with advanced concepts with realistic surface conditions

MAJOR ACCOMPLISHMENTS PLANNED IN OUTYEARS (6-18 MONTHS)

- Study the effects of TBC/MBC non-uniformities and surface roughness on film-cooling effectiveness and surface heat transfer for optimized film-cooling arrangement and advanced concepts over a range of density, mass, and momentum flux ratios
- Assess the capability of CFD in predicting film-cooling effectiveness and surface heat transfer applicable to experimental conditions.
- Develop best practice guidelines for CFD simulations of film cooling when there are non-uniformities in TBC/MBC near film-cooling holes and when there is

surface roughness, including complex film hole arrangements and enhancement concepts.

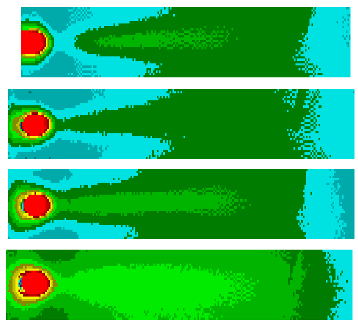
ISSUES

None

ATTACHMENTS

The Figure below shows an example of the influence of upstream ramp on the film cooling effectiveness. It is evident that upstream ramp provides notable protection for the area from immediate downstream of the ramp to the upstream edge of a film cooling hole.

M:1.36



No ramp, baseline case

α: 8.5°

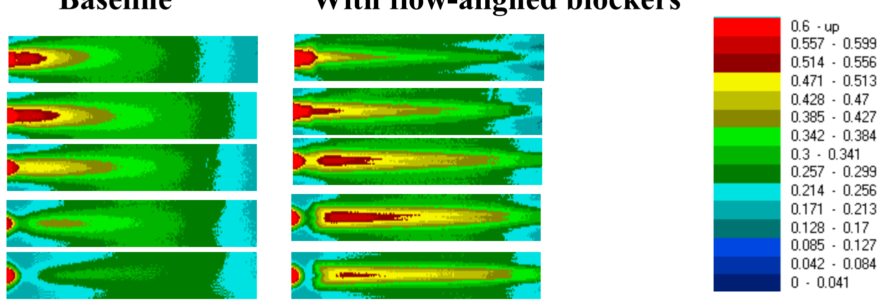
α: 15°

α: 24°

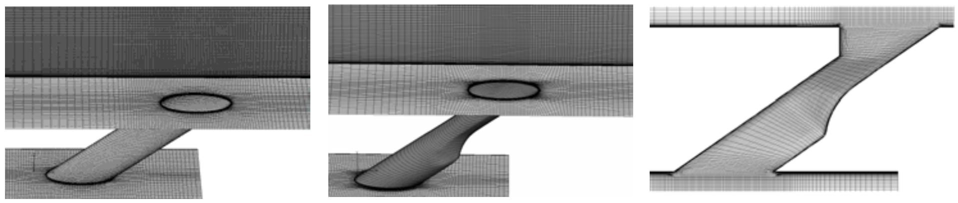
Also illustrated below is the effectiveness of using flow-aligned blocker to enhance the film cooling effectiveness. The increase in film cooling effectiveness is very evident.

M	Baseline	With flow-aligned blockers
0.29		
0.43		
0.57		
0.93		
1.36		

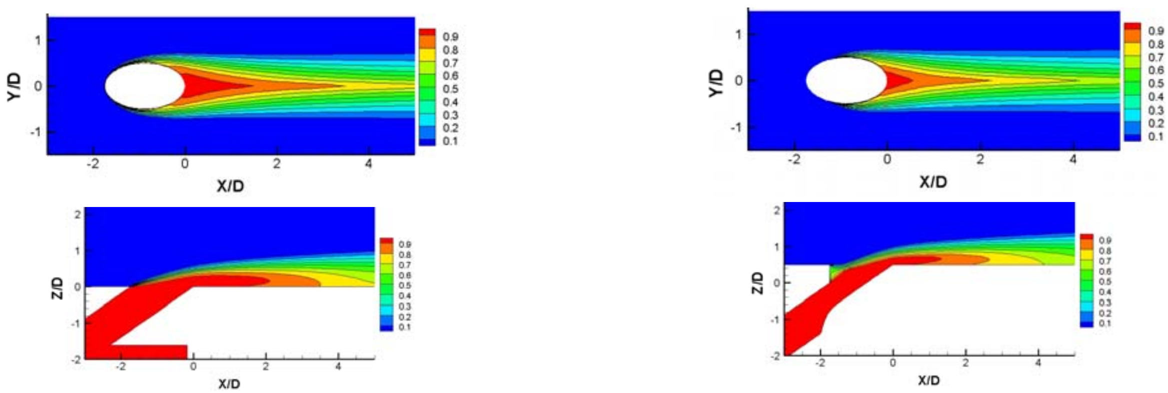
η



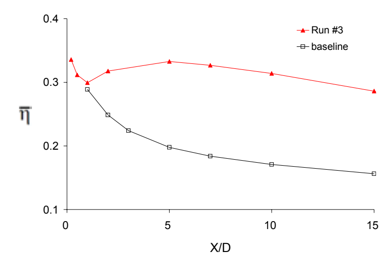
On the computational front, grid system for film cooling of a flat plate from one row of circular holes without TBC (left) and with TBC blockage (center and right).



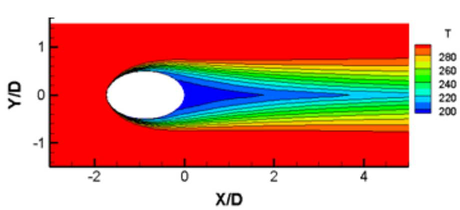
Predicted adiabatic effectiveness/normalized temperature on the flat plate and along a plane that passes through the center of the film-cooling hole at a blowing ratio (M) of 0.5 with (right) and without (left) TBC blockage. Note that with TBC blockage, the same pressure drop produces a higher blowing ratio. Thus, for a given M, the mass flow rate for the case without TBC is higher than the case with TBC.



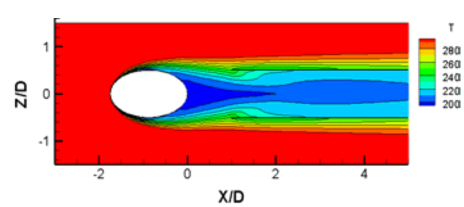
Design Concept: Flow-Aligned Blockers – Grid and Predicted Laterally Averaged (top) and Local (bottom) Adiabatic Effectiveness (red is with blockers; black is without blockers).



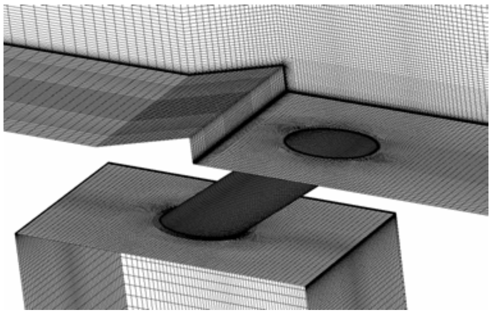
no blockers

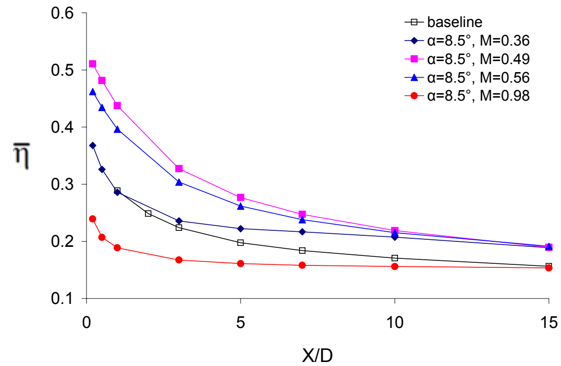


with blockers

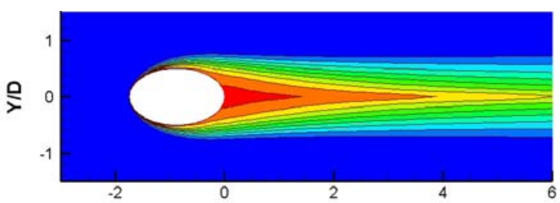


Design Concept: Upstream Ramp – Grid and Predicted Laterally Averaged (top) and Local (bottom) Adiabatic Effectiveness (red is with blockers; black is without blockers).





without ramp (M = 0.5)



with ramp (M = 0.5)