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FILM COOLING FROM A ROW OF INCLINED HOLES IN A TANGENTIAL SLOT

Mohammed S Altorairi
M.S. Candidate

Faculty Advisor: Dr. Srinath V Ekkad

ABSTRACT

Film cooling is widely used in gas turbine engines to reduce the temperature of hot components such as nozzle vanes and turbine blades. In film cooling, cooler air is injected through discrete holes on the blade surface to provide a protective coolant film on the outer blade surface. The holes are inclined along the streamwise direction at a relatively sharp angle (around 30^o) to provide high cooling effectiveness. Several studies have focused on the hole geometry of film cooling over flat surfaces with streamwise coolant injection. More recently, studies by Gritsch et al. [1], Ekkad et al. [2-3], Nasir et al. [4] presented results for various exit hole shape with no slot. Bunker et al [4] looked into the film cooling with emphasis on slot cooling. The current study is focused on effect of slot geometry on file effectiveness and heat transfer coefficient with the injection angle fixed at 35^o.

EXPERIMENTAL SET UP

In this study, heat transfer coefficient and film effectiveness distributions are investigated for a film cooling hole configuration that has inclined holes discharging into a tangential slot before interactions with the mainstream. The cylindrical holes are inclined 35-deg along the mainstream direction. The effect of coolant-to-mainstream blowing ratio is examined for M=0.5 and M=1.0. Different slot width to hole ratios and also the effect of hole exit condition (square edge and triangular edge) is considered. The mainstream velocity and free-stream turbulence intensity in the low speed wind tunnel are 9 m/s and 7% respectively and the mainstream Reynolds number based on hole diameter is around 7,100. The experiment was carried out in a low-speed wind tunnel setup with compressed air supply for coolant air. The test setup consists of a blower connected to a 12 kW heater that heats the air to a free-stream temperature of 58^{o}C. The air is then routed through a section with baffles to ensure adequate mixing of the hot air to obtain a uniform temperature across the cross-section. The bottom plate of the test section is made of 2.22-cm thick Plexiglas. This plate has a replaceable section about 25.4 cm downstream of the test section inlet for different hole geometry. The film holes are located 30.5 cm downstream of the trip. The coolant air is provided from a separate compressed air supply and is metered for flow measurement. The coolant air is then passed through a heater to heat up the air. Prior to the experiment, the hot air is routed away from the test section using a three-way diverter valve.

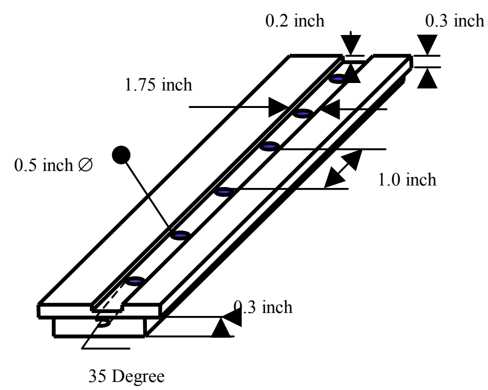

FIGURE 1. THE TEST PLAT GEOMETRY

Figure 1 shows the test plate geometry with inclined holes embedded in a transverse slot. The slot dimensions and exit geometry can be varied. The slot width is varied from ½ inch to 1.75 inch. The exit of the slot is also varied from square-edged to a more smoother slope-edged.

THEORY

The heat transfer measurements are obtained using a transient liquid crystal technique. The liquid crystal color changes were determined using an image processing system. The RGB camera is placed above the test section and is connected to the Color Frame Grabber board inside the computer. The frame grabber board is programmed through commercially available software to monitor the color change times of the liquid crystal coating. The software tracks the appearance of the green color at every pixel location during a sudden transient heating experiment.. Two similar tests are run to resolve the heat transfer coefficient and film effectiveness at every pixel location. An 8-channel A/D system is used for measuring the temperatures during the transient test.

The first test has the mainstream heated to 58-60^{o}C and the coolant heated slightly above room temperature. Both the flows are initially heated and routed away from the test section. The airflow is suddenly switched to start a transient heating of the liquid crystal coating. The image processing system and the temperature measurement system are triggered to start obtaining data at the same instant the flows are switched. The time of color change of each pixel location to change color to green since the initiation of the transient test is determined. The second test is run similarly with the coolant temperature heated to a temperature slightly above the mainstream temperature. The first test determines the film effectiveness and the second test determines the heat transfer coefficient at the same location using a simultaneous solver.

The generalized equation for the three-temperature problem using semi-infinite solid assumption and 1-D transient conduction model is given as :

$$T_w - T_i = [1 - \exp(\frac{h^2 \alpha t}{k^2}) \mathrm{erfc}(\frac{h\sqrt{\alpha t}}{k})][\eta T_c + (1-\eta) T_\infty - T_i]$$

Where T_w is the liquid crystal color change temperature (34.6^{o}C). The transient responses of the mainstream and coolant temperatures during the tests are incorporated using the Duhamels' superposition theorem. Subsequently, the two equations with different coolant temperatures and color change times are solved simultaneously to determine the local heat transfer coefficient and film effectiveness values at every single point on the test surface.

RESULTS

Figure 2 shows a sample of the obtained results for the film effectiveness (η) after processing the data. The image reflects these values from X=0.0 to X= 20d down stream the holes. The left figure represent the simple case, no slot, where cooler air is injected from holes on the test surface. The right figure is the result the test plat shown in figure 1. The air in this case is first introduced to a groove before emerging to the test surface (see figure 1). The coolant to mean stream blowing-ratio (M) is 1 in this case. Effectiveness is apparently improved for the square slot. The various colors are representation of the local value for η. For normal geometry, neglecting the noise, the maximum value for η was less 0.325 for 3X to 15X. That same η value (0.325) was the minimum achieved in the slot case.

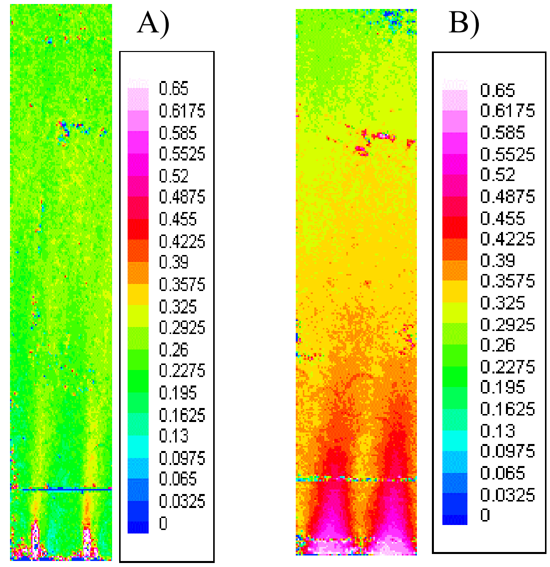

Figure
2.A) Effectiveness for M=1, normal geometry
2.B) Effectiveness for M=1, w/slot

ACKNOWLEDGMENTS

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REFERENCES

1. M. Gritsch, A. Schulz, S witting, 1997, “Adiabatic Wall Effectiveness Measurements of Film-Cooling Holes with Expanded Exits,” *International Gas turbine and Aeroengine Congress & Exhibition.*
2. Ekkad, S. V., Zapata, D., and Han, J. C., 1997, "Heat Transfer Coefficients Over a Flat Surface with Air and CO_2 Injection Through Compound Angle Holes Using a Transient Liquid Crystal Image Method," *ASME Journal of Turbomachinery*, **119**, pp. 580-586.
3. Ekkad, S. V., Zapata, D., and Han, J.C., 1997, "Film Effectiveness Over a Flat Surface with Air and CO_2 Injection Through Compound Angle Holes Using a Transient Liquid Crystal Image Method," *ASME Journal of Turbomachinery*, **119**, pp. 587-593.
4. Hasan N., Acharya S., Ekkad S. V., 2001, “Film Cooling From a Single Row of Cylindrical Angled Holes With Triangular Tabs Having Different Orientation”, *International Gas turbine and Aeroengine Congress & Exhibition.*
5. Ronald S. Bunker, 2001, “Film Cooling Effectiveness due to Discrete Holes Within transverse surface slot,” *International Gas turbine and Aeroengine Congress & Exhibition.*