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Experimental Investigation of Longitudinal Tabs Effects on Film-Cooling Effectiveness of Pea Shaped Holes in Gas Turbine Blades

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ABSTRACT: In this research, the film cooling effectiveness resulting from Pea-shaped holes equipped with the longitudinal tabs at the jet exit region are investigated experimentally applying the infrared thermography method. The measurements are performed at Re = 10000 (based on the free stream characteristics and the jet hole equivalent diameter) and the injection angle of 30˚ over the test plate applying the Pea-shaped jet holes. Several cases are investigated including three different tab heights (0.345D, 0.522D, 0.696D), three different distances between adjacent tabs (0.8D, 1D, 1.2D), and three different tab lengths (8D, 16D, 24D), in which, D is the equivalent diameter of the Pea-shaped hole. Blowing ratio effects are studied in four different cases of 0.4, 0.5, 0.7 and 0.8. The obtained results showed that the applied tabs, by controlling the injected jet flow, highly increase the film cooling effectiveness. At the best blowing ratio of each configuration, the cooling effectiveness averaged over the downstream region of the jet exit increases 44.4 percent for the holes equipped with the tabs, in comparison to the conventional holes. In fact, these tabs prevent the mixing of the hot gases with the cooling jets by controlling the counter-rotating vortices and restricting the cooling jet diffusion.

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1- Introduction

Modern gas turbines are designed to run at high turbine inlet temperatures well in excess of current metal temperature limits to improve thermal efficiency and power output. This enhancement is possible with advances in materials such as super alloys and thermal-barrier coatings and by advances in cooling technology such as internal, film, impingement, and other cooling techniques [1]. By cooling, the turbine inlet temperature can far exceed the allowable material temperature. Although cooling is an effective way to increase the turbine inlet temperature, efficiency considerations require effective cooling to be accomplished applying minimal amount of cooling air; because the injection of cooling air into a high pressure turbine system takes a lot of energy [2]. In the film cooling method, the holes are designed in such a way that by injection of air, a relatively cool insulation layer forms near the surface of the blade. So far, numerous studies have been carried out about the film cooling effectiveness for single and/or multi-row cylindrical holes over a flat plate, a curved plate and a cascade, applying either numerical or experimental methods. Film cooling can be improved in different ways such as jet hole cross-section and its channel configuration improvement, multiple injection configuration, and extending the jet hole outlet [3, 4].

In this study, in order to more improve the cooling efficiency of the pea shaped hole, a novel combination of jet hole extension having downstream tabs has been created. In fact, this study represents the first experimental study to examine the idea of placing flow aligned tabs at the downstream of the Pea shaped holes to control the jet and mainstream flows mixing.

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2- Methodology

In this paper, the closed circuit wind tunnel of the Shahid Sattari aeronautical university of science & technology is used to measure the film cooling effectiveness of Pea shape holes equipped with downstream longitudinal tabs. Also, surface temperature measurement was performed by the infrared imaging technique using the FLIR C2 thermal camera. At all tests, the main stream speed was 27 m/s. In order to warm the injected air of the compressor, the 2 kW cylindrical heater which could be controlled by a digital temperature control is applied. In all the experiments, the temperature difference between the main flow and the jet flow was set to be 20.3°C.

In Fig. 1, a view of the test plate which is used for the investigation of a row of seven injected jets into a cross flow applying longitudinal tabs in the jet downstream is shown. More

Fig. 1. A view of the test plate having a row of seven injected jets over the surface and its corresponding longitudinal tabs

details of the pea shaped geometry are given in reference [5].

It should be noted that total uncertainty of the experiments at 0<X/D<15 for a value of ηmeas=0.9 is obtained to be 2.02%, while for a value of ηmeas=0.2, the calculated total uncertainty is 9.7%.

3- Results and Discussion

In order to validate the obtained results of this study, the measured adiabatic cooling efficiency for cylindrical holes was compared with that of previous studies (Fig. 2). Validation was performed applying various experimental studies presented by Dhungel et al. [6], Lawson and Thole [7] and others. The comparisons have shown good agreements, which indicates the accuracy of the test method and the obtained results.

Based on the results obtained from different tab design investigations, the geometry of the design 2, which has the best performance, has been chosen to compare with the no-tab design case. In Fig. 3, the difference between the efficiency of the no-tab design holes and design 2 is quite evident. In other words, in all four blowing ratios studied here, for geometry which has longitudinal tabs, the cooling jet affects all the downstream region and has higher effectiveness. Therefore, the design of longitudinal tabs shows a better distribution of the cooling efficiency of the coolant jet.

As shown in Fig. 4, the most area averaged cooling effectiveness is obtained for a no-tab design, at the blowing ratio of 0.7, and while applying the aligning tabs, the optimum blowing ratio is 0.5. The percentage increase in the area averaged cooling effectiveness for each geometry in its optimal blowing ratio is about 41.4%. Therefore, applying a lower amount of cooling air, a better coolant distribution could be created in the lateral and axial directions.

4- Conclusions

In this experimental study, the idea of using flow-aligned longitudinal tabs for the Pea holes is presented. Effects of

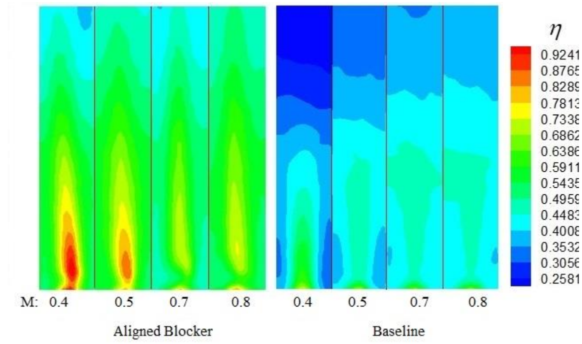

Fig. 3. Distribution of the film cooling effectiveness on the adiabatic wall using infrared thermography for no-tab holes and design 2 in different blowing ratios

three different parameters including the distance between the tabs, height of the tabs and length of the tabs in seven different designs and four blowing ratios have been investigated. The most important results which obtained are:

- Applying the tabs are very effective in preventing the hot gas ingestion by film cooling jets and can increase the film cooling effectiveness by limiting the cooling flow between the tabs. Thus, using the aligning tabs, the film cooling effectiveness increases at all of the blowing ratios.
- Among different designs which were studied, the second design which its height, thickness, and length to diameter ratios are 0.522D, D, and 24D, respectively, has the most centerline and laterally averaged film cooling effectiveness.
- Comparison of the results of the second design with that of the no-tab design showed that at the blowing ratio of 0.4, the centerline and laterally averaged film cooling effectiveness were increased by 83% and 73.8%, respectively.

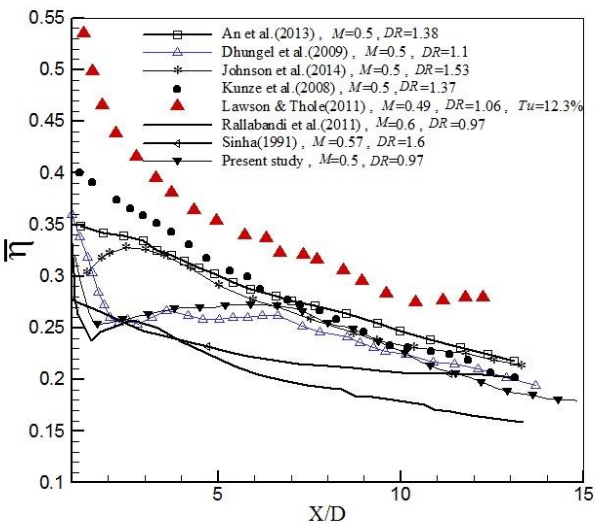

Fig. 2. Comparison of laterally averaged film cooling effectiveness of the present study with that of published in the previous studies at blowing ratio of 0.5

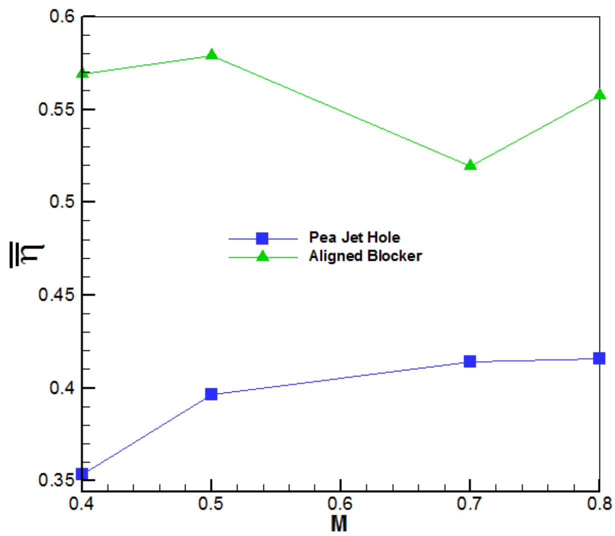

Fig. 4. Comparison of total moment vs. azimuth angle for starting mode

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