ANALYSIS ON THE EFFECT OF TRENCH GEOMETRY ON FILM COOLING EFFECTIVENESS OF SHAPED HOLES USING RANS SIMULATION

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Degree of Master of Engineering

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Thesis submitted in partial fulfillment of the requirements for the degree of Master of Engineering in Mechanical Engineering

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Name of the supervisor: Dr. R. A. C. P. Ranasinghe

Signature of the supervisor: Date:

Abstract

Diffused shaped holes have shown superior cooling performance over the other shapes of holes in many situations. In the present study, numerical simulation using realizable k-ε model with enhanced wall treatments as implemented in Ansys Fluent solver was performed to study the effect of trench geometry made at 7-7-7 shaped hole exit on cooling effectiveness. The predictions were generated at different depth ratios of the trench geometry. Three different blowing ratios of M = 1.5, 3, and 5 were employed with different depth ratios of h/D = 0.25, 0.5, and 1. Altogether nine cases were run to generate predictions and three cases without trench, h/D = 0, at different blowing ratios of M = 1.5, 3, and 5 were run as the baseline. All cases were maintained at density ratio of DR = 1.5 and turbulence intensity or Tu = 0.5%.

Based on the error analyses and the comparisons performed to flow field patterns and cooling effectiveness variations during the validation, the realizable k-ε model with enhanced wall treatment was selected among standard k-ω, SST k-ω and realizable k-ε for predictions. When compared to the baseline, not only the modified geometry presents better cooling effectiveness according to the laterally averaged effectiveness, but superior lateral spreading of coolant can also be observed at higher depth ratio of trench. Maintaining higher blowing ratios at lower slot depth ratio such as h/D = 0.25 is only a waste of coolant without improvements to cooling effectiveness while higher cooling effectiveness can be obtained by higher blowing ratios at higher trench depth ratios. Based on the laterally averaged effectiveness, the cooling effectiveness is improved by increasing the trench depth at all blowing ratios investigated. Based on the lateral effectiveness variations, the coolant jet has shown a skewness at higher blowing ratios and lower trench depth ratios while the skewness becomes invisible at lower blowing ratios and lower trench depths. A steeper decay can be observed in laterally averaged effectiveness at high blowing ratios (M = 5) and low slot depth ratios (h/D = 0.25) due to the jet penetration into mainstream thereby degrading the cooling performance.

Key words: *cooling effectiveness, film cooling, shaped hole, trench geometry, turbulence modeling*

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Thank You,

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Symbols and Abbreviations

Symbols

A	Hole cross-sectional area
AR	Area ratio, A_{exit}/A_{inlet}
D	Film cooling hole diameter
M	Blowing ration, $\rho_c U_c/\rho_\infty U_\infty$
DR	Density ratio, ρ_c/ρ_∞
h	Depth of trench
k	Turbulent kinetic energy
L	Hole length
P	Lateral distance between holes, pitch
R	Radius of diffused outlet interior edges
t	Hole breakout width
Tu	Free-stream turbulence
T	Temperature
α	Injection angle of film hole
β_{fwd}	Laidback angle for diffused outlet
β_{lat}	Lateral expansion of film hole
ε	Turbulence dissipation rate
γ	Specific heat ratio
ω	Specific turbulence dissipation rate
η	Adiabatic film cooling effectiveness, $(T_\infty - T_{aw})/(T_\infty - T_c)$
η_{th}	Thermal efficiency
x	Downstream distance measured from the hole exit
y	Vertical distance from the surface
z	Lateral distance measured from center line

Subscripts

aw	Adiabatic wall
c	Coolant at hole inlet
f	With film cooling
w	Wall
0	Without film cooling
∞	Free-stream

Abbreviation

CRVP	Counter Rotating Vortex Pair
LES	Large Eddy Simulation
RANS	Reynolds Averaged Navier Ststokes
RKE	Realizable k-ε
RSM	Reynolds Stress Models
STW	Standard k-ω
SST KW	Shear Stress Transport k-ω
URANS	Unsteady Reynolds Averaged Navier Ststokes
RMSE	Root-Mean Squared Error