

**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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University of Moratuwa

Sri Lanka

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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

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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 $M = 1.5, 3, \text{ and } 5$ were employed with different depth ratios of $h/D = 0.25, 0.5, \text{ and } 1$. Altogether nine cases were run to generate predictions and three cases without trench, $h/D = 0$, at different blowing ratios of $M = 1.5, 3, \text{ and } 5$ 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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Table of Contents

1	Introduction.....	1
1.1	Turbine blade cooling.....	2
1.2	Film cooling	4
1.3	Film cooling analysis.....	5
1.4	Scope of the research.....	6
1.5	Aim and Objectives	7
1.6	Outline of the thesis.....	7
2	Literature Review	9
2.1	Cooling performance of shaped Holes	9
2.2	Flow field with shaped hole	18
2.3	Numerical studies – RANS simulations.....	25
3	Methodology.....	33
3.1	Geometry of Computational Domain	33
3.2	Computational mesh with boundary conditions	36
3.3	Numerical Simulation.....	39
3.4	Important parameters of film cooling analysis	41
3.5	Important parameters of error analysis.....	41
3.6	Turbulence model – Realizable k- ϵ	42
3.6.1	Model equations for k and ϵ	43
3.6.2	Modeling turbulent viscosity.....	43
3.6.3	Two layer model in enhanced wall treatment	45
4	Results and Discussion	46
4.1	Validation	46
4.1.1	Velocity distribution in cross flow.....	46
4.1.1.1	Error analysis of velocity profiles.....	50

4.1.2	Film cooling effectiveness distribution.....	51
4.1.2.1	Error analysis of film cooling effectiveness	58
4.1.3	Comparison with LES results.....	59
4.2	Cooling performance of shaped hole with trench	62
4.3	Mean flow field	83
5	Conclusion	88
5.1	Validation	88
5.2	Cooling performance of shaped hole with trench	89
5.3	Significance and recommendations for future work	90
6	References.....	92

List of Figures

Figure 1-1: Turbine power output as a function of the turbine inlet temperature [1] ..	1
Figure 1-2: Ideal Brayton Cycle [3]	2
Figure 1-3: Turbine inlet temperature over the years [1]	3
Figure 1-4: Schematic illustration of different cooling techniques	4
Figure 2-1: Basic hole designs [13]	10
Figure 2-2: Two-dimensional film cooling geometries (a) porous slot (b) tangential injection (c) slot angled to mainstream [6]	10
Figure 2-3: Local film cooling effectiveness of cylindrical and fan-shaped holes at low and high blowing rates [20]	12
Figure 2-4: Schematic representation of flow phenomena typically seen in shaped holes [20]	12
Figure 2-5: Laterally averaged film cooling effectiveness (left) and related heat transfer coefficients (right) [20]	13
Figure 2-6: Local film cooling effectiveness for the cylindrical, fan-shaped, and laid-back fan-shaped hole [21]	13
Figure 2-7: Local lateral effectiveness, η for the three holes [21]	14
Figure 2-8: Effect of blowing ratio (M) on laterally averaged effectiveness η for the three holes [21]	15
Figure 2-9: Adiabatic effectiveness contours at $DR = 1.5$ and turbulence intensity of 0.5% [25]	16
Figure 2-10: Contours of time-mean stream-wise velocity and streamline on centerline plane for $DR = 1.5$, $Tu = 0.5\%$ [25]	16
Figure 2-11: 7-7-7 shaped hole centerline effectiveness at $DR = 1.5$ and free stream turbulence of 0.5% [24]	17
Figure 2-12: 7-7-7 shaped hole laterally averaged effectiveness at $DR = 1.5$ and free stream turbulence of 0.5% [24]	17
Figure 2-13: Counter rotating vortex pair within cylindrical film hole [27]	18

Figure 2-14: Basic flow structure in jet-cross flow interaction for cylindrical hole [34]	19
Figure 2-15: Vorticity magnitude ω_z of the jet (a) windward side (b) lee side (Case I) [37].....	20
Figure 2-16: Vorticity magnitude ω_z of the jet (a) windward side (b) lee side (Case II) [37].....	20
Figure 2-17: Counter rotating vortex pair (or kidney vortices) [38].....	21
Figure 2-18: Anti-kidney vortices [38].....	21
Figure 2-19: Double deck structure for low aspect ratio [38].....	22
Figure 2-20: Double deck structure for high aspect ratio [38].....	22
Figure 2-21: Contours of mean stream-wise velocity in the $x/D = 4$ cross-plane for DR = 1.5 and free stream turbulence of 0.5% [25].....	23
Figure 2-22: Local effectiveness variation with expansion angles at different blowing ratios [13].....	23
Figure 2-23: Cylindrical film hole in a trench [12].....	24
Figure 2-24: Effectiveness and streamlines on the selected planes at $M = 1.0$ [11]..	24
Figure 2-25: Time-averaged effectiveness for trenched holes at $M = 0.5$ and $M = 1.0$ [11].....	25
Figure 2-26: Computational domain and boundary conditions for the new scheme [42]	26
Figure 2-27: Jet skewness present in experimental test case [41].....	27
Figure 2-28: Centerline adiabatic effectiveness adjusted with skewness [41].....	27
Figure 2-29: Laterally averaged effectiveness predicted by the turbulence models and experimental results for $M=0.5$ [40].....	28
Figure 2-30: Centerline effectiveness predicted by the turbulence models and experimental results for $M=0.5$ [40].....	28
Figure 3-1: Design of Shaped Hole [24].....	33
Figure 3-2: Geometry of the computational domain.....	34

Figure 3-3: Experimental set-up [24].....	35
Figure 3-4: Coordinate directions for the computational domain.....	35
Figure 3-5: Mesh sensitivity analysis.....	36
Figure 3-6: 3D computational domain for validation	36
Figure 3-7: Turbulent boundary layers measured at $x/D = -4.7$, with and without the upstream turbulence grid [24]	37
Figure 3-8: Profiles of streamwise velocity fluctuation at $x/D = -4.7$, with and without the upstream turbulence grid [24]	37
Figure 3-9: Boundary conditions	38
Figure 3-10: 3D geometry of computational domain with trench.....	38
Figure 3-11: 3D computational mesh of shaped hole with trench	39
Figure 4-1: Streamwise velocity profiles in the centerline plane at $X/D = -2.4$ for $M = 3$, $DR = 1.5$, and $Tu = 0.5\%$	46
Figure 4-2: Streamwise velocity profiles in the centerline plane at $X/D = -0.4$ for $M = 3$, $DR = 1.5$, and $Tu = 0.5\%$	47
Figure 4-3: Streamwise velocity profiles in the centerline plane at $X/D = 1.6$ for $M = 3$, $DR = 1.5$, and $Tu = 0.5\%$	47
Figure 4-4: Streamwise velocity profiles in the centerline plane at $X/D = -2.4$ for $M = 1.5$, $DR = 1.5$, and $Tu = 0.5\%$	48
Figure 4-5: Streamwise velocity profiles in the centerline plane at $X/D = -0.4$ for $M = 1.5$, $DR = 1.5$, and $Tu = 0.5\%$	48
Figure 4-6: Streamwise velocity profiles in the centerline plane at $X/D = 1.6$ for $M = 1.5$, $DR = 1.5$, and $Tu = 0.5\%$	49
Figure 4-7: Contour of turbulent shear stress in the centerline plane for (a) $M = 1.5$	49
Figure 4-8: Laterally averaged film cooling effectiveness for $M = 3$	52
Figure 4-9: Lateral film cooling effectiveness at $x/D = 5$ for $M = 3$	52
Figure 4-10: Lateral film cooling effectiveness at $x/D = 30$ for $M = 3$	53

Figure 4-11: Contour plots of cooling effectiveness (a), (b), (c) and velocity (d), (e), (f) at $x/D = 5$ for $M = 3$	54
Figure 4-12: Film cooling effectiveness distributions on flat surface for $M = 3$	54
Figure 4-13: Centerline film cooling effectiveness for $M = 3$	55
Figure 4-14: Laterally averaged film cooling effectiveness for $M = 1.5$	56
Figure 4-15: Lateral film cooling effectiveness at $x/D = 5$ for $M = 1.5$	56
Figure 4-16: Lateral film cooling effectiveness at $x/D = 30$ for $M = 1.5$	57
Figure 4-17: Centerline film cooling effectiveness for $M = 1.5$	57
Figure 4-18: Local film cooling effectiveness in lateral direction at $x/D = 0$ for $M = 3$	60
Figure 4-19: Local film cooling effectiveness in lateral direction at $x/D = 10$ for $M = 3$	61
Figure 4-20: Local film cooling effectiveness in lateral direction at $x/D = 0$	61
Figure 4-21: Local film cooling effectiveness in lateral direction at $x/D = 10$	62
Figure 4-22: Laterally averaged effectiveness of $h/D = 0$	63
Figure 4-23: Laterally averaged effectiveness of $h/D = 0.25$	63
Figure 4-24: Laterally averaged effectiveness of $h/D = 0.5$	64
Figure 4-25: Laterally averaged effectiveness of $h/D = 1$	64
Figure 4-26: Laterally averaged effectiveness of $M = 1.5$	65
Figure 4-27: Laterally averaged effectiveness of $M = 3$	66
Figure 4-28: Laterally averaged effectiveness of $M = 5$	66
Figure 4-29: Streamwise velocity and cooling effectiveness for $M = 5$ and $h/D = 0.25$ at different streamwise locations	67
Figure 4-30: Local effectiveness in lateral direction, $h/D = 0$ at $x/D = 5$	68
Figure 4-31: Local effectiveness in lateral direction, $h/D = 0$ at $x/D = 30$	69
Figure 4-32: Local effectiveness in lateral direction, $h/D = 0.25$ at $x/D = 5$	69
Figure 4-33: Local effectiveness in lateral direction, $h/D = 0.25$ at $x/D = 30$	70

Figure 4-34: Local effectiveness in lateral direction, $h/D = 0.5$ at $x/D = 5$	70
Figure 4-35: Local effectiveness in lateral direction, $h/D = 0.5$ at $x/D = 30$	71
Figure 4-36: Local effectiveness in lateral direction, $h/D = 1$ at $x/D = 5$	71
Figure 4-37: Local effectiveness in lateral direction, $h/D = 1$ at $x/D = 30$	72
Figure 4-38: Local effectiveness in lateral direction, $M = 1.5$ at $x/D = 5$	73
Figure 4-39: Local effectiveness in lateral direction, $M = 1.5$ at $x/D = 30$	73
Figure 4-40: Local effectiveness in lateral direction, $M = 3$ at $x/D = 5$	74
Figure 4-41: Local effectiveness in lateral direction, $M = 3$ at $x/D = 30$	74
Figure 4-42: Local effectiveness in lateral direction, $M = 5$ at $x/D = 5$	75
Figure 4-43: Local effectiveness in lateral direction, $M = 5$ at $x/D = 30$	75
Figure 4-44: Local effectiveness contours of $M = 3$ at various slot depths	76
Figure 4-45: Velocity contours of $h/D = 0.25$ on in-trench planes of (a), (b), (c) and in-hole planes of (d), (e), (f)	77
Figure 4-46: Local effectiveness along centerline, $M = 1.5$	78
Figure 4-47: Local effectiveness along centerline, $M = 3$	78
Figure 4-48: Local effectiveness along centerline, $M = 5$	79
Figure 4-49: Local effectiveness along centerline, $h/D = 0$	79
Figure 4-50: Local effectiveness along centerline, $h/D = 0.25$	80
Figure 4-51: Local effectiveness along centerline, $h/D = 0.5$	80
Figure 4-52: Local effectiveness along centerline, $h/D = 1$	81
Figure 4-53: Local effectiveness contours of $M = 5$ at various slot depths	81
Figure 4-54: Local adiabatic effectiveness contours of $M = 1.5$ at various slot depths	82
Figure 4-55: Specific flow phenomena in shaped film holes.....	83
Figure 4-56: Jetting effect at $M = 3$ with different sloth depths	84

Figure 4-57: Streamwise velocity contours on $x/D = 1.6$ cross plane for $DR = 1.5$ and $Tu = 0.5\%$ (a) experimental results [25] (b) present study	84
Figure 4-58: Velocity vector plots at different streamwise locations for $M = 3$ and $h/D = 1$	85
Figure 4-59: For $M = 3$ and $h/D = 1$ at $X/D = 5$ (a) Vortex pairs (b) Vorticity in X direction.....	86
Figure 4-60: Variation of Vorticity in X direction along $Y/D = 0.25$ line at $X/D = 5$ for $M = 3$	86
Figure 4-61: Streamwise velocity and velocity vectors at $x/D = 5$ for $M = 3$	87

List of Tables

Table 2-1: A summary of numerical simulation studies	29
Table 3-1: Geometric Parameters for 7-7-7 shaped hole [24].....	34
Table 3-2: Number of cases for validation.....	40
Table 3-3: Number of cases for predictions for trench geometry	40
Table 4-1: Error analysis of velocity predictions	50
Table 4-2: R-Square values for each turbulence model.....	51
Table 4-3: Error analysis of laterally averaged effectiveness	58
Table 4-4: Error analysis of centerline effectiveness.....	58
Table 4-5: R-Square values for each turbulence model.....	59

Symbols and Abbreviations

Symbols

A	Hole cross-sectional area
AR	Area ratio, $A_{\text{exit}}/A_{\text{inlet}}$
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, $(T_\infty - T_{\text{aw}})/(T_\infty - T_c)$
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