FOSSEE Fellowship Report
on

FILM COOLING ON A FLAT PLATE BY AIR-WATER MIST INJECTION

Submitted by
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Contents

Nomenclature

s	Slot height, m
d_w	Water droplet diameter, m
$q^{//}$	Heat flux, W/m^2
U	Velocity, m/s
T_h	Temperature of hot gas, K
T_c	Temperature of coolant, K
T_f	Temperature after coolant injection, K
N	Phase
I	Mass transfer rate, kg/s
i, j, k	Indices
g	Gravitational acceleration, m/s^2
F	Interactive force per unit volume, N/m^3
p	Pressure, Pa
Q	Rate of heat transfer per unit mass, W/kg
W	Rate of work done per unit mass, J/kg
e*	Total internal energy per unit mass, J/kg
C_p	Specific heat capacity at constant pressure, J/kg.K
Pr	Prandtl number

Greek Symbols

θ	Secondary coolant injection angle, ^{0}
α	Volume fraction
μ	Dynamic viscosity, Pa.sec
σ_c	Phase stress tensor, Pa
ξ	Energy interaction term

Notations

$\delta/\delta t$	Partial time derivative
$\delta/\delta x$	Partial positional derivative

Chapter1

Introduction and Problem Statement

1.1. Introduction

Film cooling is mainly used in gas-turbine operation. A low-temperature secondary fluid is injected to the surface exposed to high temperature gas. The coolant fluid forms a film over the surface and protects it from the hot gas [1]. This process is known as film cooling.

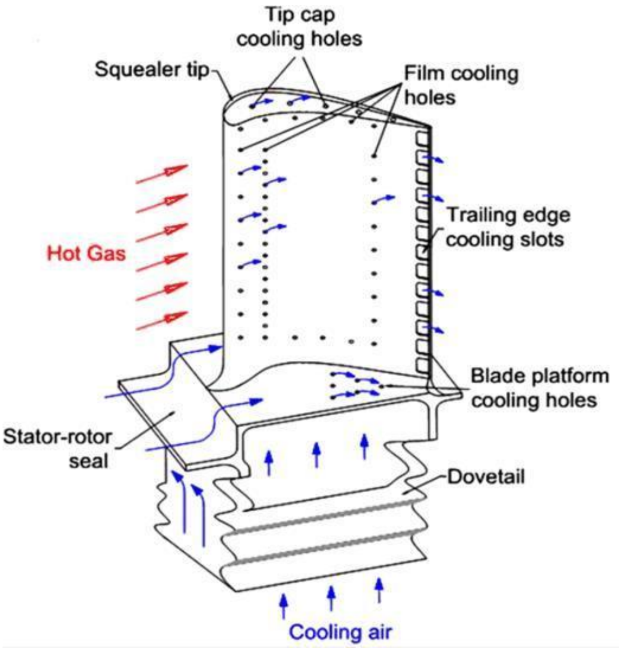

Figure 1.1(a). Film cooling in a gas turbine blade [2]

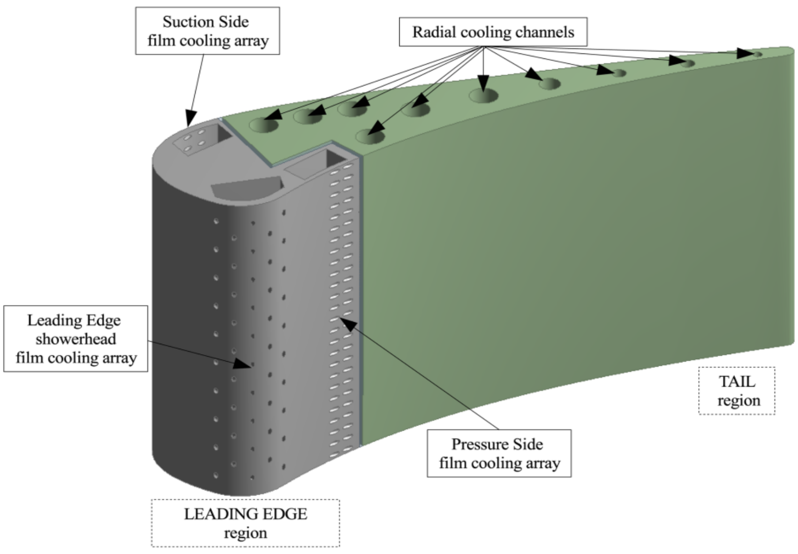

Figure 1.1(b). Cad model of film cooling holes in turbine blade [3]

1.2. Problem Statement

A film cooling problem on a flat surface was simulated by using a 2D model. The secondary hole was assumed as slotted hole with height 4 mm. The temperature of main stream fluid air, T_g and the secondary fluid air-water mist, T_c were 400K and 300K respectively. Secondary coolant fluid was injected at 35^0. Main stream velocity, U_g= 10 m/sec and U_c= 10 m/sec. The simulations were carried out for mist loading fraction, f = 2%, 5%, 15% and 25%. thermalPhaseChange phase model was implemented to capture the phase change due to temperature. A multiphase solver reactingMultiphaseEulerFoam was used to study the problem [4]. The detailing of the geometry was shown clearly in the Figure1.2.

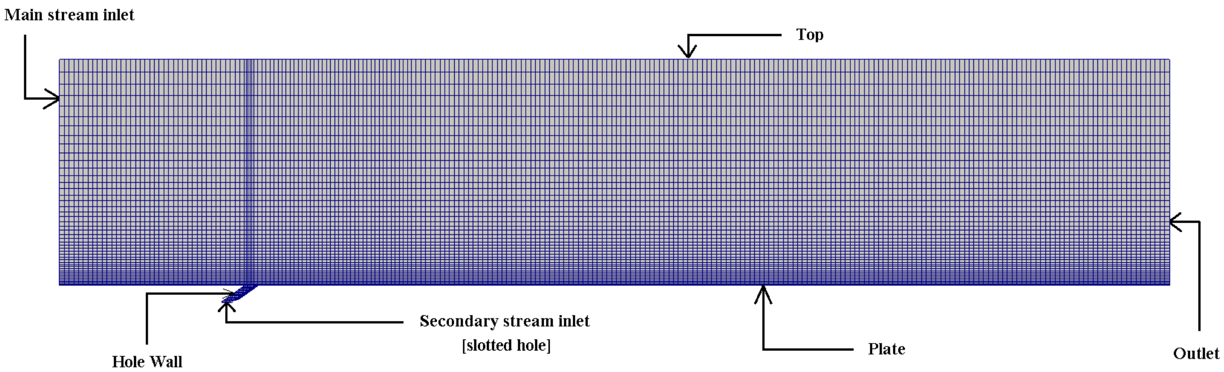

Figure 1.2. 2D Grid

Table 1. Geometry and Computational Details

Parameter	***Detail***
Model	2 Dimensional
Geometry-Mesh creating software	ICEM CFD
Number of cells	11,699
Post-processing tool	Paraview, Sigma Plot
Solver	reactingMultiphaseEulerFoam
Turbulence model	Standard $k-\epsilon$
Pressure-velocity coupling	PIMPLE algorithm [4]
Convective term solving scheme	Gauss upwind [4]
Turbulent term solving scheme	Gauss upwind [4]

Table 2. Fluid properties and initial conditions

Parameter	***Value/Condition***
μ_{water}	3.645e-05 Pa.sec
$(C_p)_{water}$	4195 J/kgK
Pr_{water}	2.289
s	0.004 m
θ	35^0
$q^{//}$	0 W/m^2
T_h	400 K
T_c	300 K
U_h (Hot)	10 m/sec
U_{air} (Coolant)	10 m/sec
U_{water} (Coolant)	0.6 m/sec

Chapter2

Equations

2.1. Individual Phase Continuity Equation [5]

$$\frac{\partial}{\partial t}(\rho_N \alpha_N) + \frac{\partial}{\partial x_i}\left(\rho_N \alpha_N U_{N_i}\right) = I_N$$

2.2. Individual Phase Momentum Equation [5]

$$\frac{\partial}{\partial t}\left(\rho_N \alpha_N U_{N_k}\right) + \frac{\partial}{\partial x_i}\left(\rho_N \alpha_N U_{N_i} U_{N_k}\right) = \alpha_N \rho_N g_k + F_{N_k} - \delta_N\{\frac{\partial p}{\partial x_k} - \frac{\partial \sigma^D{}_{C_{ki}}}{\partial x_i})$$

2.3. Individual Phase Energy Equation [5]

$$\frac{\partial}{\partial t}(\rho_N \alpha_N e^*{}_N) + \frac{\partial}{\partial x_i}\left(\rho_N \alpha_N e^*{}_N U_{N_i}\right) = Q_N + W_N + \xi_N - \delta_N \frac{\partial}{\partial x_j}(U_{C_i} \sigma_{C_{ij}})$$

2.4. Effectiveness

$$\eta = \frac{T_h - T_f}{T_h - T_c}$$

Chapter3

Results and Discussion

3.1. Validation

The effectiveness was found out over flat plate from the secondary inlet position. Then the outcomes were validated with the numerical work of Li and Wang [6].

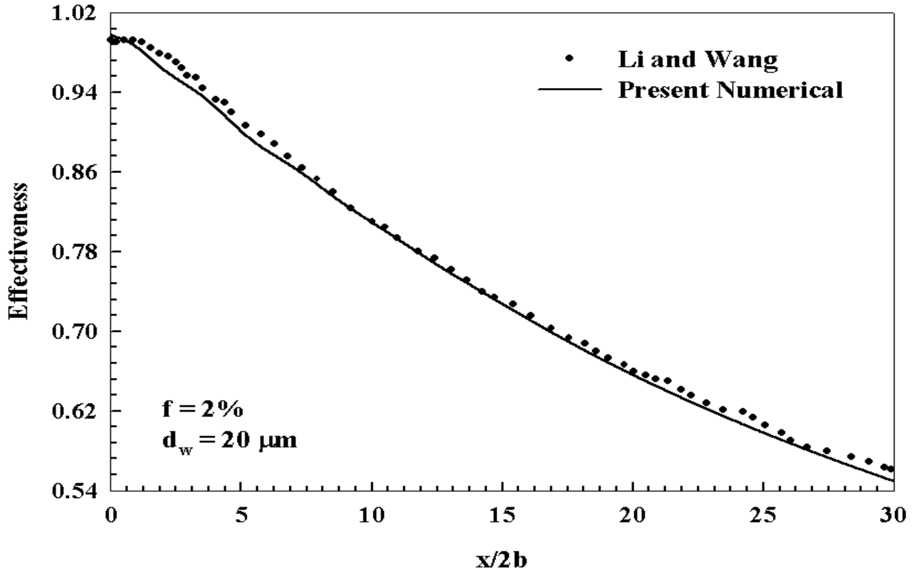

Figure 1.3. Validation

3.2. Comparison Between Results of Air and Air-Water Mist as Coolant

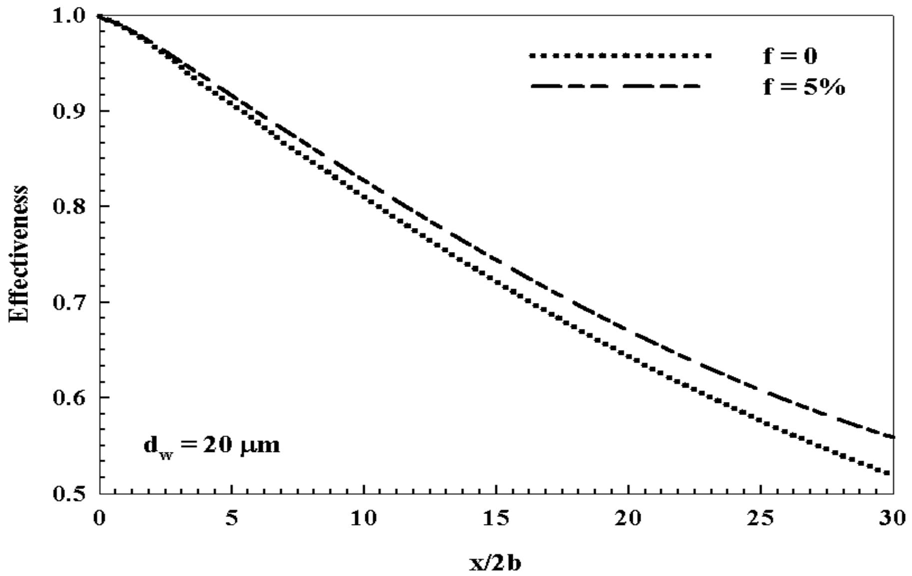

Figure 1.4. Comparison of Effectiveness for No Mist (f = 0) and Mist Injection (f = 5%)

3.3. Contours

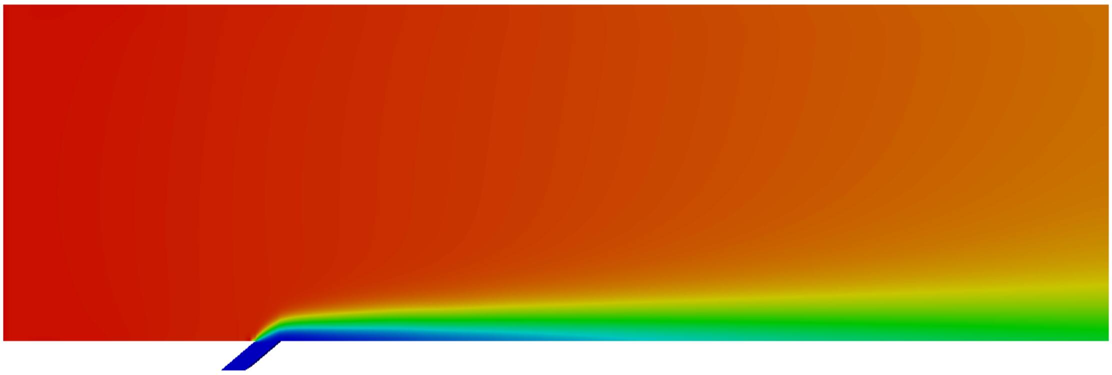

Figure 1.5. Temperature contour (f = 0)

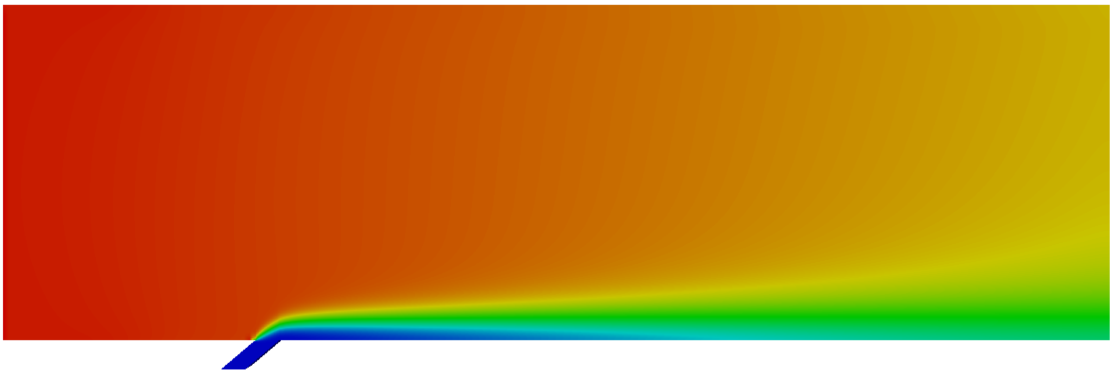

Figure 1.6. Temperature contour (f = 5%)

3.4. Conclusion

From the numerical works we can conclude that the injection of mist protects the flat surface from hot gases better than the air injection system.

Reference

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