FOSSEE Fellowship Report
on

DUST PARTICLES TRACKING INSIDE A MODEL ROOM

Submitted by

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Under the guidance of

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July, 2019

Acknowledgment

I would like to express my sincere gratitude to Prof. Shivasubramanian Gopalakrishnan for his guidance. I deeply thank Prof. Kannan M Moudgalya for starting the fellowship program and providing the project work opportunity at FOSSEE, IIT Bombay.

In addition, I am thankful to Sathish Kanniappan, research associate, FOSSEE and Deepa Vedartham, research assistant, FOSSEE for their mentorship and help during my fellowship.

Contents

Nomenclature

U	Velocity, m/s
g	Gravitational acceleration, m/s^2
F_{Drag}	Drag force, N
P	Pressure, Pa
V_p	Volume of the particle

Greek Symbols

α	Particle volume fraction
ρ	Particle density, kg/m^3
τ	stress tensor, Pa

Chapter1

Introduction and Problem Statement

Dust particle parcels driven by air inside a room was simulated using a Lagrangian solver DPMFoam [1]. The 2D geometry of the problem can be seen in the Figure 1.1. The other computational details are given in the following tables.

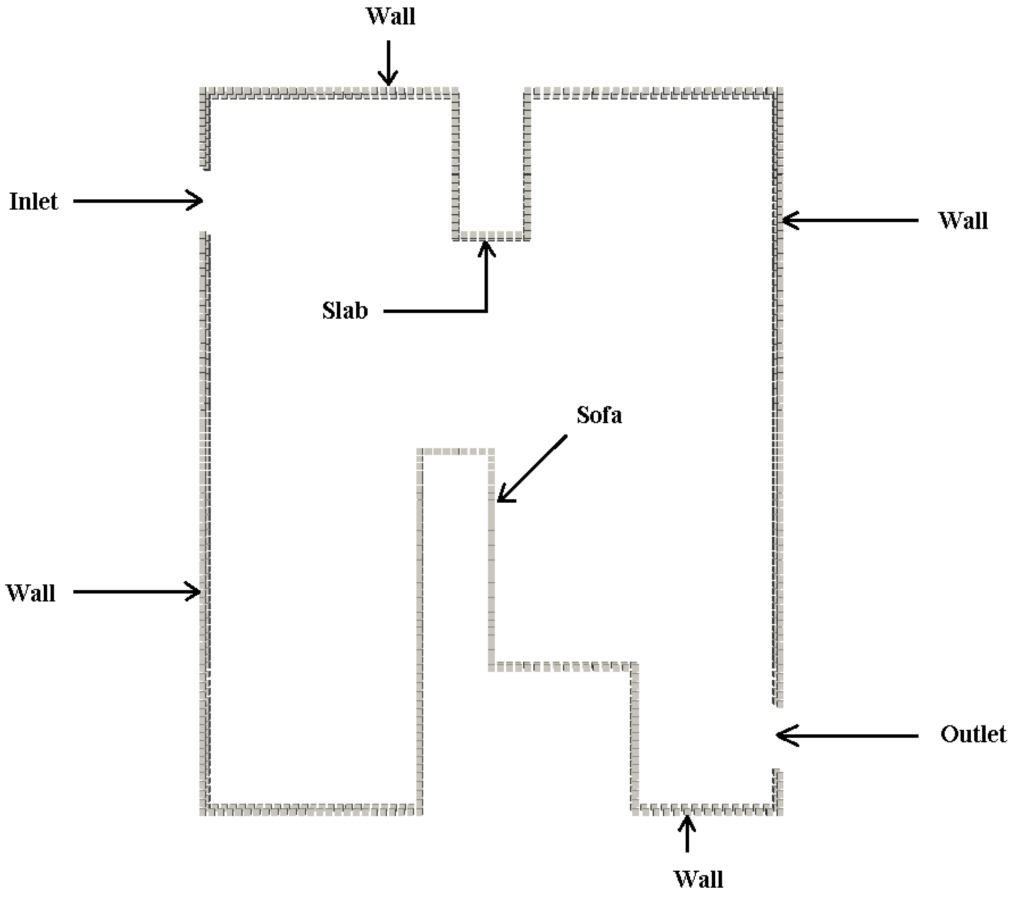


Figure 1.1. 2D Geometry

Table 1. Geometry and Computational Details

Parameter	***Detail***
Model	2 Dimensional
Geometry-Mesh creating software	ICEM CFD
Number of cells	4,906
Post-processing tool	Paraview, Sigma Plot
Solver	DPMFoam
Turbulence property	Laminar
Pressure-velocity coupling	PIMPLE algorithm [1]
Convective term solving scheme	Gauss linear upwind V unlimited [1]

Table 2. Fluid properties and initial conditions

Parameter	***Value/Condition***
Continuous phase	Air
υ_{air}	1e-05 m^2/sec
ρ_{air}	1.2 kg/m^3
$\rho_{particle}$	2600 kg/m^3
No. of particles in one parcel	1e6
Inlet injection	5000 parcels/sec
Initial parcel velocity	5 m/sec
$U_{\mathbf{air}}$	10 m/sec
Inlet	Particles escape
Outlet	Particles escape
Wall	Particles rebound
Sofa	Particles rebound
Slab	Particles rebound

Chapter2

Equations

2.1. Continuity Equation [2]

$$\frac{\partial}{\partial t}(\alpha) + \nabla.(\alpha U) = 0$$

2.2. Momentum Transfer Equation [2]

$$\frac{\partial}{\partial t}(\alpha U) + \nabla.(\alpha U U) - \nabla.\alpha\tau = -\nabla P + g + \frac{F_{Drag}}{\alpha\rho} - \frac{1}{V}\sum_p V_p \left[\frac{DU}{Dt}\right]_p$$

Chapter3

Results and Discussion

3.1. Plots

The air velocity was calculated at different positions to have an idea about the flow.

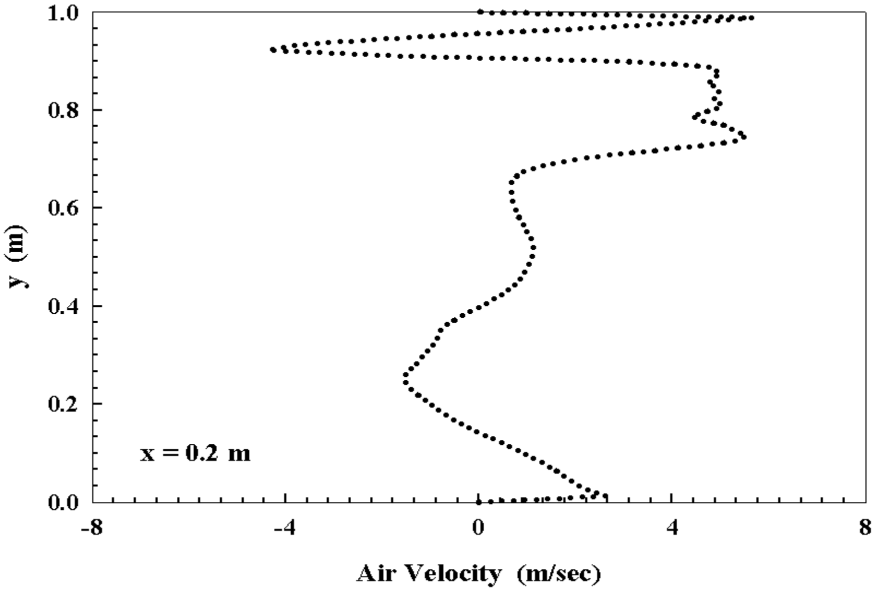


Figure 1.2. Air velocity along height at x = 0.2m

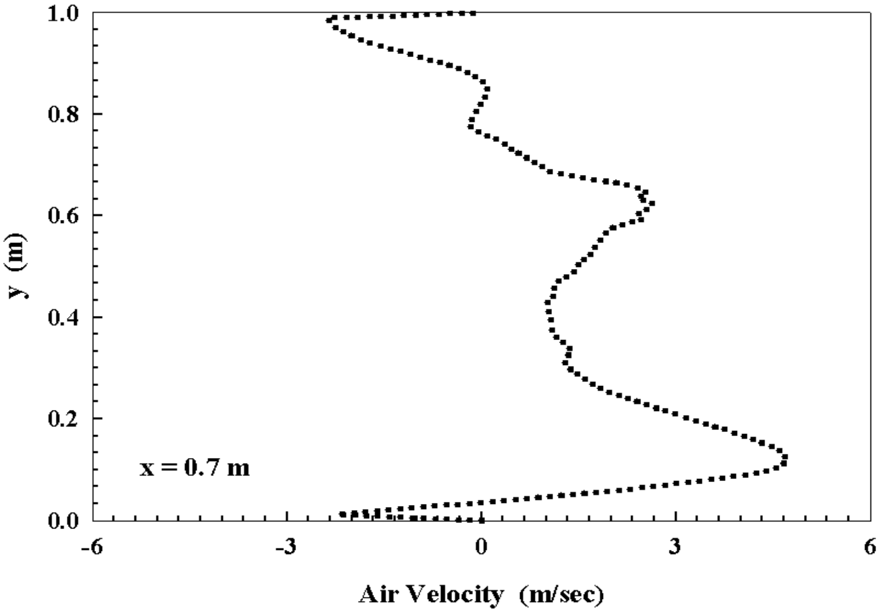
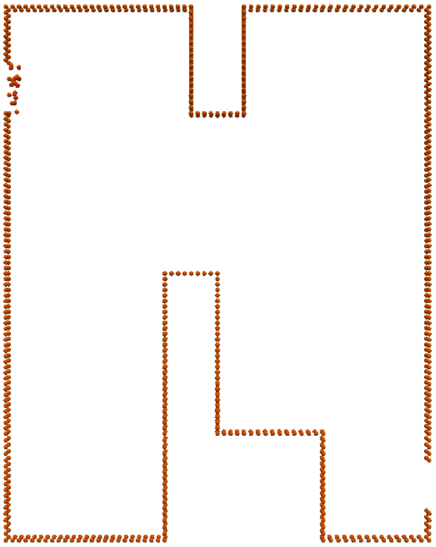
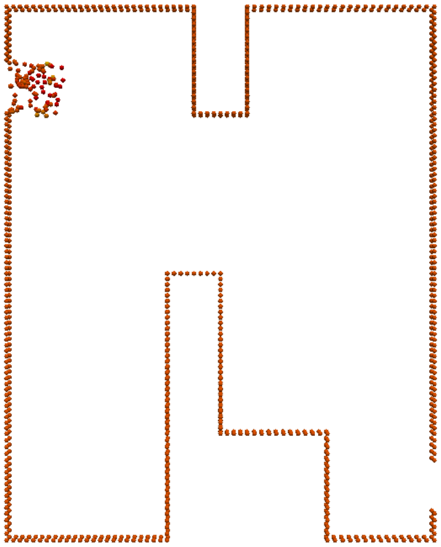


Figure 1.3. Air velocity along height at x = 0.7m

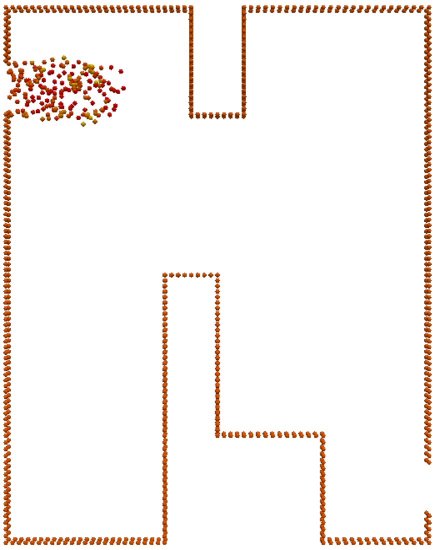
3.2. Contours



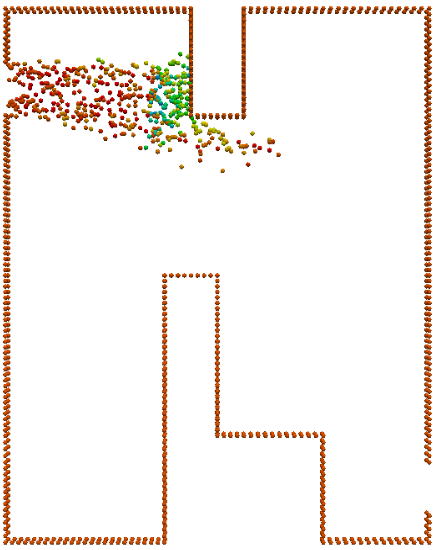
(a)



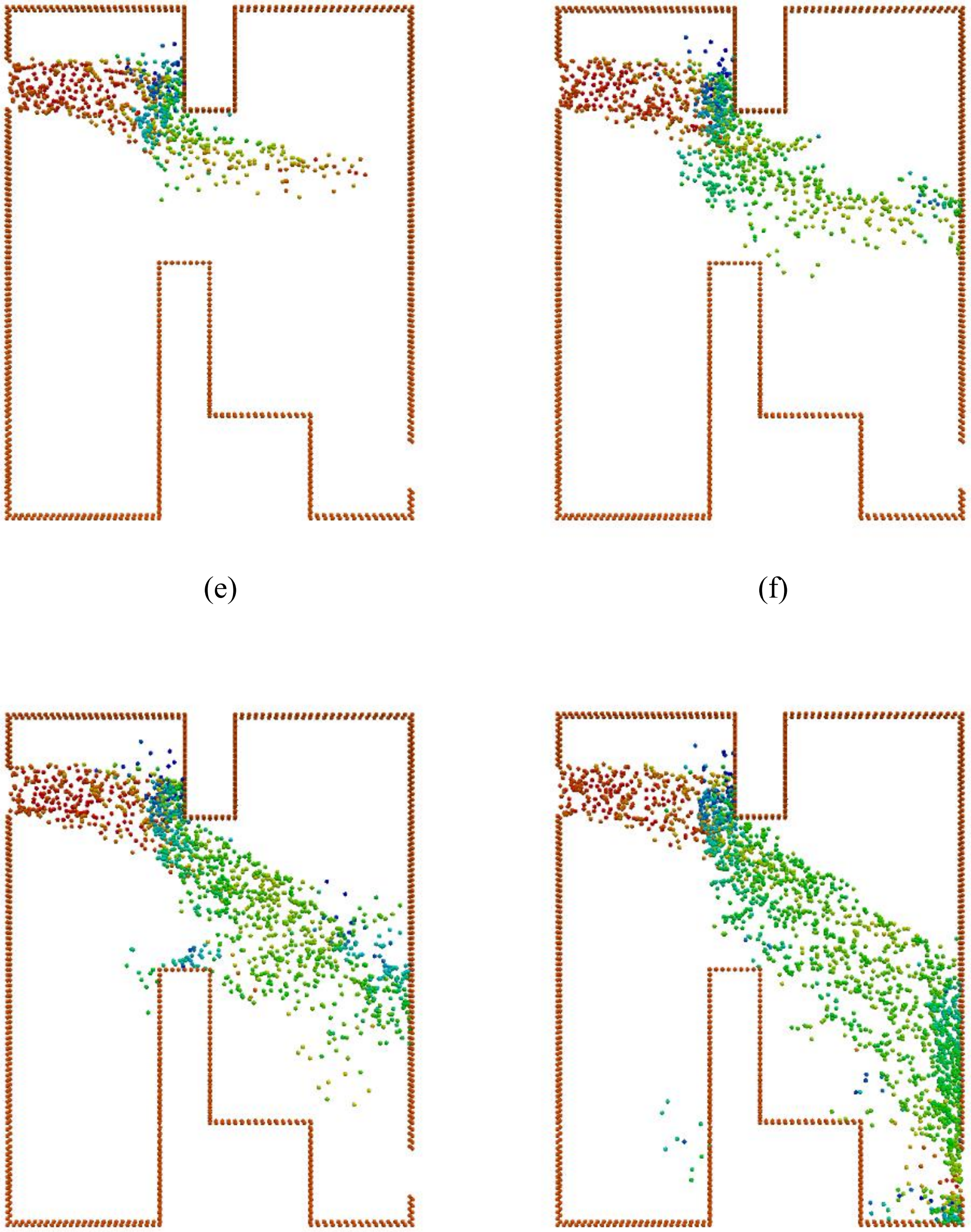
(b)



(c)



(d)



(e) (f)

(g) (h)

Figure 1.4. Particle tracked inside the room at (a) 0.0003, (b) 0.001, (c) 0.002, (d) 0.005, (e) 0.007, (f) 0.01, (g) 0.014 and (h) 0.021 sec

3.3. Conclusion

The locations of all the particle parcels can be tracked at different time with the DPMFoam solver.

Reference

[1] OpenFOAM User Guide version 6.0 (2018)

[2] Hofman J., Understanding DPMFoam/MPPICFoam (2015)

FOSSEE Fellowship Report
on

MODEL VERTICAL AXIS WIND TURBINE WITH DYNAMIC MESH

Submitted by

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Contents

Nomenclature

U	Velocity, m/s
g	Gravitational acceleration, m/s^2
P	Pressure, Pa

Greek Symbols

υ	Kinematic viscosity, m^2/sec
ω	Angular speed, rad/sec

Chapter1

Introduction and Problem Statement

1.1. Introduction

A vertical axis wind turbines (VAWT) is a type of wind turbine where the main rotor shaft is set transverse to the wind (but not necessarily vertically) while the main components are located at the base of the turbine [1]. VAWT does not require any complex mechanism or motors to yaw the rotor and pitch the blades [2]. One of the major challenges of this technology is dynamic stall of the blades as the angle of attack varies rapidly [3] [4] [5].

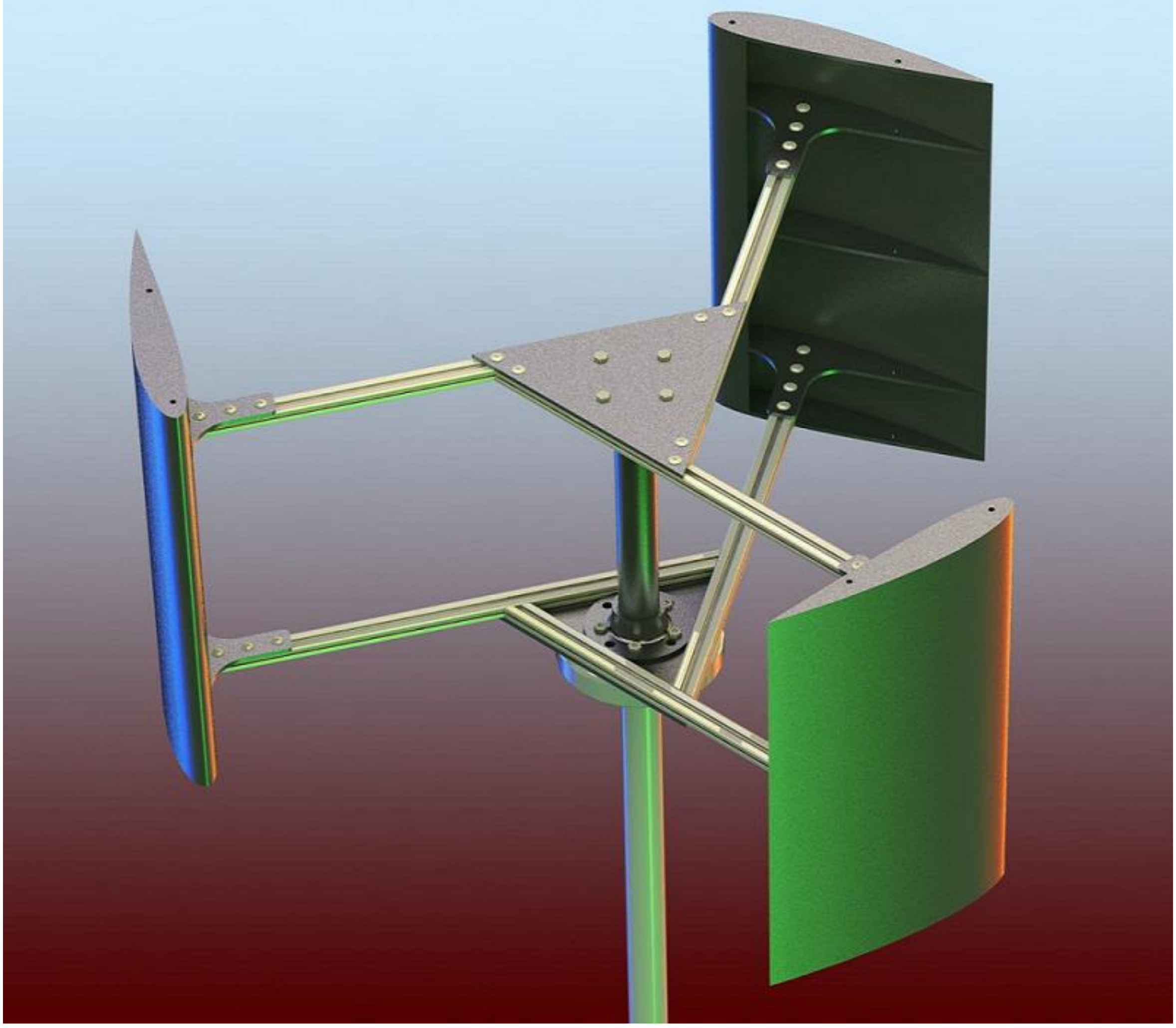


Figure 1.1. CAD model of VAWT [6]

1.2. Problem Statement

A model VAWT of 2D geometry was considered for the numerical study of a laminar flow. The details of the geometry can be found in the Figure1.2. Here whole the mesh was created with two different regions so that inner mesh of rotor can be rotated in CCW direction.

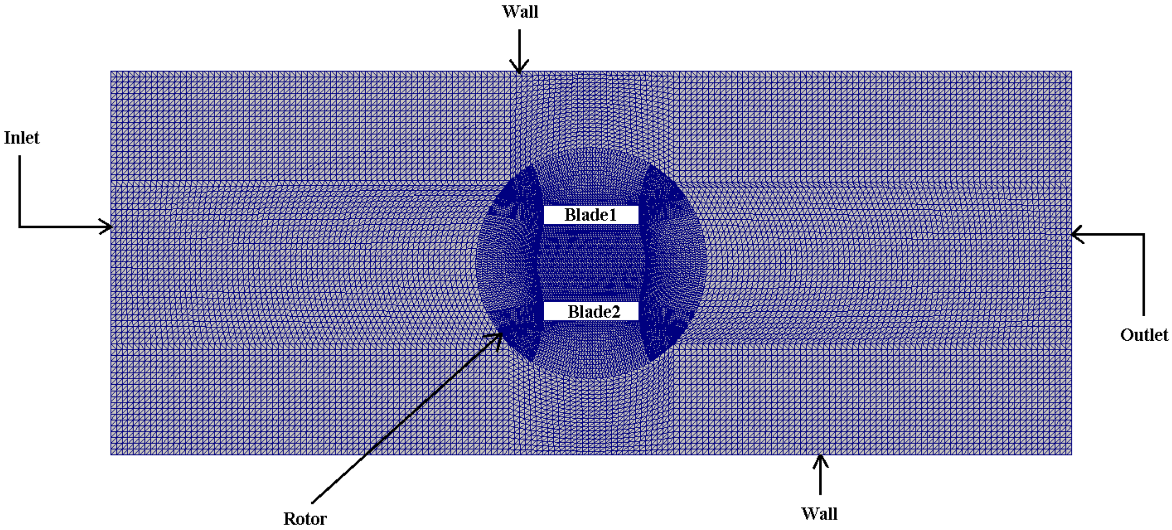


Figure 1.2. 2D Geometry with Mesh

Table 1. Geometry and Computational Details

Parameter	***Detail***
Model	2 Dimensional
Geometry-Mesh creating software	ICEM CFD
Number of cells	17,209
Post-processing tool	Paraview, Sigma Plot
Solver	pimpleFoam
Pressure-velocity coupling	PIMPLE algorithm [7]
Convective term solving scheme	Gauss linear upwind [7]

Table 2. Fluid properties and initial conditions

Parameter	***Value/Condition***
$\boldsymbol{\upsilon}_{\text{air}}$	1e-05 m2/sec
U_{air}	1 m/sec
Wall	No slip
Inlet	Free stream velocity
Blades	Moving wall velocity
Rotor rotation	CCW
ω	10 rad/sec

Chapter2

Equations

2.1. Continuity Equation [8]

$$\nabla . \mathrm{U} = 0$$

2.2. Momentum Transfer Equation [8]

$$\frac{\partial \mathrm{U}}{\partial \mathrm{t}} + \nabla . (\mathrm{UU}) + \nabla . (\upsilon_{\mathrm{eff}} \nabla \mathrm{U}) = -\nabla \mathrm{P} + \mathrm{g}$$

Chapter3

Results and Discussion

3.1. Plots

The velocity and pressure were calculated at the downstream of rotor.

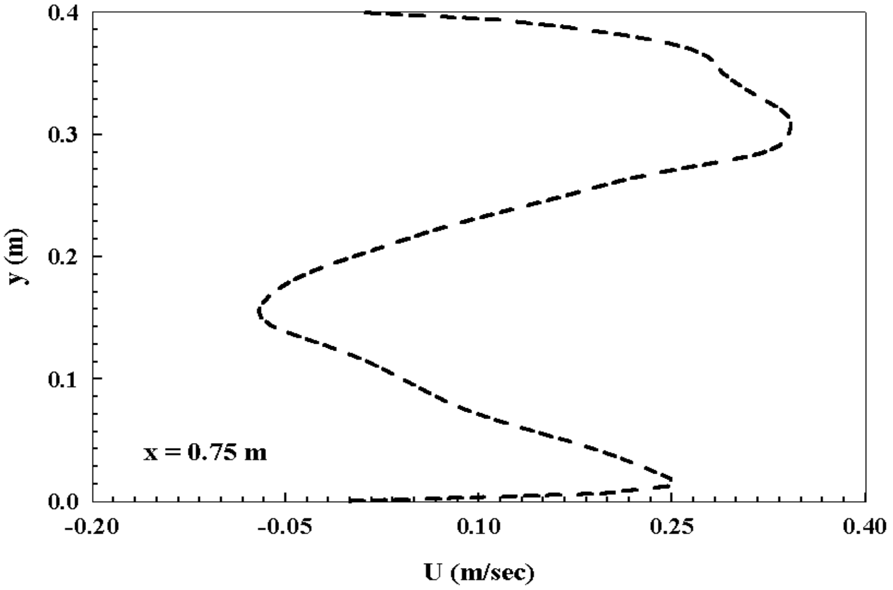


Figure 1.3. Velocity along height at x = 0.75m

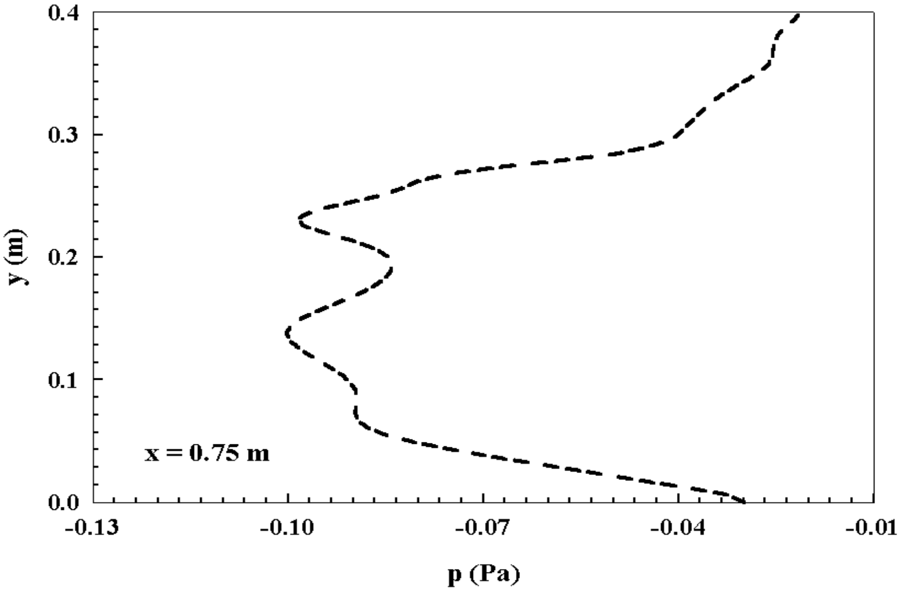


Figure 1.4. Pressure along height at x = 0.75m

3.2. Contours

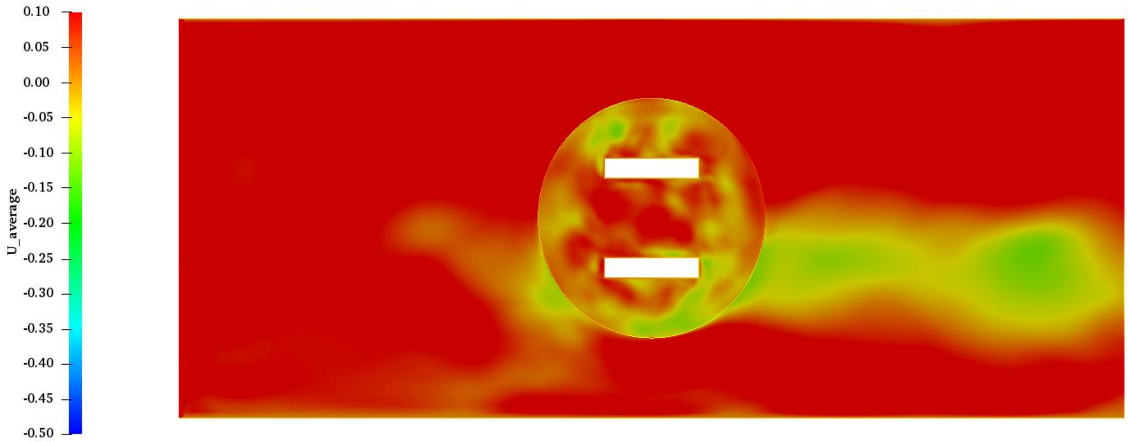


Figure 1.5. Velocity contour

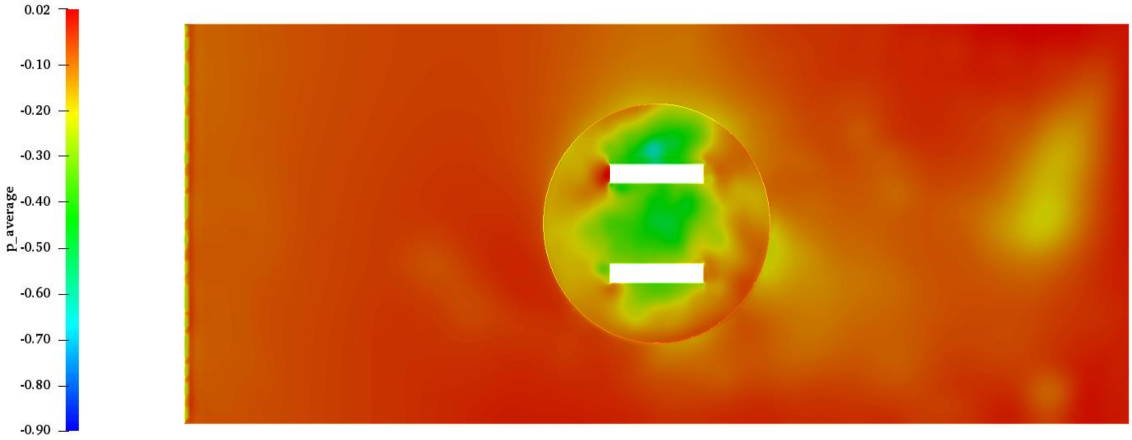
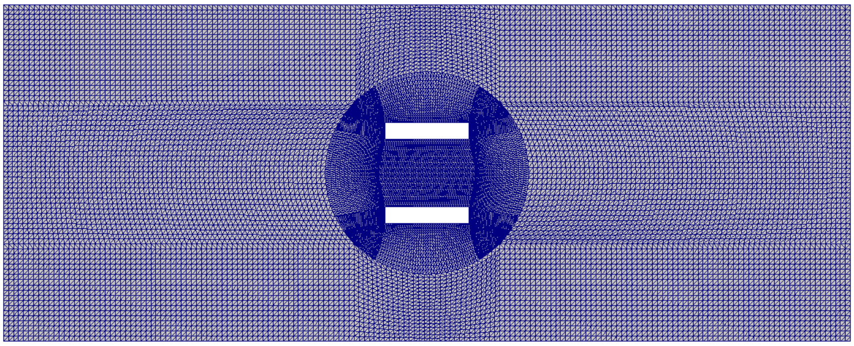


Figure 1.6. Pressure contour

3.3. Dynamic Mesh



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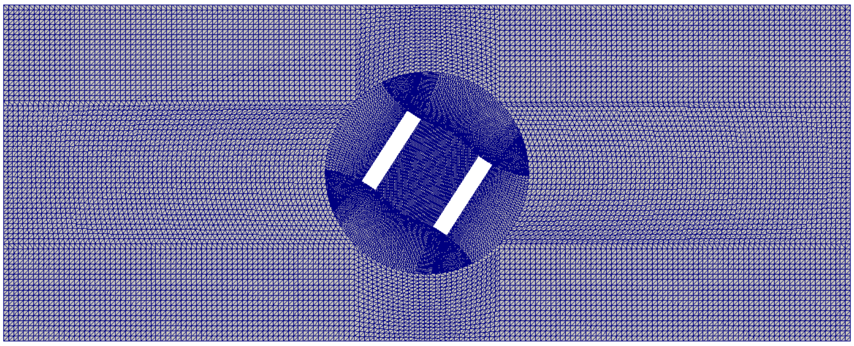

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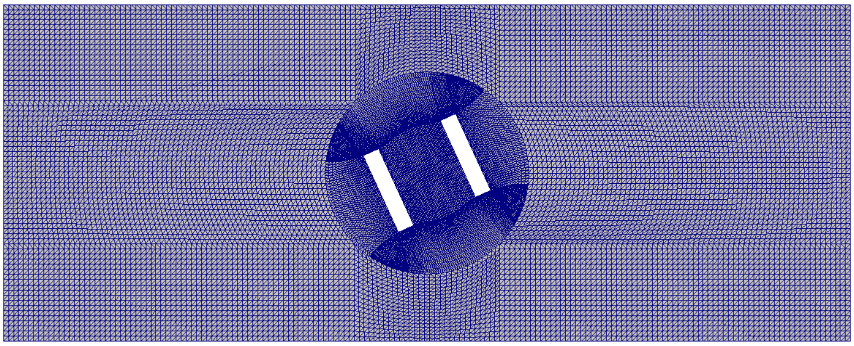

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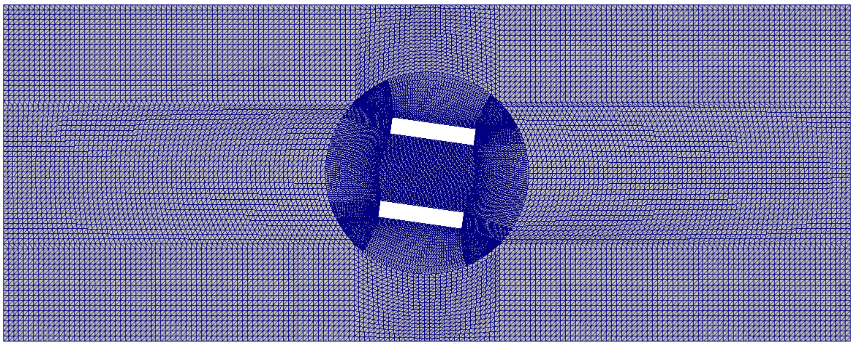

0.3 sec

Figure 1.7. Moving mesh at different time

3.4. Conclusion

A physical problem of vertical axis wind turbine can be simulated for dynamic mesh with pimpleFoam solver.

Reference

[1] https://en.wikipedia.org/wiki/Vertical_axis_wind_turbine

[2] AIP Conference Proceedings 1931, 030040 (2018)

[3] Buchner A.J., Soria J., Honnery D., Smits, A.J., Dynamic stall in vertical axis wind turbines: Scaling and topological consideration, Journal of Fluid Mechanics, 841: 746–66 (2018)

[4] Buchner A.J., Lohry M.W., Martinelli L., Soria J., Smits A.J., Dynamic stall in vertical axis wind turbines: Comparing experiments and computations, Journal of Wind Engineering and Industrial Aerodynamics, 146: 163–71 (2015)

[5] Carlos S.F., Gijs V.K., Gerard V.B., Fulvio S. Visualization by PIV of dynamic stall on a vertical axis wind turbine, Experiments in Fluids, 46: 97–108 (2008)

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[7] OpenFOAM User Guide version 6.0 (2018)

[8] Romanò Francesco, 2-D Flow Past an Airfoil, [302.044] Numerical Methods in Fluid Dynamics (2015)

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

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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.

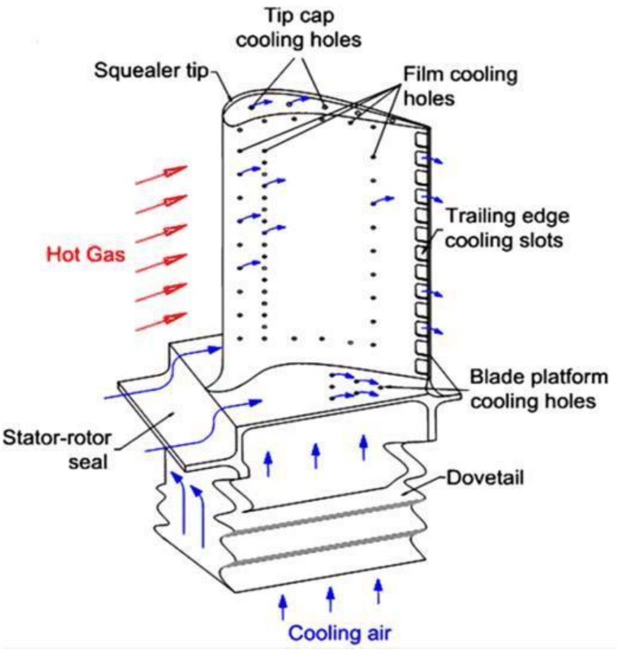

Figure 1.1(a). Film cooling in a gas turbine blade [2]

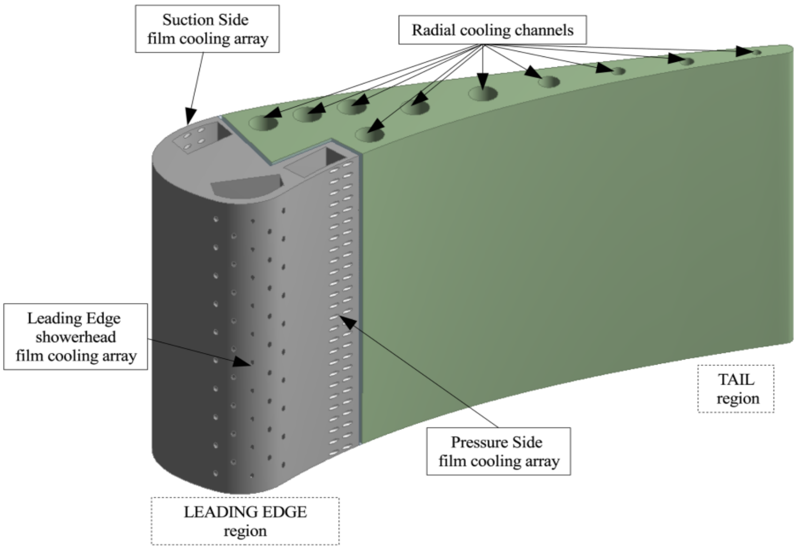

Figure 1.1(b). Cad model of film cooling holes in turbine blade [3]

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.

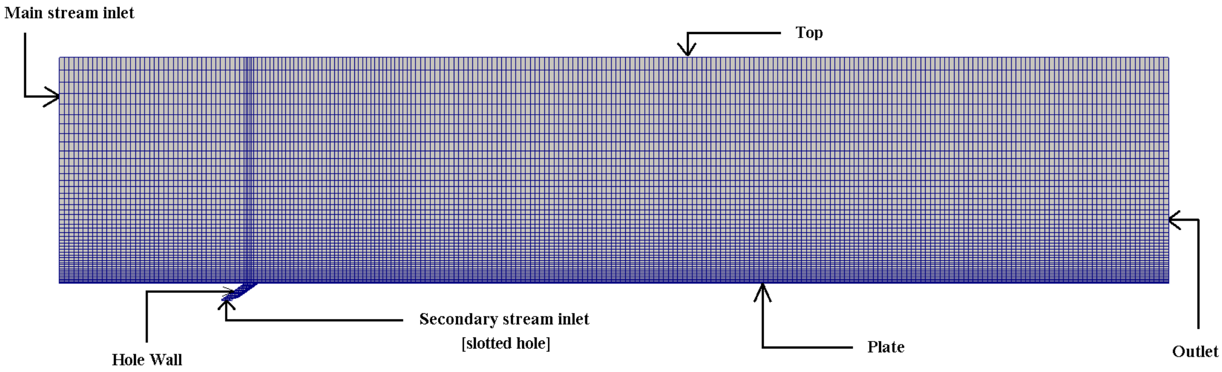

Figure 1.2. 2D Grid

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].

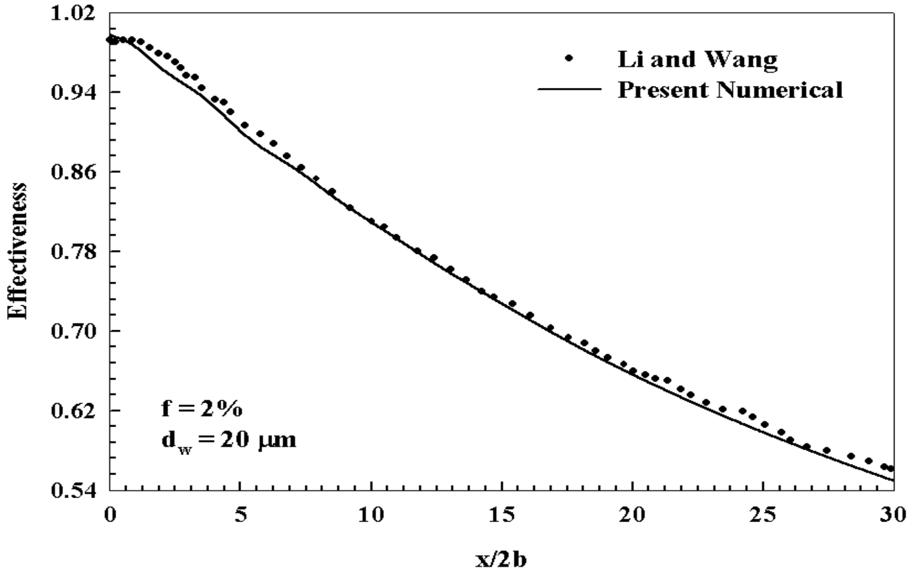

Figure 1.3. Validation

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

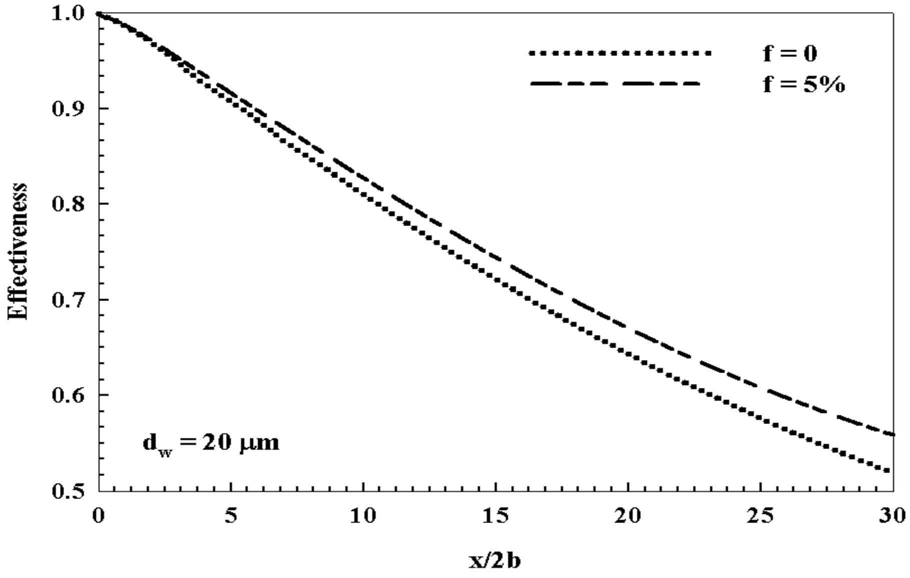

Figure 1.4. Comparison of Effectiveness for No Mist (f = 0) and Mist Injection (f = 5%)

3.3. Contours

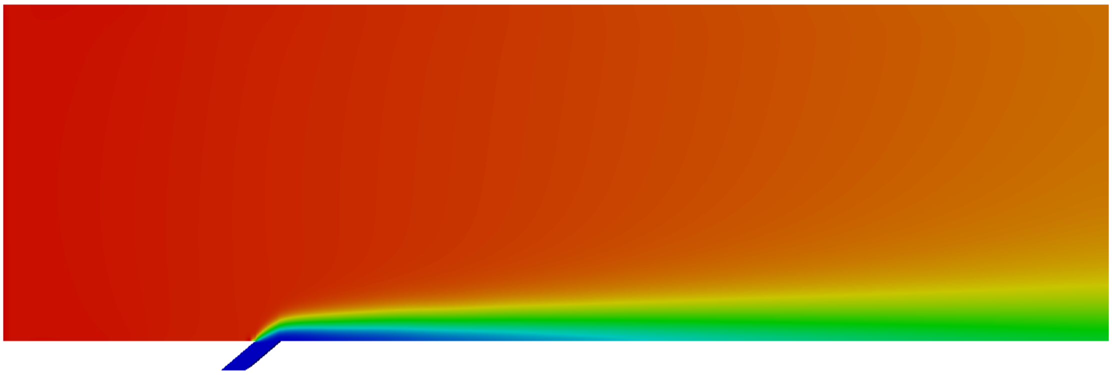

Figure 1.5. Temperature contour (f = 0)

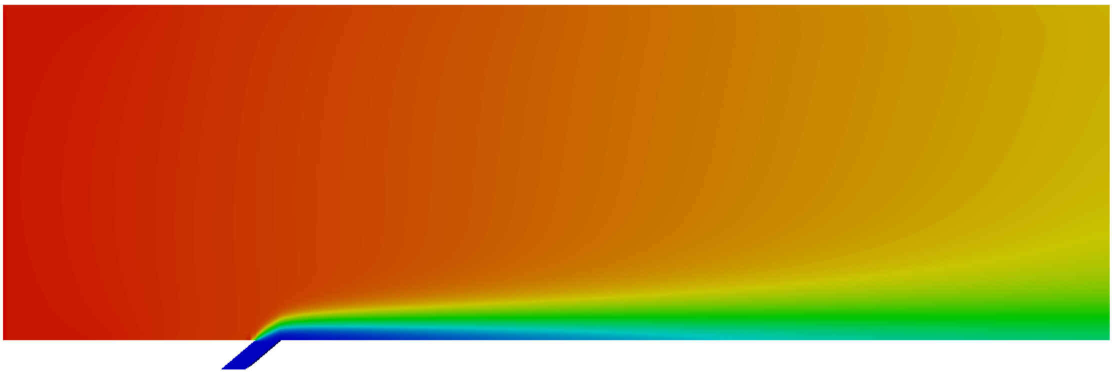

Figure 1.6. Temperature contour (f = 5%)

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

[1] Irvine T. F., Jr. and Hartnett J. P., Advances in Heat Transfer, Film Cooling, Volume VII, Academic Press, New York (1971)

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[3] Andrei L. et al., Film Cooling Modeling for Gas Turbine Nozzles and Blades: Validation and Application, J. Turbomach 139(1) 011004, doi: 10.1115/1.4034233 (2016)

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[6] Li X.C. and Wang T., Simulation of Film Cooling Enhancement with Mist Injection, ASME J. Heat Transfer, vol. 128, pp. 509–519, doi:10.1115/1.2171695 (2006)