HYBRID CFD-ML APPROACH TO PREDICT 3D FIN TEMPERATURE DISTRIBUTIONS USING 2D MID-PLANE DATA

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ABSTRACT

This study presents a machine learning approach to predict 3D fin temperatures using 2D midplane simulations, reducing computational costs. ANSYS Fluent generates 3D and 2D temperature data, from which a correction factor (ΔT = T3D - T2D) is derived. An artificial neural network (ANN) is trained to predict this correction factor, enabling efficient 3D thermal predictions without full CFD simulations. The model is validated against numerical results, demonstrating strong agreement while offering significant speedup. This method bridges the gap between simplified 2D analyses and high-fidelity 3D simulations, providing a practical tool for fin design optimization in heat transfer applications.

Keywords: *Fins, Natural Convection*

NOMENCLATURE

v	Velocity(m s^{-1})
P	Pressure(pa)
T	Temperature (K)
K	Thermal Conductivity (W/m·K)
$\dot{q}$	Volumetric Heat Generation (W/m^3)
S	Inter-Fin Spacing(m)
N	No. of fins
Greek Symbols	
μ	Dynamic Viscosity(Pa-s)
∇	Gradient (dimensionless)
ρ	Density(kg m^{-3})

1. INTRODUCTION

This study focuses on enhancing heat transfer predictions for 3D extended surfaces (fins) by developing a correction factor model that bridges the gap between simplified 2D midplane simulations and full 3D thermal analyses. ANSYS Fluent simulations are employed to generate high-fidelity temperature data for both 2D and 3D fin configurations, capturing key thermal gradients and convective effects. The derived correction factor, obtained by subtracting 2D midplane results from 3D solutions, serves as the target for an artificial neural network (ANN) to enable rapid and accurate 3D thermal predictions without exhaustive computational fluid dynamics (CFD) simulations.

1.1 Literature Review

In their research, Sultan et. al performed a numerical analysis of a rectangular fin array attached to a horizontal heat sink to assess its natural convection heat transfer performance. Their study meticulously documented variations in temperature and velocity, alongside fluid trajectories. They also investigated how intensifying heat flow and manipulating heat flux impacted the fins' cooling efficiency.[1]

For a system of 2-D fins, Karmakar et. al observed that the heat transfer first increases with the more fins and decreases with further added fins. The visualization of the temperature contour can make the reader know the behavior of the temperature distribution. [2]

2. PROBLEM DESCRIPTION

2.1 Geometry and Boundary Conditions

This 2D and 3D analysis investigates natural convection heat transfer from an array of vertical aluminum fins mounted on a base surface. The system, enclosed in an air-filled chamber, with two fins. The base surface is maintained at 340 K, with the ambient air at 300 K. The fluid surfaces are kept as pressure outlets. The primary objective is to determine the temperature distribution at different points. For the type of flow around fins in the setup above is within Ra less than 108 that is laminar flow and the fluid properties are assumed under

Bossenique's Approximation. Fig. 1 shows the schematic of the problem.

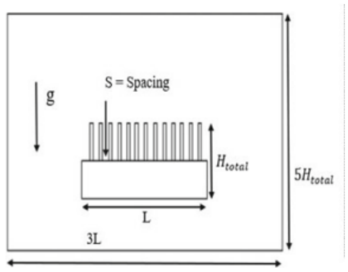

Fig. 1 Schematic of Computational Domain

For 3-D domain the domain was extruded by 600mm. The fluid domain was extruded 100mm extra from front and the back. The length (L) along horizontal axis is about 190 mm with fins of height (H=30 mm) installed of thickness (t=3 mm) with inter-fin spacing as (S). The fin is mounted on a base surface of thickness (t_{base} 30mm). The fin apparatus is made of aluminum due to higher conductivity of material. The setup is encapsulated in an enclosure of height 5Htotal and a width of 3L filled with air in it.

2.2 Meshing and Grid Independence

The default meshing techniques are used for both the 3-D and 2-D simulations and the cell size is varied to test the grid independence.

2.3 Numerical Modelling

Using a finite volume technique, the governing differential equations were integrated and discretized into algebraic equations. These equations were then solved iteratively using FLUENT 19 R3's algebraic multigrid solver, with boundary conditions applied. A second-order upwind scheme was utilized for the momentum and energy equations, while the SIMPLE algorithm was used to couple the pressure and velocity terms. The convergence criteria were set to 10^{-6} for the energy equation and 10^{-3} for continuity and momentum. To ensure solution convergence, specific under-relaxation factors were applied for pressure, density, body force, momentum, and energy, as detailed in the Table 1.

Table 1 Under-relaxation factors

Pressure	Density	Body Force	Momentum	Energy
0.8	1	0.7	0.01	1

3. EQUATIONS

Continuity equation for an incompressible flow is given in Eqn. 1.

$$\nabla \cdot \mathbf{v} = 0 \qquad (1)$$

Momentum conservation in Eqn. 2 is given by-

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla\mathbf{v}\right) = -\nabla p + \mu\nabla^2\mathbf{v} \qquad (2)$$

The conduction equation at steady state and no heat generation is given in Eqn. 3.

$$\nabla^2 T = 0 \qquad (3)$$

The equation at the interface is given by Eqn. 4. –

$$h_c * A * \Delta T = -k\frac{dT}{dx} = Q \qquad (4)$$

Equation 5 shows the Bossinesque approximation-

$$\rho = \rho_0[1 - \beta(T - T_0)] \qquad (5)$$

Equation 6 shows the fin spacing formaulation –

$$S = \frac{[L - (nt)]}{n} \qquad (6)$$

4. RESULTS

The resuts of the temperature contours for the 2-D and at different frontal planes across the 3-D domain have been studied. The contours for 2-D and the 3-D mid plane analysis have been shown.

5. REFERENCES

Journals

[1] Numerical investigation of natural convection from a horizontal heat sink with an array of rectangular fins: https://doi.org/10.1016/j.csite.2024.104877

Conference Papers

[2] 2D Numerical Analysis of Natural Convection in Vertical Fins on Horizontal Base: http://dx.doi.org/10.1007/978-981-13-1903-7_48