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Effect of Air Flow Direction on Forced Convection Over a Single Fin

Mohammad O. Hamdan
mhamdan@aus.edu
American University of Sharjah
University City, Sharjah, UAE
mhamdan@aus.edu

Abstract **–** This work employs numerical analysis to analyse the impact of velocity direction on the heat transfer for single fin under specific conditions. A steady state conjugate heat transfer is considered with constant wall temperature as heat source. A two-dimensional numerical simulation is conducted via ANSYS–fluent release 2021. The study aims to help thermal engineers to decide on push or pull modes of cooling. The results show that push mode of cooling perform better cooling when compared to pull mode. For given fin dimension and under constant wall temperature of 80 degree Celsius, push mode is able to remove more heat compared to the pull model when air speed exceeds 0.5 m/s with while the air pushing flow against gravity.

Keywords**:** fin cooling; forced convection; conjugate heat transfer; electronics cooling.

1. Introduction

The heatsink is an important component for electronics cooling since it used to dissipate the heat produce by electronic devices or systems. The heatsink dissipates any heat generated by the electronics device due to operation and maintain the electronics device within acceptable operating temperature. The effectiveness of heat sink in dissipating heat is closely related to fin design and flow structure around the heatsink.

In literature, different techniques have been used to assure effective cooling of fins such cooling fans [1], porous inserts [2-4], porous fins [5], single phase liquid cooling [6], phase change material [7], jet impingement [8, 9], heat pipes [10] and loop heat pipes [11-13]. Different fin geometries have been examined in literature such as plate fin shape [14, 15], square pin fin shape [16], in-line and staggered arrangements fin [17].

Electronic thermal management engineers are always asked regarding what mode of cooling should be used in cooling heatsink. The answer to such question depends on heatsink arrangement, geometry, and shape. It has been reported experimentally [18] that pulling mode gives better performance when used with high fin density heatsink while pulling mode provides better performance in less fin density heatsink. In this paper, the effect of push mode and pull mode of air cooling has been examined on a specific single plate fin heatsink. Also, the study examines the effect of fin height on heat transfer.

2. Problem Formulation

A schematic of the computational domain is shown in Figure 1, which resembles a forced air cooling of a single flat fin via push mode (figure 1a) and pull mode (figure 1b). A specific design dimension has been selected for current study, as shown in Table 1. This study employs a two-dimensional numerical simulation which is conducted using ANSYS Fluent Release 2021. A uniform velocity has been used for both push and pull air cooling modes. Outlet pressure of zero gage pressure has been enforced at the outlet for the push mode and zero gage inlet pressure has been enforced for the pull mode. All interface walls between fluid and solid are set as no-slip condition with coupled thermal condition. The left wall in the solid is set as symmetry wall. A constant wall temperature of 80 ℃ has been assumed at the bottom solid surface which is always dictated by electronic cooling specifications. Air is used as the cooling fluid and all its properties are set as homogenous and maintained constant throughout the simulation except for density which is modeled using Boussinesq approximation.

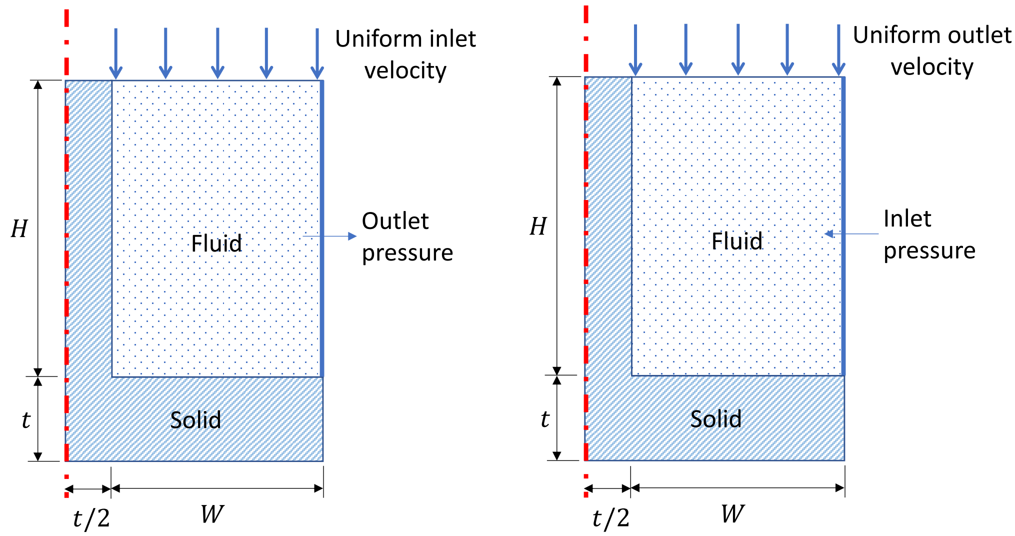


Fig. 1 Schematic of single fin being cooled using (a) push air model and (b) pull air mode.

The ANSYS Fluent software makes use of the conservation laws for mass, momentum and energy which can be written as follow:

$$\frac{\partial u_i}{\partial x_i} = 0 \#(1)$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial}{\partial x_j}\left(u_i u_j\right) = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu\frac{\partial^2 u_i}{\partial x_j \partial x_j} + g\beta(T - T_\infty) \#(2)$$

$$\frac{\partial T}{\partial t} + \frac{\partial}{\partial x_i}(T u_i) = \nu\frac{\partial^2 T}{\partial x_i \partial x_i} \#(3)$$

where ρ, u, p and ν refer to density, velocity, pressure and kinematic viscosity, respectively. T, c_p and k refer to temperature, heat capacity and thermal conductivity, respectively.

Table 1: Dimension and boundary condition of the computational domain

Parameters	Unit	Values
Fin base width (W)	mm	20
Fin thickness (t)	mm	2
Fin height (H)	mm	10, 20, 40, 60, 80, 100
Inlet velocity (push or pull model)	m/s	0.1, 0.5, 1, 2
Inlet temperature	℃	25
Bottom wall constant temperature	℃	80

The flow is assumed laminar flow and the problem was solved using couple scheme algorithm. All numerical residuals are set to less than 10^{-6} for all parameters except temperature which has be set to less than 10^{-9}.

3. Results and Discussion

Based on mesh independent study results which is shown in figure 2, a uniform mapped mesh with 50 divisions per 1 cm length has been adopted. The thermal resistance of single heat fin heat sink as function of fin height is shown in figure 3. It is clear that as fin height increases heatsink thermal resistance decreases. The increases in fin height increases conduction thermal resistance but decreases the convection thermal resistance. The heat sink thermal resistance consists of the summation of conduction and convection thermal resistances. Hence it is clear that the decrease in thermal convection thermal is higher the increases in the conduction thermal resistance. This behavior is expected since heat sink material is Aluminum which has high thermal conductivity. The bottle neck in heat transfer in the convection thermal resistance, hence any improvement on this front produce great drop in the value of heatsink thermal resistance.

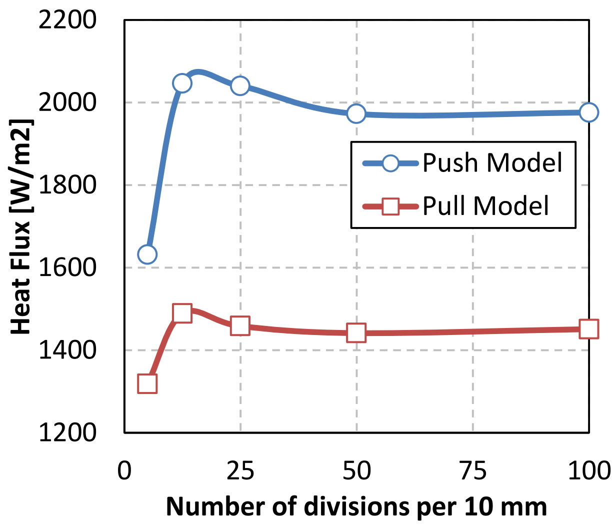


Fig. 2 Mesh independent study showing heat flux removed using push and pull modes for velocity of 1 m/s and fin height of 20 mm.

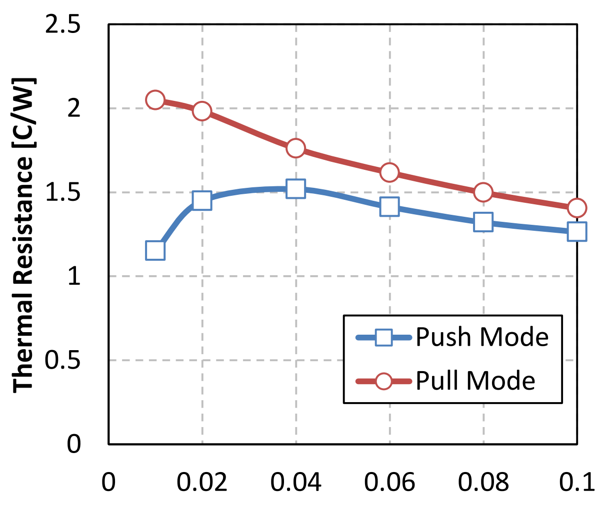


Fig. 2 Thermal resistance as function of fin height for push and pull modes with velocity of 1 m/s.

The effect of air speed on cooling is shown in figure 3 which shows that over all the thermal resistance push mode is better than pull model. However, the push mode suffers from inconsistency specially at low speed where natural convection become dominant and could hinder the heat transfer. For five single fin case the region of such drop in the performance happen between 0.4 m/s and 0.6 m/s. This region will vary depends on number of fins and depends on size of the fin.

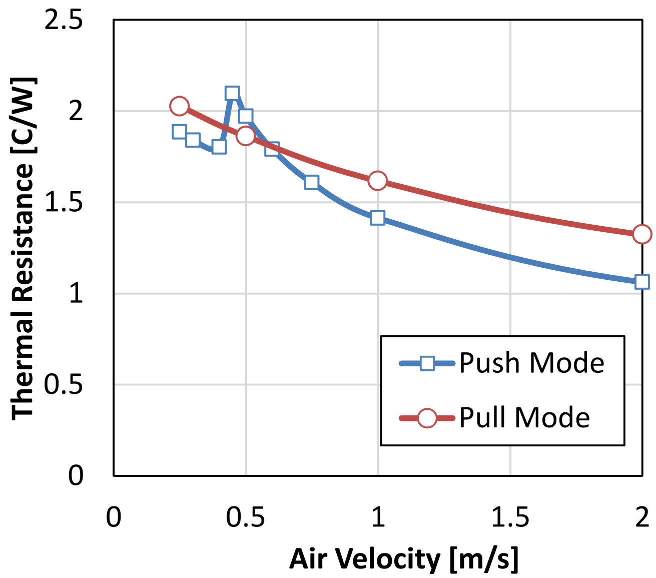
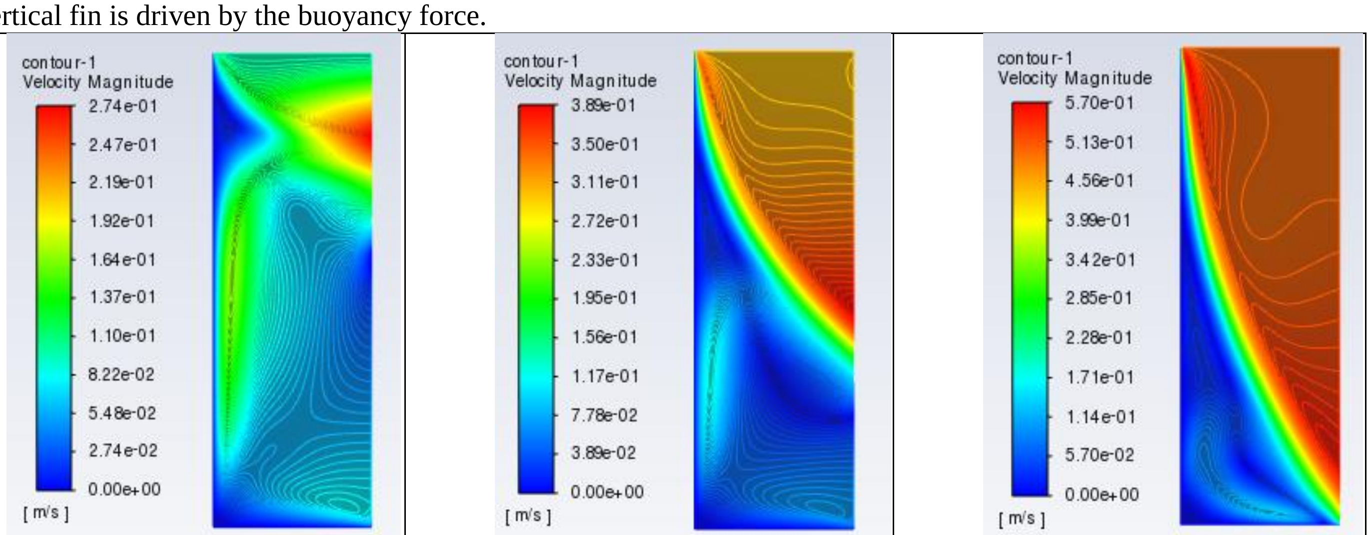


Fig. 3 Thermal resistance variation with velocity for fin height of 60 mm.

The contours for the push mode at three different velocities, namely, 0.1 m/s, 0.3 m/s and 0.5 m/s are shown in Figure 4. As shown in the figure, at velocity of 0.1 m/s the natural convection is dominating the heat transfer hence the air coming from the top surface does not get a chance to remove the heat from the vertical surface. The upward flow near vertical fin is driven by the buoyancy force.



(a)	(b)	(c)

Fig. 4 The velocity contour under push mode for three different velocity (a) 0.1 m/s (b) 0.3 m/s, and (c) 0.5 m/s.

4. Conclusion

The study is helping thermal engineers to answer the question regarding the use of push or pull modes in cooling. It has been shown that push mode could suffer inconsistency and irregularity in flow specially at air speed around 0.4 m/s for given fin design. The region of drop in cooling does not happen in pull model since buoyancy driven natural convection supports the fan flow. It is recommended to do full test of any heatsink before deciding on push or pull cooling model. Other reason could affect the decision of push or pull mode such as dust accumulation.

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