29. Flow over a Heat Sink

29.1 Objective

Heat sinks are mounted in circuit boards to provide additional surface area for heat loss from components that produce a high heat flux. However, heat sinks create additional resistance to flow and the result is that some of the flow bypasses them. This undesirable effect of bypass on the thermal performance of the heat generating component needs to be accurately predicted during the early design stages. Further, the effect of increased flow resistance in PCBs on overall airflow distribution needs to be accurately estimated during the conceptual design stage.

In the present study, MacroFlow is used to construct a model of a test cell used to characterize the performance of heat sinks. It includes a general network model of flow over a heat sink in the presence of bypass as proposed by Butterbaugh and Kang [1]. The predicted flow characteristics of the heat sink are compared with the experimental measurements provided by Biber [2]. The network model is extremely easy to construct, it runs very quickly, and accurately predicts the airflow distribution around the heat sink. The MacroFlow model of the heat sink can be effectively used to determine the benefit of incorporating heat sinks on the component-level thermal performance and also to predict the resulting system-level airflow distribution.

29.2 Physical System

Pressure drop and heat transfer characteristics of heat sinks are determined from wind tunnel testing as shown in Figure 29.1 [3].The heat sink is situated inside a duct (wind tunnel). Screens or perforated plates may cover the inlet and the exit of the duct. The flow within the duct is driven by a fan situated near the inlet and its rate is varied by controlling the opening of the orifice. Further, the duct size can be varied (by moving the walls or using different sized ducts) to study the effect of bypass on the performance of the heat sink. A diffuser is incorporated in the duct to recover the velocity head before the flow exits the system. The cross-sectional view of the duct with the fin sink is shown in Figure 29.2.

The fin sink, manufactured by Wakefield Engineering [2], has the following characteristics.

Table 29.1 Geometry of the fin sink manufactured by Wakefield Engineering

Dimension	Value (in)
Length	2.2
Width	4.6
Fin Height	0.75
Fin Pitch	0.1
Fin Thickness	0.012

Experiments have been carried out at Wakefield Engineering [2] for measuring the pressure drop through the heat sink over a range of air flow rates for the no bypass configuration. In the present study, a MacroFlow model for the wind tunnel test cell has been constructed for the general case of flow over the fin sink with the bypass using the methodology proposed by Butterbaugh and Kang [1]. The results of the model for the no bypass configuration have been compared with experimental measurements.

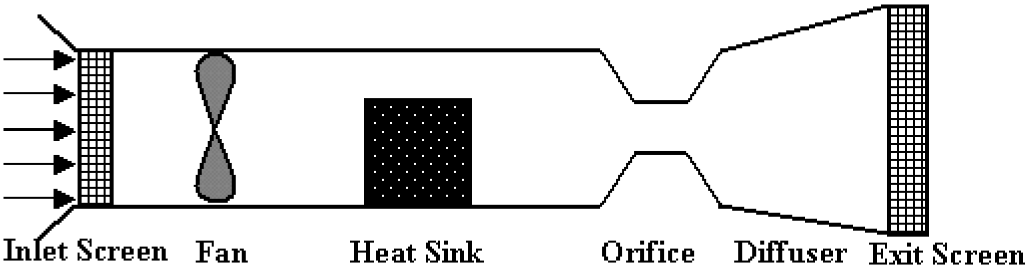

Figure 29.1The wind tunnel test cell for characterizing heat sink performance

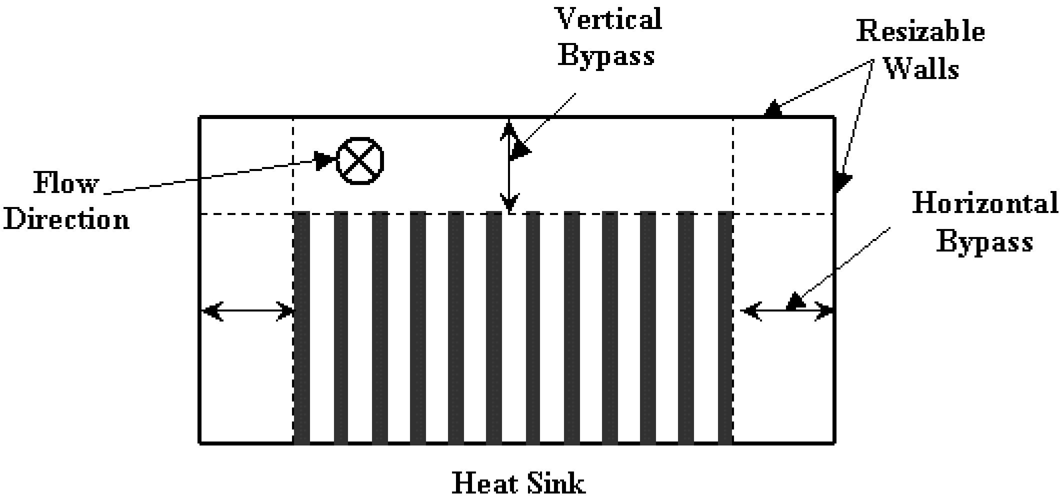

Figure 29.2 Cross-sectional view of the heat sink with bypass

29.3 Network Representation

The network representation of flow passage with the heat sink is shown in Figure 29.3. The important features of the model are as follows:

- The inlet and exit sections of the duct are represented using the Inlet/Exhaust with screen component available in MacroFlow. The screen is characterized by appropriate specification of the fractional open area and the geometry of a representative orifice.
- The fan performance curve is chosen from the library of Rotron fan characteristics provided in MacroFlow.
- The interfin spaces (a total of forty-six) are represented as channels with a rectangular cross-section. Note that as the flow enters each interfin space, it goes through an area contraction. Similarly, the flow goes through an area expansion when it exits an interfin

space. Correspondingly, the flow network contains contraction and expansion components upstream and downstream of each interfin space. A multiplier of forty-six is applied to the assembly of the contraction-interfin channel-expansion passage to signify that there are 46 such channels parallel to each other. The multiplier is a very powerful of MacroFlow that can be used for representing a number of identical flow paths that are in parallel.

- The two horizontal bypasses on the two sides of the sink are represented as passages of the same length as the fin sink, but with appropriate cross-sectional dimensions corresponding to the clearance between the fin wall and the duct wall. A multiplier of two signifies that there are two such bypasses in parallel with each other. A single rectangular channel is specified corresponding to the vertical bypass. The no bypass configuration is simulated by simply specifying the clearance dimension in these passages to be very small.
- The orifice downstream of the sink is a flow control element. The flow through the channel is controlled by the opening of the orifice.
- The portions of the duct before and after the sink are represented as rectangular passages with appropriate dimensions.
- The diffuser enables pressure recovery before the flow leaves the system. The Generic Nodes used in the network represent the junctions where the flow streams meet or from which flow streams divide. Thus, a Generic Node represents junctions in which no losses take place.
- Calculations have been done with ambient air (20 degrees ^{o}C, 1 atm) flowing through the duct.

Analogous to the experimental setup, the operating point of the system is determined by the orifice opening. By running the model for different orifice openings, the variation of the pressure drop in the fin sink with the flow rate is determined for the no bypass situation. Similarly, in presence of the bypass, the flow split as a function of the flow rate can also be determined.

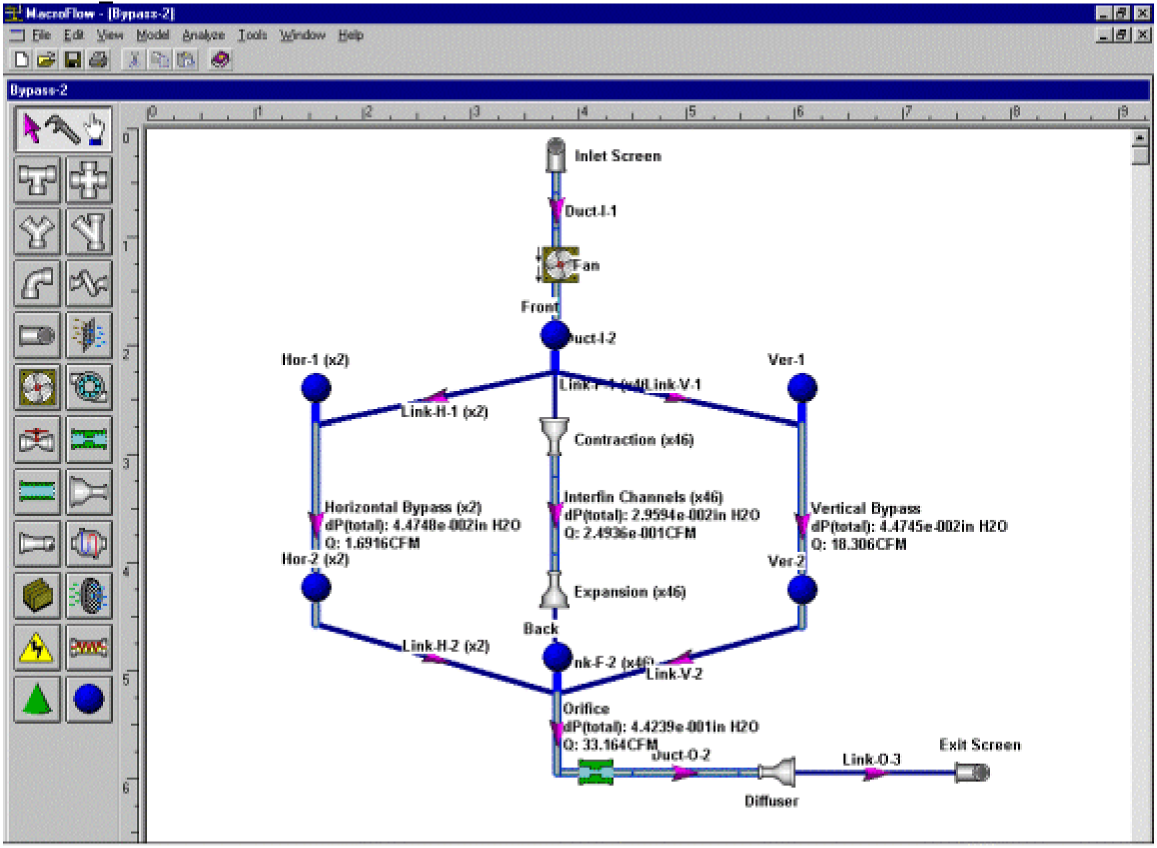

Figure 29.3 MacroFlow representation of the test cell used characterizing the heat sink performance

29.4 Flow Impedance Characteristics

The network representation of the entire test cell has been carried out using the standard components available in MacroFlow components and links. Their flow impedence characteristics are therefore determined internally from the corresponding library of loss coefficients. Note that MacroFlow accurately accounts for losses in laminar and turbulent flows. MacroFlow internally characterizes the flow regime based on the Reynolds number for the flow and chooses the appropriate variation of the pressure losses with the flow rate to determine the flow resistance. For example, since the flow in interfin passages is laminar MacroFlow will use the friction factor for laminar flow in a rectangular channel to characterize the corresponding flow resistance.

29.5 Results

MacroFlow predicts the distribution of the flow through the heat sink and the flow around it in the presence of bypass passages and the pressure drop in all parts of the systems. The predicted pressure drop-flow rate relationship and its comparison with the measurements [2] for the no bypass situation are shown in Figure 29.4. It can be seen that the physically motivated MacroFlow representation of the heat sink as parallel passages in combination with contraction and expansion components accurately predicts the heat sink performance.

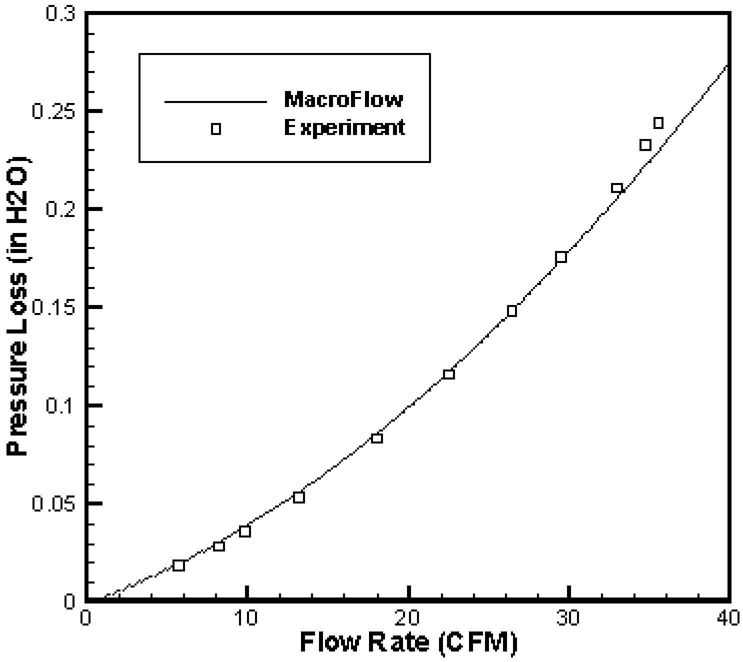

Figure 29.4 Variation of the pressure drop through the fin sink with the flow rate with no bypass

This representation can also be used in presence of bypass to predict the flow split. The bar chart in Figure 29.5 shows the variation of the pressure losses in various parts of the system. Similar plots can be made for any other quantity of interest to examine the flow distribution in the system. Figure 29.6 shows the fraction of the flow going through the heat sink as a function of the total flow rate through the duct for a fixed bypass (0.2 inches on the side and 0.25 inches above the fin tips).

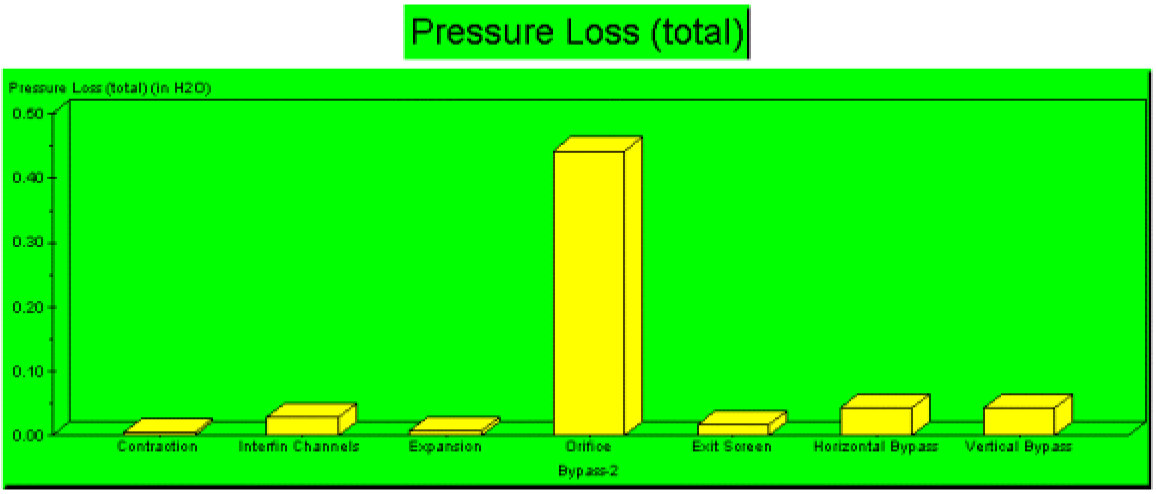

Figure 29.5 Pressure losses through various parts of the flow system with bypass

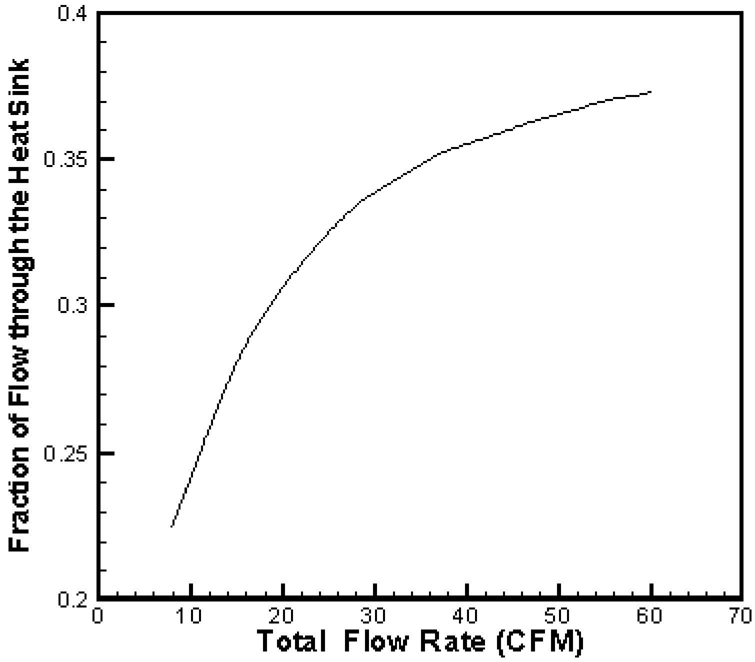

Figure 29.6 Variation of the fraction of the flow passing through the sink as a function of the total flow rate in the passage in presence of a specified bypass

29.6 Conclusions

In the present study, MacroFlow has been used to model a wind tunnel test cell employed for characterizing the performance of heat sinks. The innovative approach in this study is the successful use of a very simple generalized network representation of a heat sink for predicting flow through and around it. The model accurately reproduces the measured pressure drop characteristics of the heat sink under no-bypass conditions. MacroFlow can be used at many levels of the system for quick and accurate prediction of the airflow distribution needed during the Conceptual and Detailed Design stages. First, the heat sink model can be used to evaluate how the placement of a heat sinks affects the flow through the heat sink and hence the thermal performance of heat dissipating components on a particular circuit board. Second, the network model of a passage containing the heat sink can be used to determine the increase in the flow impedence in that passage. Third, these impedence characteristics can be used in the network model of the entire system to determine its airflow performance. The resulting flow distribution can, in turn, be used in the board-level model to determine the thermal performance under actual operating conditions. Finally, MacroFlow can also be used for designing wind tunnel test cells used for determining the flow impedence characteristics of subsysyems such as Power Supplies, Card Arrays, and Disk Units etc. With the user-friendly framework of MacroFlow, the construction of flow networks is extremely easy and accurate results are obtained in a very short time.