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Comparison of Airflow Testing Methods

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1.0 INTRODUCTION

One of the major concerns when purchasing a COTS board is whether the module will function in the thermal environment specified by the purchaser. The purchaser gains confidence that the module will meet his requirements if the vendor can supply test data. The type of airflow test conducted is critical in determining whether the module will function in its environment. In general there are two types of tests used to determine the thermal characteristics of a module. One type of test data specifies the required airflow as a linear velocity such as feet per minute and the other as a volumetric flow rate such as cubic feet per minute. The type of test used determines whether the module will function in the design environment. This article discusses both methods and provides guidelines for choosing the proper test. Examples are given as to magnitude of the error that will result if the wrong test method is chosen.

2.0 DISCUSSION OF TEST METHODS

2.1 Linear Velocity Test

There are two general methods for specifying the airflow requirements for an electronic circuit card: One is to specify the airflow in terms of a linear velocity in feet per minute, and the second is to specify flow requirements in terms of volumetric airflow per slot, in cubic feet per minute. While this difference may appear to be minor, in fact, the two are really quite different, and if used inappropriately, can lead to serious errors.

One of the critical requirements in the design of any kind of hardware, whether electronic or mechanical, is that it should be possible to verify all of the specified parameters easily and unambiguously. When one specifies an airflow requirement as a linear velocity, such as feet per minute (FPM), the major issue becomes one of how and where does one measure the velocity. If the PWB is supposed to operate as a freestanding card in an open space, then specifying the flow in terms of FPM makes sense. The card can be tested by installing it in an airflow chamber and measuring the free stream velocity with either a Pitot tube or a Hot Wire anemometer. However, most circuit cards are designed to operate in a card cage. When this is the case, the problem becomes one of how the velocity is to be measured since the typical PWB-to-PWB centerline spacing for VME and CPCI is 0.8 inches. If one measures the velocity in the card slot without the presence of a card, there is absolutely no guarantee that this measured velocity will be the same after the card is inserted. In fact, if the component layout on the card is extremely dense; the airflow may be greatly restricted. Furthermore, the measurement of the airflow velocity in a card slot is not easy and prone to errors, since the diameter of a hot wire anemometer or a pitot tube is large enough to disrupt the local airflow, making the placement of the instrument critical.

Another problem associated with specifying airflow requirements in terms of a linear velocity is that it is not consistent with system requirements, and is difficult to implement and verify. Chassis designers specify airflow requirements in terms of volumetric flow rate and pressure drop. This means that sooner or later someone will have to specify the cross-sectional area that is appropriate for the specified velocity.

If all of this weren't enough of a headache, there is the problem of differing flow fields and thermal radiation. The flow field surrounding a single flat plate in a free stream is different from the flow field in a high aspect ratio channel. The boundary layer thickness for a plate in a free stream is typically on the order of 0.25 inches and is not influenced by other surfaces. However, in a card cage, where the free space between adjacent cards is on the order of 0.5 inches, the boundary layer, and hence the heat transfer coefficient on the test PWB will be influenced by its neighboring cards. Different flow fields will result in different heat transfer coefficients. An incorrect heat transfer coefficient will have a major effect on the temperature because the heat transfer coefficient usually represents the largest thermal resistance between the PWB and the air stream.

The thermal radiation problem is more serious. When an individual card is placed in an airflow chamber and powered up, it will lose heat by convection to the air stream and by radiation to the external walls. The radiation heat transfer from a 20° C black body to a 19° C heat sink is 0.53 WATTS/SQ. FT. - °C. At 300 FPM and 600 FPM, the heat lost by convection is 0.89 WATTS/SQ. FT- °C and 1.26 WATTS/SQ. FT- °C respectively. This means that for an individual PWB in a test chamber, 37% and 30% of the heat transfer transferred is by radiation to the chamber walls. It is not possible to reduce this radiation by coating the inside chamber walls with a low emittance material since the area of the chamber is so much larger than the PWB. However in a typical card cage, each card is adjacent to other cards at comparable temperatures, and this reduces the heat transferred by radiation substantially. Essentially, radiation is not an effective heat transfer mechanism in a card cage. This means that test data from an individual PWB overstates the heat transfer because radiation, which is present here is not a factor in a card cage.

2.2 Volumetric Flowrate Test

It is recommended that circuit cards that are designed for use in a card cage be evaluated using a volumetric flow measurement technique. This method calls for attaching a card cage containing the article under test, along with two adjacent PWBs, to an airflow chamber. A typical test setup is shown in Figure 1. Figure 2 shows the test setup schematically. All three PWBs are powered up, the flow is varied, and temperature and pressure drop data is taken. No attempt is made to measure the linear flow rate or its distribution through the card slot, only the volumetric flow rate is measured. Since all of the air passes through the card slot containing the test card, the data collected can be used directly by the chassis designer to design the air moving system. Typically the data would look like the data presented in Figure 3. . Shown here is the temperature rise of the board relative to the inlet air temperature and the pressure drop of the card when in a card cage. If the flow rate were 12 CFM, the PWB would undergo a 38 °C temperature rise with respect to the inlet air and a pressure drop of 0.063 Inches of Water. The advantages of performing such an airflow test are apparent. The two biggest advantages are:

1) the environment is now similar to that of its deployed usage, and
2) the parameters that the system designer is most interested in, airflow and pressure drop, are obtained directly from the test. Also, pressure drop and flow data can be obtained inexpensively and with a high degree of accuracy.

2.3 Airflow Chamber Description

An air flow chamber, sometimes colloquially referred to as a "wind tunnel", is used to provide the controlled volumetric air flow. It consists of a duct, typically several diameters in length, containing airflow straighteners, a fan or blower to move air, and an adjustable blast gate or other means for adjusting air flow rate. A means for measuring the rate of air flow is provided, typically one or more calibrated nozzles, whose pressure-flow curve is known, or one or more pitot tubes to measure uniform velocity through a controlled cross section. Airflow chambers may also be used for fan performance testing and/or impedance testing.

Taps for manometers are typically provided at several points for pressure measurements. The equipment under test (EUT) is attached to the chamber inlet by means of transition ducting, usually fabricated from foam core or other smooth material to minimize resistance to airflow.

Airflow chambers come in various sizes, and can provide specified volumetric flow rates ranging from a few CFM to thousands of CFM. Pressure measuring equipment can be a set of draft manometers, or an electronic pressure instrument, depending on the accuracy required.

Overall accuracy is affected by a number of factors, including ambient barometric pressure, air temperature, and relative humidity. Corrections for each of these effects can be made by using the methods indicated in AMCA Bulletin 210-74[1].

[1]Air Movement and Control Association International www.amca.org

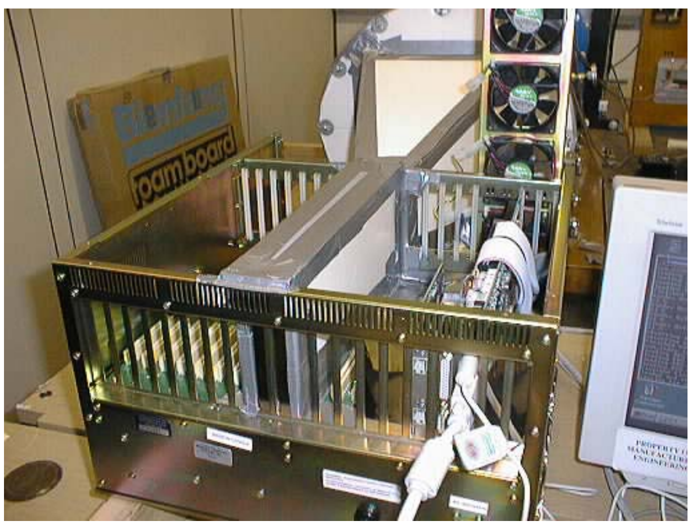

Figure 1.
The test configuration shown is used for measuring airflow impedance for a "Sandwich" of Three PWBs, approximating airflow in an enclosure. Air is drawn through the PWBs through the transition section and into the air flow chamber at the rear.

Diagram of Air Flow Test Setup

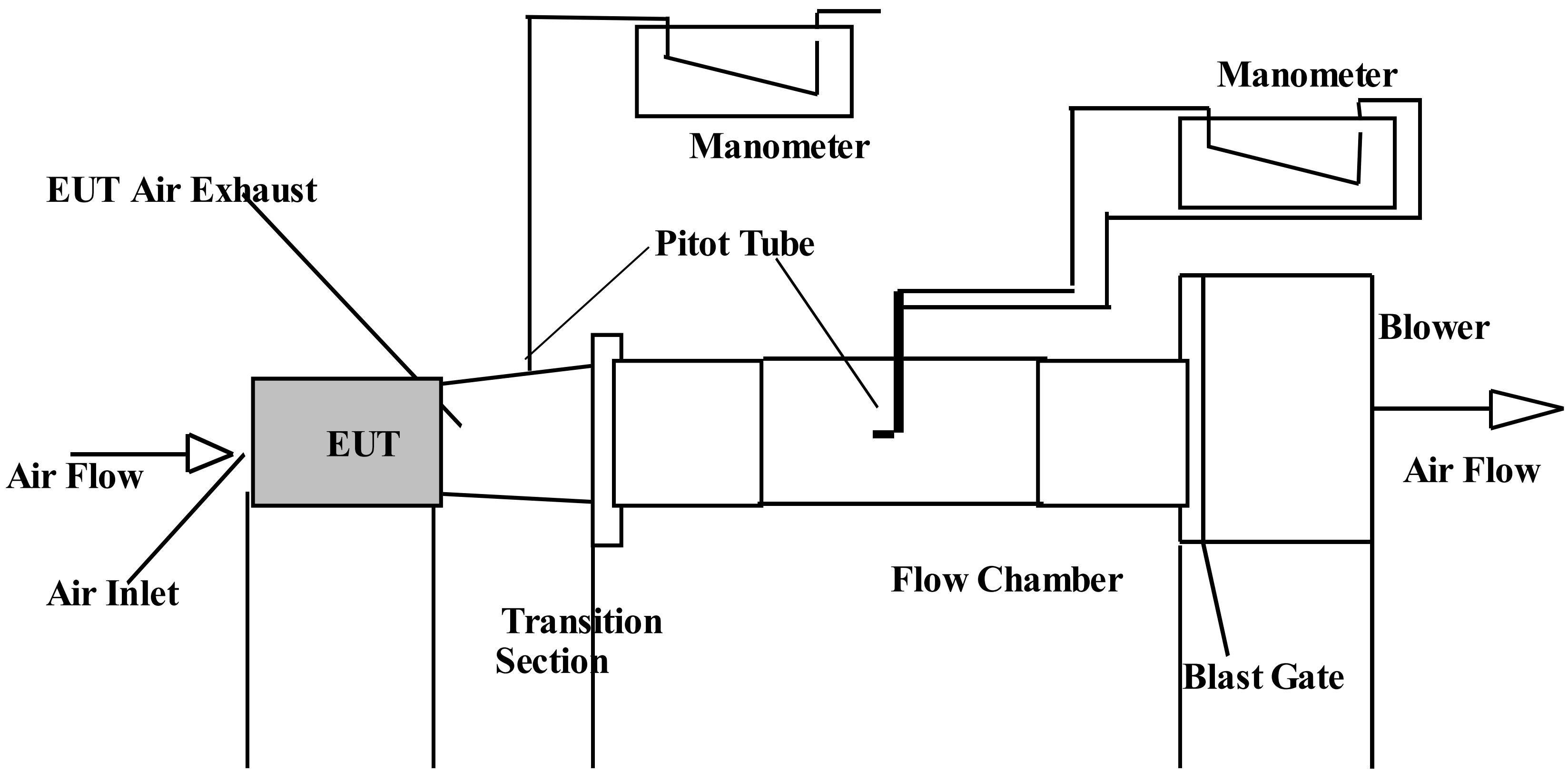

Figure 2. A Typical Air Flow Test Setup is shown in this diagram. Air is drawn through the Equipment under Test (EUT) through the airflow chamber.

3.0 TEST COMPARISON

Having discussed the linear and volumetric test methods, it is of interest to calculate the expected differences between them. For the analysis, it was assumed that we are dealing with a flat, smooth circuit card with uniform heat distribution. For the first case, it is assumed that the PWB is in a free stream and the air velocity is varied from 200 FPM to 1,000 FPM. For the second case, it is assumed that the card is in a chassis, and the volumetric flow is varied so that the linear velocity is the same as in the linear flow test. This allows us to compare the data directly. The following properties are assumed for both cases.

PWB Dimensions	6 x 10 inches
PWB Power	60 Watts uniformly distributed, both sides
PWB Internal Construction	5 layers of 1 oz copper
Ambient Temperature	20° C
Ambient Pressure	Sea Level
Heat Transfer Surface	Both Surfaces

For the free stream configuration, the average free stream heat transfer coefficient was calculated using the following equation[1]:

$$Nu = 0.664\ Re^{.5}\ Pr^{.333} \qquad (1)$$

Where: Nu = Nusselt Number
Re = Reynolds Number
Pr = Prandtl Number

It was further assumed that the PWB has an emissivity of 0.9, and was radiating to a 20° C sink. The PWB temperature was calculated by hand.

For the volumetric flow case, (card cage condition), it was assumed that there was a 0.4-inch spacing between cards, and there was no radiation between adjacent cards. Although the typical PWB centerline spacing is 0.8 inches, a 0.4-inch spacing was used for the heat transfer and pressure drop calculations to account for the PWB, electronic parts, and other hardware mounted on the card.

[1] Principles of Heat Transfer, 4th Ed., Kreith and Bohn, Page 236

The average turbulent heat transfer coefficient was calculated using the Gnlienski equation[1]:

$$Nu = \frac{(f/2)(\text{Re}-1{,}000)(\text{Pr})}{1+(12.7((f/2)^{.5})(\text{Pr}^{.667}-1))} \qquad (2)$$

$$f = 0.0054 + \frac{2.3x10^{-8}}{\text{Re}^{-1.5}} \qquad 2300<\text{Re}<4000 \qquad (3)$$

$$f = 0.00128 + \frac{0.1143}{\text{Re}^{-0.311}} \qquad 4000<\text{Re}< 10^{7} \qquad (4)$$

Where: Nu = Nusselt Number
Re = Reynolds Number
Pr = Prandtl Number
f = Friction Factor

Two different equations are used to calculate the friction factor because it is difficult to find a single equation that accurately describes the friction factor over the entire turbulent flow range.

Calculating the heat transfer coefficient from the Nusselt Number from equations (1) and (2), the PWB temperature was then calculated using [2]TAS™, a finite difference solver. The results of both of these analyses are shown in Figure 4. This graph shows the temperature rise of the inlet air and the average PWB temperature rise for the free stream case (linear flow) and for the card cage case (volumetric flow). It is noted that the card cage PWB shows a major discontinuity at velocities between 300 and 500 FPM. This represents the transition from laminar to turbulent flow. The point at which the flow changes from laminar to turbulent is defined as when the Reynolds number exceeds 2,300. For this particular geometry it occurs at 339 FPM. However, this is not an exact point, and the transition can occur when the Reynolds number is between 2,300 and 3,000, (339 to 443 FPM). No such transition for the flat plate case is shown because in the free stream the laminar to turbulent transition occurs at a much higher Reynolds number. What this means is that accurate temperature predictions in the transition region is extremely difficult.

Note that at a flow velocity of 400 FPM, which is typical for a card cage, a PWB tested using the free stream or linear flow method will show a temperature rise of 45 ° C while a PWB tested in a card cage will exhibit a temperature rise of anywhere from 55 to 105 °C. This represents an error that may be as large as 60 °C or a percentage difference of anywhere from 22 % to over 100%. Clearly, if someone has purchased a module for use in a card cage and is using data derived from a module that was tested using the linear flow method, they may be in for a severe disappointment.

[1] Handbook of Single-Phase Convective Heat Transfer, Kakac, Shah, and Aung, page 4-145
[2] TAS, Harvard Thermal, Harvard MA, www.HarvardThermal.com

4.0 CONCLUSION

Two different test methods for evaluating the thermal behavior of PWB circuit cards were discussed, a linear or free stream test and a volumetric or card cage test. At flow ranges that are typical of card cages, these tests yield substantially different results. It is recommended that for designs where the PWB is used in a card cage, airflow requirements be specified in terms of volumetric flow per card slot and the assembly be tested in an equivalent manner. For PWBs that are used as a freestanding module, a linear flow test is recommended. Substantial errors may result if this is not done. Such types of tests can be performed at any number of test houses. QUEST Engineering Solutions in Billerica MA has such equipment and has been performing tests of this type for over 10 years. In addition to test services, Quest can furnish a range of analytic and design services.

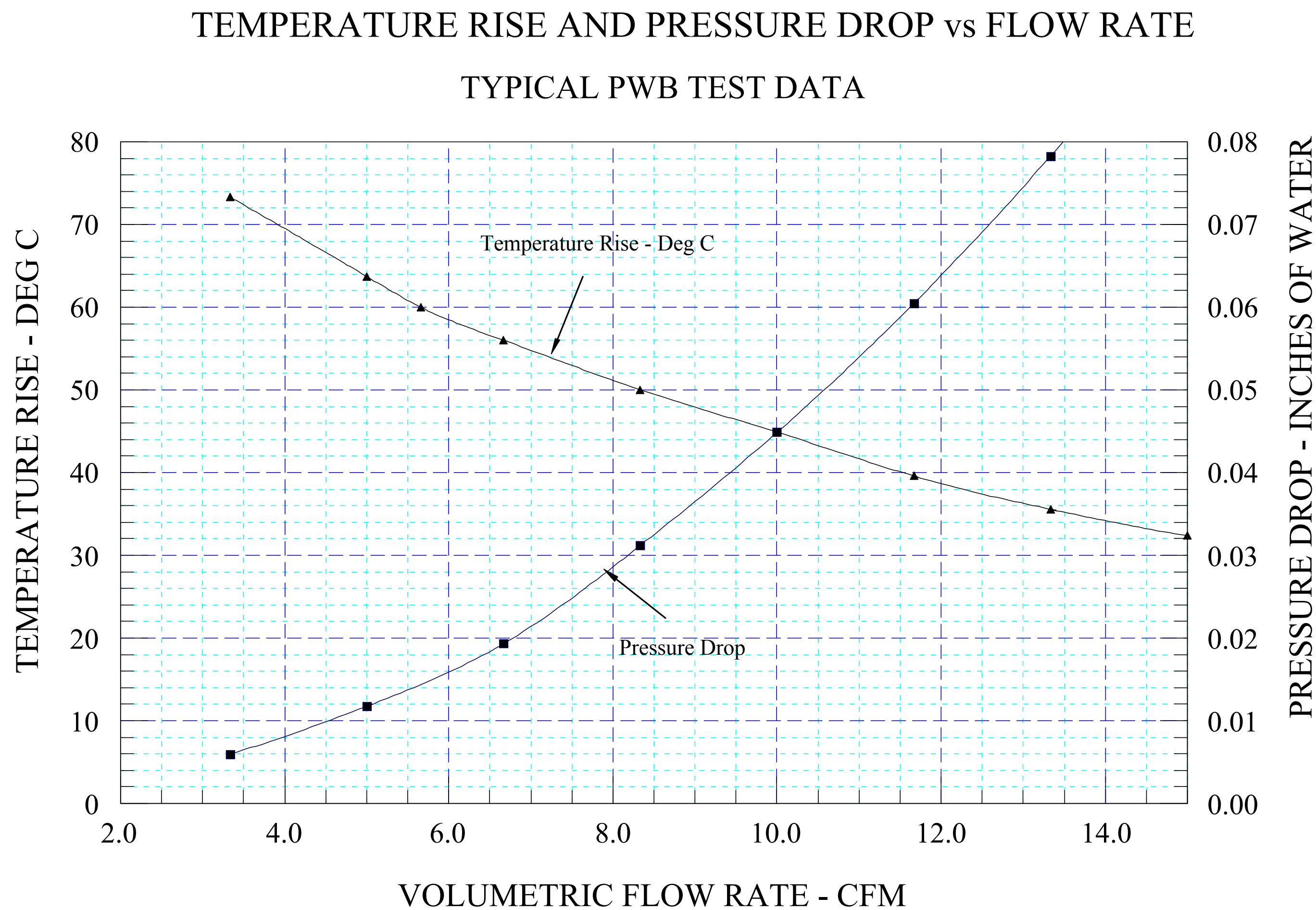

Figure 4. Typical test data from a Volumetric Flow Test. The PWB temperature rise is referenced to the inlet air temperature. The pressure drop is a measured value for the test hardware.

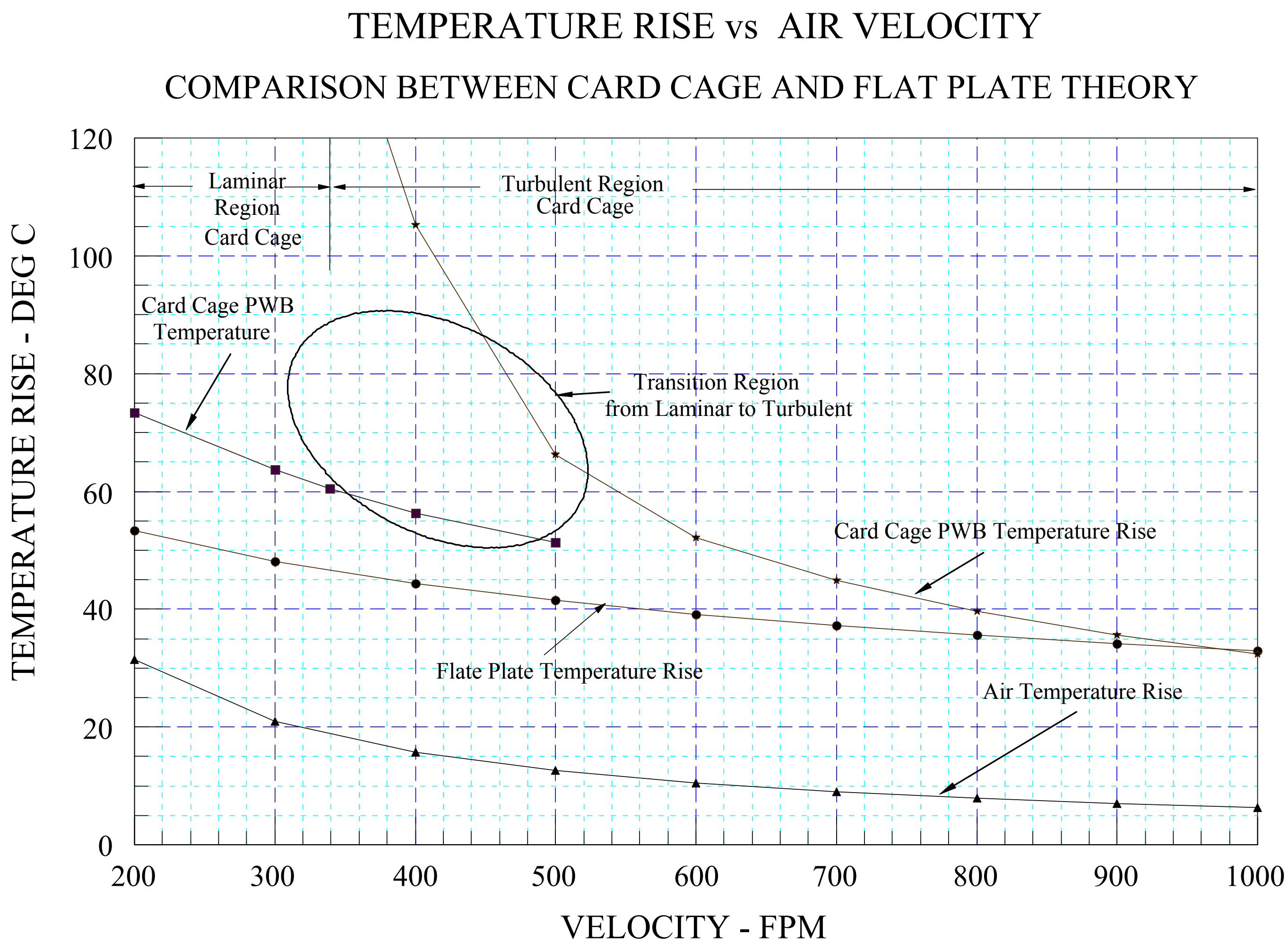

Figure 4. A comparison of temperature rise and pressure drop between a linear and a volumetric flow test. Note the difference in the temperature rise at 400 FPM. Using linear flow test data for hardware installed in a card cage can lead to large errors.