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EFFECT OF FREE STREAM TURBULENCE LEVEL ON EMBEDDED THERMISTOR ANEMOMETERS

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ABSTRACT

Experiments were conducted in a wind tunnel to observe the behaviour of an embedded thermistor anemometer in turbulent flow. Symmetric grids were used to increase tunnel turbulence levels, while tunnel temperature was held constant. A hot-wire anemometer was used to determine velocity and turbulence intensity of the flow over the thermistor. Measurements showed a change in tunnel turbulence level significantly affected the output of an embedded thermistor anemometer. The results were inconclusive as to the exact effect of turbulence intensity and scale. The use of thermistor anemometers in turbulent environments should be undertaken with caution, until the effects of turbulence are further quantified.

1. INTRODUCTION

Thermistors are commonly used as single point thermal anemometers, behaving as slow response, robust hot-wires. The two major effects on heat transfer, and therefore output, from a thermistor are the fluid flow rate and the temperature differential between the thermistor and the fluid. It is common practice to calibrate thermistors in low turbulence wind tunnels at known velocity and temperature points. Such a calibration for one particular thermistor is shown in Figure 1, as made by the author. When a thermistor is used to find the velocity of a flow of known temperature a voltage measurement is taken, and the flow velocity determined from the calibration plot.

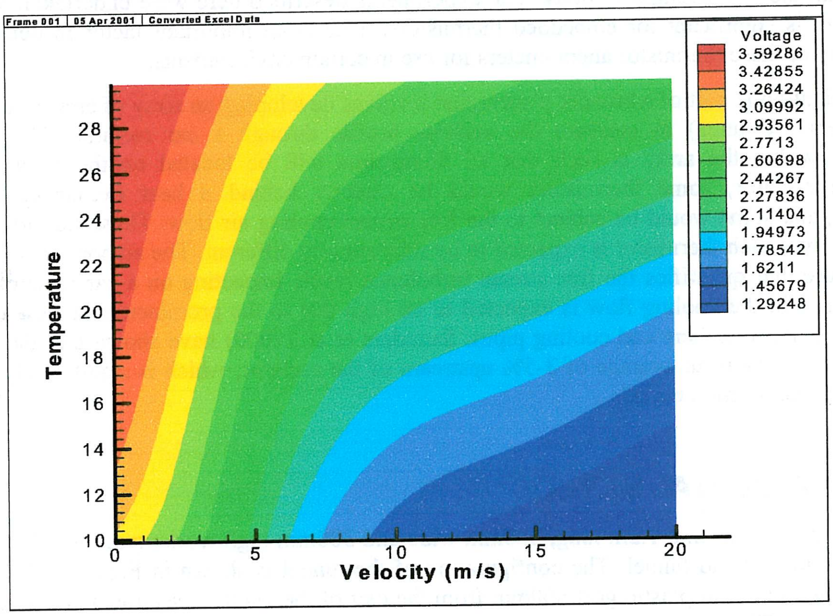

Figure 1 : Thermistor Calibration.

Inadequate attention has been paid to the effects of free stream turbulence levels on thermistor anemometer accuracy. Unlike a hot-wire which, being extremely small with a fast response can be treated as a body in a time dependent stream, the thermistor with a high thermal mass averages readings over time. Thus, the effect of turbulence on thermistor performance must be considered.

An increase in turbulence intensity, with other flow properties held constant, will generally produce an increase in Nusselt number (Nu). For heat transfer purposes, the simplest and most representative way to model a thermistor is by a sphere in free space. Whilst the thermistor used in this experiment was not in free space, nor perfectly spherical, an evaluation of the Nusselt number of a sphere is relevant because it highlights the flow properties that may affect heat transfer. Achenbach (1978) obtained relationships for heat transfer from a sphere in cross-flow with Prandtl number equal to 0.71, the results show the Nusselt number for a sphere to be a function of both Reynolds (Re) and Prandtl numbers. Kestin (1966) collated the results of Maizel and Sherwood (shown in Figure 2.) which indicate for a given Reynolds number the variation in Nusselt number was as much as 40 per cent over a range of turbulence intensities. Thus the Nusselt number is a function of turbulence parameters, in addition to the Reynolds and Prandtl numbers.

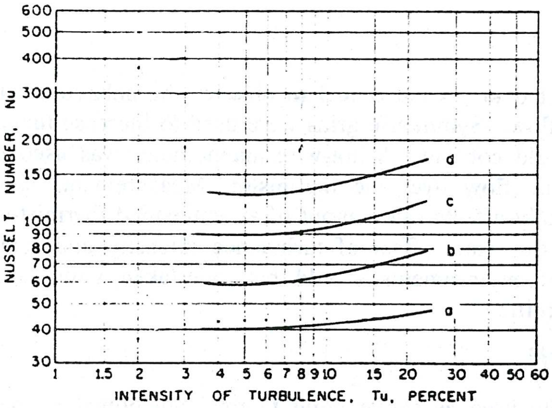

Figure 2: Effect of Turbulence Intensity on Nu of Spheres. (a) Re = 2440, (b) Re = 6060, (c) Re = 12450, (d) Re = 19500 (Kestin, 1966)

Given these results it is unreasonable to assume that a calibration in a low turbulence intensity wind tunnel will be applicable to measurements in a highly turbulent airflow. In such a situation it would expected that high turbulence levels would cause the output of the thermistors to indicate a higher velocity than the true average velocity. The experiments described here were undertaken to determine if this effect is significant for embedded thermistors. This is an important factor in determining the applicability of these thermistor anemometers for use in certain environments.

This investigation is part of a broader project that involves developing an array of embedded thermistor anemometers (96 units) to measure the velocity profile through a car radiator. The location of thermistors within the array is such that all thermistors will be located on the front face of the automotive radiator, some thermistors would be directly behind a heat exchanger (automotive condenser), and some would be subject to the free stream cooling air flow. Thus, the turbulence level of the flow over each thermistor is expected to be substantially different. The author has been unable to find literature that quantifies the free stream turbulence levels impacting on a car radiator. However, the turbulence in the cooling flow is expected to be high due to the prominence of flow obstructions such as structural members and cooling pipes. Saunders et al. (2000) have shown that the free stream turbulence intensity is an average of 3-5% upstream of the radiator, which is significantly larger than exists in most calibration tunnels.

2. EXPERIMENTAL METHOD

Tests were undertaken in a 1.2m long, 300mm wide and 300mm high working section that was placed in a closed circuit wind tunnel. The configuration of the tunnel is shown in Figure 3. The thermistor was positioned in a thin plastic grid 600mm from the exit of the working section and 600mm from the contraction exit. The thermistor anemometer consisted of two thermistors, embedded on opposite sides of the structure (see Figure 4). The front thermistor is used for speed sensing and the rear thermistor to detect any flow reversal. For the purpose of this experiment only the front thermistor was tested.

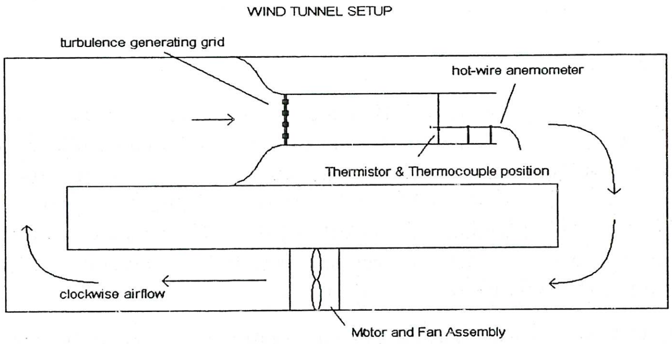

Figure 3: Wind tunnel set-up.

The thermistor was integrated into a Wheatstone bridge circuit that was supplied with a constant voltage. A calibrated thermocouple was located 20mm from the thermistor to measure flow temperature. Velocity and turbulence intensity was measured using a hot-wire anemometer. The hot-wire anemometer was calibrated isothermally against a pitot-static tube at 25°C. The bridge or thermistor output voltage, velocity and temperature were monitored by a data acquisition system.

The probe could not be located behind the thermistor, as it would be in the wake of the thermistor grid, and thus be subject to unrepresentative turbulence levels. Similarly, placement of the probe in front of the thermistor would cause a wake over the thermistor. To avoid this the probe was placed 10mm upstream and 20mm above the thermistor, and an assumption was made that the turbulence levels measured at this point were representative of those at the thermistor.

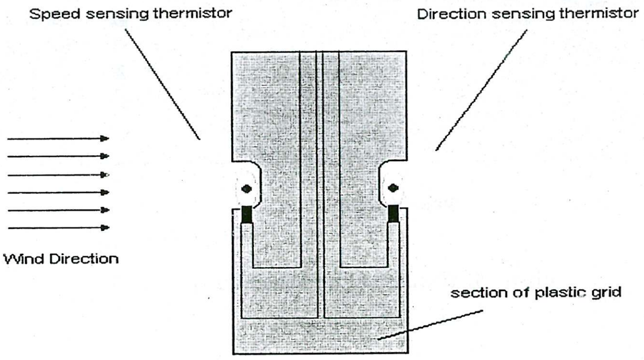

Figure 4: Thermistors embedded in plastic grid.

To generate varying levels of turbulence three different grids were alternately placed in the wind tunnel at the contraction exit. Table 1 shows the grid dimensions. Turbulence length scale measurements were not made, however the relative length scale is proportional to grid slat size. Thus, it is assumed that grid #1 has the greatest length scale and grid #3 the smallest. Data was obtained for each grid over a range of velocities by varying the tunnel fan speed, with all readings taken at constant temperature of 25°C.

	Slat Width (mm)	**# Slats**	**Blockage Percentage**	**Turbulence Intensity**
Grid 1	**70**	**2**	**63.5%**	**29.9%**
Grid 2	**35**	**6**	**76.1%**	**28.4%**
Grid 3	**20**	**8**	**67.4%**	**21.9%**
No Grid	**-**	**-**	**-**	**1.0%**

Table 1. Grid Dimensions and Turbulence Intensities

3. RESULTS AND DISCUSSION

It was found that the output of the thermistors drifted slightly so it was necessary to take a reading at zero velocity before and after each grid was tested. This enabled a corrected voltage to be calculated. An increase in this corrected voltage output indicates an increase in heat transfer from the thermistor. The average turbulence intensity level for each grid is shown in Table 1. A plot of voltage versus velocity is shown in Figure 5. This highlights the effects of the different flow regimes on thermistor heat transfer. It can be seen that for all grids an increase in turbulence level caused a corresponding increase in thermistor heat transfer, relative to the no grid case.

It was expected that the tests would establish an obvious relation whereby an increase in turbulence intensity could be linked to an increase in heat transfer. Similarly, a relation between turbulence length scale and thermistor heat transfer was sought. However, no relationship could be established that quantifiably linked specific changes in turbulence characteristics to increases in thermistor output. It could only be stated that the embedded thermistor anemometer, when placed in flow of a turbulent nature, exhibited significantly different and increased heat transfer rates to those displayed when in laminar flow. Further research will be undertaken to better quantify the effect of scale and intensity on thermistor heat transfer. The experiment will be repeated using lower blockage grids, and a greater distance between the turbulence generating grids and the thermistor to ensure the flow is homogeneous.

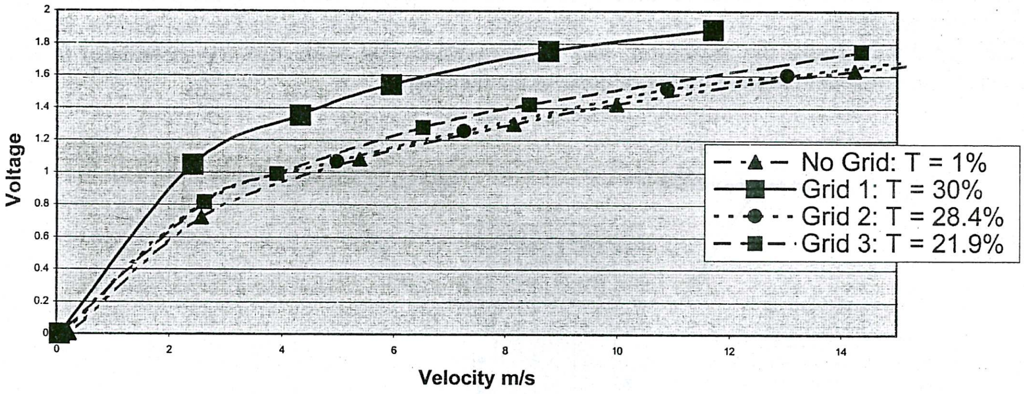

Figure 5: Thermistor Calibration Curve

4. CONCLUSION

This investigation was undertaken to determine whether the effect of turbulence on the performance of an embedded thermistor anemometer was significant. The results showed that a large increase in turbulence intensity and scale did significantly affect the thermistor heat transfer and therefore the voltage output. The relative effect of scale and intensity has not been found conclusively and warrants further investigation. Before using thermistor anemometers for velocity measurement in turbulent environments, the turbulence levels expected should be known and the effects quantified.

5. ACKNOWLEDGEMENTS

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