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HOT WIRE/FILM ANEMOMETRY FOR ROOM AIR MOTION STUDIES

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SYNOPSIS

Application of hot wire/film anemometry in room air flows presents difficulties because: (1) the effect of natural convection due to the heated wire becomes significant for low air velocity measurements; (2) the angle sensitivity of a hot wire becomes small at low air velocities, which makes it difficult to resolve the direction of each velocity component. This study aimed at quantifying the uncertainty of the hot wire anemometry and examining the angle sensitivity of a hot wire in low air velocity measurements. Based on the experiments, it was concluded that: (1) the uncertainties due to natural convection in the velocity measurements with a single component hot wire probe operating at 200 °C wire temperature are within ±15%, ±5%, ±3%, ±1% and 0.5% for velocities of 0.05~0.1 m/s, 0.1~0.15 m/s, 0.15~0.25 m/s and 0.25~0.5 m/s, respectively, and correction can be made based on the visualization of the room air flow pattern to achieve higher accuracy; (2) air velocity components can not be measured simultaneously with multi-component hot wire probes if the air velocity is below 0.2 m/s since the angle sensitivity of the probe will be heavily contaminated by the noise signal due to the natural convection.

1. INTRODUCTION

Hot wire/film anemometers belong to the family of thermal anemometers which include hot wire, film and ball (i.e., omnidirectional) sensors. They measure the fluid velocity by sensing the changes in heat transfer from a small, electrically heated sensing element exposed to the fluid motion. This technique is most widely used in measuring room air flows because it satisfies most of the following requirements for a ideal instrument:

(1) have high sensitivity for measuring turbulent fluctuations,
(2) measure a wide velocity range,
(3) be small in size for an essentially point measurement,
(4) have high accuracy,
(5) have high resolution (low noise),
(6) create minimal flow disturbance,
(7) be unsensitive to the air temperature variation within the room,
(8) measure velocity components and detect flow reversal,
(9) be low in cost, and

(10) be easy to use.

Many researchers studying room air motion have used the omnidirectional probe (e.g., Awbi and Nemri[1], Holfman[4], Popiolek[6], and Zhang et al.[9]) which is insensitive to the velocity direction and therefore essentially measures the total speed. Special attention has been paid to the design of this type of sensor so that it is mainly for low velocity measurements (0 to 3.5 m/s). Due to the relatively large size of its sensing element (1 to 2 mm in diameter), this type of sensor typically has a time constant of about 2 seconds. Therefore, it is excellent for measuring mean velocity, but not suitable for measuring velocity fluctuations.

Hot wire/film probes have small sensing elements (typically 4 to 50 μm in diameter by 1 to 1.5 mm long) and can detect high frequency velocity fluctuations. They have been used for studying the mean and turbulent characteristics of the room air flow (e.g., Sandberg[7] and Zhang et al.[10]). The small probe size is also critical to the measurement of velocity profiles at the diffuser and within the boundary layers over surfaces of ceiling, wall, floor and internal obstructions. Sandberg[8] used a wire probe to measure the velocity profile within the boundary layer over the ceiling surface.

Multi-component sensors have also been used to detect the direction of air velocity as well as its magnitude, but applications have so far been limited to the measurements in reduced scale rooms with high air flow rates (Murakami and Komine[5]). Resolving components low air velocities is more difficult because the angle sensitivity of the hot wire/film probes decreases as velocity decreases. Studies are needed to quantify the angle sensitivity of multi-component hot wire/film probes in the low velocity range.

A difficulty involved in low air velocity measurements with the hot wire/film anemometers is to account for the effect of natural convection over the sensing element. The natural convection creates local air movement around the sensing element and causes error in the actual velocity signal. This error becomes significant when the air velocities are low (<0.25 m/s), which is typical in the occupied regions of ventilated rooms. Therefore, the uncertainty in measuring low air velocities with the hot wire/film anemometers needs to be quantified and when necessary, measured values adjusted to account for the error due to the natural convection.

Another problem with the hot wire/film anemometers is its difficulty in detecting flow reversal. A so called "flying hot wire anemometry" is developed for detecting flow reversal (Foss[3]), but the flying probe support is likely to disturb the flow field significantly since room air flows usually involve recirculations. Therefore, flow visualization techniques are usually used to complement thermal anemometers to obtain the general air flow patterns within the room.

2. OBJECTIVES

(1) Quantify the uncertainty of the hot wire/film anemometry in low air velocity measurements;

(2) Examine the angle sensitivity of a multi-component hot wire probe in low air velocity measurements.

3. FACILITY AND PROCEDURES

The experimental set up is shown in Figure 1. Air jets were generated by a commercial calibrator (TSI model 1125) of hot wire/film probes, the principles of which are described in detail by Fingerson[2]. Velocities of the jets were determined by the pressure drops across the nozzle, which were measured with a high precision pressure transducer (Valendyn model DP103). The air jet was directed either upward or downward to study the effect of thermal buoyancy on the air velocity measurement. The probe tested was a 2-D cross wire probe (TSI model 1247A) which had two tungsten wires (4 μm in diameter) perpendicular to each other. The probe can be rotated around its axis so that the angle between the wires and the jet flow direction can be varied to study the angle sensitivity of the hot wire probe.

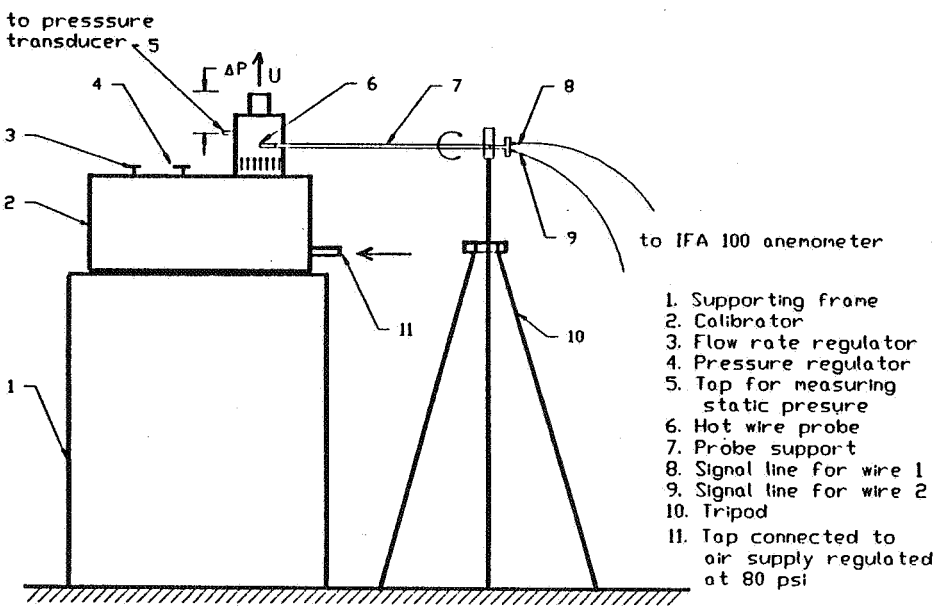


***Figure 1** Experimental set up for testing a hot wire probe*

Tests were conducted in an air conditioned laboratory which provided a constant ambient air temperature of 24±0.5 °C during the experiments. Two different wire operating temperatures (200 °C and 250 °C, respectively) were used for all the tests to study the effects of the wire operating temperature on the velocity measurements.

4. RESULTS AND DISCUSSIONS

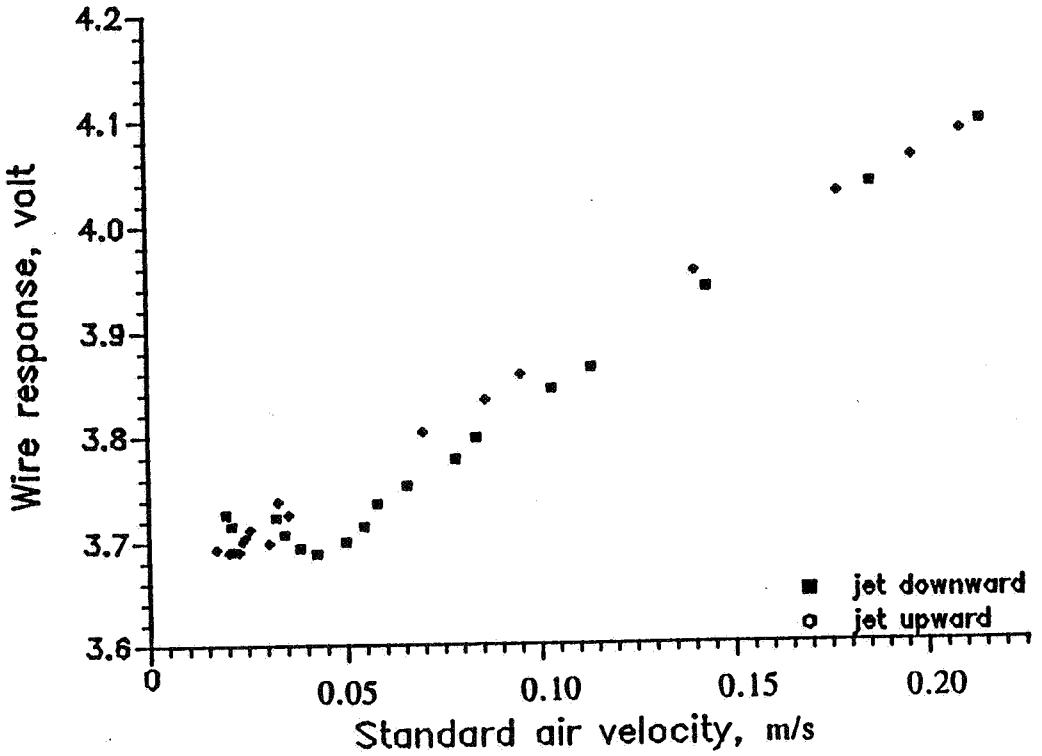
4.1 Uncertainty due to Natural Convection

Hot wire probes operate at higher temperature than the ambient air temperature. The temperature gradient between the wire and the air results in thermal buoyancy which moves air around the wire upward. The thermal buoyancy enhances the flow when the air jet is directed upward, but retards the flow when the air jet was downward. Half the difference between the two is the maximum possible uncertainty (error) due to the natural convection, assuming that the direction of the measured air flow relative to the probe orientation is unknown and that the calculation curve is selected based on horizontal flow.

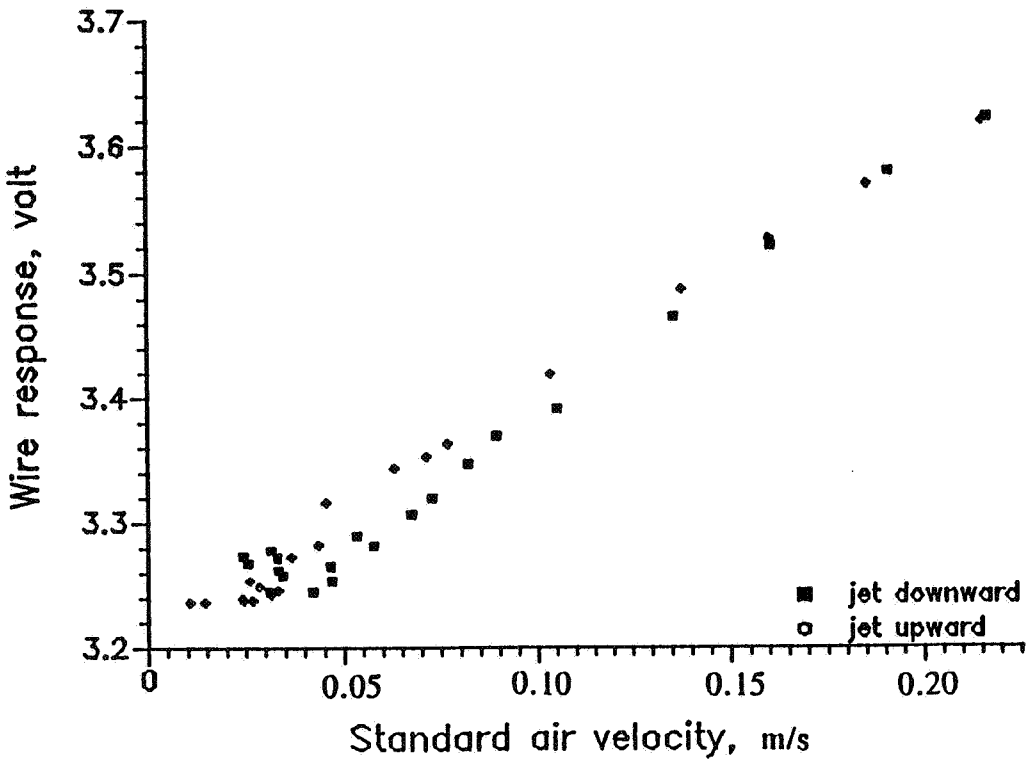
As shown in Figure 2, the difference of the wire output between the two jet orientations became larger as the air velocity decreased. The effect of thermal buoyancy was insignificant when the air velocity was higher than about 0.23 m/s. An interesting phenomena can be seen from the plots for the case when the air jet was downward, in which the wire response decreased when the air velocity increased from 0.025 m/s to about 0.046 m/s. This was because the natural convection was opposing the forced convection and natural convection had the dominating effect on the air movement around the wire when the air velocity (forced convection flow) was below 0.046 m/s.

Figure 3 was obtained by (1) fitting the data in Figures 2a and 2b for each air jet direction with a second order polynomial function using the Least Square Method; (2) calculating the wire response (volts) for a given air velocity (i.e., the X axis) with the obtained curve when the air jet is upward; (3) calculating the velocity corresponding to the wire response (volt) with the obtained curve when the air jet is downward; and (4) calculating half the difference of the two velocities in percentage (i.e., the Y axis). It can be seen that a higher operating temperature of the wire resulted in a higher uncertainty due to the natural convection. At the velocity of 0.05 m/s, the uncertainty was about $\pm 15\%$ and $\pm 20\%$ for 200 °C and 250 °C operating temperatures, respectively.

The relative uncertainty increases when the velocity decreases. Based on Figure 3, the uncertainty in measuring air velocity with 200 °C operating temperature is estimated to be $\pm 15\%$, $\pm 5\%$, $\pm 3\%$, $\pm 1\%$ and $\pm 0.5\%$ for velocities of 0.05 to 0.1 m/s, 0.1 to 0.15 m/s, 0.15 to 0.25 m/s, 0.25 to 0.5 m/s and >0.5 m/s, respectively for the probe operating at 200°C. In other words, the uncertainty due to the natural convection is within ± 0.015 m/s for velocities less than 0.5 m/s, assuming the measured air flow direction is unknown.



a. T_{op} = 250 °C



b. T_{op} = 200 °C

***Figure 2** Outputs of wire #1 for two different jet orientations (T_{op} is the operating temperature of the probe)*

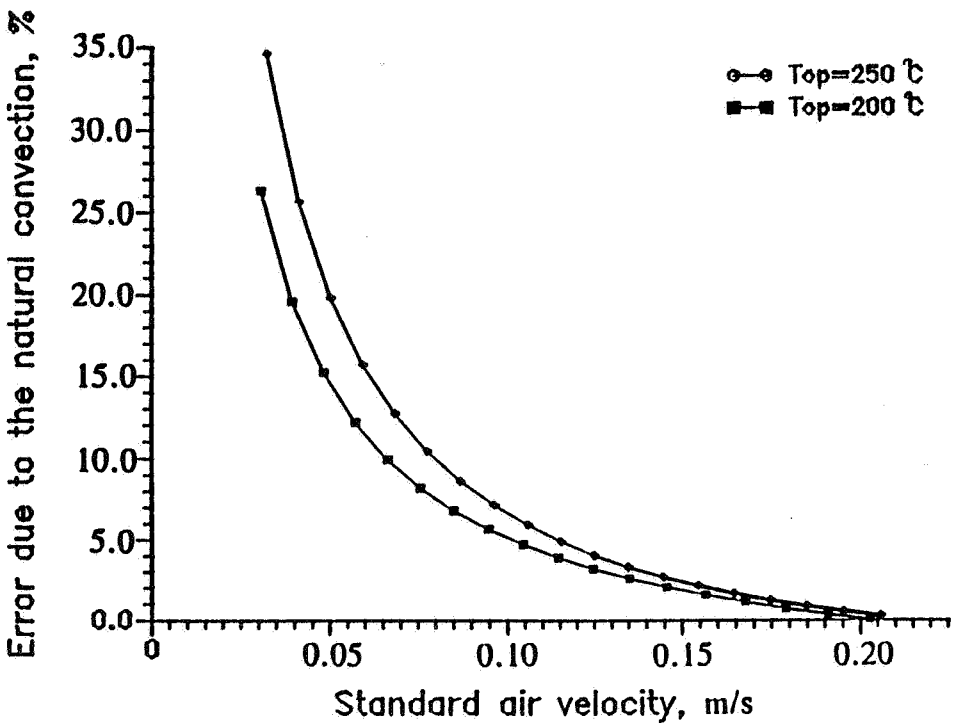


Figure 3 Error due to the natural convection
(T_{op} is the operating temperature of the probe)

If one knows the direction of the measured air flow, the above uncertainty due to natural convection becomes a systematic error and can be corrected by calibrating the probe at different orientations relative to the direction of the natural convection flow (i.e., upward). In the measurements of room air ventilation flows, one can use flow visualization techniques to determine the general air flow pattern within the room. The direction of the air flow at measured points can be easily estimated within ± 15 degrees with flow visualization techniques. The systematic error due to the natural convection can then be corrected to improve the accuracy of the velocity measurements significantly.

A lower wire operating temperature would reduce the effect due to the natural convection, but at the same time would also reduce the signal to noise ratio and affect the performance of frequency response. Further studies are needed to determine the optimal wire operating temperature which minimizes the uncertainty due to the natural convection while still provides sufficient signal to noise ratio and satisfactory frequency response performance.

It should be noted that other uncertainty sources such as calibration, voltage measurement, probe positioning and alignment exist in measuring room air velocities. Zhang[11] conducted a detailed analysis of the uncertainties involved in measuring room air velocity distribution.

4.2 Angle Sensitivity of the Hot Wire Probe

The angle sensitivity of the probe was tested by measuring the wire response at different angles between the wires and the jet flow direction (Figure 4). As expected, the output from a wire decreased when the angle between the wire and the jet direction decreased. However, the difference between the outputs at the different angles also decreased as the air velocity decreased and became not appreciable when the velocity was below about 0.18 m/s.

As shown in Figure 5, the angle sensitivity may actually be overwhelmed by the uncertainty due to the natural convection when the air velocity is below 0.20 m/s. As the air velocity increased, the uncertainty decreased and the angle sensitivity increased. Additionally, for a lower wire operating temperature (i.e., 200°C), both the uncertainty due to the natural convection and the angle sensitivity were smaller, but the decrease of the angle sensitivity was much smaller than the decrease of the uncertainty. Therefore, one can use a lower wire operating temperature to reduce the uncertainty due to the natural convection while still maintain relative high angle sensitivity. Again, further studies are needed to determine the optimal wire operating temperature.

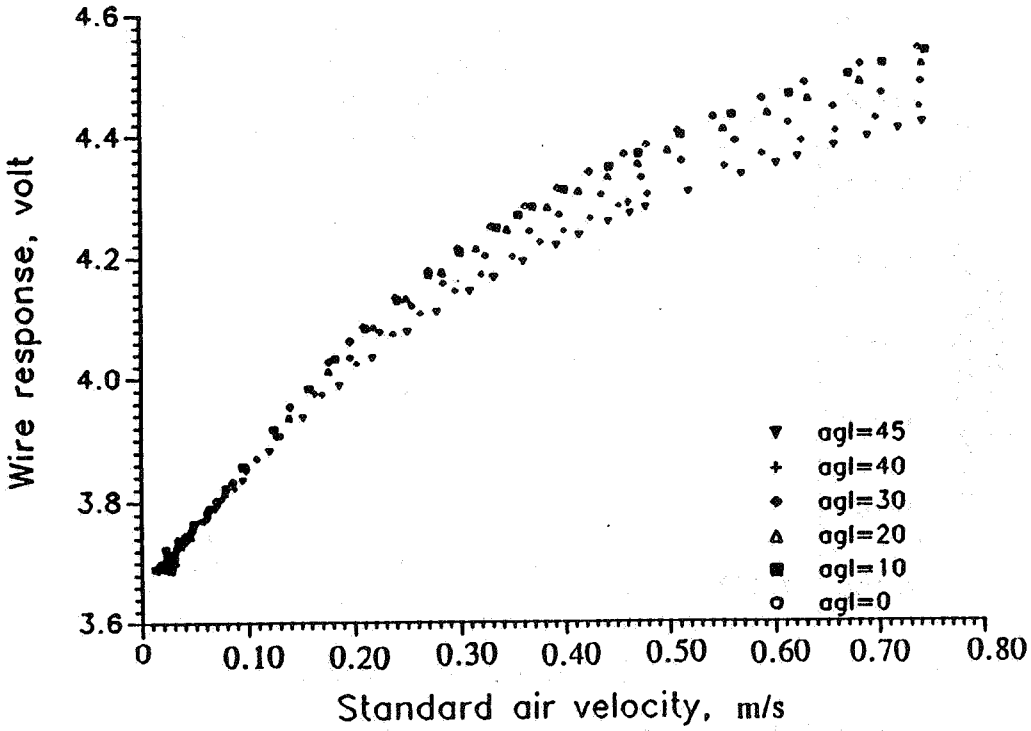
CONCLUSIONS

Based on the above analysis, the following conclusions can be made:

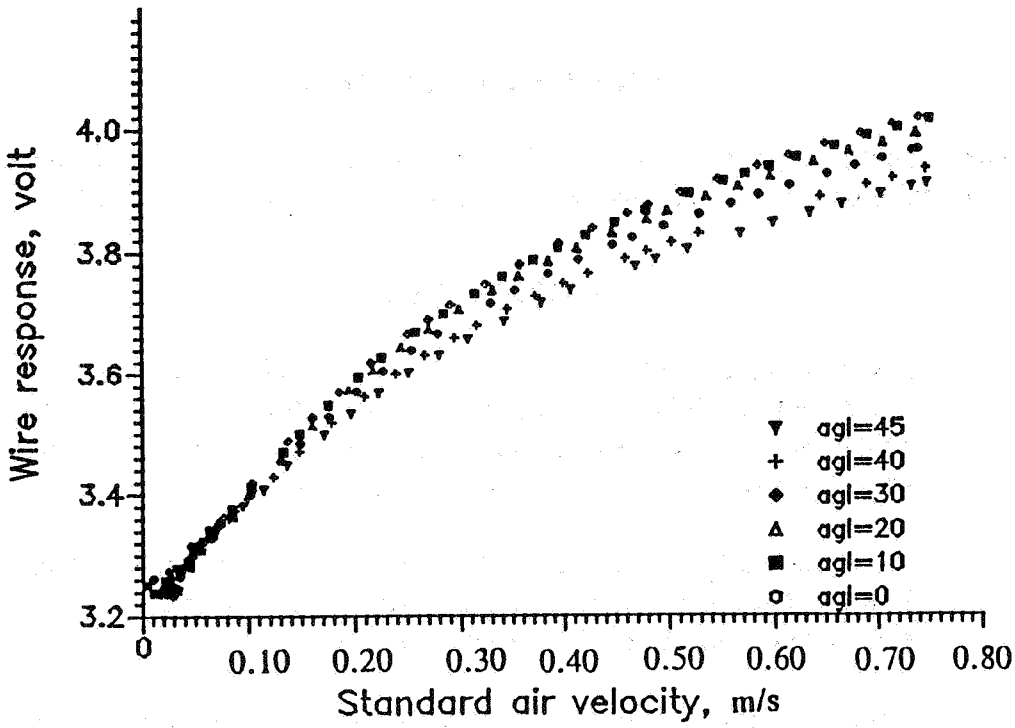
(1) The uncertainties due to natural convection in the velocity measurements with a single component hot wire probe operating at >200 °C are estimated to be ±15%, ±5%, ±3%, ±1% and 0.5% for velocities of 0.05 to 0.1 m/s, 0.1 to 0.15 m/s, 0.15 to 0.25 m/s, 0.25 to 0.5 m/s and >0.5 m/s, respectively, assuming that the direction of the measured air flow is unknown. Flow visualization techniques can be used to determine the air flow directions at the measured points within rooms approximately and improve the measurement accuracy significantly.

(2) Air velocity components should not be measured simultaneously with multi-component hot wire probes operating at >200 °C if the air velocity is below 0.2 m/s, since the angle sensitivity of the probe will be heavily contaminated by moise signal due to the natural convection.

Further studies are needed to determine an optimal probe operating temperature which minimizes uncertainty due to the natural convection while still provides sufficient signal to noise ratio and satisfactory frequency response performance.



a. T_{op} = 250 °C



b. T_{op} = 200 °C

Figure 4 Outputs of wire #1
(agl is the angle between the air jet and the normal plane of wire #1)

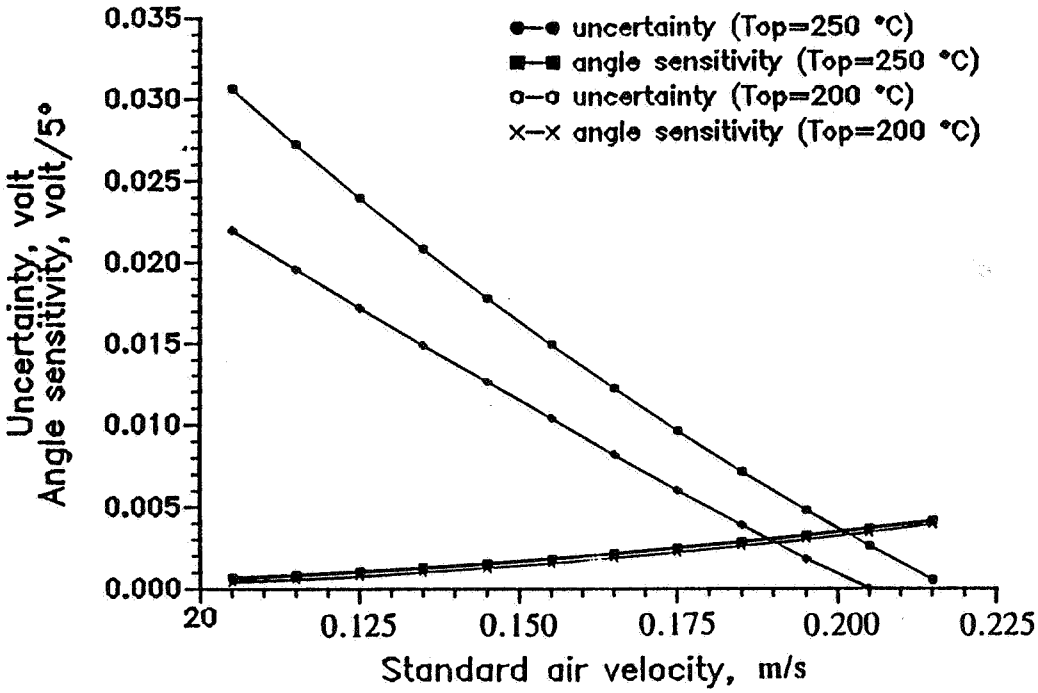


***Figure 5** Comparisons between the angle sensitivity and the measurement uncertainty of the hot wire anemometer (T_{op} is the operating temperature of the probe)*

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