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Calibration of Anemometers used in the Ship Survivability Enhancement Program

G.I. Gamble and F.M. Marian

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Maritime Platforms Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

Part of the Ship Survivability Enhancement Program (SSEP) was a series of smoke experiments. These experiments used cold smoke (training smoke cannisters) and hot smoke (produced from fires) to record the propagation of smoke through a naval vessel, in order to test the effectiveness of different smoke clearance techniques. Temperature, smoke density and air velocity data were recorded. Air velocity was measured with the use of bidirectional anemometer sensors, connected to Air Monitor Corporation Veltron 5000AZ series differential pressure transmitters. An air velocity calibration for these systems was required to interpret the measurements. Equations based on data recorded using known air velocities in a wind tunnel have been developed to enable this translation.

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Executive Summary

The Ship Survivability Enhancement Program (SSEP) used a near operational warship, the former HMAS Derwent, to conduct several series of blast, fire and smoke experiments. The smoke series of experiments was designed to investigate smoke transport behaviour and clearance procedures during fires. Air and smoke velocities were measured using bidirectional anemometer sensors. This report presents a calibration of these systems. This calibration enables the data recorded during the smoke series of experiments to be converted to air and smoke movement velocities so that the behaviour of the shipboard fires and smoke propagation can be analysed.

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Grant Gamble graduated with a B.Sc. (Physics and Computer Science) from La Trobe University in 1990. In 1991 he joined the Department of Defence, Materials Research Laboratory, now the Aeronautical and Maritime Research Laboratory, Defence Science and Technology Organisation (DSTO). Since joining AMRL he has worked in the area of naval fire research and has been involved in developing computer based fire models and training aids for the Royal Australian Navy.

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Frank commenced work at AMRL in 1969 and has been involved in a diverse range of activities. Since 1987 he has worked in the area of specialised instrumentation and has conducted field and laboratory experiments to measure transient parameters associated with air and underwater blast. He was involved with aspects of fire and blast during the SSEP trials. In more recent time his work area has focused on experiments related to structural response of naval targets to underwater detonation and is responsible for the AMRL underwater test facility in Melbourne.

Contents

1. Introduction

The Ship Survivability Enhancement Program (SSEP) [1], a joint program between the Defence Science and Technology Organisation and the Royal Australian Navy, was conducted on the former HMAS Derwent at Fleet Base West, HMAS Stirling, in Cockburn Sound, in Western Australia, in late 1994. The program included a smoke series of experiments which used cold smoke (training smoke cannisters) and hot smoke (produced from fires) to spread smoke through a section of the ship in order to test various smoke clearance techniques [2].

Temperature, smoke density and air velocity data were recorded for each experiment. Air velocity was measured with the use of bidirectional anemometer sensors [2, 3], connected to Air Monitor Corporation Veltron 5000AZ series differential pressure transmitters [4]. In order to interpret the measurements each of the anemometer sensor/Veltron transducer combinations required an individual calibration curve.

2. Experimental Setup

2.1 SSEP

In this paper a series of calibration curves for most of the anemometers used in the SSEP smoke series experiments are presented. For the SSEP experiments the anemometer sensors were grouped in three trees (A1, A2 and A3). The term 'tree' refers to the arrangement of the sensors on horizontal arms connected to a common vertical pole that resembles a tree. The anemometer sensors were distributed between the floor and ceiling. There were six positions available for anemometer sensors on each tree. The location of each sensor was designated by a position number, with position one being the lowest and six the highest. Trees A1 and A2 used all six positions, and tree A3 used five. There was no anemometer sensor at position two on tree A3. The Veltron transducers used at position two on trees A1 and A2 were not available for calibration, so have not been included in this report. The location of each anemometer sensor can be described with the following notation: Am/An, where m is the tree number and n the position on the tree. This will be used throughout this report.

Each anemometer sensor was connected to a Veltron transducer by two flexible rubber hoses of equal length. The Veltron transducers were adjusted for 4 to 20 mA outputs, which were measured using a Data Electronics Datataker 500 data logger [5]. The zero velocity output of the transducers is 12mA. The output increases with positive air velocities and decreases with negative air velocities. This technique was also used to record the calibration data.

The Veltron transducers used covered two different ranges of differential pressure; ±2.49 Pa and ±12.45 Pa. The pressure range of the transducers at each of the anemometer sensor locations is summarised in Table 1.

Table 1. The pressure range of the transducers at each of the anemometer sensor locations.

Anemometer	±2.49 Pa	±12.45 Pa
A1/A1		✓
A1/A2	✓	
A1/A3	✓	
A1/A4	✓	
A1/A5		✓
A1/A6		✓
A2/A1	✓	
A2/A3	✓	
A2/A4	✓	
A2/A5	✓	
A2/A6		✓
A3/A1	✓	
A3/A3	✓	
A3/A4	✓	
A3/A5	✓	
A3/A6		✓

2.2 Calibration

A wind tunnel, at AMRL Maribyrnong, with a variable speed fan drive was used to provide stable air velocities for the calibration. Negative air velocities were achieved by rotating the anemometer sensors through 180°. A Kurz Instruments 441 portable air velocity meter was used to measure air velocity. The air velocity meter was NATA certified by the CSIRO [6] to measure air velocity with an error of less than 5%. The air velocity meter was within the recommended calibration period at the time of use.

3. Results

3.1 Calibration Data

The plotted calibration data for each anemometer sensor and Veltron transducer combination is shown in Appendix A. The calibration data for the anemometer at position A3/A3 is presented in Figure 1. The method used to fit a function to the calibration data is illustrated in Figure 2, where the difference from zero velocity output of the Veltron transducer has been plotted against air velocity. Functions were fitted to the resulting data using Kgraph[1] [7]. They were found to take the form:

$$O_v = a(V_a + b)^{\frac{3}{2}} + c \tag{1}$$

for the small range Veltron transducers, and;

$$O_v = d(V_a + b)^2 + c \tag{2}$$

for the large range Veltron transducers;

where O_v is the Veltron transducer output (mA), V_a is the air velocity (m s^{-1}), a, b, c and d are constants (c is the Veltron transducer output in mA with air velocity at zero).

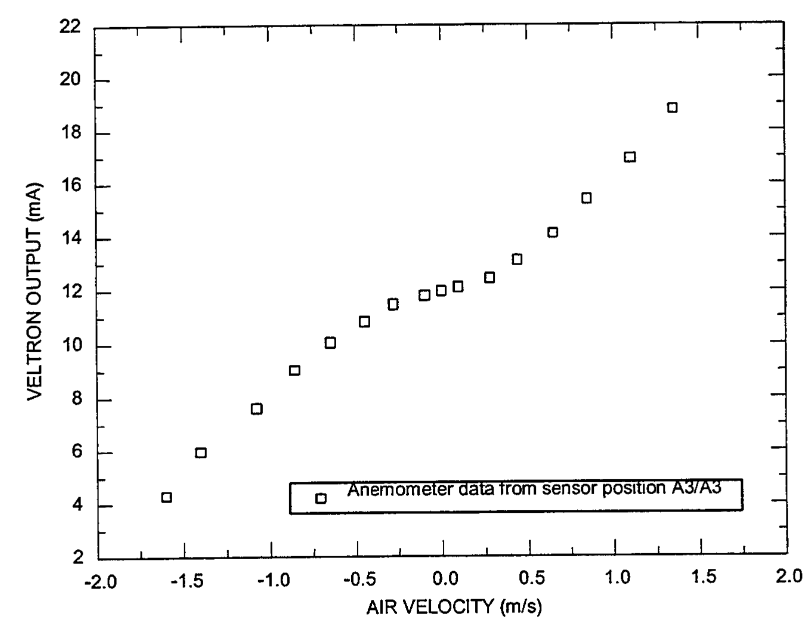

Figure 1. Calibration data from anemometer sensor/Veltron transducer combination A3/A3.

[1] Kgraph is a computer based data plotting and analysis program.

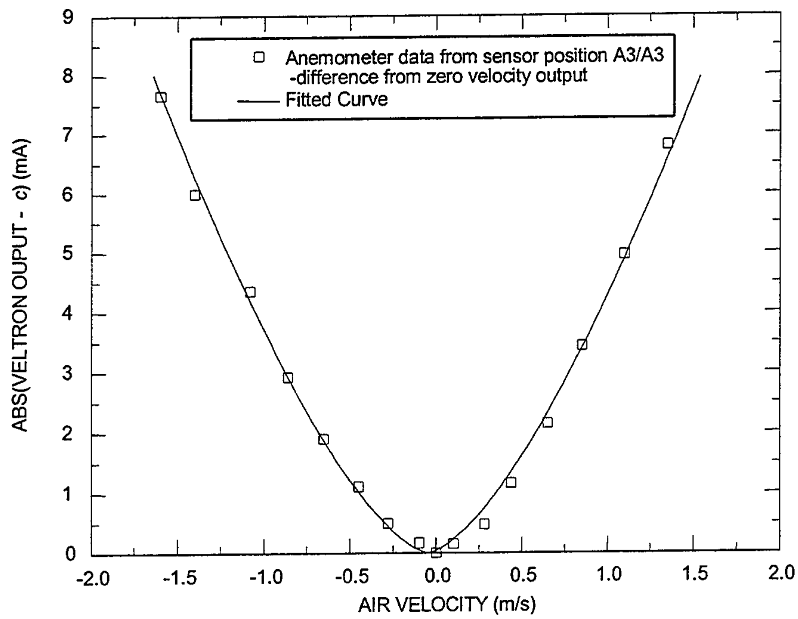

Figure 2. Curve fitted to modified data from anemometer sensor/Veltron transducer combination A3/A3.

Rearranging Equations 1 and 2, and considering the original Veltron transducer data (Figure 1), gives for the small range Veltron transducers:

$$V_a = \left(\frac{O_v - c}{a}\right)^{\frac{2}{3}} - b \text{ where } O_v > c$$

and

$$V_a = -\left(\frac{c - O_v}{a}\right)^{\frac{2}{3}} - b \text{ where } O_v < c \qquad (3)$$

and for the large range Veltron transducers:

$$V_a = \left(\frac{O_v - c}{d}\right)^{\frac{1}{2}} - b \text{ where } O_v > c$$

and

$$V_a = -\left(\frac{c - O_v}{d}\right)^{\frac{1}{2}} - b \text{ where } O_v < c \qquad (4)$$

The calibration data and the fitted curves for each anemometer are shown Appendix A. Values obtained from Kgraph for the constants *a, b, c* and *d* in Equations 3 and 4 along with the RMS errors for the fitted curves are shown in Tables 2 and 3.

Table 2. Equation 3 coefficients for small range Veltron transducers.

Anemometer	a (mA m$^{-3/2}$ s$^{3/2}$)	b (m s^{-1})	c (mA)	RMS error
A1/A3	3.777	0.0357	11.982	0.046
A1/A4	4.167	0.0136	11.955	0.030
A2/A1	4.034	-0.0103	12.656	0.040
A2/A3	4.194	-0.0375	12.106	0.040
A2/A4	4.551	0	11.943	0.038
A2/A5	4.176	-0.0397	12.010	0.037
A3/A1	4.032	-0.0127	12.094	0.051
A3/A3	3.983	0.0462	11.961	0.036
A3/A4	4.069	-0.0270	11.932	0.033
A3/A5	3.578	0.0790	12.124	0.056

Table 3. Equation 4 coefficients for large range Veltron transducers.

Anemometer	d (mA m^{-2} s^{2})	b (m s^{-1})	c (mA)	RMS error
A1/A1	0.551	0.133	11.928	0.028
A1/A5	0.568	0.159	11.897	0.034
A1/A6	0.544	0.135	12.016	0.025
A2/A6	0.157	-0.253	11.964	0.012
A3/A6	0.543	0.297	11.997	0.033

3.2 Veltron Transducer and Anemometer Sensor Connecting Hose Lengths

Each anemometer sensor and Veltron transducer was connected using two flexible rubber hoses of equal length during the SSEP. The hose lengths varied between anemometer sensor/Veltron transducer systems. The standard hose lengths used during the calibration were six metres. Data were recorded for anemometer tree A1, position five with both the standard hose length as well as a hose length of two metres. The Veltron transducer output plotted against air velocity for the two hose lengths is shown in Figure 3. The Veltron transducer output for each of the two hose lengths, which spanned the range of lengths used during the SSEP, were identical.

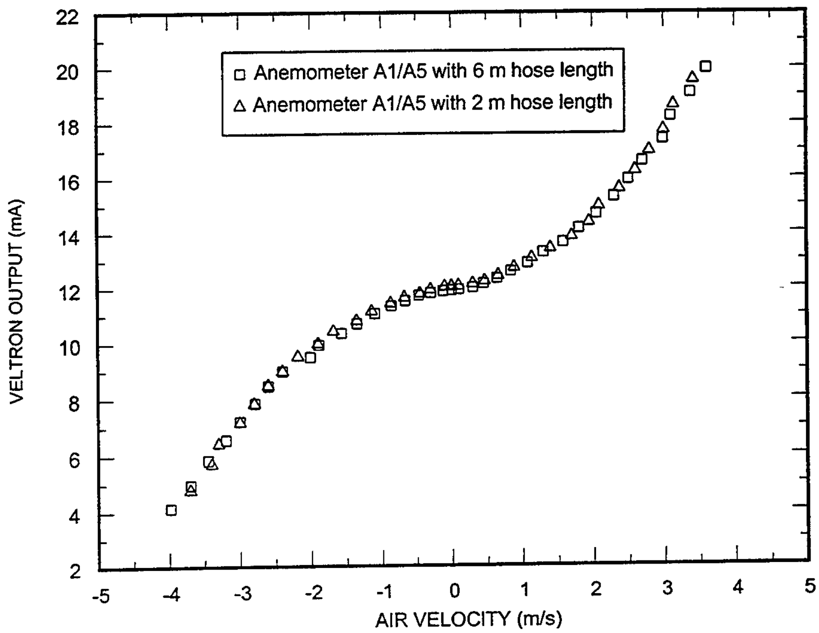

Figure 3. Comparison between anemometer sensor and Veltron transducer connected using six metre hoses and two metre hoses.

3.3 Comparison of Calibration with SSEP Data

During the SSEP smoke series, while smoke clearance activities were underway, measurements were taken with a hand-held rotary anemometer close to the locations of the anemometer sensors. The hand held rotary anemometer was not calibrated. However the data collected with it can be used to check the validity of the calibration. At each sensor position data recorded with the hand held anemometer were averaged over several minutes at a particular ventilation condition. The SSEP data were also averaged over a similar period. Measurements taken have been normalised to one of the anemometer measurements (sensor position A3/A4). The comparison between the two measurements is shown in Figure 4 (anemometer tree A2) and Figure 5 (anemometer tree A3) for the smoke clearance component of SSEP smoke series 'sequence 5' experiment [2].

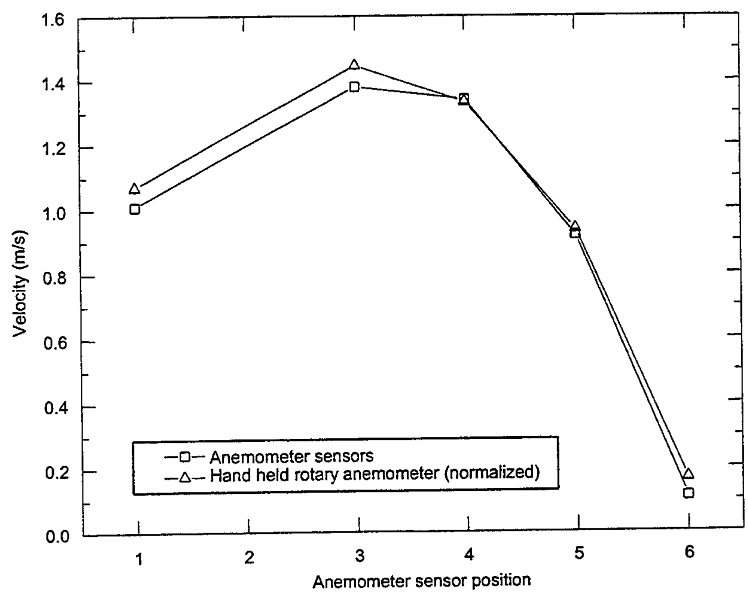

Figure 4. Comparison of hand held rotary anemometer with anemometer sensors for tree A2 (The solid lines connecting the data points are only guides).

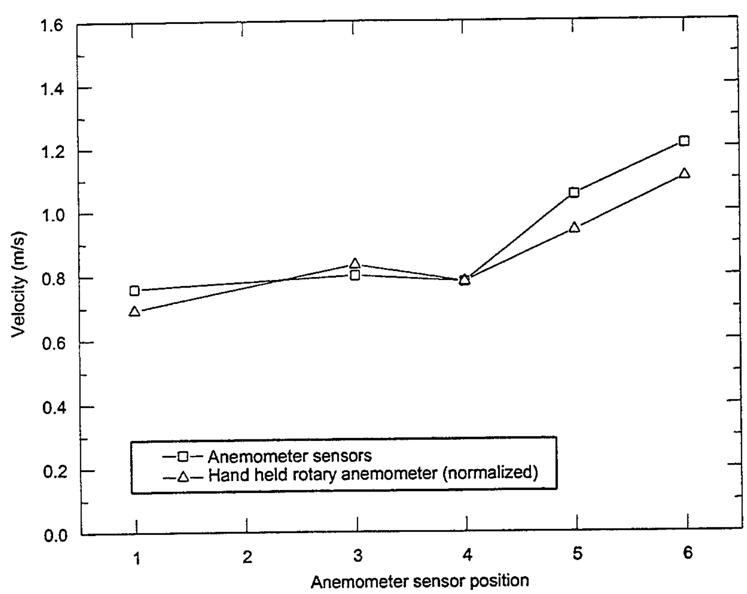

Figure 5. Comparison of hand held rotary anemometer with anemometer sensors for tree A3 (The solid lines connecting the data points are only guides).

The good agreement between the data shown in Figures 4 and 5 can be used to make the inference that the measurement behaviour of the anemometers used during the SSEP remained stable over the period between the SSEP experiments and the calibration at AMRL some time later.

4. Summary

A calibration of each of the anemometer sensor and Veltron transducer combinations available was undertaken. Simple functional forms have been found to match the form of the data for the two different pressure range Veltron transducers. Functions were fitted to the calibration data for each anemometer sensor and Veltron transducer combination. These functions can be easily written in data handling computer software, such as a spreadsheet, to convert the experimental data to air velocity measurement.

5. Acknowledgements

The authors thank Dr Stephen Kennett, Dr Peter Lambrineas and Mr Steve Boyd of the Aeronautical and Maritime Research Laboratory for their suggestions on the draft version of this document.

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7. *The Interactive Plotting Program Graph – Revised Manual,* Kennett S.R., DSTO AMRL General Document MRL-GD-0010, 1987.

Appendix A. Anemometer Calibration Data

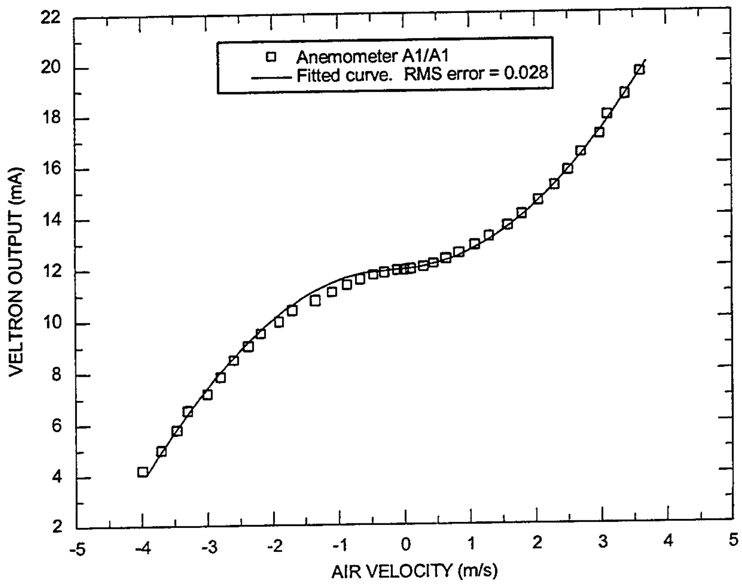

Figure A.1. Calibration data and fitted curve for A1/A1 (Veltron transducer range ±12.45 Pa)

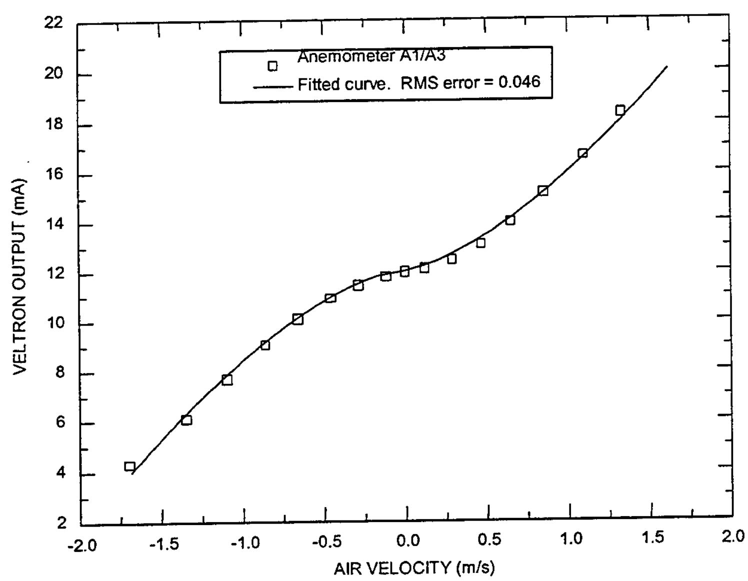

Figure A.2. Calibration data and fitted curve for A1/A3 (Veltron transducer range ±2.49 Pa)

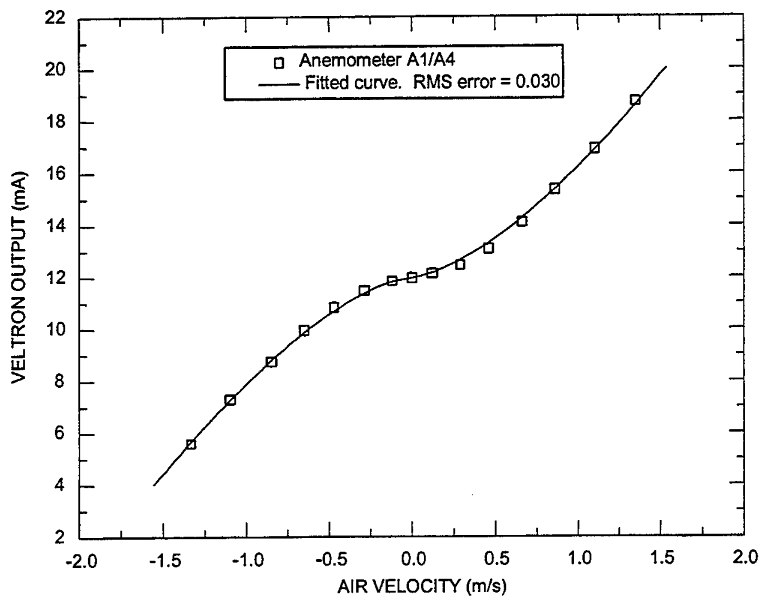

Figure A.3. Calibration data and fitted curve for A1/A4 (Veltron transducer range ±2.49 Pa)

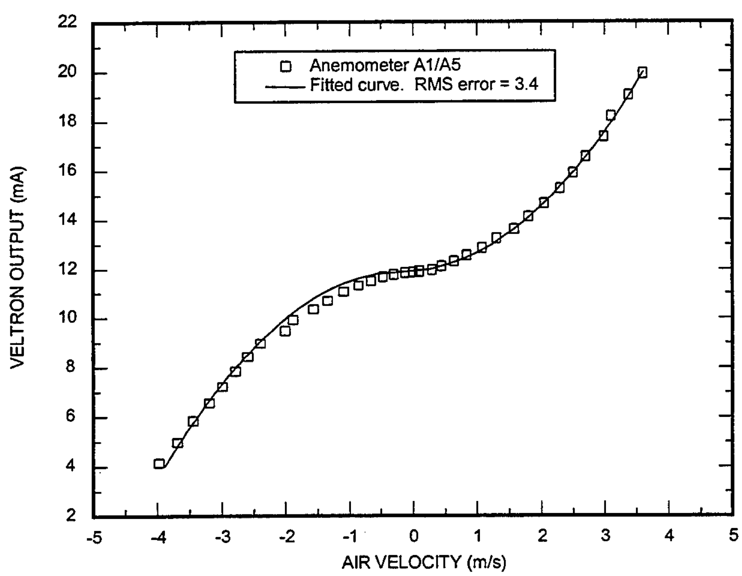

Figure A.4. Calibration data and fitted curve for A1/A5 (Veltron transducer range ±12.45 Pa)

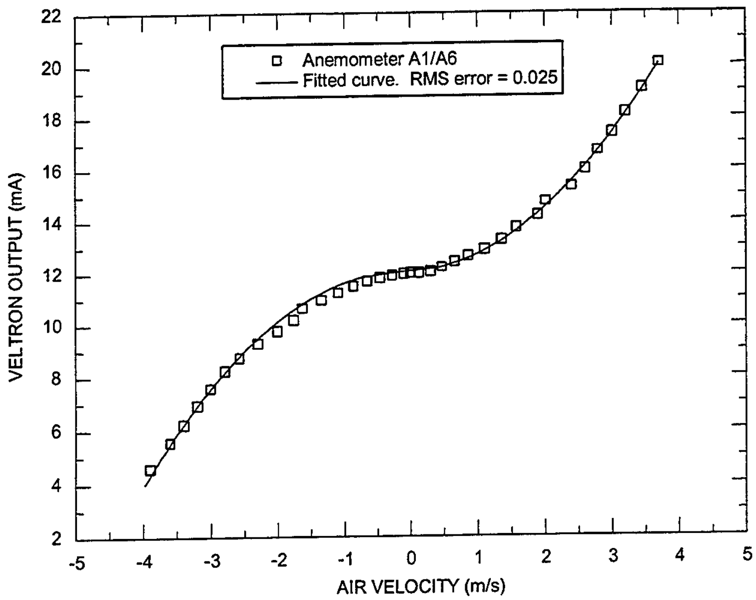

Figure A.5. Calibration data and fitted curve for A1/A6 (Veltron transducer range ±12.45 Pa)

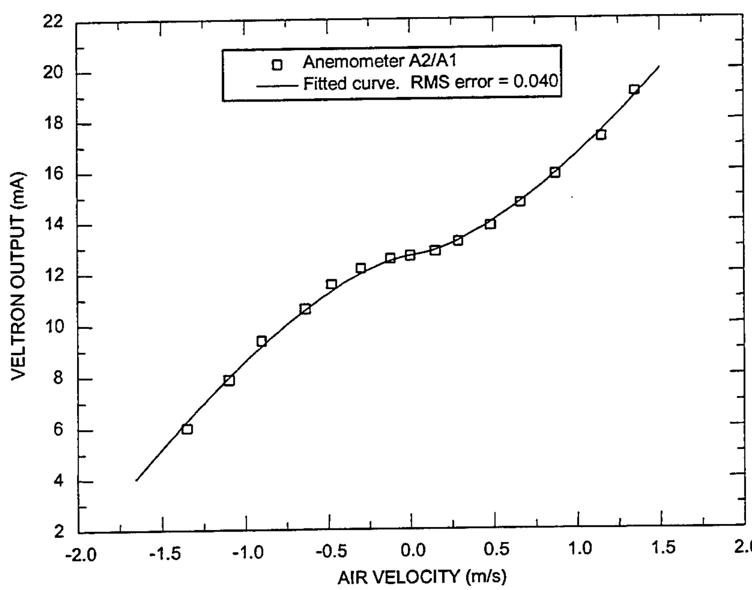

Figure A.6. Calibration data and fitted curve for A2/A1 (Veltron transducer range ±2.49 Pa)

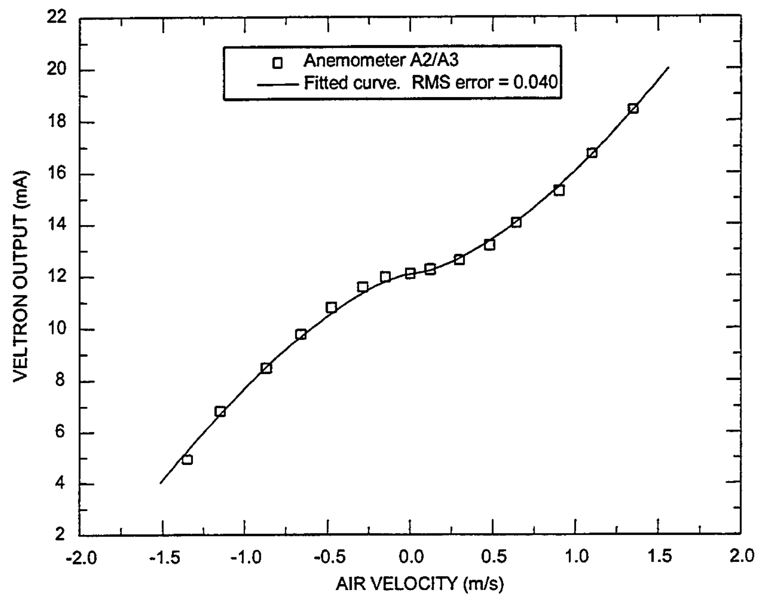

Figure A.7. Calibration data and fitted curve for A2/A3 (Veltron transducer range ±2.49 Pa)

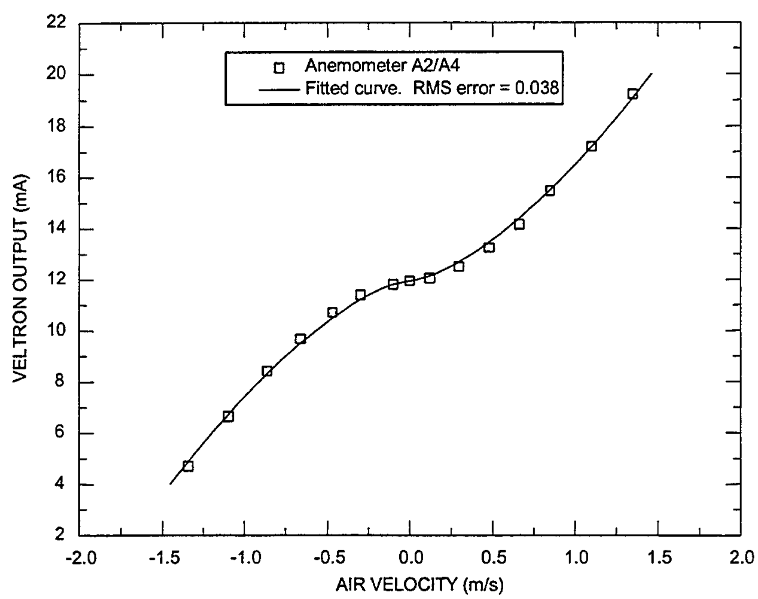

Figure A.8. Calibration data and fitted curve for A2/A4 (Veltron transducer range ±2.49 Pa)

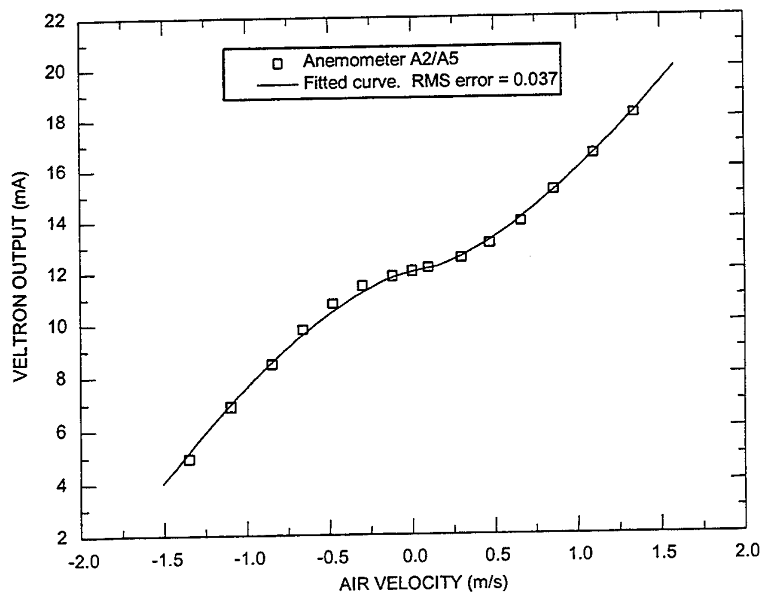

Figure A.9. Calibration data and fitted curve for A2/A5 (Veltron transducer range ±2.49 Pa)

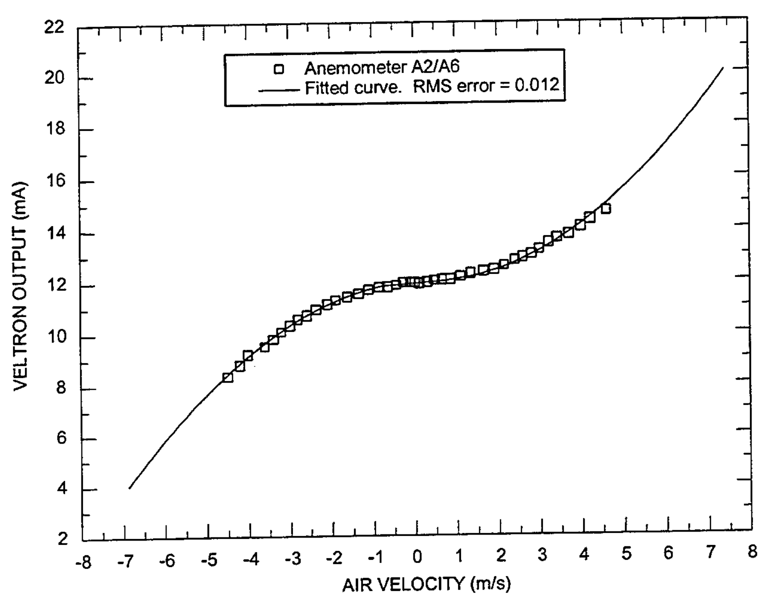

Figure A.10. Calibration data and fitted curve for A2/A6 (Veltron transducer range ±12.45 Pa)

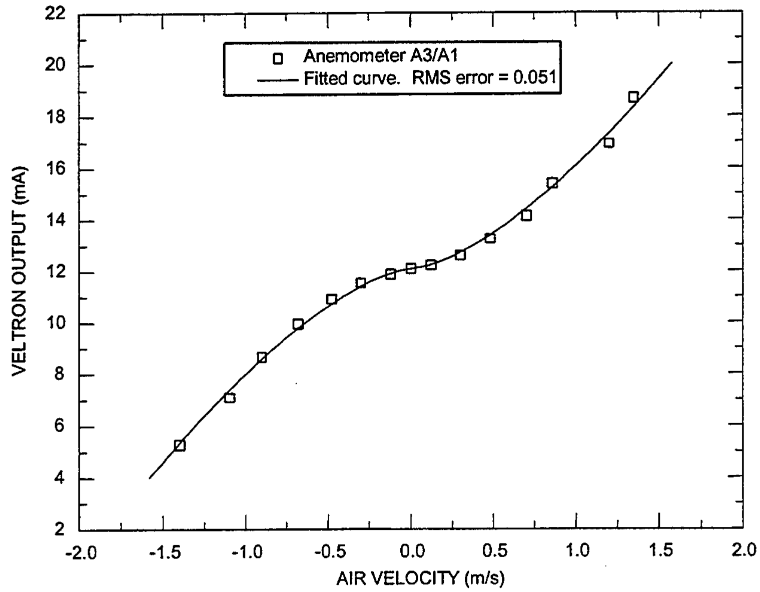

Figure A.11. Calibration data and fitted curve for A3/A1 (Veltron transducer range ±2.49 Pa)

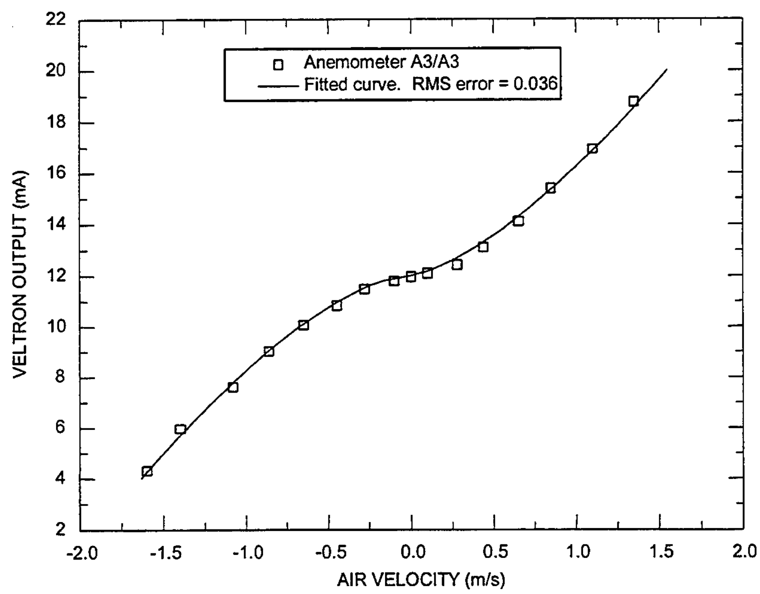

Figure A.12. Calibration data and fitted curve for A3/A3 (Veltron transducer range ±2.49 Pa)

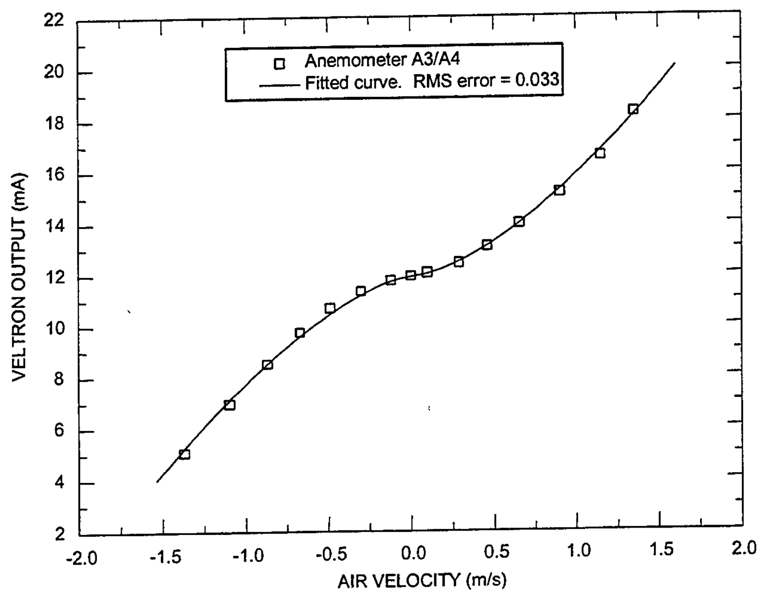

Figure A.13. Calibration data and fitted curve for A3/A4 (Veltron transducer range ±2.49 Pa)

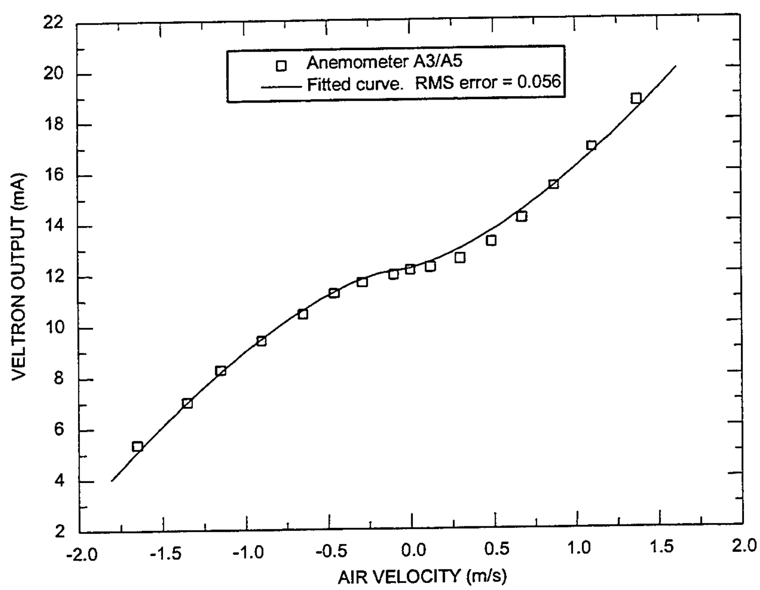

Figure A.14. Calibration data and fitted curve for A3/A5 (Veltron transducer range ±2.49 Pa)

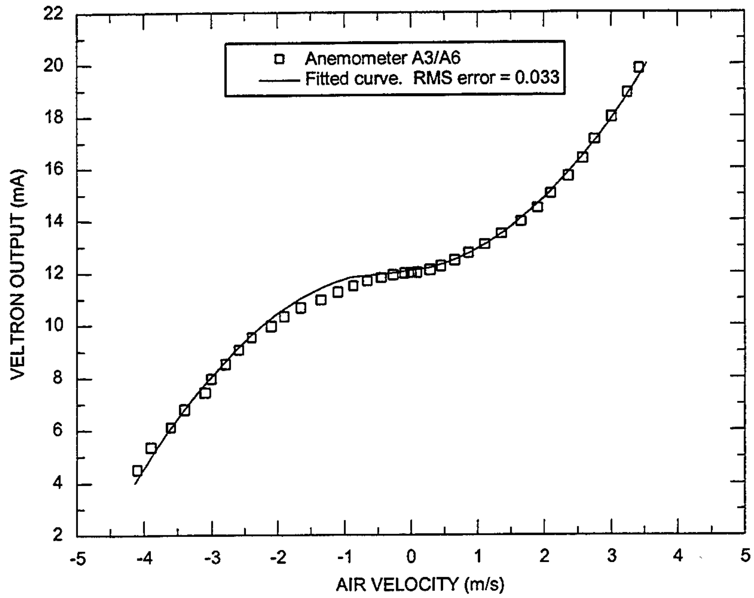

Figure A.15. Calibration data and fitted curve for A3/A6 (Veltron transducer range ±12.45 Pa)

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19. ABSTRACT

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