ABSTRACT

AIR FLOW CHARACTERISTICS OF A SCALE MODEL CHAMBER

By

Stephen Arthur Weller

Adequate ventilation of a confined area, is an important requirement for the good health of its occupants. This investigation was conducted to determine the air flow characteristics of a scale model air chamber, equipped with a particular ventilation system. The air chamber was two feet by eight feet by ten feet. The ventilation inlet consisted of a one half inch slot located across the top of one end. A four inch circular exhaust outlet was located at top center of the opposite end.

Air velocity fluctuations were detected by a hot wire anemometer and recorded for 126 data points located on a vertical plane perpendicular to the inlet at its midpoint. Recordings, of five seconds duration, were made at each data point for two components and, in several cases, for two flow rates.

Information on mean velocity, variance of velocity fluctuation, turbulent intensity and dispersion factor of the air at each point was obtained by means of a statistical analysis of the air velocity records. This information was then statistically analyzed to produce profiles, scatter diagrams and correlations. From this a fairly clear picture was obtained as to the behavior of the air within the chamber, for the given type of ventilation system.

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To:

Cornelia, Michael and Maria

Mr. and Mrs. Donald Weller

Mr. and Mrs. Arthur Miner

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Mr. and Mrs. Leo Krone

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1. INTRODUCTION

As stated by Stephan (1960), "Proper ventilation must supply oxygen, and also dilute and remove carbon dioxide, ammonia, disease organisms and water vapor without causing drafts or producing an excessively low air temperature within the room". A requirement of maximum production is proper environment, which is a product of proper ventilation. It is necessary to control the ambient air conditions in shelters so as to induce a favorable response from the birds and result in a high-quality product (Longhouse, 1960; Esmay 1960).

Ventilating systems range from allowing air to enter by means of leakage around windows, through cracks and under doors to controlled entry through designed and installed inlets. One inlet system consists of a horizontal slot located along the top of one side of the room. Within the room, the exhaust fan causes the air to circulate throughout and finally to be exhausted. This type of ventilation system was chosen and its air characteristics were studied.

This thesis was primarily concerned with a study of air movement in a vertical plane passed perpendicular to the inlet slot and near its midpoint. This study was carried out in a scale model air chamber and included an investigation of mean velocity, variance of velocity fluctuations, turbulent intensity and dispersion factors for the air fluctuations of the given plane.

2. LITERATURE REVIEW

2.1. Introduction

As one reviews the literature, looking for information on the distribution and mixing of ventilation air, he begins to realize that a great deal of work has been done on free jet streams but not very much on the effects of enclosures or on air characteristics adjacent to the jet stream.

In and near the jet stream, measurable parameters are fairly well defined. As one moves farther away from the boundry layer or farther down stream from the jet inlet, parameters become more difficult to establish.

2.2. Characteristics of Ventilation Air Jets

Parker and White (1965) made a study of velocity profiles, flow patterns, throw and entrainment resulting from the Kentucky fan-baffle system. The study was also to determine if relationships similiar to those developed for free air jets can be applied to the plane radial jets produced by this system.

It is important in ventilation studies to know the degree to which incoming air is mixed and modified by the air already contained in the ventilated space. This can be determined (Parker and White, 1965) from the entrainment ratio (E_x) which is defined as the quantity of air entrained by the jet air stream up to any given point along the jet divided by the total quantity of air flowing from the ventilation inlet. In equation form:

$$E_x = \frac{Q_x - Q_o}{Q_o} \qquad (2.1)$$

where: E_x = entrainment ratio

Q_o = air flow (cfm) at the jet inlet

Q_x = air flow (cfm) in the jet envelope at any distance x from the inlet

Farguharson (1952) expressed the entrainment ratio in the form

$$E_x = Cx/\sqrt{A_\ell} \qquad (2.2)$$

where: C = a constant

x = distance from inlet

A_ℓ = effective area of inlet

For very long slots Farguharson (1952) has confirmed that the axial velocity in a free jet falls off according to the equation:

$$\frac{V_x}{V_o} = K'\frac{b}{x} \qquad 6.5b < x < 6.5a \qquad (2.3)$$

where: x = distance measured along the air stream from inlet (feet)

V_x = maximum velocity (fpm) at any distance x along the jet

V_o = velocity of air at the vena contracta (fpm)

a = length of rectangular inlet

b = width of rectangular inlet

K' = is a constant for each particular type of slot inlet

If the jet inlet is in the proximity of walls or ceilings an increase in throw is obtained (Parker and White, 1965). Also these jet streams will be drawn to and remain close to that surface (Parker and White, 1965; Becker, 1950; Farguharson, 1952).

Tilley (1964) states that "a jet of air coming from the air inlet into a room will spread out, unbaffled, at an inclusion angle of between 15° and 20°".

2.3. Statistical Methods

In order to obtain a better understanding of the air characteristics of a chamber, a statistical description of the turbulent field is required. Taylor (1921) introduced the basic concepts involved in the statistical theory of turbulence and then later developed them (Taylor, 1935). In general, the statistical concept involves the correlation between simultaneous velocities at two fixed points or between the velocity of a particle at one time and that of the same particle at a later time. These are referred to as the Eulerian and the Lagrangian description respectively (Frenkiel, 1953).

Statistical aspects of turbulent flow are reviewed by Frenkiel (1953). The instantaneous velocity usually consists of two parts. They are the mean velocity $\bar{u}$ and the turbulent velocity $u'(t)$, such that

$$u(t) = \bar{u} + u'(t) \tag{2.4}$$

for all t. A measure of the spread of the fluctuating turbulent velocity u' can be obtained from the variance $\overline{u'^2} \neq 0$ or the standard deviation $\sqrt{\overline{u'^2}}$. The ratio of such a standard deviation to the mean velocity (when $\bar{u} \neq 0$) is called the intensity of turbulence and is given by the expression

$$\sqrt{\overline{u'^2}}/\bar{u}$$

Frenkiel (1953) defines the Eulerian longintudinal correlation coefficient for velocity as:

$$R_x(x) = \frac{\overline{u'_P \; u'_Q}}{\sqrt{\overline{u'^2_P}}\sqrt{\overline{u'^2_Q}}} \tag{2.5}$$

Theoretically $R_x(x)$ will range from one, when $x = 0$ and the two points coincide, to zero, when $x = \infty$ and there is practically no correlation between the components of the velocity at the two points.

Frenkeil (1953) also defines the Lagrangian longitudinal correlation coefficient as:

$$R_{tL}u(h) = \frac{\overline{u'_A(t) \quad u'_A(t+h)}}{\sqrt{(u'_A(t))^2} \; \sqrt{(u'_A(t+h))^2}} \tag{2.6}$$

Derived from Taylor's (1921) theory, Harrington (1965) given

$$K = \overline{u'^2} \int_0^\infty R_{tL}u(h)dh \tag{2.7}$$

or

$$K = \beta\overline{u'^2} \int_0^\infty R_x(x)dx \tag{2.8}$$

where:

K = eddy diffusivity

β = $\sqrt{\pi}/4i$

i = intensity of turbulence.

3. THEORETICAL CONSIDERATIONS

3.1. Flowmetering

Eckman (1950) gives the following equation for venturi tube flow of compressible fluids:

$$q = \frac{\pi}{4} \frac{C_{VT}\beta^2 D^2}{\sqrt{1 - \beta^4}} \frac{\phi \upsilon_b}{M_b} \sqrt{\frac{M_1(\gamma_m - \gamma_f)}{\upsilon_1}} \sqrt{2gh} \qquad (3.1)$$

where:

q	=	flow rate, ft^3/sec
C_{VT}	=	venturi discharge coefficient
β	=	diameter ratio = d/D
d	=	venturi throat diameter, ft
D	=	pipe diameter, ft
ϕ	=	rational expansion factor
υ_b	=	specific volume of gas at base conditions, ft^3/lb
υ_1	=	specific volume of gas at upstream conditions, ft^3/lb
M_b	=	moisture factor at base conditions
M_1	=	moisture factor at upstream conditions
γ_m	=	weight density of fluid over manometer fluid, lb/ft^3
γ_f	=	density of fluid over manometer fluid, lb/ft^3
g	=	acceleration due to gravite, ft/sec^2
h	=	manometer differential, ft

According to Olson (1961) a compressible fluid expands in passing through the throat of the venturi tube. Hence, the effect is to reduce the flow rate of the fluid for given initial conditions and pressure drop as compared with the flow rate if incompressible flow were assumed. At low flow rates, such as used in this experiment, the error produced in assuming incompressible flow will not be very large. Kunze (1964) stated that it was suggested in the AE 430, Laboratory Exercise II, entitled "Measurements of Flow of Gases" that the equation

$$V_m = K\sqrt{\frac{2gh\ (\gamma_m - \gamma_f)}{\rho}} \qquad (3.2)$$

be used where K = 0.258 and V_m has units of ft/sec.

Eckman (1950) gives the following equation for venturi tube flow for incompressible fluids:

$$q = \frac{\pi D^2}{4}\ \frac{C_{VT}\beta^2}{\sqrt{1-\beta^4}}\ \sqrt{\frac{2gh(\gamma_m - \gamma_f)}{\rho}} \qquad (3.3)$$

where:

ρ = density of flowing fluid, lb/ft^3.

Equation (3.3) may be written

$$V_m = \frac{C_{VT}\beta^2}{\sqrt{1-\beta^4}}\ \sqrt{\frac{2gh\ (\gamma_m - \gamma_f)}{\rho}} \qquad (3.4)$$

where $q = V_m A$. If $C_{VT}\beta^2/\sqrt{1-\beta}$, then equation (3.4) is equivalent to equation (3.2) if $\beta = .5$ and $C_{VT} = 1$; K = 0.255.

The fluid over the manometer fluid is the same as the fluid flowing through the venturi, thus $\gamma_f = \rho$. The liquid used in the manometer has a specific gravity of 0.797. However, its calibration is such as to read "h" directly in inches of water. This then is interpreted to be equivalent to the situation where water is actually used as the manometer fluid and thus would represent the density of water at the operating temperature.

For most accurate results, C_{VT} should be obtained from a calibration curve for the particular venturi tube. However, Eckman (1950) states that "Normally the discharge coefficient is greater than 0.90 and less than 1.0." Daugherty (1954) states that "Unless specific information is available for a given venturi tube, the value of C_{VT} may be assumed to be about 0.99 for the large tubes and about 0.97 or 0.98 for small ones, provided the flow is such as to give reasonable high Reynolds numbers." From the graph on page 306 of Pao (1961) Table 3.1 is formed, relating Reynolds number and discharge coefficient, for a diameter ratio of 1/2.

Table 3.1. -- Relation between Reynolds number and Discharge coefficient for a diameter ratio of 1/2

Reynolds number	discharge coefficient
2×10^4	.968
3×10^4	.974
6×10^4	.981
1×10^5	.984
4×10^5	.988
1×10^6	.989

According to Eckman (1950), Reynolds number is directly proportional to flow rate and is determined from

$$R_D = \frac{4}{\pi} \frac{\rho q}{\mu \beta D}$$

where: μ = absolute viscosity of flowing fluid, lb/ft-sec. For example, let ρ = 0.0823 lb/ft^3 = density of air at 83°F dry bulb and 63°F wet bulb, μ = 0.0000124 lb/ft-sec at 83°, (page 20 of Henderson (1955)), β = 0.5, D = 4 in. and q = 1.5 ft^3/sec.

Then

$$R_D = \frac{4}{\pi} \frac{(.0723)(1.5)}{(0.0000124)(.5)(4/12)} = 6.68 \times 10^4$$

From the above tabulation, this corresponds to a discharge coefficient of about 0.981. For the above conditions γ_m = 62.19 lb/ft^3 and $\gamma_f = \rho$. Let g = 32.174 ft/sec^2 and h = 1.0 in.

$$q = \frac{\pi(1/9)}{4} \frac{(0.981)(1/4)}{\sqrt{1-1/16}} \sqrt{\frac{2(32.174)(1)(62.19 - .0723)}{(.0723)12}} = 1.5 \text{ ft}^3/\text{sec}$$

Let h = .5 and if q = 1.0 ft^3/sec, then $R_D = 4.45 \times 10^4$ which corresponds to C_{VT} = 0.977. This in turn gives a q = 1.06.

The flow rates used in the above example are approximately to those used in the laboratory. Over this range of flow rates, C_{VT} could be approximated by 0.979 with only a small error resulting. Since the assumption of incompressible flow (top of page 7) would lead to a flow rate that is too large, it is suggested that a C_{VT} of 0.95 be used as a means of compensation.

3.2. Wire Calibration

A hot-wire anemometer is a rapid-response instrument used to measure the velocity of air or other fluids. Its operation is based on the cooling of an electrically heated wire filament, as measured by the change in electrical resistance of the wire. The cooling of the wire depends upon stream velocity, temperature and pressure. By operating the wire at a fixed resistance ratio, (Flow Corporation, Bulletin 37, page 11) any significant effect of stream temperature on average velocity can be eliminated. For streams where the Mach Number is less than .3, the wire heating current I, where I is the current required to hold the resistance ratio fixed, is then dependent only on the product of pressure p and velocity V.

Each wire used, must be calibrated by relating known values of p and V to I. (A typical calibration curve is shown in Figure 3.1.) The plot of I^2 versus $\sqrt{pV}$ is substantially a straight line up to a Mach Number of about .3, hence a calibration curve can be obtained from just two pV to I relations. This linear portion is also correct over a wide range of pressures.

If wide ranges of temperature occur, then the entire curve translates vertically. The distance of translation measured in percentage of the intercept is .9 times the percent change of the absolute stream temperature. If a calibration curve was obtained for a stream temperature of 530°R and the temperature is actually 540°R, then the correct calibration curve should be shifted downwards by (10/530)(.9)(100) = 1.7 percent of the intercept as less current would be required to maintain wire temperature.

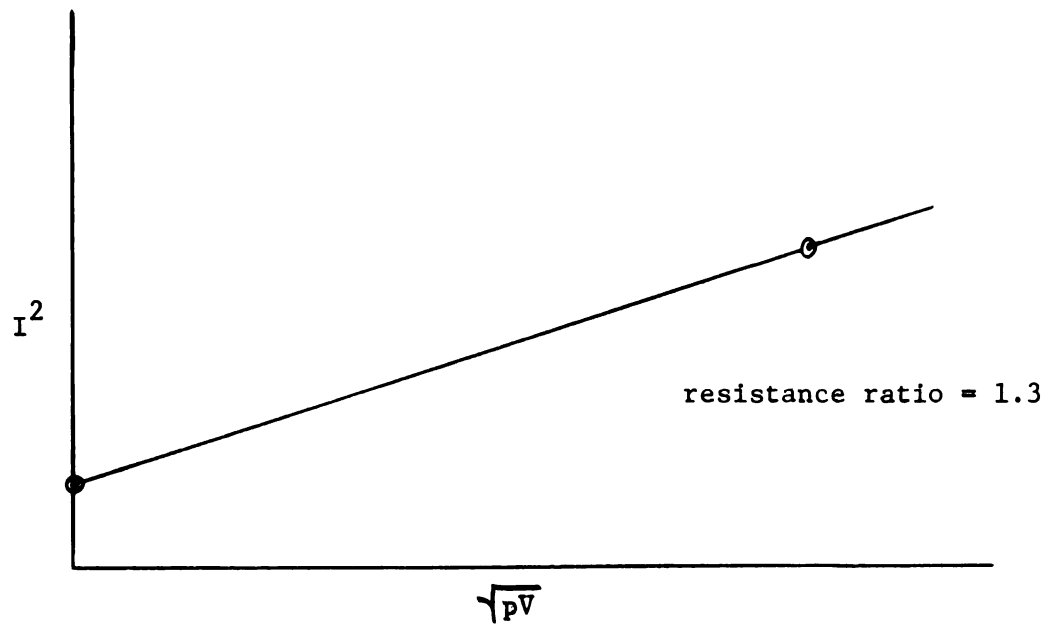


Figure 3.1. -- A typical calibration curve for a given resistance ratio with I being the current to hold it fixed as the product of pV is changed.

For the two point calibration curve, the first point that can be used is the intercept point. At this point I has the value required to maintain wire temperature at zero stream velocity. The second point must be based on a known velocity and pressure.

The second point can be obtained by measuring I with the wire perpendicular to a known stream velocity. By placing a pitot tube near the wire, parallel to the direction of flow, the stream velocity can be obtained. According to Eckman (1950), equation 3.5 can be used to obtain stream velocity.

$$V_1 = C_{PT}\sqrt{(\gamma_m - \gamma_f)\upsilon_1}\ \sqrt{2gh} \qquad (3.5)$$

Equation 3.5 can be written in the form

$$V_1 = C_{PT}\sqrt{2gh(\gamma_m - \gamma_f)/\rho} \qquad (3.6)$$

where C_{PT} is the velocity coefficient and has a value between 0.98 and 1.02 for a pitot tube with a long-opening extension. A value of $C_{PT} = 1$ will be used.

3.3 Air Flow and Turbulent Measurements

From the calibration curve of Figure 3.1 a curve of ρV versus I can be constructed for each constant resistance ratio. If ρ is assumed to remain constant, then a certain fluctuation in V can be determined from this curve if the equivalent change ΔI in I were known. According to the Flow Corporation Bulletin (1958), ΔI can be obtained from

$$\Delta I = I\left[\sqrt{1 - \frac{2ie_{if}}{Ie_{is}}} - 1\right] \qquad (3.7)$$

where: I = wire current, ma

i = square-wave current, ma

e_{is} = zero to peak square wave amplitude, volts

e_{if} = voltage deflection due to velocity fluctuations, volts.

The square-wave current i can be obtained from

$$i = \frac{3.05}{1 + (B)(N)/400} \qquad (3.8)$$

where: B = bridge null reading

N = resistance ratio used

3.4. Velocity Fluctuations

The equations of section 3.3 pertain to the constant current method. That is, the heating current to the wire is kept constant and the voltage across the wire is examined. If the voltage fluctuations are to represent velocity fluctuations then certain conditions must be met based on the limitations of the instrument being used.

The assumptions are as follows:

1. The velocity component is perpendicular to the wire axis.
2. The distortion due to large slow fluctuations does not have an adverse effect on the desired results.
3. The static pressure remains constant; $p = \text{constant}$.

3.5. Turbulence

The instantaneous velocity at a given point A can be divided into two parts, the mean velocity $\bar{u}_A$ and the turbulent velocity $u'_A(t)$, such that

$$u_A(t) = \bar{u}_A + u'_A(t)$$

for all t. Consider in a turbulent field a set of orthogonal axes 0_{xyz} with the axis 0_x parallel to the direction of a constant mean velocity. Let u, v, w denote the three components of the instantaneous velocity vector on the x, y, and z axes respectively. Since 0_x was chosen parallel to the mean velocity, we have $\bar{u} = \text{constant}$, $\bar{v} = 0$, $\bar{w} = 0$, and the components of the turbulent velocity are $u' = u - \bar{u}$, $v' = v$ and $w' = w$.

The values of the variances $\overline{u'^2}$, $\overline{v'^2}$, $\overline{w'^2}$ or their square roots, the standard deviations $\sqrt{\overline{u'^2}}$, $\sqrt{\overline{v'^2}}$, $\sqrt{\overline{w'^2}}$ are a measure of the spread of the fluctuation turbulent velocities u', v', and w'. Frenkiel (1953) defines the ratio of such a standard deviation to the mean velocity (when $\bar{u} \neq 0$) as the intensity of turbulence. There are three such intensities. They are as follows:

1. $\frac{\sqrt{\overline{u'^2}}}{\bar{u}}$ longitudinal intensity of turbulence
2. $\frac{\sqrt{\overline{v'^2}}}{\bar{u}}$ transverse intensity of turbulence
3. $\frac{\sqrt{\overline{w'^2}}}{\bar{u}}$ transverse intensity of turbulence

3.6. Correlation Coefficients

Correlation is the degree of relationship between two or more variables. Frenkiel (1953) gives expressions for two correlation cœfficients used in relation to turbulent diffusion. The first is the Eulerian correlation coefficient and is given by the ratio

$$R_x(x) = \frac{\overline{u'_P \; u'_Q}}{\sqrt{\overline{u'^2_P}} \sqrt{\overline{u'^2_Q}}} \qquad (3.9)$$

The two points P and Q are on a line which is parallel to the direction of the mean velocity and separated by a distance $x = x_2 - x_1$. The instantaneous longitudinal components of the turbulent velocities at the two points are $u'_P(t)$ and $u'_Q(t)$.

The second is Lagrangian correlation coefficient and is given by the ratio

$$R_{tL}^{u}(h) = \frac{\overline{u_A'(t)\ u_A'(t+h)}}{\sqrt{\overline{(u_A'(t))^2}}\ \sqrt{\overline{(u_A'(t+h))^2}}} \ . \tag{3.10}$$

During the time interval h, A has moved from, say, point P_1 to point P_2. Neither of these two forms are satisfactory for the experimentation being considered as the point of measure must be fixed.

Frenkiel (1953) suggested that an Eulerian time correlation coefficient $R_E(\xi)$ can be defined in a manner similar to equation 3.9 which would describe the correlation between the turbulent velocities at the same point, but at two different times ξ and $\xi + t$. This coefficient would have the form

$$R_E(t) = \frac{\overline{u'(\xi)\ \ u'(\xi+t)}}{\overline{u'^2(\xi)}} \ . \tag{3.11}$$

3.7. Eddy Diffusivity

Derived from Taylor's (1921) theory, Harrington (1965) gives

$$K = \overline{u'^2} \int_0^\infty R_{tL}^{u}(h)\,dh \tag{3.12}$$

as the expression for eddy diffusivity. Since measurements will be made in an Eulerian frame of reference it will be necessary to substitute $R_E(t)$ for $R_{tL}^{u}(h)$, where $h = \beta t$. The eddy diffusivity becomes

$$K = \beta\overline{u'^2}\int_0^\infty R_E(t)\,dt \tag{3.13}$$

where: $\beta = \frac{\sqrt{\pi}}{4i}$ (3.14)

and i is the intensity of turbulence.

3.8. Regression, Standard Error of Estimate and Correlation

It is often desirable to observe and measure the association which occurs between two statistical series. If the two series are plotted with the independent variable on the x axis and the dependent variable on the y axis, the result is known as the scatter diagram.

If the two series are related, the plotted points will follow a definite line of movement. The trend or direction of this movement may be approximated with a curve known as the line of regression and may be of the form:

1. $Y_c = a + bX$
2. $Y_c = a + bX + cX^2$

A measure of the variation or scatter about the line of regression is given by the expression (Arkin, 1963)

$$S_y \doteq \sqrt{\Sigma(d^2)/N} \qquad (3.15)$$

where: S_y = standard error of estimate

$d = Y - Y_c$

Y = actual values

Y_c = theoretical values obtained from the equation for the line of regression

N = number of points

One standard error of estimate will include 68% of the cases when measured off plus and minus about the line of regression if the distribution is a normal one.

The standard error of estimate is a measure of the degree of association between two series but its size is expressed in terms of the orginal unit of the Y variable. A comparative measure of association, which is independent of the original unit of the Y variable, is termed the coefficient of correlation r for the linear case and the index of correlation ρ for the non-linear case. They are defined by the expression

$$\sqrt{1 - \frac{Sy^2}{\sigma_y^2}} \qquad (3.16)$$

where: σ_y = variance of the Y values.

4. EXPERIMENTAL PROCEDURES AND EQUIPMENT

4.1. Equipment

Apparatus for the collection of data (Figure 4.1) was set up in a large room with a temperature of 75° ± 3° F and a relative humidity which varied with weather conditions.

4.1.a. Air Chamber

An air chamber, with inside dimensions of two feet by eight feet by ten feet, was constructed, to a quarter scale, to represent a "ventilation section" of a poultry house with inside dimensions of 8 feet by 32 feet by 40 feet. All inside surfaces, except one side, were constructed of 1/4 inch plywood and held in place by a rigid frame (see Appendix A.1. for construction details). The front side, which was parallel to the vertical plane being sampled, was constructed of 1/8 inch plexiglas to allow for a visible view of apparatus located within the chamber.

An inlet, measuring 1/2 inch by 8 feet, was constructed at the left end at ceiling level. This inlet (Figure 4.2) ran parallel to the ceiling and was designed with a 3-5/8 inch approach, constructed from two parallel boards set 1/2 inch apart. The purpose of this was to produce an air stream which was parallel to the ceiling on entry into the chamber.

An outlet, measuring four inches in diameter, was constructed at the right end with its center at the horizontal midpoint and six inches down from the ceiling. To this outlet a two foot length of four inch diameter tubing was connected. This was in turn connected to the exhaust fan (Figure 4.1) with an adjustable air flow.

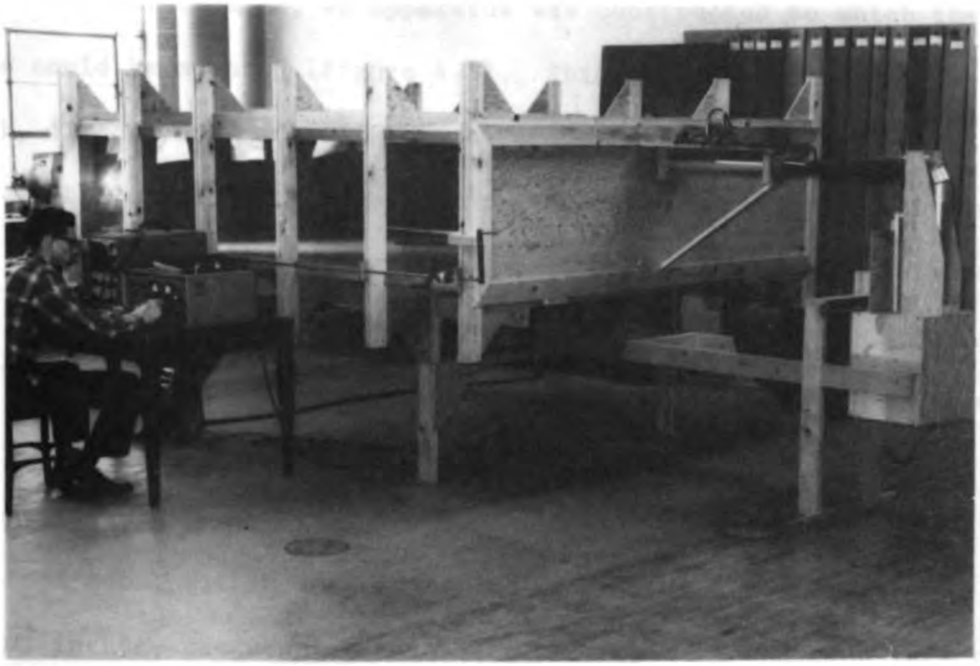


Figure 4.1. -- Experimental apparatus used for the collection of data.

Figure 4.2. -- Air chamber inlet.

Inside the air chamber, an apparatus was constructed to which the hot-wire probe could be mounted (Figure 4.3). This apparatus provided for two, horizontal, directional movements of the probe to be made from outside (Figure 4.4) the chamber and a third, or vertical, movement with the inlet end open. The two horizontal movements could be monitored from outside the chamber. This allowed for free movement of the probe to any location in the front half of a horizontal plane. When a horizontal plane of different elevation was desired, the chamber was opened and the probe adjusted.

4.1.b. Venturi Tube

A venturi tube, with a large diameter of four inches and a throat diameter of two inches, was used as a means of determining the flow rate of air through the chamber. To the venturi was connected a manometer (Figure 4.5) to obtain the pressure differential of the venturi. Using equation 3.3 a computer program (see Appendix A.2 for program description) was written to generate data required to form a calibration curve of the venturi (Figure 4.7).

4.1.c. Wire Calibration

The wire filament used to obtain air flow and turbulence data was calibrated with the use of a wind tunnel, pitot tube, manometer and hot-wire anemometer. The data obtained were used with program CALIBRAT, (see Appendix A.3 for program description) which then produced values for a calibration curve of the given wire filament (Figure 4.8 and 4.9).

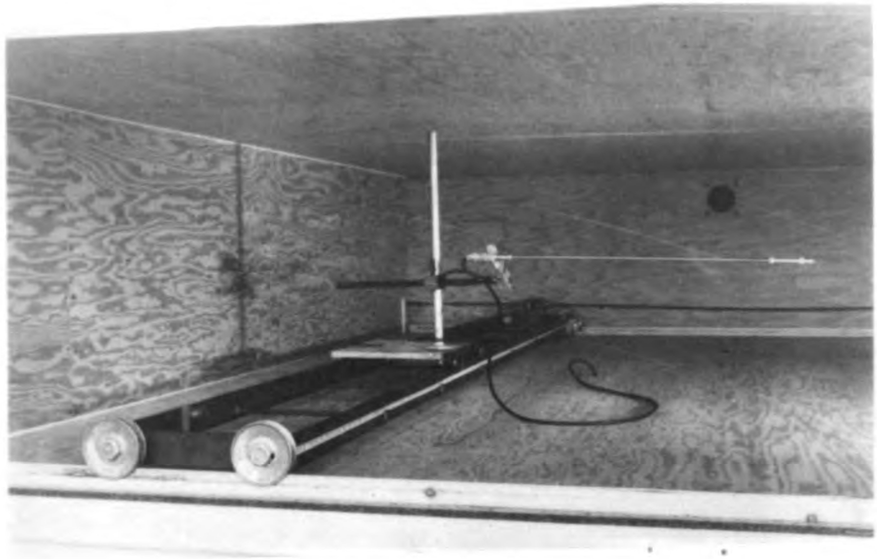


Figure 4.3. -- Apparatus to which probe was mounted.

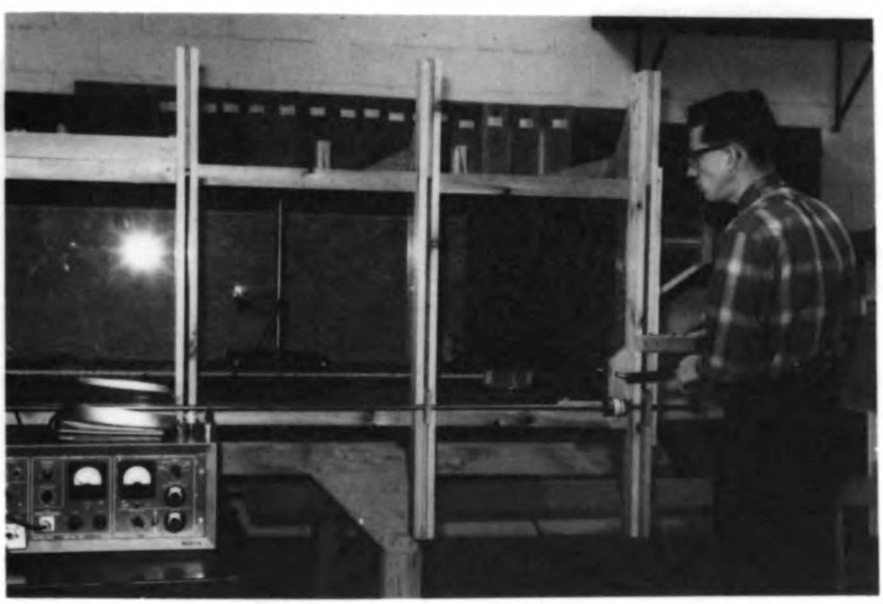


Figure 4.4. -- The crank in the left hand controls the left to right movement while the crank in the right hand controls the front to back movement.

Figure 4.5. -- View at outlet end of chamber showing venturi and manometer.

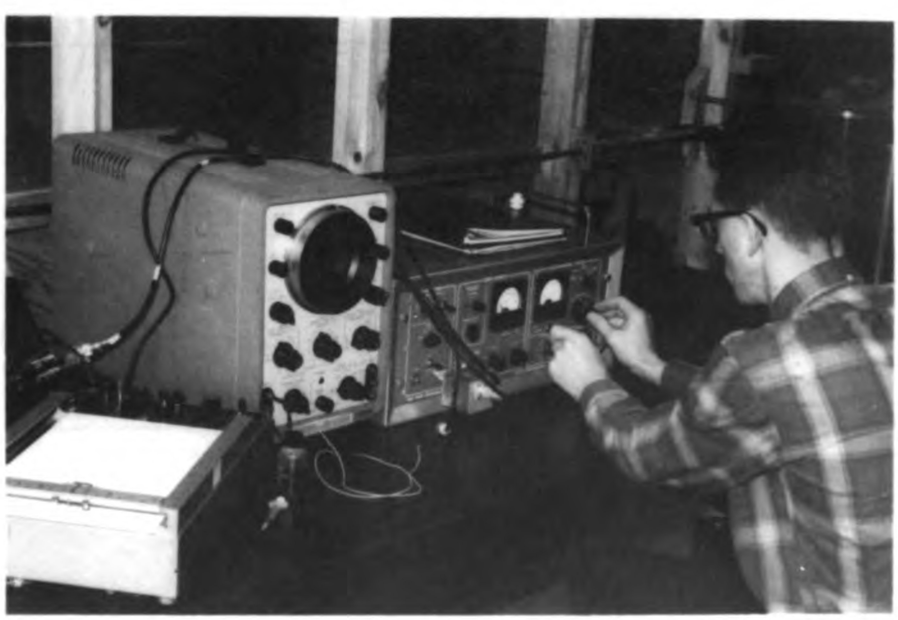


Figure 4.6. -- Apparatus used to measure and record air velocity fluctuations.

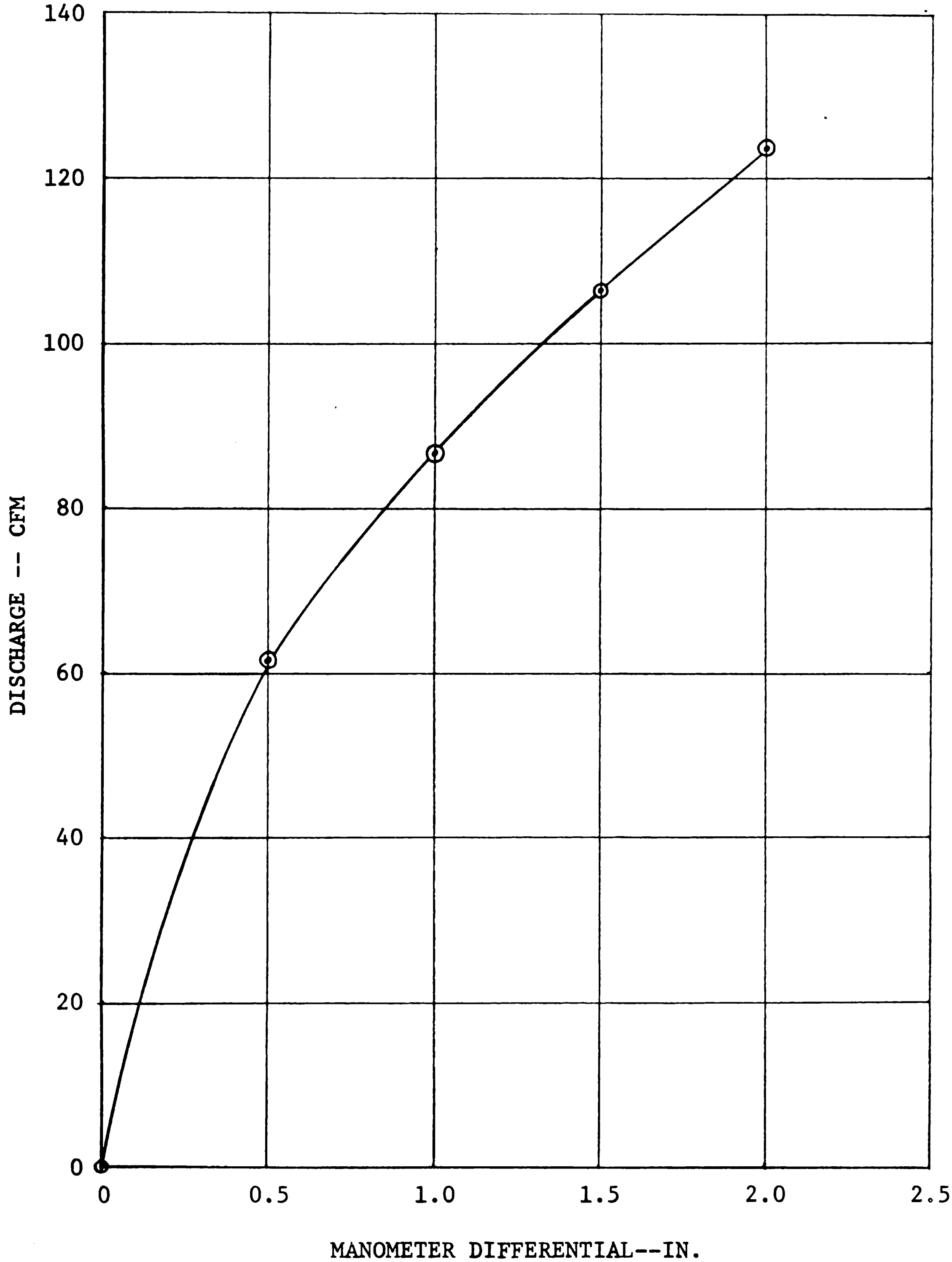


Figure 4.7. -- Calibration curve of venturi tube used in measuring air flow.

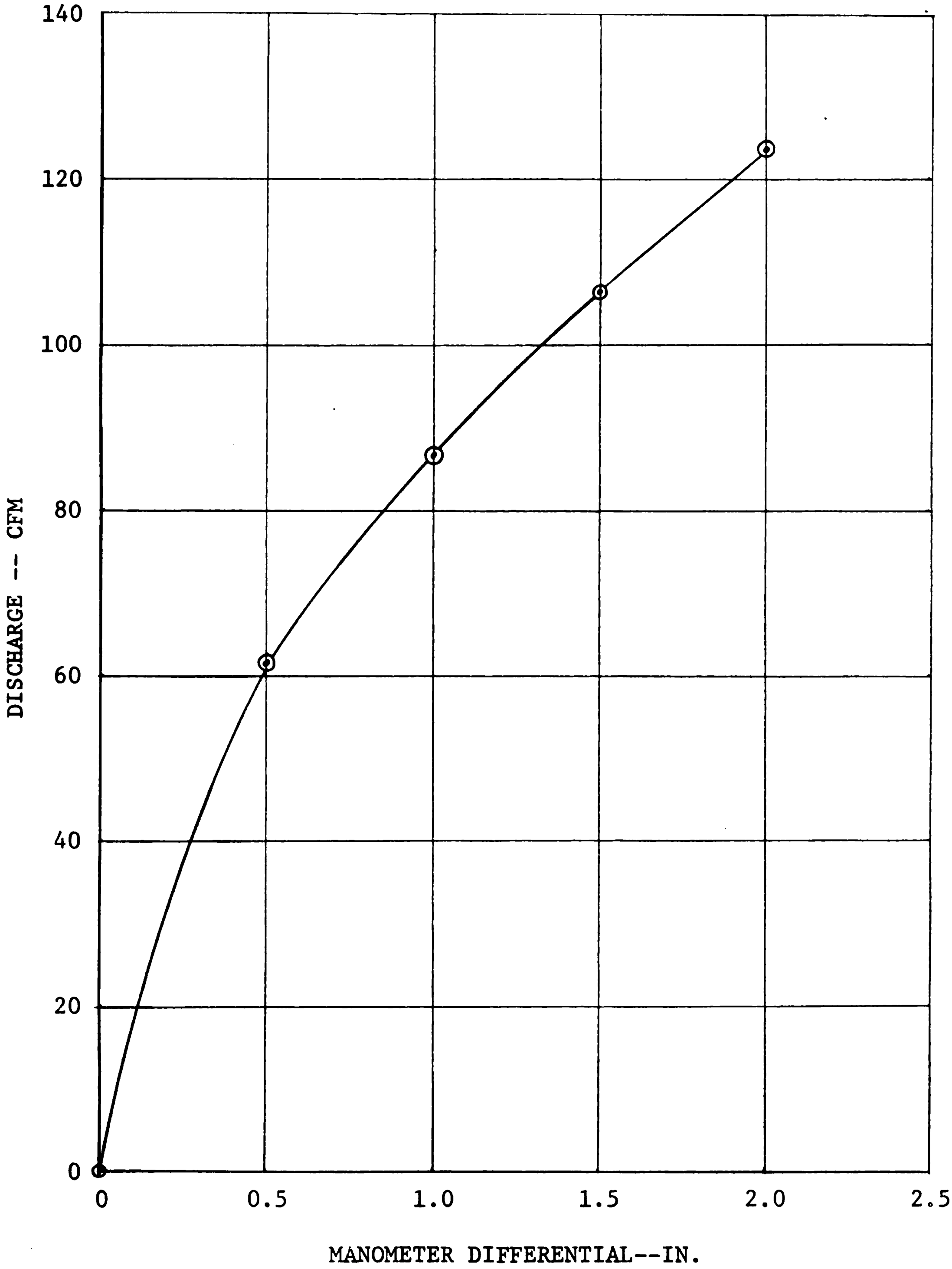


Figure 4.7. -- Calibration curve of venturi tube used in measuring air flow.

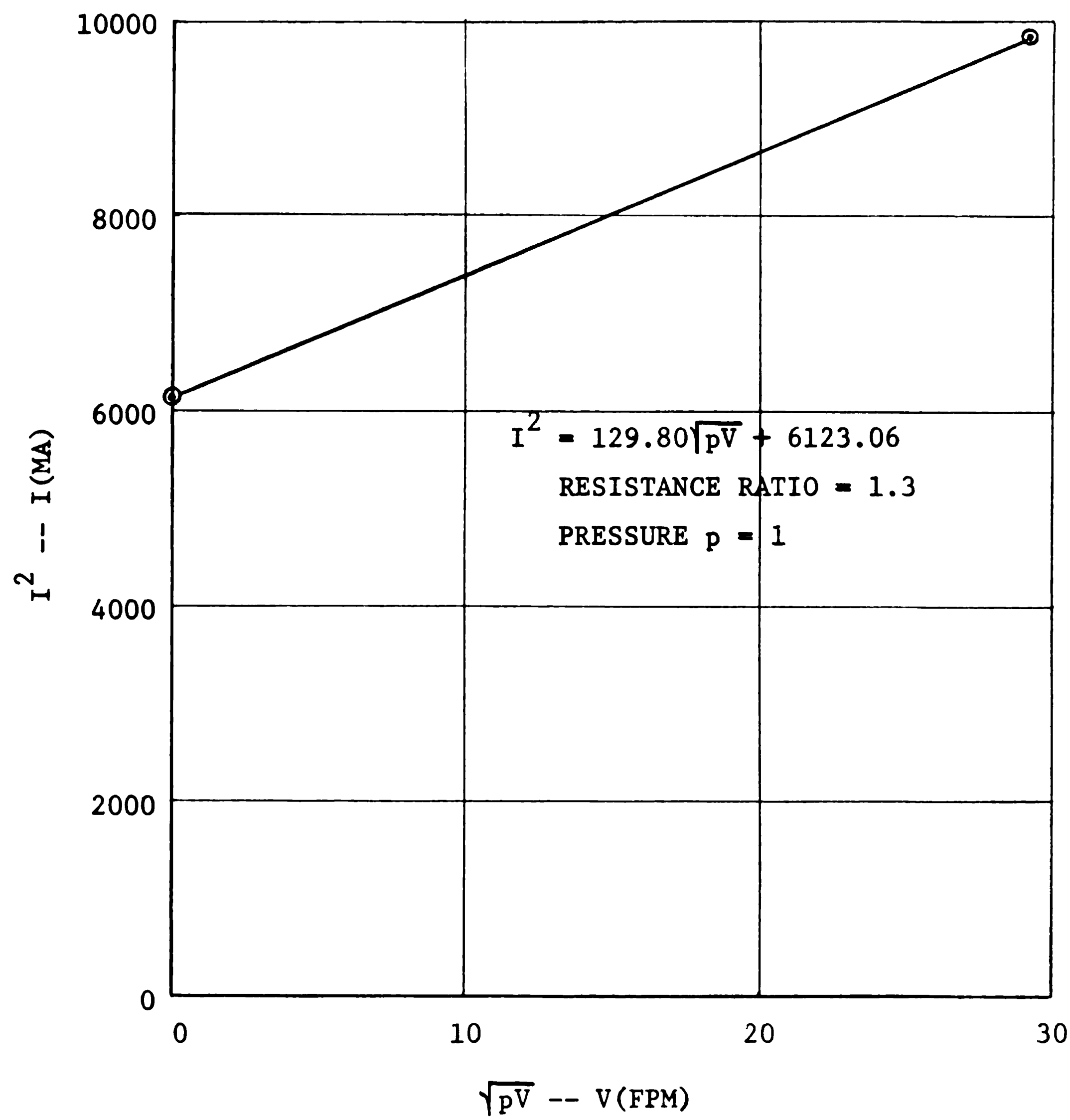


Figure 4.8. -- Calibration curve of hot-wire filament used in measuring air flow. (I^2 versus $\sqrt{pV}$)

4.1.d. Air Flow and Turbulence Measurement

A constant current hot-wire anemometer (Model HWB No. 216 by Flow Corporation, Arlington, Mass.) was used as a means of converting air velocity fluctuations into voltage fluctuations. These voltage fluctuations were recorded on Moseley X-Y recorder (Figure 4.6). Each recording represents a five second history of a given point for a given flow component. Each recording was then divided up into 100 equally spaced intervals. A reference was then chosen to ensure that the amplitude at each interval end point would be greater than zero as this was a requirement of program TURB. The relative amplitude for each of the 101 points was punched on data cards and represents a "data set". Values for wire position, square wave voltage, null reading, voltage amplification factor, mean current, resistance ratio and wire calibration information were recorded for each "data set". This process was carried out for each point for two flow components.

Program TURB (see Appendix A.4 for program description) was then written, using the equations of section 3.3 through 3.7, to analize these data and to produce for each "data set" a mean velocity, a variance of velocity fluctuations, a turbulent intensity and a disperion factor. This information was printed and punched out for further analysis.

4.2. Scope of Tests

The investigation of air fluctuations within the air chamber was limited to a single vertical plane, perpendicular to the inlet and six inches in front of the center plane. This plane was marked off into a grid of seven rows and 18 columns (Figure 4.10).

It was assumed that air flow, within the air chamber, parallel to the inlet was negligable. The probe was then given two orientations at each grid point so as to record a five second history of both the horizontal and the vertical flow component, for a given air flow rating.

At an air flow of 93.5 CFM, recordings were taken at each grid point for each orientation. However, at an air flow of 61.7 CFM, recordings were taken at just a few grid points (Figure 4.10) near the inlet and only for the horizontal component.

4.3. Analysis of Air Flow and Turbulence Measurements

The output data from program TURB were analyzed by the CDC 3600 computer using two different programs. There were programs ANAL1 and ANAL2. From these programs the following were obtained:

1. resultants of the velocity components
2. scatter diagrams of two or more statistical series
3. lines of regression
4. correlations between the statistical series
5. profiles of the statistical series

The features of these two programs are described below.

4.3.a. Statistical Analysis

Program ANAL1 (see Appendix A.5 for program description) was written to accept and to analyze the punched output data of program TURB. These data consist of four statistical series for each of the two components. From these data a nineth series was produced by determining the velocity resultant of the two component velocities. The angles these resultants make with respect to a horizontal position are also determined.

Considering any desired groups of two of the nine statistical series, program ANAL1 will

1. produce a scatter diagram,
2. approximate it with a linear and a non-linear line of regression, and
3. determine a correlation factor.

For the scatter diagrams, the range of each statistical series was determined and then divided up into the proper number of steps for plotting on a computer output page. Each division of the two ranges was related to a corresponding row and column of a storage array. The respective pairs of values of the two series were then related to their proper row and column of the storage array. At the proper location in this array, an asterisk is placed to represent the corresponding pair. After all pairs have been transferred to an asterisk in the array, the array is printed out along with the value of each row and column.

4.3.b. Profiles

It would be very desirable to be able to plot, on a grid (Figure 4.10), an indication of the value of the statistical series being considered. Program ANAL2 (see Appendix A.6 for program description) was written to do this. The values of a given series are divided up into five equal subranges and zero. The greater the value, the darker will be the mark printed at the proper grid location. A value of zero, will be printed as a blank. After all grid locations have been considered, the profile is printed out (see section 5.4 and 5.5).

In order to obtain more information about the series, only the values in the lowest range were considered. These values were then divided into five more equal subranges and another profile was obtained. This profile will yield information about the lower intensities found adjacent to the inlet jet.

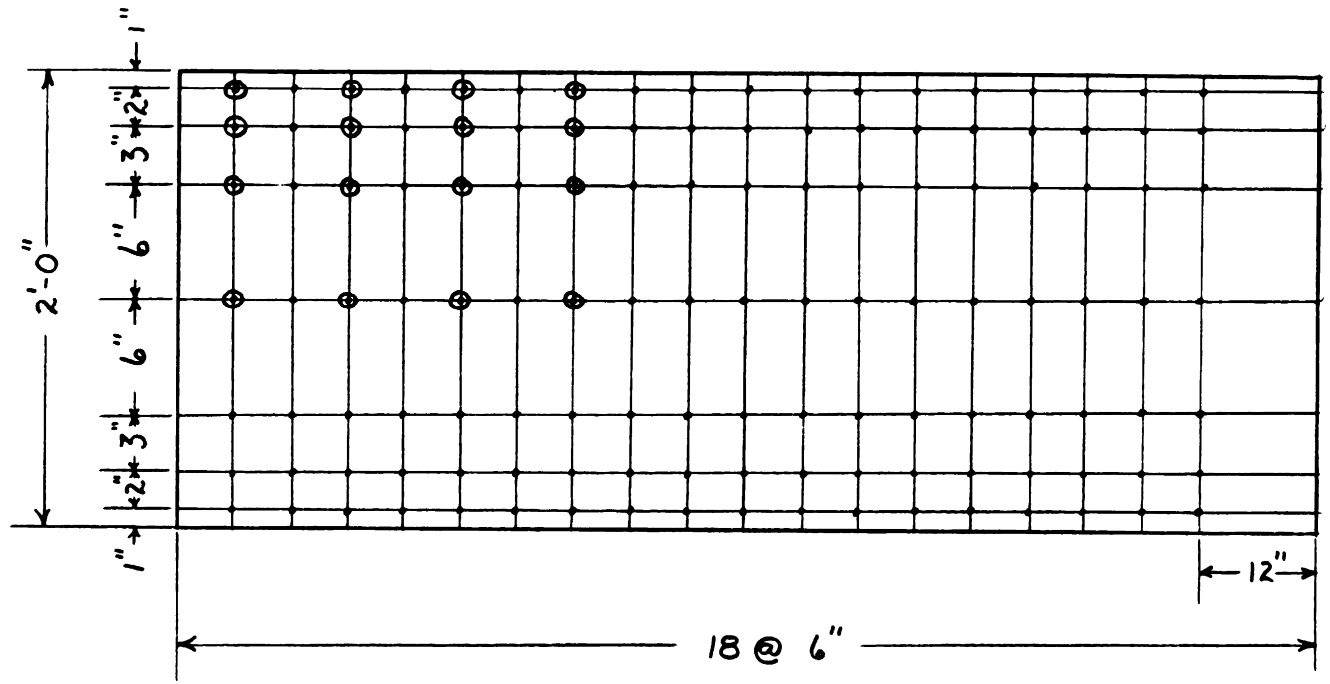


Figure 4.10. -- Location of data points in plane under investigation.

. -- grid points at which measurements were taken for an air flow of 93.5 CFM.

⊙ -- grid points at which measurements were taken for an air flow of 61.7 and 93.5 CFM.

5. RESULTS AND DISCUSSION

5.1. Flow Rate

The flow rate, measured at the venturi, was 61.7 CFM and 93.5 CFM. Since the air chamber had a volume of 160 cubic feet, there would be an air change every 2.59 minutes at the lower rate and every 1.71 minutes at the higher rate. At a full scale of 10,240 cubic feet and allowing 1.25 square foot per bird, this would correspond to a flow rate of 3.9 to 5.9 CFM per bird. It was on this basis that the above flow rates were chosen.

5.2. Results of Program TURB

Intensity of turbulence was defined (section 3.5) as the ratio of the standard deviation of the velocity component being considered to the constant mean velocity. In the air chamber used there was no one directional, constant, mean velocity. A single orthogonal axies 0_{XYZ} could not be chosen to ensure that both $\bar{v}$ and $\bar{w}$ be equal to zero. As a result it was decided to use in place of the constant mean velocity, the mean velocity of the component in question. The new ratios thus obtained will be defined as "turbulent intensity" and are as follows:

$$TI_X = \frac{\sqrt{\overline{u'^2}}}{\bar{u}} \quad \text{longitudinal turbulent intensity} \qquad (5.1.a.)$$

$$TI_Y = \frac{\sqrt{\overline{v'^2}}}{\bar{v}} \quad \text{transverse turbulent intensity} \qquad (5.1.b.)$$

$$TI_Z = \frac{\sqrt{\overline{w'^2}}}{\bar{w}} \quad \text{transverse turbulent intensity} \qquad (5.1.c.)$$

Eddy diffusivity is given by equation 3.13. Using the definition of turbulent intensity given by equation 5.1 and the coefficient of equation 3.11, equation 3.13 can be written as follows:

$$DF_X = \beta_X \overline{u'^2} \int_0^t R_{E_X}(t)dt \qquad (5.2.a.)$$

$$DF_Y = \beta_Y \overline{v'^2} \int_0^t R_{E_Y}(t)dt \qquad (5.2.b.)$$

$$DF_Z = \beta_Z \overline{w'^2} \int_0^t R_{E_Z}(t)dt \qquad (5.2.c.)$$

where β_f is defined by equation 3.14. The expression of equation 5.2 will be defined as "dispersion factors".

The interval of time over which the integral was taken was chosen to be one half of the fluctuation history. The interval chosen was somewhat arbitrary but was influenced by the behavior of some of the correlation coefficient curves. A correlation coefficient curve (Figure 5.1) should start at a value of one and, theoretically, decay to a value of zero. The area below this curve is given by an integral of equation 5.2. In practice, this curve decays by means of a damped oscillation. Therefore, the negative areas should contribute in a positive sense to the forming of the values of the integral. In some of the graphs that were produced, it was observed that near the center of the interval there was a slight increase in oscillation amplitude. It was felt that this extra area should not be included and hence a 50% factor was used.

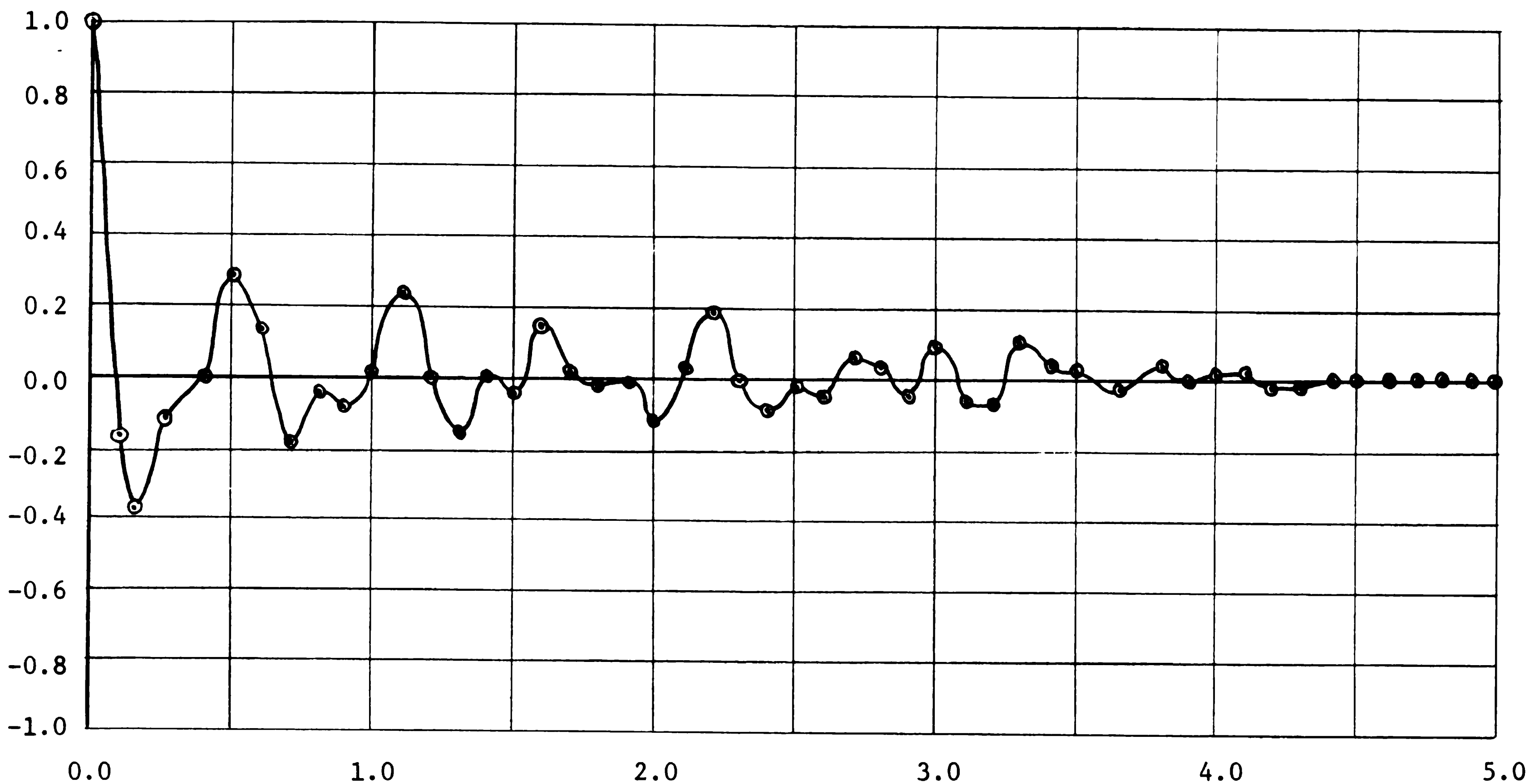


Figure 5.1. -- A typical correlation curve used in obtaining a dispersion factor.

As TI approaches zero, β approaches infinity. Hence a limit will have to be set on how small TI can become. This limit was set to 10^{-6} as any value of TI less than this would be zero as velocity fluctuation amplitudes of such a small magnitude could not be interpreted from the recordings.

After making the above modifications in program TURB, it was used to obtain a value for mean velocity, variance of velocity fluctuations, turbulent intensity and dispersion factor for each "data set" (page 26). These data were punched on cards, as output from program TURB, and analyzed. A complete tabulation of the output data of program TURB is contained in Appendix A.7.

5.3. Resultant Velocities

The X and Y component of mean velocity was converted to a resultant and an angle with respect to the X axis using program ANAL1. The angles made by the velocity resultants are shown in Figure 5.2. The directions of the resultants are not definitely known, but based on some preliminary smoke experiments, the orientations shown were chosen for illustration.

Several of the angles appear to be in error, especially locations 1-18, 2-17, 6-4 and 7-15. Because of the low velocities a small change in one of the components would have a large effect on the angle of the resultant. This error could have been caused in particular by fluctuations in discharge rate, by incorrectly reading the value of mean current displayed on the anemometer, or by an incorrect value of square wave voltage, e_{is}.

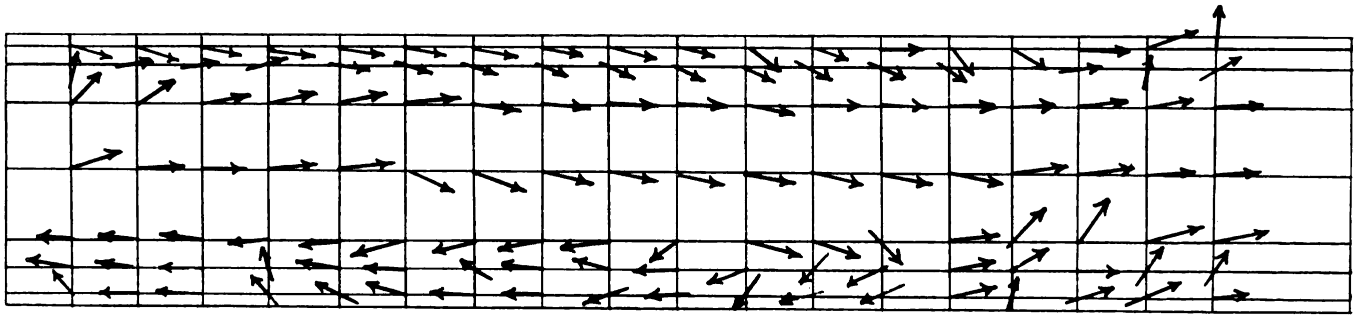


Figure 5.2. -- The resultant angles at each grid point.

(See page 30 for dimensions.)

Manometer readings at the venturi indicated a fluctuation in discharge rate of ± 2CFM. These fluctuations were sporadic and gave the impression that there was a weak scale turbulence at the entrance to the outlet pipe. The effect that this had on the air flow within the chamber is not known. A history of mean velocity of more than five seconds might show this effect, but since a means was not available for making a continuous recording of more than five seconds, this effect was not investigated.

If this fluctuating flow rate were to cause a variation in air velocity in the chamber, it could effect the angle of the resultant. If the mean velocity of an X and Y component were established at a time of low and high fluctuation, respectively, then the resultant angle would be too large as at location 1-18.

A greater source of error extends from the reading of the value of mean current displayed on the anemometer. To obtain this reading, adjustments of the bridge resistance are made to obtain a zero reading on the galvanometer. Since the air at the hot wire filament is turbulent, the galvanometer needle will tend to oscillate about the zero mark. If the amplitude of the turbulent oscillation is small, when compared to the mean velocity, and if it has a high oscillation rate, then the mean setting can be obtained very accurately. However, if the oscillation amplitude is large, with respect to the mean velocity, and if the rate of oscillation is low, then the galvanometer needle oscillates rather wildly about the zero setting. When this occurs it is very difficult to judge what the mean setting should be. Since most of the readings were made under these adverse conditions it is believed that this is the reason for most of the inconsistencies of Figure 5.2

When the oscillation amplitude becomes large, with respect to the mean velocity, and the oscillation rate is slow, the X-Y recording may not represent the true turbulent history of the time of recording. Such large scale oscillations cause the anemometer to operate in a nonlinear mode causing distortion of the recording. Since the above conditions existed in some degree, at all points of measurement, it is felt that the results will still give a good indication of what is happening within the chamber.

Another source of error is in the establishment of square wave voltage, e_{is}. From equation 3.7 it can be seen that e_{is} inversely affects ΔI, from which velocity is obtained. As e_{is} is increased ΔI becomes smaller and thus the associated velocity is less.

There are many factors which may have caused errors in the recordings that were made. It is believed that the three listed above were the main ones and any others that may have existed would be insignificant in relation to the above.

5.4. Profiles

Using program ANAL2 a profile of the resultant velocities (Figure 5.3), turbulent intensities (Figure 5.4) and dispersion factors (Figure 5.5) were produced. There is an upper and lower profile for each of the above three sets. The upper profile represents the range of values divided up into five equal subranges and zero. Zero is represented by a blank. The lowest range, which includes the samllest number greater than zero, is represented by a -. In order, the highest ranges are represented by (-,I), (-,I,L), (-,I,L,H) and (-,I,L,H,K) overprint.

The lowest range, those represented by a -, is further divided into five equal parts. Each part is represented by a dot in the lower profile. Again all zero are represented by a blank.

Four profiles are shown in each of Figure 5.4 and 5.5. The left and right profiles represent the horizontal and vertical components, respectively. All profiles shown are for an air flow of 93.5 CFM.

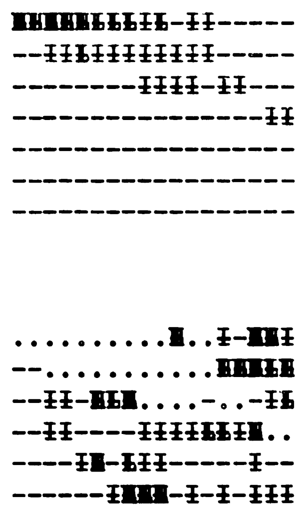


Figure 5.3. -- Profiles of resultant velocities which show inlet air jet.

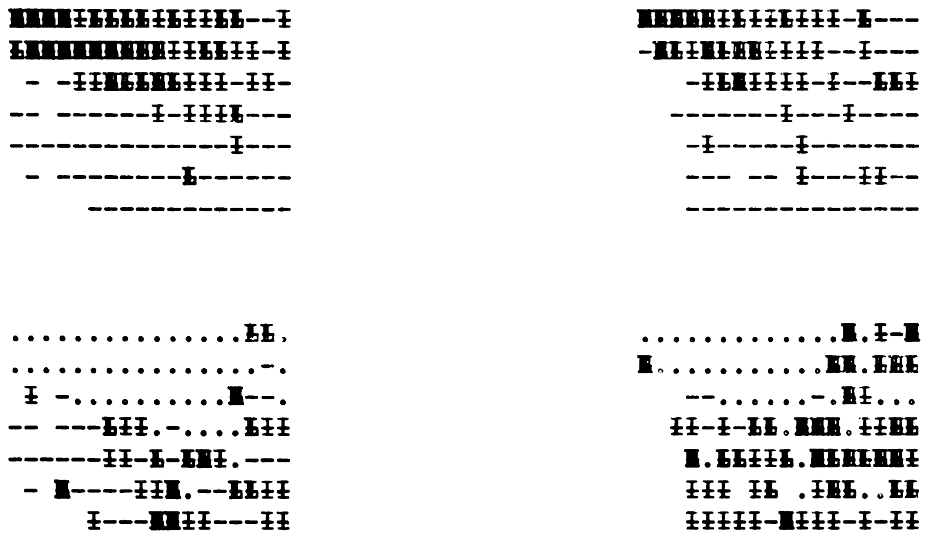


Figure 5.4. -- Profiles of turbulent intensities.
(horizontal component, left; vertical component, right)

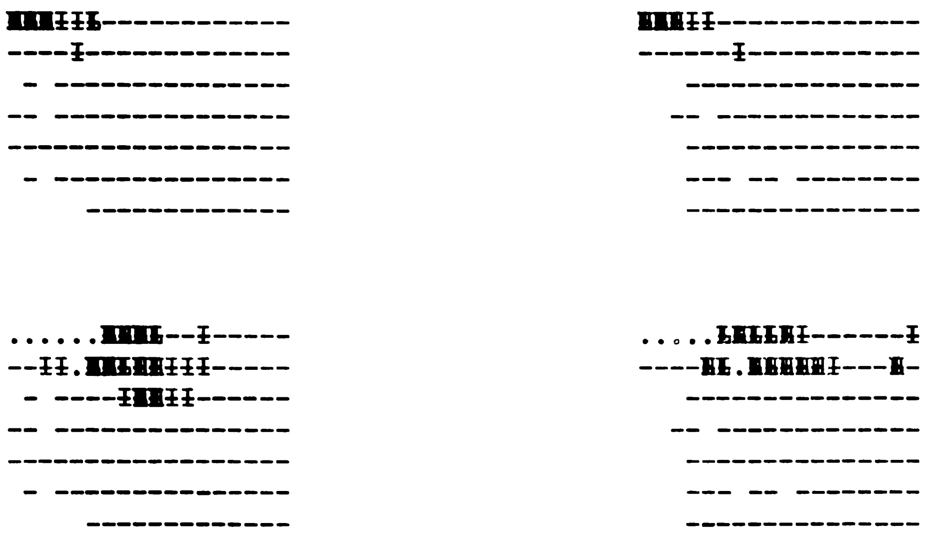


Figure 5.5. -- Profiles of dispersion factors.
(horizontal component, left; vertical component, right)

5.5. Discussion of Profiles

All three figures (Figures 5.3, 5.4 and 5.5) indicate that air is entering at the upper left and fanning out as it moves across the chamber. These figures indicate that there is a boundry to this fanning and can be calculated to be roughly 6° from horizontal which would give an inclusion angle of 12°. 12° is a little less than the 15° given by Tilley (1964) but if attraction by the ceiling is considered, (Becker, 1950; Farguharson, 1952; Parker and White, 1965) then 12° is very acceptable.

Another common observation, is the lack of activity in the lower left region of the plane. There the air is fairly still with low velocities, no measurable turbulence and hence no dispersion. This would indicate a problem area for this type of ventilation system.

In the other areas, conditions are not very well defined. The highest determined velocity resultant was only 108 feet per minute. But even at these border line measuring conditions, a better understanding of what is happening can be obtained.

For example, in the region bounded by the ceiling and grid row four and by grid column seven and thirteen, the outside air has mixed fairly well with the inside air and will now be mixed in varying proportions throughout the chamber and exhausted. Just how well this air is mixed throughout the chamber is not completely answered but it is known that it is poor in the lower left region.

Figure 5.2 and the lower profile of Figure 5.3 indicate that as the inlet air fans out, after entry into the chamber, the lower portion reaches the floor at about the midpoint. Here a small portion is drawn around to the left to circulate through the lower left region. The rest circulates through the lower right region and then is exhausted.

5.6. Profile Intensities

The plane was divided into four areas as follows:

1. area 1 - rows 1-3, columns 1-9.
2. area 2 - rows 1-3, columns 10-18.
3. area 3 - rows 4-7, columns 1-9.
4. area 4 - rows 4-7, columns 10-18.

Table 5.1 gives the maximum and minimum value for each of the two velocity components, for the velocity resultants and for the two components of velocity variances, turbulent intensities and dispersion factors of the four areas.

Table 5.1 indicates, as did the profiles, that conditions were not very uniform within the air chamber. The largest values were found in area one at the inlet, as expected. These large values extended across into area two, indicating that most of the activity is in the upper portion of the plane as would be expected since it contains the inlet and outlet.

Table 5.1 also indicates that isotropic turbulence does not exist as the magnitudes of the variance of the horizontal mean velocities and of the variance of the vertical mean velocities are not equal. It can be seen that the horizontal component is much greater.

Table 5.1. -- Area maximum and minimum.

Variable	Area	High	Low
horizontal velocity (FPM)	1	105.7318	0.0912
	2	43.2137	0.3695
	3	18.6140	0.0914
	4	27.7150	0.3669
vertical velocity (FPM)	1	28.5066	0.0912
	2	16.0486	0.3659
	3	4.5523	0.0912
	4	4.5536	0.0917
resultant velocity (FPM)	1	108.0035	0.1289
	2	44.7064	2.7717
	3	18.6175	0.3771
	4	27.8110	1.1754
horizontal velocity variance	1	2865.6167	0.0000
	2	147.8001	0.0058
	3	0.1244	0.0000
	4	2.2617	0.0015
vertical vleocity variance	1	91.2435	0.0000
	2	3.1057	0.0001
	3	0.0023	0.0000
	4	0.0379	0.0000
horizontal turbulent intensity	1	0.5439	0.0000
	2	0.3766	0.0495
	3	0.0481	0.0000
	4	0.2478	0.0119
vertical turbulent intensity	1	0.3340	0.0000
	2	0.2265	0.0198
	3	0.1018	0.0000
	4	0.2326	0.0000
horizontal dispersion factor	1	7.7683	0.0000
	2	0.7729	0.0001
	3	0.0151	0.0000
	4	0.0581	0.0001
vertical dispersion factor	1	0.3565	0.0000
	2	0.0378	0.0000
	3	0.0003	0.0000
	4	0.0011	0.0000

Table 5.1 and Figures 5.3, 5.4 and 5.1 tend to indicate a good correlation between the variables being considered. The large values are well grouped, but are the lower values? Section 5.7 and 5.8 will investigate and discuss this.

5.7. Statistical Methods

Section 4.3.a lists three forms of output produced by program ANAL1. They are as follows:

1. the scatter diagram
2. linear and non-linear line of regression
3. correlation factor

Figure 5.6 shows a typical scatter diagram and the lines of regression associated with it. The particular one used as an example, shows the relation between turbulent intensity and mean velocity for the horizontal component for an air flow of 93.5 CFM. The coefficients of the equations describing the lines of regression and the correlation factors are listed in Tables 5.2 and 5.3.

The following key is to be used with Tables 5.2 and 5.3:

MV - mean velocity

RV - resultant velocity

VVF - variance of velocity fluctuations

TI - turbulent intensity

DF - dispersion factor

S_y - standard error of estimate

r - coefficient of correlation

ρ - index of correlation

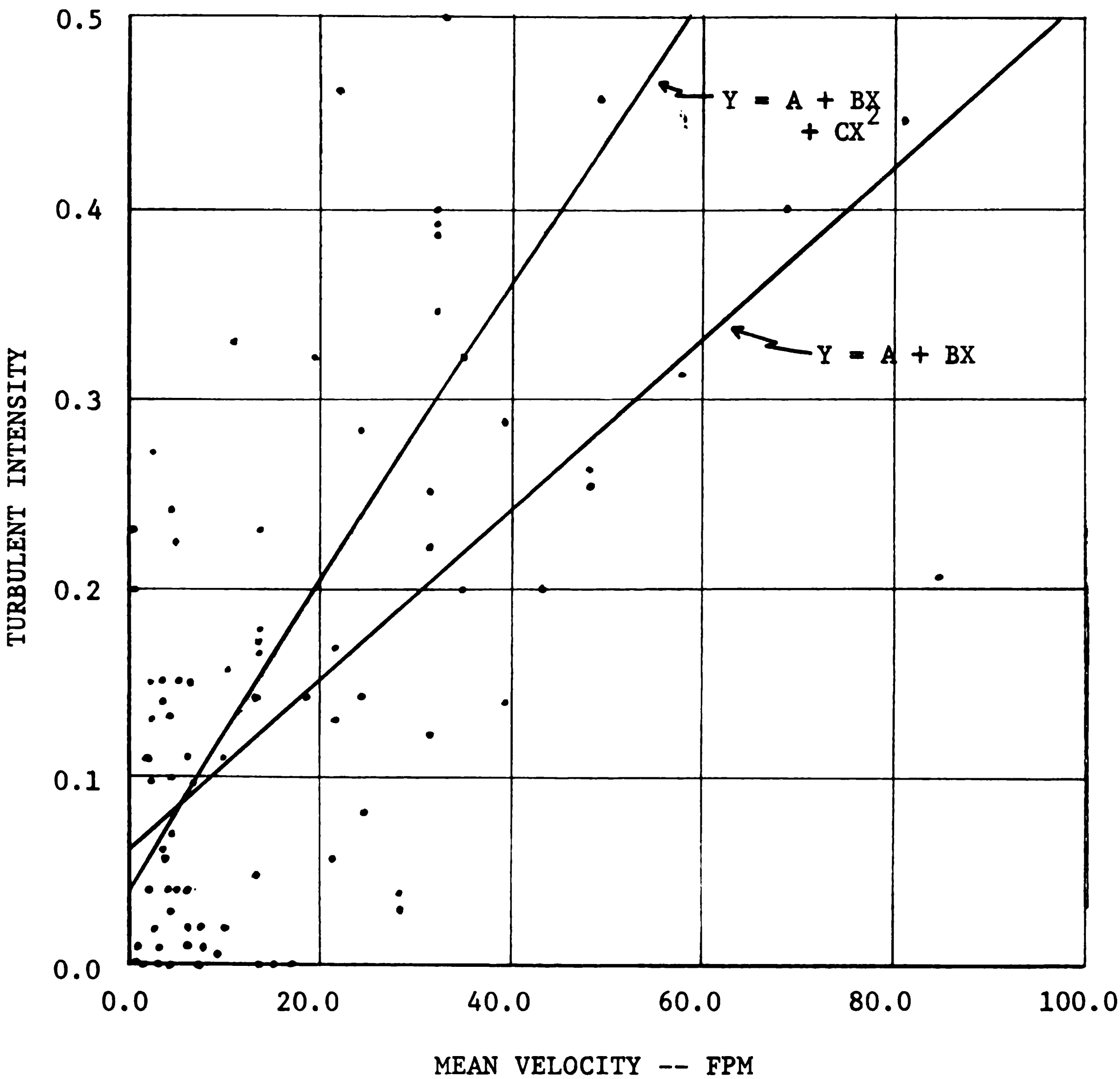


Figure 5.6. -- Typical scatter diagram.

When used, these symbols may have a "vc" or an "hc" as a subscript. "vc" and "hc" stand for vertical component and horizontal component, respectively. The left column of each table, indicated which two variables were considered. The left and right variable, of the column, indicate the Y and X axis of the scatter diagram, respectively. The right most column gives a measure of the degree of association between the variables listed in the left most column.

5.8. Discussion of Tables 5.2 and 5.3

The correlation coefficients ranged from 0.509 to 0.969 and the index of correlation ranged from 0.549 to 0.970. A comparison of the two tables indicate that in several cases the non-linear trend gave a much more accurate representation of the data.

The correlation between the two variance velocity components was 0.969 and 0.970 which would indicate that many of the resultant angles are of similar size. Figure 5.2 shown this to be true. Most of the angles are small due to a predominate horizontal component. If all the resultant angles were the same, correlation would be perfect. The more varied the size of the angles the lower will be the correlation.

Because of the definitions adopted for turbulent intensity and dispersion factor, it is expected that correlations of the other components will also be high. For the components of mean velocity, turbulent intensity and dispersion factor, the correlation coefficients were 0.843, 0.804 and 0.926 and the indexes of correlation were 0.844, 0.805 and 0.930 respectively. Because of the very high linear correlation, it is not expected to have much improvement in the non-linear case. The small variation in the above correlations is due to the effect the equations of definition have on therelative scattering of

Table 5.2. -- Results of program ANAL1 for the case of linear correlation.

$$Y = A + BX$$

Variables X	Y	A	B	r
TI_{hc}	- VVF_{hc}	1.1340-01	2.3191-04	0.509
TI_{vc}	- VVF_{vc}	7.0539-02	4.3315-03	0.544
VVF_{vc}	- VVF_{hc}	-2.0933-01	3.3971-02	0.969
TI_{hc}	- RV	6.1800-02	4.4897-03	0.648
TI_{vc}	- RV	3.7386-02	2.8167-03	0.644
DF_{hc}	- RV	-4.1636-01	5.0526-02	0.862
DF_{vc}	- RV	-1.4333-02	1.7658-03	0.779
DF_{hc}	- TI_{hc}	-2.2698-01	4.5299+00	0.535
DF_{vc}	- TI_{vc}	-1.1293-02	3.0072-01	0.562
TI_{vc}	- TI_{hc}	1.6388-02	4.9233-01	0.804
TI_{hc}	- MV_{hc}	6.4425-02	4.5344-03	0.638
DF_{hc}	- MV_{hc}	-3.9622-01	5.1667-02	0.860
DF_{vc}	- MV_{vc}	-1.3288-02	7.1004-03	0.829
MV_{vc}	- MV_{hc}	3.2413-01	2.2918-01	0.843
DF_{vc}	- DF_{hc}	-1.0839-04	3.5831-02	0.926
TI_{vc}	- MV_{vc}	4.5253-02	9.6590-03	0.604

Table 5.3. -- Results of program ANAL1 for the case of non-linear correlation.

$$Y = A + BX + CX^2$$

Variables Y	X	A	B	C	ρ
TI_{hc}	- VVF_{hc}	9.9257-02	6.6748-04	-1.9355-07	**0.638**
TI_{vc}	- VVF_{vc}	6.3465-02	1.3887-02	-1.3058-04	**0.664**
VVF_{vc}	- VVF_{hc}	-3.2665-01	3.7583-02	-1.6053-06	**0.970**
TI_{hc}	- RV	3.5882-02	8.0278-03	-4.3879-05	**0.683**
TI_{vc}	- RV	3.7084-02	2.8580-03	-5.1205-07	**0.664**
DF_{hc}	- RV	1.7926-02	-8.7666-03	7.3538-04	**0.962**
DF_{vc}	- RV	1.7835-03	-4.3459-04	2.7289-05	**0.879**
DF_{hc}	- TI_{hc}	-8.3606-02	1.4750+00	6.8946+00	**0.549**
DF_{vc}	- TI_{vc}	3.7646-04	-4.3546-02	1.1494+00	**0.602**
TI_{vc}	- TI_{hc}	1.9165-02	4.3315-01	1.3355-01	**0.805**
TI_{hc}	- MV_{hc}	4.0811-02	7.984-03	-4.4229-05	**0.671**
TI_{vc}	- MV_{vc}	4.4231-02	1.0304-02	-3.1708-05	**0.604**
DF_{hc}	- MV_{hc}	1.0310-02	-7.6229-03	7.6141-04	**0.956**
DF_{vc}	- MV_{vc}	2.8346-03	-3.0708-03	5.0021-04	**0.968**
MV_{vc}	- MV_{hc}	5.1454-01	2.0141-01	3.5664-04	**0.844**
DF_{vc}	- DF_{hc}	1.3143-03	2.4749-02	1.6865-03	**0.930**

the points. For example, the equations for dispersion factor had a tendency to force a tighter scattering pattern while the equations for turbulent intensity tended to amplify the scattering. In any case the effect was small.

The correlations between unlike variables were low with one important exception. The correlation between mean velocity and dispersion factor was high. Since it was assumed that the dispersion factor was a measure of air mixing, the above correlation would imply that the greater the velocity, the greater the mixing.

5.9. Summary

Figures 5.3, 5.4 and 5.5 and Table 5.1 show that the lower left region below the inlet has very little air movement. There the air velocity was the lowest of any place in the air chamber and the air fluctuations were too small to be measured. As a result the turbulent intensity and dispersion factor were zero. This would tend to indicate that this region was poorly ventilated.

From the scatter diagrams, that were produced at the time the data of Tables 5.2 and 5.3 was obtained, the following was observed:

1. At points of high velocity, there was also high turbulence and dispersion.
2. There were points of low velocity and moderately high turbulence.
3. Points did not exist in which there was low velocity and moderately high to high dispersion.

The above observations were supported by the correlations of Tables 5.2 and 5.3. The correlation between velocity and turbulent intensity was low, but between velocity and dispersion it was very high.

From this study it cannot be concluded if ventilation is adequate or not. This would depend on the requirements of the occupants. However, it was shown what conditions existed in the vertical plane being studied. There was a jet stream of high velocity, turbulence and dispersion in which outside air was mixed with inside air. The higher the velocity in this region, the greater the air will be mixed. From the flow characteristics shown in Figure 5.2 it can be seem that a portion of this mixed air is exhausted without first circulating through the lower portion of the chamber. Figures 5.3 show that this mixed air is not distributed uniformly throughout the lower portion of the chamber.

This study does present a procedure for determining the characteristics of a ventilation system. It may indicate where problem areas might exist. From this information a design improvement may be realized. Once an optimum system is developed which exhibits desirable characteristics is it then an adequate ventilation system? This question must be answered based on the requirements of the occupants.

5.10. <u>Discussion of Low Flow Rate</u>

Up to this point, all discussion has pertained to the 93.5 CFM flow rate. Because of such poorly defined conditions, at the lower flow rate of 61.7, measurements were taken only in the area of the inlet. Because of the limited number of measurements made, it is not possible to adequately relate the two.

There were two important observations:

1. An inlet jet again formed and had a similiar inclusion angle. As before the major activity was confined to this jet.
2. There were larger areas outside the air jet in which air movement was too small to be measured.

6. CONCLUSIONS

Based upon this study the following conclusions are made:

1. Air entering through the inlet fanned out forming an inclusion angle of about 12°. The boundary of this air jet was defined over about the first third of the chamber.
2. Most of the activity was in this jet. As expected maximum values of velocity, variance of velocity fluctuations, turbulent intensity and dispersion factors were contained within it. In many cases, values outside of the jet were negligible compared to values within the jet.
3. The air in the area just below the inlet is very still, indicating the possibility of inadequate ventilation. In many locations of this area, there was no measurable turbulence or dispersion.
4. There was a correlation as high as 96.8% between velocity and dispersion factor. This would indicate a good relation between velocity and the rate of mixing.
5. It can not be stated whether ventilation was adequate or not. There were areas in which it was felt to be inadequate; in particular the lower left area below the inlet. What is adequate ventilation and what value of dispersion factor, if any, can be associated with it cannot be answered, based on this study.

7. RECOMMENDATIONS FOR FUTURE WORK

The results of this investigation indicate the need for additional work in the following areas:

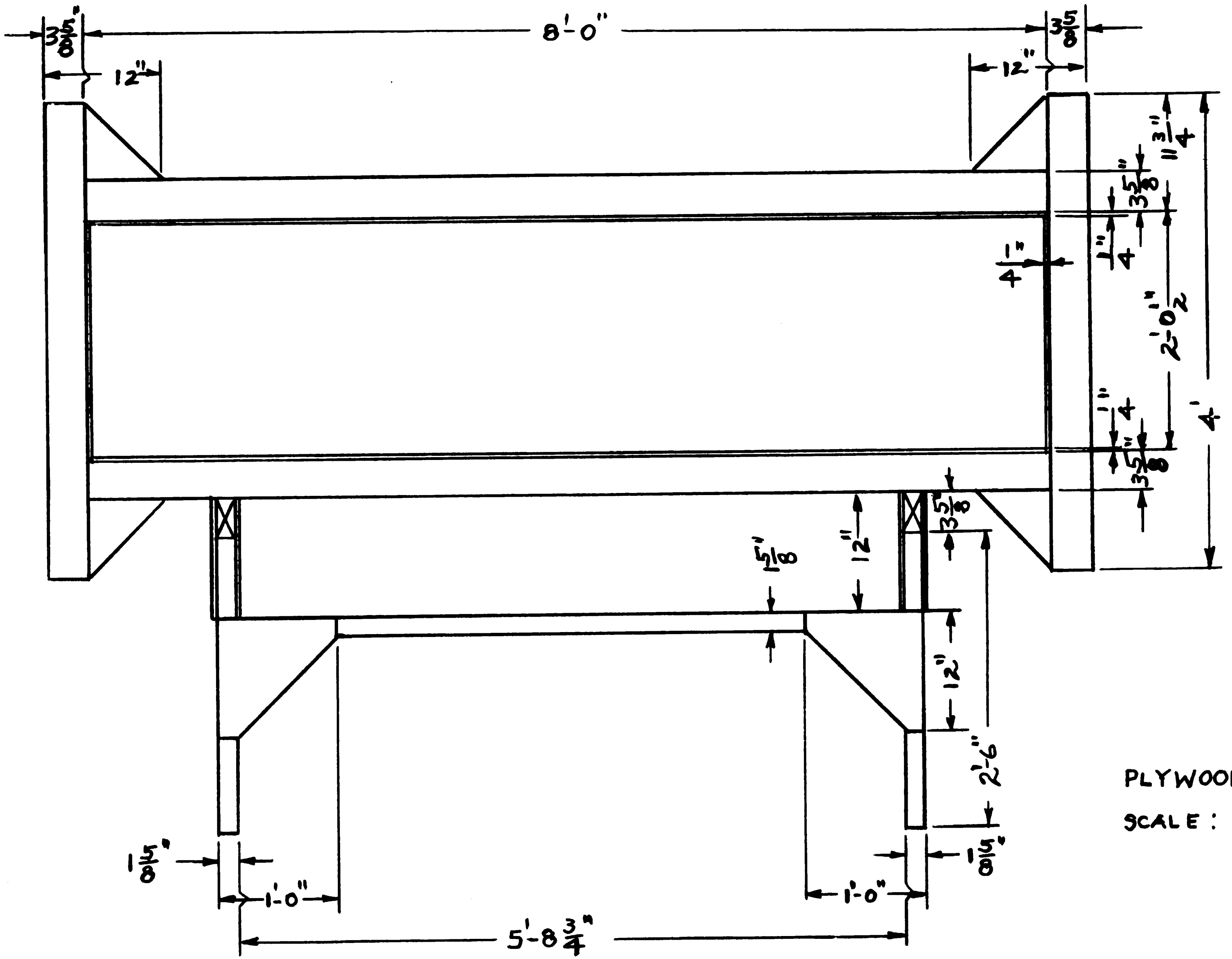
1. Investigation between dispersion factor and adequate ventilation.
2. The same type of investigation as was carried out only at higher flow rate so as to obtain more definite relationships and hence produce a clearer picture of what is happening.
3. Investigate the assumptions of negligible air velocity in the Z direction.
4. Investigate the effects of temperature.
5. Investigate other ventilating systems
6. Study the relationships between the scale model and the full scale.

APPENDIX

APPENDIX

A.1. Construction Details of Air Chamber

The construction details of the air chamber used are shown in Figures A.1, A.2, A.3 and A.4. The stand used to support the air chamber was constructed from fir 2 x 4's and 1/2 in AC exterior plywood gussets. The rigid framing of the air chamber was constructed from white pine 1 x 4's and 1/2 in. AC exterior plywood gussets. To this framing was attached 1/4 in. AC exterior plywood forming the top, bottom, ends and back. The front of the chamber was formed by attaching 3/16 in. plexiglas to the framing. Across the top of the left end, a 1/2 in. inlet slot was formed. At the right end a 4 in. outlet was provided with its center located 6 in. from the top and 2 ft. from the front of the chamber.



PLYWOOD GUSSETS -- 1/2"
SCALE : 3/4" = 1'

Figure A.1. -- End view of air chamber.

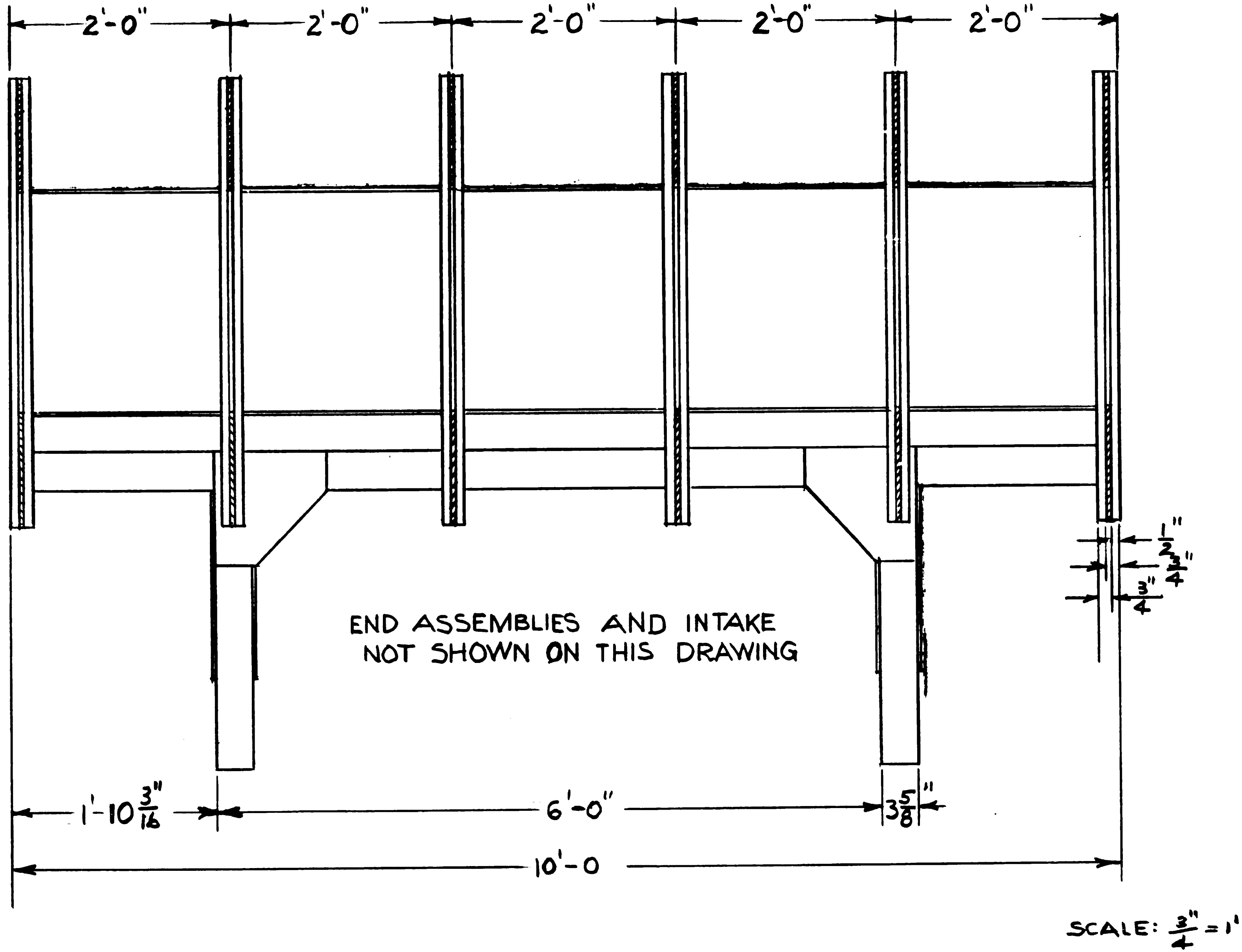


Figure A.2. -- Side view of air chamber.

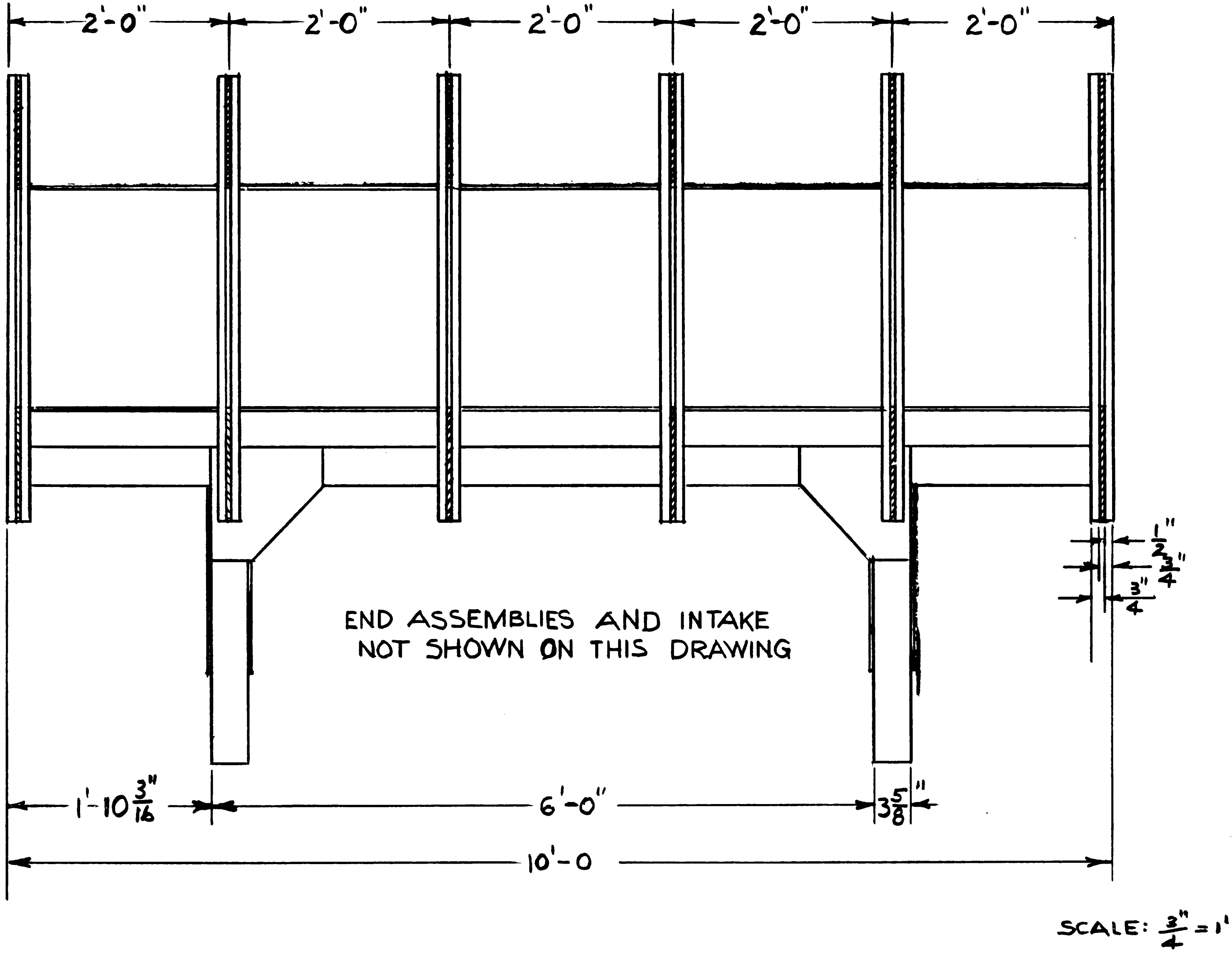


Figure A.2. -- Side view of air chamber.

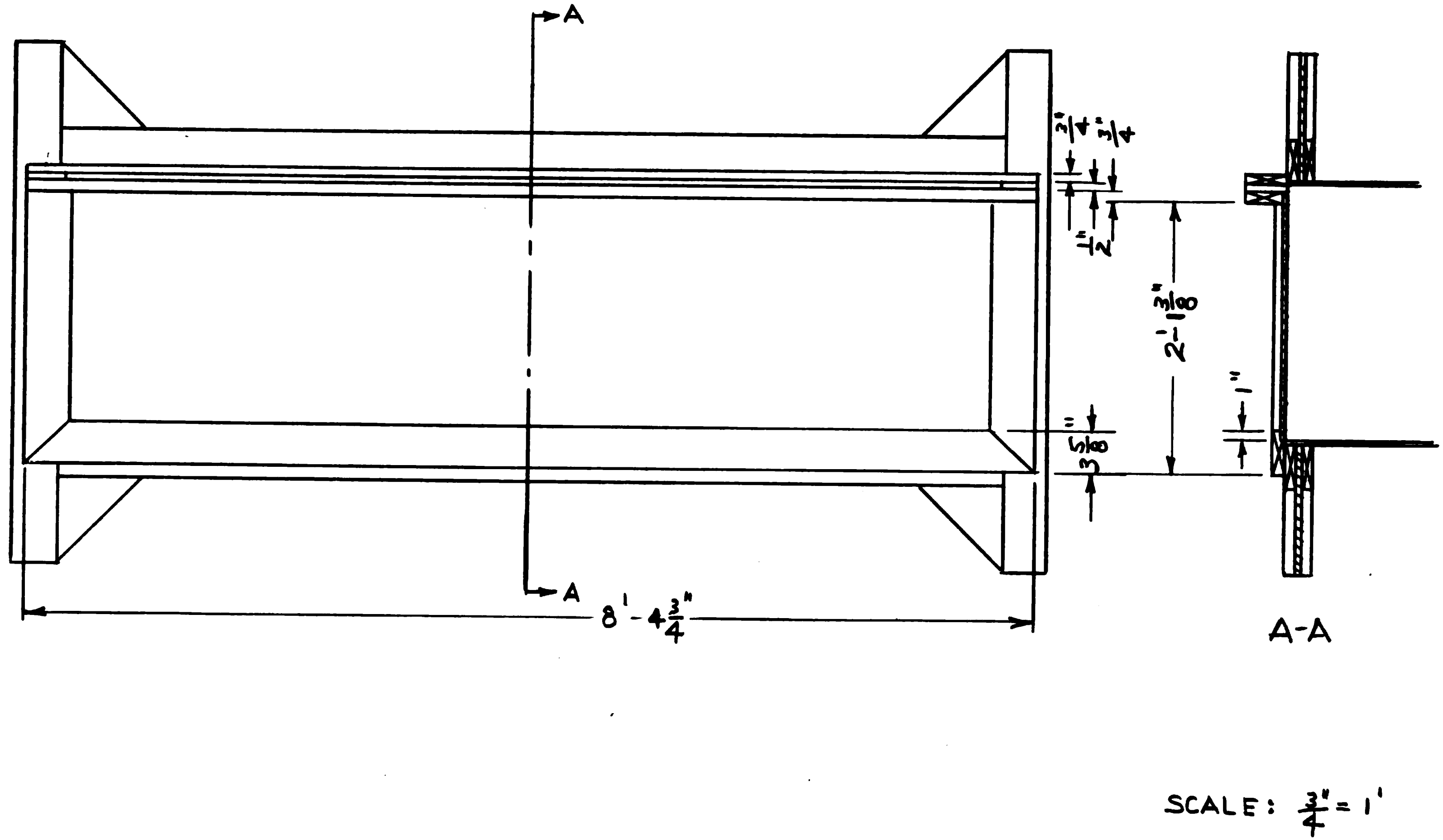


Figure A.3. -- Details of inlet end.

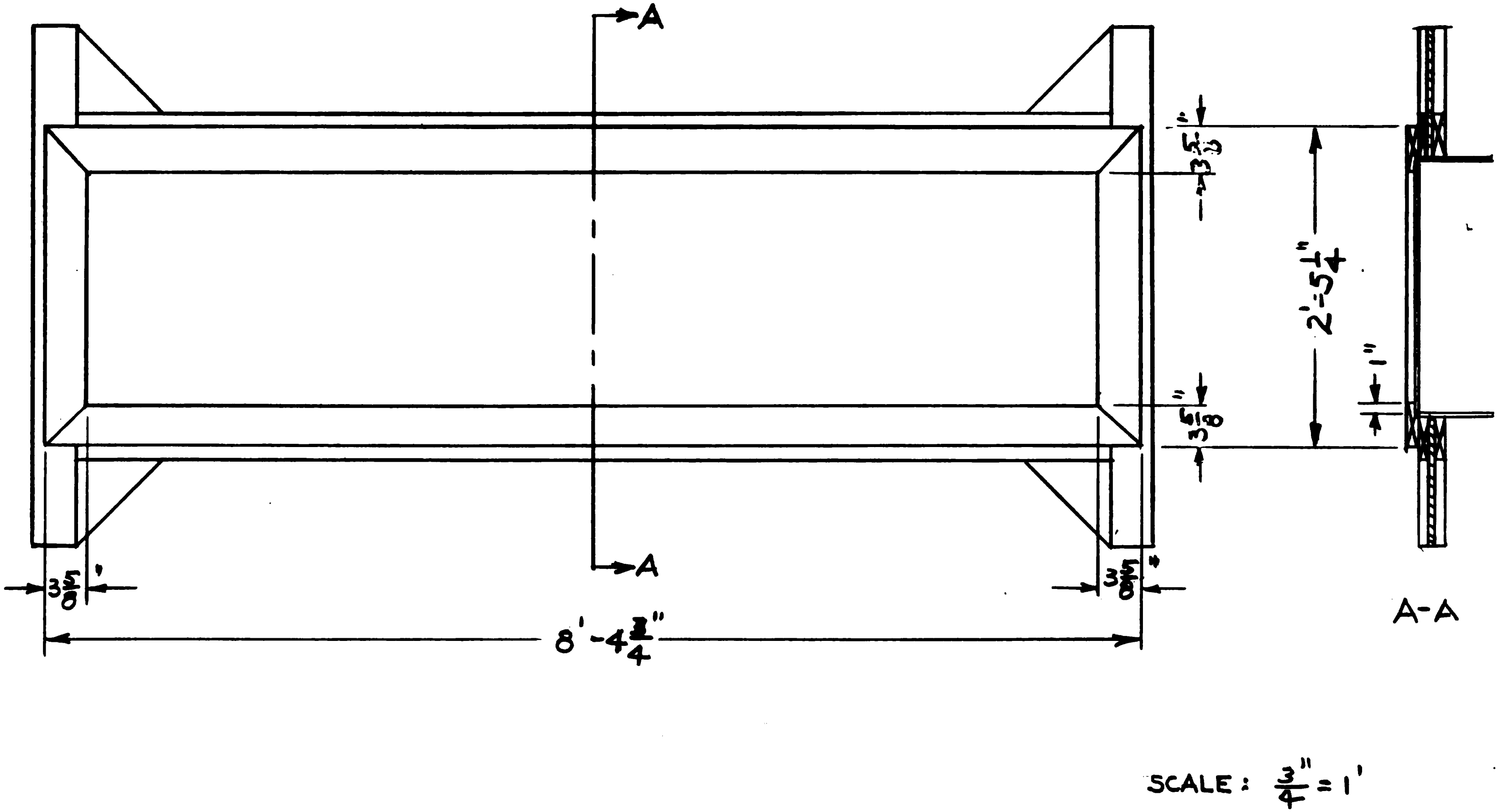


Figure A.4. -- Details of outlet end.

A.2. Program VENTURI

Program VENTURI was written for the purpose of obtaining data for the plotting of a calibration curve for a given venturi (Figure 4.7).

With the assumption of section 3.1 in mind and using equation 3.3, values of q(CFM) are produced when given values for the following:

BD = D = pipe diameter, in.

SD = d = venturi throat diameter, in.

G = g = acceleration due to gravity, ft/sec^2

RO = ρ = density of flowing fluid, lb/ft^3

GM = γ_m = density of manometer fluid, lb/ft^3

GF = γ_f = density of fluid over manometer fluid, lb/ft^3

CVT = C_{VT} = venturi discharge coefficient

CH = change in manometer differential, in.

PN = number of data points desired for plot

A sample of input data is shown below and is explained at the beginning of the program listing.

Sample of input data:

```
4.0
2.0
32.174
0.0723
62.19
0.0723
0.95
0.1
21.0
```

```
      PROGRAM VENTURI
C
C     DATA CARD 1 -- LARGE DIAMETER OF VENTURI, IN.
C     DATA CARD 2 -- SMALL DIAMETER OF VENTURI, IN.
C     DATA CARD 3 -- ACCELERATION DUE TO GRAVITY, FT/SEC SQ
C     DATA CARD 4 -- DENSITY OF FLOWINT FLUID, LB/FT CU
C     DATA CARD 5 -- DENSITY OF MANOMETER FLUID, LB/FT CU
C     DATA CARD 6 -- DENSITY OF FLUID OVER MANOMETER FLUID, LB/FT CU
C     DATA CARD 7 -- VENTURI DISCHARGE COEFFICIENT
C     DATA CARD 8 -- CHANGE IN MANOMETER DIFFERENTIAL, IN.
C     DATA CARD 9 -- NUMBER OF POINTS DESIRED
C          VALUES FOR THE ABOVE ARE TO BE PUNCHED, WITH DECIMAL
C          POINT, IN THE FIRST TEN COLUMNS OF EACH RESPECTIVE
C          DATA CARD.
C
      READ 200,BD,SD,G,RO,GM,GF,CVT,CH,PN
      N=PN
      PRINT 201
      PRINT 202,BD,SD,G,RO,GM,GF,CVT
      PI=3.14159265
      A=PI*BD*BD/4./144.
      B=SD/BD
      F=B*B/SQRT(1.-B**4)
      AF=A*F*60.
      FG=2.*G/12.
      FF=FG*(GM-GF)/RO
      H=0.
      PRINT 203
      DO 100 I=1,N
      STG=AF*CVT*SQRT(FF*H)
      PRINT 204,H,STG
  100 H=H+CH
  200 FORMAT(F10.0)
  201 FORMAT(*1*)
  202 FORMAT(E20.6*  PIPE DIAMETER,IN.*/E20.6*  VENTURI THROAT DIAMETER,
     CIN.*/E20.6*  ACCELERATION DUE TO GRAVITY*/E20.6*  DENSITY OF FLOWI
     CNG FLUID*/E20.6*  DENSITY OF MANOMETER FLUID*/E20.6*  DENSITY OF F
     CLUID OVER MANOMETER FLUID*/E20.6*  VENTURI DISCHARGE COEFFICIENT*/
     C7(/))
  203 FORMAT(* *,9X,*H(IN)*,11X,*Q(CFM)*,/)
  204 FORMAT(3X,F12.4,F17.4)
      END
```

A.3. Program CALIBRAT

Program CALIBRAT was written for the purpose of obtaining data for the plotting of two types of calibration curves for a given hot-wire.

With the assumptions of section 3.2 in mind and using equations 3.6, values for the $\sqrt{V}$, I^2 and the slope of the calibration curve of Figure 4.8 and values of V and I for the calibration curve of Figure 4.9 are produced when given values for the following:

G = g = acceleration due to gravity, ft/sec^2

RO = ρ = density of flowing fluid, lb/ft^3

GM = γ_m = density of manometer fluid, lb/ft^3

GF = γ_f = density of fluid over manometer fluid, lb/ft^3

CPT = C_{PT} = inlet coefficient

H = h = manometer differential, in.

FIZRO = $4I_o$ = current at zero velocity, ma

FI = $4I$ = current at velocity calibration point, ma

CV = change in velocity between points considered, in.

PN = number of points considered

A sample of input data is shown below and is explained at the beginning of the program listing.

Sample of input data:

```
32.174
0.0723
62.19
0.0723
1.0
0.0440
313.0
398.4
10.
91.
```

```
      PROGRAM CALIBRAT
C
C     DATA CARD 1 -- ACCELERATION DUE TO GRAVITY, FT/SEC SQ
C     DATA CARD 2 -- DENSITY OF FLOWING FLUID, LB/FT CU
C     DATA CARD 3 -- DENSITY OF MANOMETER FLUID, LB/FT CU
C     DATA CARD 4 -- DENSITY OF FLUID OVER MANOMETER FLUID, LB/FT CU
C     DATA CARD 5 -- INLET COEFFICIENT
C     DATA CARD 6 -- MANOMETER DIFFERENTIAL, IN.
C     DATA CARD 7 -- 4I ZERO (MA)
C     DATA CARD 8 -- 4I (MA)
C     DATA CARD 9 -- CHANGE IN VELOCITY BETWEEN POINTS CONSIDERED
C     DATA CARD 10 - NUMBER OF POINTS CONSIDERED
C          VALUES FOR THE ABOVE ARE TO BE PUNCHED, WITH DECIMAL
C          POINT, IN THE FIRST TEN COLUMNS ON RESPECTIVE DATA CARDS.
C
      READ 200,G,RO,GM,GF,CPT,H,FIZRO,FI,CV,PN
      V=CPT*SQRT(2.*G*(GM-GF)/RO*H/12.)*60.
      B=(FIZRO/4.)**2
      SRV=SQRT(V)
      F=(FI/4.)**2
      SLOPE=(F-B)/SRV
      PRINT 201
      PRINT 202,G,RO,GM,GF,CPT,H,V,B,F,SRV,SLOPE
      N=PN
      V=0.
      PRINT 203
      DO 100 I=1,N
      SRV=SQRT(V)
      CSQ=SLOPE*SRV+B
      CUR=SQRT(CSQ)
      PRINT 204,V,SRV,CSQ,CUR
  100 V=V+CV
  200 FORMAT(F10.0)
  201 FORMAT(*1*)
  202 FORMAT(E20.6*  ACCELERATION DUE TO GRAVITY*/
     C         E20.6*  DENSITY OF FLOWING FLUID*/
     C         E20.6*  DENSITY OF MANOMETER FLUID*/
     C         E20.6*  DENSITY OF FLUID OVER MANOMETER FLUID*/
     C         E20.6*  INLET COEFFICIENT*/
     C         E20.6*  MANOMETER DIFFERENTIAL*/
     C         E20.6*  V AT 4I*/
     C         E20.6*  CURRENT SQUARED INTERCEPT*/
     C         E20.6*  OTHER CURRENT VALUE SQUARED*/
     C         E20.6*  SQRT(V) FOR OTHER CURRENT VALUE*/
     C         E20.6*  SLOPE OF CALIBRATION CURVE*7(/))
  203 FORMAT(9X,*V(FPM)*,8X,*SQRT(V)*,9X,*I-SQ*,11X,*I(MA)*,/)
  204 FORMAT(4F15.3)
      END
```

A.4. Program TURB

Program TURB was written for the purpose of obtaining a mean velocity, a velocity variance, a turbulent intensity and a dispersion factor for each "data set". This information is printed and punched out for further computer analysis by more specialized programs. In addition to the above, program TURB has a feature programmed in that will result in a plot of voltage fluctuations, delta i, instantaneous velocity and correlation coefficients for each data set.

The input data, order and the control cards required for program TURB are explained at the beginning of the program listing. Interpretation of this is as follows:

1. The parameter card controls the plotting, punching of results and the percent of the correlation curve that is to be used when determining the dispersion factor. If the full area is desired, a 100 would be used. This parameter card remains in effect, until a "data set" is encountered which is followed by a blank control card. If more data is to follow, then a new parameter card is required.
2. The location and flow message card is used as a means of identifying each "data set". The row, column and layer position indicator are integers, right justified in their respective fields. The "message" allows for further identification, i.e. flow component.
3. Calibration and data constants are numbers with a decimal point and can be positioned any place in their respective fields.
4. A value of zero in the "data set" indicates the end of the set. Be sure to chose a reference, when recording raw data, that will produce

only positive numbers. If the number of points in the set is a multiple of 14, a blank card will have to be added to produce the required "control zero". Otherwise one is not to be added. Do not confuse this blank card with card N + 1.

Three error checks have been programmed in. They are as follows:

1. If more than 3000 data points are read in for a given "data set" only the first 2999 and the last one are considered. A message to this effect is printed out.
2. A test of the expression $1 + \frac{2iE_{if}}{IE_{is}}$ is made to see if it is less than zero as the square root of it is to be taken. If the value is less than zero it is replaced by zero and a message is printed out.
3. When using the wire calibration curve to convert from current to velocity it is necessary to check the current to see if it is equal to or greater than the current at zero velocity. If the value of current is less than the current at zero velocity, then a print out of the data point, the square of the current being converted, the value of the square of the current for zero velocity and the mean current squared is produced.

Program TURB has two subprograms which are described below.

```
      PROGRAM TURB
C
C                                      ARRANGEMENT OF DATA
C
C     CARD 1.  PARAMETER CARD
C
C          COLUMN    CODE                              MEANING
C
C            1        0 OR 1        1--A GRAPH OF EIF IS PRODUCED
C            2       ,0 OR 1        1--A GRAPH OF DELTA I IS PRODECED
C            3        0 OR 1        1--A GRAPH OF VELOCITY IS PRODUCED
C            4        0 OR 1        1--A GRAPH OF CORRELATION IS PRODUCED
C            5        0 OR 1        1--RESULTS ARE PUNCHED OUT
C           6-8                     PERCENT OF CORRELATION CURVE TO
C                                        CONSIDER FOR DISPERSION FACTOR
C
C
C     CARD 2.  LOCATION AND MESSAGE
C
C          COLUMNS                INFORMATION
C
C            1-5       THE ROW POSITION (INTEGER)
C            6-10      THE COLUMN POSITION (INTEGER)
C           11-15      THE LAYER POSITION (INTEGER)
C           20-59      MESSAGE
C
C
C     CARD 3.  CALIBRATION AND DATA CONSTANTS
C
C          COLUMNS                INFORMATION
C
C            1-10      SQUARE WAVE VOLTAGE,EIS
C           11-20      NULL READING
C           21-30      TOTAL TIME TO RECORD SET OF DATA
C           31-40      VOLTAGE AMPLIFICATION FACTOR
C           41-50      MEAN CURRENT (4I)
C           51-60      RESISTANCE RATIO USED, I.E. 1.3
C           61-70      SLOPE OF CALIBRATION CURVE
C           71-80      CURRENT SQUARED AT ZERO VELOCITY
C                ALL OF THE ABOVE ARE NUMBERS WITH DECIMAL
C
C
C     CARDS 4-N.  SET OF DATA
C
C          THESE CARDS CONTAIN THE TURBLENT DATA ARRANGED IN 14 FIELDS
C          OF 5 COLUMNS EACH.  IF THE LAST DATA CARD CONTAINS 14 SETS
C          OF NUMBERS, THEN THE NTH CARD IS TO BE A BLANK CARD.  A
C          LIMIT OF 3000 POINTS HAS BEEN SET.  SET REFERENCE SO THAT
C          ALL DATA POINTS ARE GREATER THAN ZERO.
C
C
```

```
C       CARD N+1.  SAME AS CARD 2
C
C              REPEAT THE ABOVE CARDS UNTIL ALL DATA FOR A GIVEN COMPONENT
C              HAS BEEN CONSIDERED, THEN INSERT A BLANK CARD.  IF THERE IS
C              ANOTHER COMPONENT TO CONSIDER, REPEAT THE ABOVE STARTING AT
C              CARD 1.  THIS MAY BE REPEATED FOR ANY NUMBER OF COMPONENTS.
C
C
C
C              MEANING OF LETTER CODES USED IN OUTPUT
C
C
C       CODE                          MEANING
C
C        I               ROW POSITION IN WHICH SAMPLE WAS TAKEN
C        J               COLUMN POSITION IN WHICH SAMPLE WAS TAKEN
C        K               LAYER POSITION IN WHICH SAMPLE WAS TAKEN
C        A               MEAN OF VELOCITIES
C        B               VARIANCE OF VELOCITIES
C        C               TURBULENT INTENSITY
C        D               DISPERSION FACTOR
C
C
C
      DIMENSION STORE(14)
      COMMON/1/R1(500,4),SG(3000),STG(3000,2),C(3000),MR(500,3)
      COMMON N,CT,ICOFF,NP
  100 READ 200,NEIF,NDI,NVI,NCP,NPUNCH,ICOFF
      IF(EOF,60)127,101
  101 DO 102 J=1,4
      DO 102 I=1,500
  102 R1(I,J)=0.
      NP=0
  103 NP=NP+1
      READ 201,MR(NP,1),MR(NP,2),MR(NP,3),WA,WB,WC,WD,WE
      IF(MR(NP,1).EQ.0)  GO TO 123
      N=0
      READ 202,EIS,B,TF,VAF,AC4T,RER,SL,YIC
      AC=AC4T/4.
      ACSQD=AC*AC
  104 READ 203,(STORE(I),I=1,14)
      DO 105 I=1,14
      IF(STORE(I).EQ.0.)  GO TO 106
      N=N+1
      IF(N.LE.3000)  GO TO 105
      N=3000
      IFLAG=1
      GO TO 104
  105 SG(N)=STORE(I)
      GO TO 104
  106 CT=TF/(N-1)
      T=0.
```

```
      DO 107 I=1,N
      STG(I,1)=T
  107 T=T+CT
      PRINT 204,MR(NP,1),MR(NP,2),MR(NP,3),WA,WB,WC,WD,WE
      IF(IFLAG.EQ.1)  PRINT 205
      PRINT 206,AC,N,CT,B,RER,VAF,EIS
      PRINT 207,(SG(I),I=1,N)
      SUM=0.
      DO 108 I=1,N
  108 SUM=SUM+SG(I)
      Q=N
      YB=SUM/Q
      DO 109 I=1,N
  109 SG(I)=SG(I)-YB
      DO 110 I=1,N
  110 SG(I)=SG(I)*VAF
      IF(NEIF.NE.1)  GO TO 112
      DO 111 I=1,N
  111 STG(I,2)=SG(I)
      PRINT 208
      CALL GRAPH
  112 SI=3.05/(1.+B*RER/400.)
      BGG=0.
      SMM=1.00E+300
      DO 115 I=1,N
      TBR=1.+2.*SI/AC*SG(I)/EIS
      IF(TBR.LT.SMM)  SMM=TBR
      IF(TBR.GT.BGG)  BGG=TBR
      IF(TBR.LT.0)113,114
  113 SG(I)=0.
      PRINT 209,MR(NP,1),MR(NP,2),MR(NP,3),I
      GO TO 115
  114 SG(I)=AC*(SQRT(TBR)-1.)
  115 CONTINUE
      IF(NDI.NE.1)  GO TO 117
      DO 116 I=1,N
  116 STG(I,2)=SG(I)
      PRINT 210
      CALL GRAPH
  117 BDD=ACSQD
      DO 118 I=1,N
      DD=(AC+SG(I))**2
      IF(DD.LT.BDD)  BDD=DD
      IF(DD.LT.YIC)  PRINT 215,I,DD,YIC,ACSQD
  118 SG(I)=((DD-YIC)/SL)**2
      IF(NVI.NE.1)  GO TO 120
      DO 119 I=1,N
  119 STG(I,2)=SG(I)
      PRINT 211
      CALL GRAPH
  120 CALL STAT
      IF(NCP.NE.1)  GO TO 122
      DO 121 I=1,N
  121 STG(I,2)=C(I)
      PRINT 212
      CALL GRAPH
```

```
122 PRINT 213
    PRINT 214,(R1(NP,K),K=1,4),SI,SMM,BGG,ACSQD,YIC,BDD
    GO TO 103
123 NP=NP-1
    PRINT 216
    DO 124 I=1,NP
    IF(NPUNCH.EQ.0)  GO TO 124
    PUNCH 217,(MR(I,J),J=1,3),(R1(I,J),J=1,4)
124 PRINT 218,(MR(I,J),J=1,3),(R1(I,J),J=1,4)
    IF(NPUNCH.EQ.0)  GO TO 100
    PUNCH 219
    GO TO 100
127 CONTINUE
200 FORMAT(5I1,I3)
201 FORMAT(3I5,4X,5A8)
202 FORMAT(8F10.2)
203 FORMAT(14F5.1)
204 FORMAT(*1*,*ROW*I3,*  COLUMN*,I3,*  LAYER*,I3,5X,5A8,2(/))
205 FORMAT(22X,*MORE THAN 3000 DATA POINTS WERE ENTERED.  ONLY THE FIR
   CST 2000 WERE CONSIDERED*,2(/))
206 FORMAT(5X,F15.5,*  OPERATING CURRENT, MA.*/
   C        5X,I15   ,*  NUMBER OF DATA POINTS PER GRAPH*/
   C        5X,F15.5,*  TIME INTERVAL BETWEEN POINTS, SEC.*/
   C        5X,F15.5,*  NULL READING*/
   C        5X,F15.5,*  OPERATING RESISTANCE RATIO, OHMS*/
   C        5X,F15.5,*  VOLTAGE AMPLIFICATION FACTOR*/
   C        5X,F15.5,*  SQUARE WAVE VOLTAGE, VOLTS*,3(/))
207 FORMAT(1X,15F9.3)
208 FORMAT(*1*,10X,*PLOT OF EIF*,2(/))
209 FORMAT(10X,4I5,*  NEGATIVE*)
210 FORMAT(*1*,10X,*PLOT OF DELTA I*,2(/))
211 FORMAT(*1*,10X,*PLOT OF V(T) -- FEET PER MIN*,2(/))
212 FORMAT(*1*,10X,*PLOT OF CORRELATION*,2(/))
213 FORMAT(*-*)
214 FORMAT(5X,F15.5,*  MEAN OF VELOCITY*/
   C        5X,F15.5,*  VARIANCE OF VELOCITY*/
   C        5X,F15.5,*  INTENSITY OF TURBLENCE*/
   C        5X,F15.5,*  DISPERSION FACTOR*/
   C        5X,F15.5,*  SQUARE WAVE CURRENT*/
   C        5X,F15.5,27H  SMALL 1.+2.*SI/AC*EIF/EIS,/
   C        5X,F15.5,27H  LARGE 1.+2.*SI/AC*EIF/EIS,/
   C        5X,F15.5,*  MEAN CURRENT SQUARED*/
   C        5X,F15.5,*  ZERO VELOCITY CURRENT SQUARED*/
   C        5X,F15.5,*  SMALLEST CURRENT SQUARED*)
215 FORMAT(*-*,12X,*ERROR*,I10,3F15.5)
216 FORMAT(*1*,3X,*I*,3X,*J*,3X,*K*,64H ****** A ****** ****** B *****
   C* ****** C ****** ****** D ******,/)
217 FORMAT(1X,3I3,4F15.5)
218 FORMAT(1X,3I4,4F16.5)
219 FORMAT(* *)
    END
```

A.4.a. Subprogram STAT

Subprogram STAT contains the equations that produce the mean velocity, velocity variance, turbulent intensity and dispersion factor for a "data set" when called.

```
      SUBROUTINE STAT
      COMMON/1/R1(500,4),SG(3000),STG(3000,2),C(3000),MR(500,3)
      COMMON N,CT,ICOFF,NP
      SUM=0.
      DO 100 I=1,N
100   SUM=SUM+SG(I)
      B=N
      YB=SUM/B
      SUM=0.
      DO 101 I=1,N
101   SUM=SUM+(SG(I)-YB)**2
      VAR=SUM/B
      SD=SQRT(VAR)
      TI=SD/YB
      R1(NP,1)=YB
      R1(NP,2)=VAR
      R1(NP,3)=TI
      K=N
      L=0
      IC=0
      BETA=1.
      IF(TI.LT..000001)  GO TO 102
      BETA=SQRT(3.141592)/(4.*TI)
102   SUM=0.
      DO 103 I=1,K
      M=I+L
103   SUM=SUM+(SG(I)-YB)*(SG(M)-YB)
      K=K-1
      L=L+1
      IC=IC+1
      C(IC)=SUM/VAR/B
      IF(K.GE.1)102,104
104   CONTINUE
      SUM=0.
      NH=(N*ICOFF)/100
      DO 105 I=2,NH
105   SUM=SUM+ABS(C(I-1)+C(I))/2.*CT
      R1(NP,4)=VAR*SUM*BETA/60.
      END
```

A.4.b. Subprogram GRAPH

Subprogram GRAPH was written for the purpose of obtaining a visual representation of the data, if desired.

```
      SUBROUTINE GRAPH
      DIMENSION KP(101)
      COMMON/1/R1(500,4),SG(3000),STG(3000,2),C(3000),MR(500,3)
      COMMON N,CT,ICOFF,NP
      DATA(KM=1H-),(KI=1HI),(KH=1H*)
      B=-1.00E+300
      S=+1.00E+300
      DO 100 I=1,N
      IF(STG(I,2).LT.S)  S=STG(I,2)
      IF(STG(I,2).GT.B)  B=STG(I,2)
  100 CONTINUE
      STEP=(B-S)*.01
      SS=-S
      IC=1
      IF(S.LT.0.)  IC=-S/STEP+1.5
      DO 102 I=2,100
  102 KP(I)=KM
      KP(1)=KI  $  KP(IC)=KI  $  KP(101)=KI
      PRINT 200,(KP(I),I=1,101)
      DO 104 I=1,N
      DO 103 J=1,101
  103 KP(J)=8H
      KP(1)=KI  $  KP(IC)=KI  $  KP(101)=KI
      IL=(STG(I,2)+SS)/STEP+1.5
      KP(IL)=KH
  104 PRINT 201,STG(I,1),STG(I,2),(KP(K),K=1,101)
  200 FORMAT(* *,6X,*X*,13X,*F(X)*,8X,101A1)
  201 FORMAT(1X,E12.5,2X,E15.8,3X,101A1)
      END
```

A.4.c. Sample of Input Data

```
     1 50
     1       1       1     HORIZONTAL FLOW
        2.00      90.00       5.00       1.00     344.00       1.30     129.80     6123.06
 8.7   7.0   5.0   4.0   7.8   6.8   7.0   7.0   4.0   4.0   7.7   9.0   8.7  11.4
 9.0   4.5   2.0   4.6   6.9   5.2   6.8   6.2   5.0   5.1   6.3   7.0   6.8   6.6
 8.0   5.6   5.2   6.9   6.2   7.0   6.0   6.7   5.1   6.0   8.3   7.9   4.8   4.9
 6.9   9.4   7.4   5.6   5.4   6.0   7.8   5.0   5.9   8.8   6.0   5.2   7.0   7.8
 5.7   6.0   5.2   4.0   6.0   8.0   9.0   9.6   7.2   4.9   3.2   5.1   6.2   4.7
 5.9   7.2   6.2   6.0   5.0   3.6   7.4   8.7   6.4   2.4   3.0   7.0   6.3   4.0
 5.2   7.2   7.1   4.4   5.0   8.0   7.0   4.4   7.9   7.0   4.0   4.0   6.0   9.0
 7.0   5.4   9.0

     1 50
     1       1       1     VERTICAL FLOW
        2.00      90.00       5.00       1.00     330.00       1.30     129.80     6123.06
    50    61    49    38    60    47    57    56    42    51    52    60    50    68
    48    49    33    53    52    50    50    54    51    60    47    44    49    53
    46    62    60    51    46    47    50    50    52    60    50    52    50    50
    53    54    49    53    50    47    62    60    47    57    40    40    55    67
    50    43    55    50    49    50    50    63    50    48    50    54    48    54
    51    50    59    50    46    53    49    56    62    40    56    50    50    51
    56    57    47    48    56    60    50    58    42    53    58    51    51    52
    54    44    51
```

A.5. Program ANAL1

The functions of program ANAL1 are explained in section 4.3.a.

```
      PROGRAM ANAL1
C
C     DATA CARDS 1 TO 253.  PUNCHED DATA AS RECEIVED FROM PROGRAM
C          TURB.  126 CARDS FOR EACH COMPONENT, SEPARATED BY A
C          BLANK CARD.
C     DATA CARDS 254 TO N.  COLUMNS OF ARRAY D TO BE PAIRED.
C
      COMMON/1/D(200,13)
      COMMON/2/ARM(20,20),NZ,BR(20,1),MTS,DET
      DIMENSION L(51,101),Z(51),NR(7,101),ML(101)
      DATA(KM=1H*),(KB=1H ),(KI=1HI),(KS=1H-),(KP=1H.),(KPS=1H+)
      N=126
      NP1=N+1
      DO 100 I=1,NP1
  100 READ 300,(D(I,J),J=1,7)
      PRINT 203
      DO 101 I=1,N
      READ 302,(D(I,J),J=8,11)
      D(I,12)=SQRT(D(I,4)*D(I,4)+D(I,8)*D(I,8))
      D(I,13)=ATAN(D(I,8)/D(I,4))*57.296
  101 PRINT 303,(D(I,J),J=1,13)
  102 READ 201,IX,IY
      IF(EOF,60)125,103
  103 BX=D(1,IX)
      DO 106 I=1,N
      IF(D(I,IX).GT.BX)  BX=D(I,IX)
  106 CONTINUE
      SX=BX*0.01
      DO 107 I=1,101
      AI=I-1
      NX=SX*AI*10000.
      DO 107 J=1,7
      K=NX-(NX/10)*10
      NR(J,I)=K
  107 NX=NX/10
      BY=D(1,IY)
      DO 108 I=1,N
      IF(D(I,IY).GT.BY)  BY=D(I,IY)
  108 CONTINUE
      SY=BY*0.02
      Z(51)=0.
      DO 109 I=1,50
      AI=I
  109 Z(51-I)=SY*AI
```

```
      DO 110 I=1,51
      DO 110 J=1,101
  110 L(I,J)=KB
      DO 111 I=1,N
      IRR=D(I,IY)/SY+0.5
      IR=51-IRR
      JC=D(I,IX)/SX+1.5
  111 L(IR,JC)=KM
      X=0.  $  Y=0.  $  XY=0.  $  X2=0.  $  X2Y=0.  $  X3=0.  $  X4=0.
      D2=0.  $  D3=0.  $  Y2=0.
      DO 112 I=1,N
      DX=D(I,IX)
      DY=D(I,IY)
      D5=DY*DY
      D6=DX*DY
      D7=DX*DX
      D8=D6*DX
      D9=D7*DX
      D10=D9*DX
      X=X+DX
      Y=Y+DY
      XY=XY+D6
      X2=X2+D7
      Y2=Y2+D5
      X2Y=X2Y+D8
      X3=X3+D9
      X4=X4+D10
  112 CONTINUE
      AN=N
      Q=AN*X2-X*X
      A=(X2*Y-X*XY)/Q
      B=(AN*XY-X*Y)/Q
      DO 113 I=1,N
      YC=A+B*D(I,IX)
  113 D2=D2+(D(I,IY)-YC)**2
      SY=SQRT(D2/AN)
      ZY=SQRT(Y2/AN-(Y/AN)**2)
      COC=SQRT(1-SY*SY/(ZY*ZY))
      PRINT 200,IX,IY
      PRINT 209,A,B,SY,COC
      DO 116 J=1,101
      IF(NR(7,J).EQ.0)114,116
  114 NR(7,J)=8H
      IF(NR(6,J).EQ.0)115,116
  115 NR(6,J)=8H
  116 CONTINUE
      BR(1,1)=Y
      BR(2,1)=XY
      BR(3,1)=X2Y
```

```
      ARM(1,1)=AN
      ARM(1,2)=X
      ARM(1,3)=X2
      ARM(2,1)=X
      ARM(2,2)=X2
      ARM(2,3)=X3
      ARM(3,1)=X2
      ARM(3,2)=X3
      ARM(3,3)=X4
      NZ=3
      MTS=1
      CALL MATINV
      A=BR(1,1)
      B=BR(2,1)
      C=BR(3,1)
      DO 117 I=1,N
      YC=A+B*D(I,IX)+C*D(I,IX)*D(I,IX)
  117 D3=D3+(D(I,IY)-YC)**2
      SY=SQRT(D3/AN)
      RHO=SQRT(1-SY*SY/(ZY*ZY))
      PRINT 210,A,B,C,SY,RHO
  119 PRINT 203
      DO 120 I=1,51
  120 PRINT 202,Z(I),KI,(L(I,J),J=1,101),KI
      DO 121 I=1,101
  121 ML(I)=KS
      PRINT 205,KI,(ML(I),I=1,101),KI
      DO 122 I=1,4
  122 PRINT 206,(NR(I,J),J=1,101)
      DO 123 I=1,101
  123 ML(I)=KP
      PRINT 211,(ML(I),I=1,101)
      DO 124 I=5,7
  124 PRINT 206,(NR(I,J),J=1,101)
      GO TO 102
  125 CONTINUE
  200 FORMAT(*1*,4X,*COLUMNS*,I3,* AND*,I3,* OF THE ABOVE WERE USED*)
  201 FORMAT(2I2)
  202 FORMAT(F10.4,1X,103A1)
  203 FORMAT(*1*)
  205 FORMAT(11X,103A1)
  206 FORMAT(12X,101R1)
  209 FORMAT(*0*,10X,*Y = A + B X*// 6X,*WHERE   A=*,E17.9,//,14X,
     C      *B=*,E17.9,//,
     C      11X,*THE STANDARD ERROR OF ESTIMATE IS*,E17.9//
     C      11X,*THE COEFFICIENT OF CORRELATION IS*,E17.9)
  210 FORMAT(*0*,10X,*Y = A + B X + C X X*//6X,*WHERE   A=*,E17.9,//,
     C      14X,*B=*,E17.9,//,14X,*C=*,E17.9,//,
     C      11X,*THE STANDARD ERROR OF ESTIMATE IS*,E17.9//
     C      11X,*THE INDEX OF CORRELATION IS*,E17.9)
  211 FORMAT(12X,101A1)
  300 FORMAT(1X,3I3,4F15.5)
  302 FORMAT(10X,4F15.5)
  303 FORMAT(3X,3I3,10F12.5)
      END
```

A.5.a. Subprogram MATINV

MATINV was obtained from the Computer Library at Michigan State University. The CO-OP identification is Fl NBSB MATINV. Its title is "Matrix Inversion with Accompanying Solution of Linear Equations", written by Burton S. Garbow.

MATINV was used to determine the solution of the linear equation produced by program ANAL1.

```
      SUBROUTINE MATINV
C
C     F1 NBSB MATINV  MATRIX INVERSION
C     MATRIX INVERSION WITH ACCOMPANYING SOLUTION OF LINEAR EQUATIONS
C
      COMMON/2/A(20,20),N,B(20,1),M,DETERM
      DIMENSION IPIVOT(20),INDEX(20,2),PIVOT(20)
C
C     INITIALIZATION
C
   10 DETERM=1.0
   15 DO 20 J=1,N
   20 IPIVOT(J)=0
   30 DO 550 I=1,N
C
C     SEARCH FOR PIVOT ELEMENT
C
   40 AMAX=0.0
   45 DO 105 J=1,N
   50 IF (IPIVOT(J)-1) 60, 105, 60
   60 DO 100 K=1,N
   70 IF (IPIVOT(K)-1) 80, 100, 740
   80 IF (ABSF(AMAX)-ABSF(A(J,K))) 85, 100, 100
   85 IROW=J
   90 ICOLUM=K
   95 AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
  110 IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C
C     INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
C
  130 IF (IROW-ICOLUM) 140, 260, 140
  140 DETERM=-DETERM
  150 DO 200 L=1,N
```

```
  160 SWAP=A(IROW,L)
  170 A(IROW,L)=A(ICOLUM,L)
  200 A(ICOLUM,L)=SWAP
  205 IF(M) 260, 260, 210
  210 DO 250 L=1, M
  220 SWAP=B(IROW,L)
  230 B(IROW,L)=B(ICOLUM,L)
  250 B(ICOLUM,L)=SWAP
  260 INDEX(I,1)=IROW
  270 INDEX(I,2)=ICOLUM
  310 PIVOT(I)=A(ICOLUM,ICOLUM)
  320 DETERM=DETERM*PIVOT(I)
C
C     DIVIDE PIVOT ROW BY PIVOT ELEMENT
C
  330 A(ICOLUM,ICOLUM)=1.0
  340 DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
  355 IF(M) 380, 380, 360
  360 DO 370 L=1,M
  370 B(ICOLUM,L)=B(ICOLUM,L)/PIVOT(I)
C
C     REDUCE NON-PIVOT ROWS
C
  380 DO 550 L1=1,N
  390 IF(L1-ICOLUM) 400, 550, 400
  400 T=A(L1,ICOLUM)
  420 A(L1,ICOLUM)=0.0
  430 DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  455 IF(M) 550, 550, 460
  460 DO 500 L=1,M
  500 B(L1,L)=B(L1,L)-B(ICOLUM,L)*T
  550 CONTINUE
C
C     INTERCHANGE COLUMNS
C
  600 DO 710 I=1,N
  610 L=N+1-I
  620 IF (INDEX(L,1)-INDEX(L,2)) 630, 710, 630
  630 JROW=INDEX(L,1)
  640 JCOLUM=INDEX(L,2)
  650 DO 705 K=1,N
  660 SWAP=A(K,JROW)
  670 A(K,JROW)=A(K,JCOLUM)
  700 A(K,JCOLUM)=SWAP
  705 CONTINUE
  710 CONTINUE
  740 RETURN
  750 END
```

A.6. Program ANAL2

The function of program ANAL2 is explained in section 4.3.b.

```
      PROGRAM ANAL2
C
C     DATA CARDS 1 TO 253.  PUNCHED DATA AS RECEIVED FROM PROGRAM
C          TURB.  126 CARDS FOR EACH COMPONENT, SEPARATED BY A
C          BLANK CARD.
C     DATA CARDS 254 TO N.  COLUMN OF ARRAY D TO BE USED.
C
      COMMON/1/D(200,13)
      DIMENSION IM(6),IW(100),STG(100)
      DATA(IM=1H-,1HT,1HL,1HH,1H=,1H )
      N=126
      NP1=N+1
      DO 100 I=1,NP1
  100 READ 200,(D(I,J),J=1,7)
      PRINT 208
      DO 101 I=1,N
      READ 201,(D(I,J),J=8,11)
      D(I,12)=SQRT(D(I,4)*D(I,4)+D(I,8)*D(I,8))
      D(I,13)=ATAN(D(I,8)/D(I,4))*57.296
  101 PRINT 202,(D(I,J),J=1,13)
      NIW=18
  104 READ 207,ISET
      IF(EOF,60)113,105
  105 PRINT 208,ISET
      DO 111 IZ=1,2
      SM=+1.00E+300
      BG=-1.00E+300
      DO 106 I=1,N
      IF(D(I,ISET).EQ.0.)  GO TO 106
      IF(D(I,ISET).LT.SM)  SM=D(I,ISET)
      IF(D(I,ISET).GT.BG)  BG=D(I,ISET)
  106 CONTINUE
      STEP=(BG-SM)/5.
      PRINT 204
      IF=0
      K=0
  107 DO 108 I=1,NIW
      K=K+1
      IF(K.EQ.N)  IF=1
  108 STG(I)=D(K,ISET)
      DO 110 I=1,5
```

```
      IJ=I-1
      DO 109 J=1,NIW
      IW(J)=IM(6)
      IF(STG(J).GE.SM+STEP*IJ)  IW(J)=IM(I)
  109 CONTINUE
  110 PRINT 205,(IW(JJ),JJ=1,NIW)
      PRINT 206
      IF(IF.NE.1)  GO TO 107
      PRINT 204
      DO 111 I=1,N
      IF(D(I,ISET).GT.STEP)  D(I,ISET)=0.
  111 CONTINUE
      GO TO 104
  113 CONTINUE
  200 FORMAT(1X,3I3,4F15.5)
  201 FORMAT(10X,4F15.5)
  202 FORMAT(3X,3I3,10F12.5)
  203 FORMAT(2I10)
  204 FORMAT(*-*)
  205 FORMAT(*+*,10X,100A1)
  206 FORMAT(* *)
  207 FORMAT(I2)
  208 FORMAT(*1*,4X,*COLUMN*,I3,* OF THE ABOVE WAS USED*2(/))
      END
```

A.7. Program TURB Output

For each of the two tabulations the following key will be used:

I - row position in which sample was taken

J - column position in which sample was taken

K - layer position in which sample was taken

A - mean velocities (FPM)

B - variance of mean velocities

C - turbulent intensity

D - dispersion factor

A.7.a. Horizontal Component

I	J	K	A	B	C	D
1	1	1	103.16799	2865.61671	0.51888	7.76830
1	2	1	81.38393	1318.69226	0.44620	6.55796
1	3	1	105.73176	1264.52801	0.33632	7.51664
1	4	1	69.09943	782.76204	0.40489	2.66035
1	5	1	84.56966	314.40131	0.20967	2.36208
1	6	1	57.77905	324.69438	0.31187	3.58720
1	7	1	47.91953	157.69940	0.26206	1.02215
1	8	1	47.89539	152.87151	0.25815	0.92225
1	9	1	39.46102	127.80799	0.28649	0.96937
1	10	1	43.21369	75.13250	0.20058	0.56877
1	11	1	13.76886	10.35076	0.23366	0.07909
1	12	1	21.58245	13.21400	0.16843	0.10720
1	13	1	38.88841	28.95535	0.13837	0.44699
1	14	1	4.61190	1.09328	0.22672	0.00680
1	15	1	2.33742	0.27517	0.22442	0.00199
1	16	1	21.45046	1.38033	0.05477	0.04563
1	17	1	13.59832	0.45352	0.04952	0.01988
1	18	1	0.36946	0.00583	0.20664	0.00006
2	1	1	0.09242	0.00046	0.23263	0.00000
2	2	1	1.59814	0.75546	0.54386	0.00149
2	3	1	23.03937	148.16834	0.52833	0.50105
2	4	1	22.76979	110.14264	0.46091	0.44088
2	5	1	49.81214	522.12541	0.45872	2.07107
2	6	1	33.26733	283.07316	0.50574	0.86896
2	7	1	33.20042	299.03021	0.52085	1.19944
2	8	1	32.38358	165.93026	0.39778	0.68546
2	9	1	32.31534	157.70653	0.38861	0.79400
2	10	1	32.27799	147.80006	0.37664	0.73600
2	11	1	31.52786	48.70920	0.22137	0.33868
2	12	1	31.27795	15.88211	0.12741	0.24003
2	13	1	31.61639	63.19010	0.25143	0.33491
2	14	1	13.68789	5.47917	0.17101	0.04565
2	15	1	13.70143	5.75899	0.17515	0.06639
2	16	1	18.70706	6.94874	0.14091	0.10638
2	17	1	1.47700	0.02815	0.11360	0.00036
2	18	1	13.65626	3.73322	0.14148	0.03821
3	1	1	0.09116	0.00000	0.00000	0.00000
3	2	1	1.47287	0.00278	0.03578	0.00009
3	3	1	4.55221	0.00000	0.00000	0.00000
3	4	1	4.55231	0.00185	0.00946	0.00025
3	5	1	3.35131	0.21745	0.13914	0.00270
3	6	1	13.67968	5.13755	0.16569	0.04345
3	7	1	11.71780	14.89947	0.32941	0.10284
3	8	1	19.17067	37.94895	0.32134	0.24066
3	9	1	35.66828	133.43355	0.32385	0.83819

3	10	1	32.10888	124.14436	0.34701	0.77291
3	11	1	24.97369	50.27442	0.28392	0.25971
3	12	1	35.20492	53.05541	0.20690	0.47919
3	13	1	21.54057	9.06827	0.13980	0.11318
3	14	1	24.58980	12.56912	0.14418	0.12262
3	15	1	24.50881	4.60498	0.08756	0.08444
3	16	1	3.35194	0.25229	0.14985	0.00362
3	17	1	5.98479	0.48562	0.11644	0.00646
3	18	1	9.40898	1.11922	0.11244	0.02437
4	1	1	2.30815	0.00213	0.02000	0.00010
4	2	1	5.96522	0.01660	0.02160	0.00082
4	3	1	7.57267	0.00000	0.00000	0.00000
4	4	1	2.30807	0.00138	0.01608	0.00030
4	5	1	2.30824	0.00299	0.02368	0.00019
4	6	1	2.30796	0.00041	0.00878	0.00008
4	7	1	2.30929	0.01236	0.04814	0.00040
4	8	1	4.55444	0.03988	0.04385	0.00183
4	9	1	5.96774	0.07401	0.04559	0.00197
4	10	1	4.57825	0.47786	0.15099	0.00598
4	11	1	5.98331	0.44321	0.11127	0.00946
4	12	1	4.57999	0.49117	0.15302	0.00588
4	13	1	9.43739	2.15975	0.15572	0.02057
4	14	1	9.44160	2.26173	0.15928	0.02205
4	15	1	4.62494	1.31321	0.24778	0.01056
4	16	1	13.60069	0.59162	0.05655	0.01941
4	17	1	27.71255	1.00784	0.03623	0.04701
4	18	1	27.71497	1.27510	0.04074	0.05811
5	1	1	1.47250	0.00062	0.01696	0.00005
5	2	1	0.82571	0.00034	0.02226	0.00003
5	3	1	1.47248	0.00048	0.01488	0.00006
5	4	1	3.33401	0.00108	0.00987	0.00020
5	5	1	2.30800	0.00078	0.01213	0.00007
5	6	1	2.30815	0.00213	0.02000	0.00018
5	7	1	2.30899	0.00980	0.04287	0.00058
5	8	1	4.55314	0.01722	0.02882	0.00097
5	9	1	7.57318	0.01540	0.01638	0.00168
5	10	1	2.30915	0.01149	0.04642	0.00047
5	11	1	4.55246	0.00469	0.01504	0.00085
5	12	1	3.33756	0.04849	0.06598	0.00163
5	13	1	4.55800	0.10801	0.07210	0.00199
5	14	1	4.55414	0.03536	0.04129	0.00201
5	15	1	2.31841	0.09471	0.13274	0.00087
5	16	1	1.47698	0.02689	0.11102	0.00029
5	17	1	9.37939	0.03596	0.02022	0.00324
5	18	1	9.37995	0.05670	0.02539	0.00435

6	1	1	3.33393	0.00000	0.00000	0.00000
6	2	1	2.30797	0.00045	0.00918	0.00008
6	3	1	1.47240	0.00000	0.00000	0.00000
6	4	1	0.09138	0.00008	0.09991	0.00000
6	5	1	4.55226	0.00091	0.00662	0.00035
6	6	1	13.59014	0.00811	0.00663	0.00241
6	7	1	2.30818	0.00245	0.02142	0.00022
6	8	1	9.37925	0.03070	0.01868	0.00242
6	9	1	4.55399	0.03172	0.03911	0.00145
6	10	1	7.57477	0.06288	0.03310	0.00325
6	11	1	3.34265	0.11679	0.10224	0.00220
6	12	1	0.83661	0.03572	0.22590	0.00036
6	13	1	2.30815	0.00217	0.02018	0.00026
6	14	1	3.33424	0.00417	0.01936	0.00036
6	15	1	1.47325	0.00501	0.04805	0.00018
6	16	1	5.96899	0.10619	0.05459	0.00412
6	17	1	2.30833	0.00389	0.02700	0.00023
6	18	1	1.47266	0.00153	0.02657	0.00015
7	1	1	2.30792	0.00000	0.00000	0.00000
7	2	1	3.33393	0.00000	0.00000	0.00000
7	3	1	1.47240	0.00000	0.00000	0.00000
7	4	1	0.36578	0.00000	0.00000	0.00000
7	5	1	0.82561	0.00000	0.00000	0.00000
7	6	1	1.47269	0.00172	0.02820	0.00013
7	7	1	7.57316	0.01481	0.01607	0.00180
7	8	1	18.61395	0.02608	0.00868	0.00237
7	9	1	16.00132	0.12435	0.02204	0.01510
7	10	1	13.60836	1.00308	0.07360	0.03270
7	11	1	2.31419	0.05979	0.10566	0.00087
7	12	1	4.55379	0.02880	0.03727	0.00157
7	13	1	3.33501	0.01435	0.03592	0.00072
7	14	1	5.96501	0.01151	0.01799	0.00184
7	15	1	0.36687	0.00165	0.11068	0.00004
7	16	1	4.55237	0.00294	0.01190	0.00055
7	17	1	4.55567	0.06236	0.05481	0.00205
7	18	1	4.55396	0.03136	0.03889	0.00179

A.7.b. Vertical Component

I	J	K	A	B	C	D
1	1	1	28.50664	91.24353	0.33508	0.28082
1	2	1	28.28282	62.34143	0.27917	0.35651
1	3	1	22.03529	49.56181	0.31949	0.22612
1	4	1	13.84533	13.15841	0.26200	0.07258
1	5	1	13.90525	16.35394	0.29083	0.07662
1	6	1	11.43297	2.19728	0.12965	0.02434
1	7	1	11.47599	4.22947	0.17921	0.04174
1	8	1	11.45011	3.00362	0.15136	0.02737
1	9	1	11.44509	2.80231	0.14626	0.02162
1	10	1	11.45582	3.19941	0.15614	0.03126
1	11	1	9.40686	1.02929	0.10785	0.01171
1	12	1	7.59383	0.61265	0.10307	0.00757
1	13	1	1.47500	0.01503	0.08311	0.00030
1	14	1	5.97182	0.17207	0.06946	0.00485
1	15	1	1.48956	0.11138	0.22405	0.00090
1	16	1	1.47280	0.00234	0.03285	0.00014
1	17	1	4.55265	0.00809	0.01976	0.00071
1	18	1	5.97081	0.15120	0.06512	0.01747
2	1	1	0.36614	0.00054	0.06323	0.00001
2	2	1	0.37707	0.01586	0.33399	0.00007
2	3	1	4.61015	0.97744	0.21445	0.00591
2	4	1	5.99411	0.71348	0.14092	0.00838
2	5	1	9.73475	13.50344	0.37748	0.03842
2	6	1	9.50255	4.54554	0.22436	0.02682
2	7	1	13.93578	19.10922	0.31368	0.10298
2	8	1	11.60246	7.68699	0.23896	0.04817
2	9	1	13.64184	2.80282	0.12272	0.03164
2	10	1	16.03217	2.02289	0.08871	0.03650
2	11	1	16.02910	1.89115	0.08579	0.03778
2	12	1	16.04862	3.10567	0.10981	0.03610
2	13	1	11.39649	0.57208	0.06637	0.01395
2	14	1	7.58044	0.22847	0.06306	0.00716
2	15	1	2.31504	0.06800	0.11264	0.00301
2	16	1	3.33568	0.02297	0.04543	0.00078
2	17	1	9.38686	0.31287	0.05959	0.02958
2	18	1	5.96651	0.04704	0.03635	0.00168
3	1	1	0.09116	0.00000	0.00000	0.00000
3	2	1	0.82561	0.00000	0.00000	0.00000
3	3	1	0.82561	0.00000	0.00000	0.00000
3	4	1	0.82568	0.00024	0.01892	0.00001
3	5	1	0.82761	0.00607	0.09417	0.00010
3	6	1	0.83310	0.02188	0.17755	0.00021
3	7	1	2.37969	0.59699	0.32469	0.00335
3	8	1	2.31233	0.03946	0.08590	0.00068
3	9	1	2.32124	0.12099	0.14985	0.00116

3	10	1	2.31852	0.09824	0.13519	0.00140
3	11	1	4.56220	0.18033	0.09308	0.00254
3	12	1	2.31109	0.02962	0.07447	0.00067
3	13	1	2.31415	0.07462	0.11804	0.00049
3	14	1	1.47338	0.00580	0.05170	0.00025
3	15	1	0.36585	0.00010	0.02746	0.00001
3	16	1	0.37004	0.00613	0.21153	0.00006
3	17	1	1.49183	0.11414	0.22646	0.00077
3	18	1	0.36675	0.00142	0.10262	0.00003
4	1	1	0.82561	0.00000	0.00000	0.00000
4	2	1	0.82561	0.00000	0.00000	0.00000
4	3	1	0.36585	0.00011	0.02865	0.00001
4	4	1	0.36584	0.00010	0.02702	0.00001
4	5	1	0.36578	0.00001	0.00795	0.00000
4	6	1	0.82573	0.00040	0.02424	0.00003
4	7	1	0.82568	0.00025	0.01909	0.00003
4	8	1	0.82585	0.00083	0.03478	0.00003
4	9	1	0.82602	0.00134	0.04432	0.00005
4	10	1	0.82785	0.00745	0.10427	0.00012
4	11	1	0.82671	0.00366	0.07317	0.00018
4	12	1	0.82638	0.00254	0.06104	0.00010
4	13	1	0.82628	0.00224	0.05730	0.00008
4	14	1	0.83718	0.03793	0.23262	0.00035
4	15	1	0.82572	0.00039	0.02383	0.00003
4	16	1	2.30851	0.00545	0.03198	0.00032
4	17	1	2.31004	0.01852	0.05891	0.00041
4	18	1	2.30868	0.00694	0.03609	0.00036
5	1	1	0.09116	0.00000	0.00000	0.00000
5	2	1	0.09116	0.00000	0.00000	0.00000
5	3	1	0.09116	0.00000	0.00000	0.00000
5	4	1	0.09123	0.00003	0.05548	0.00000
5	5	1	0.09139	0.00009	0.10182	0.00000
5	6	1	0.82588	0.00093	0.03695	0.00005
5	7	1	0.82601	0.00134	0.04430	0.00007
5	8	1	0.82580	0.00062	0.03025	0.00005
5	9	1	0.82581	0.00067	0.03127	0.00005
5	10	1	1.47319	0.00468	0.04645	0.00013
5	11	1	1.47511	0.01644	0.08693	0.00023
5	12	1	0.82636	0.00250	0.06049	0.00010
5	13	1	4.55355	0.02453	0.03439	0.00107
5	14	1	0.82606	0.00152	0.04716	0.00006
5	15	1	2.30873	0.00763	0.03784	0.00045
5	16	1	2.30968	0.01644	0.05552	0.00065
5	17	1	2.30940	0.01389	0.05103	0.00044
5	18	1	2.30826	0.00310	0.02413	0.00023

6	1	1	0.36578	0.00000	0.00000	0.00000
6	2	1	0.36578	0.00000	0.00000	0.00000
6	3	1	0.09116	0.00000	0.00000	0.00000
6	4	1	0.36586	0.00011	0.02897	0.00001
6	5	1	0.82570	0.00032	0.02168	0.00001
6	6	1	0.82569	0.00027	0.02004	0.00002
6	7	1	0.82561	0.00000	0.00000	0.00000
6	8	1	0.82569	0.00029	0.02052	0.00002
6	9	1	0.82638	0.00234	0.05853	0.00005
6	10	1	0.82561	0.00000	0.00000	0.00000
6	11	1	0.82745	0.00614	0.09467	0.00012
6	12	1	0.82569	0.00029	0.02063	0.00002
6	13	1	0.82629	0.00219	0.05665	0.00008
6	14	1	0.82601	0.00138	0.04489	0.00004
6	15	1	0.82734	0.00549	0.08953	0.00010
6	16	1	0.09169	0.00018	0.14767	0.00000
6	17	1	3.33515	0.01626	0.03824	0.00110
6	18	1	3.33527	0.01822	0.04047	0.00059
7	1	1	2.30792	0.00000	0.00000	0.00000
7	2	1	0.09116	0.00000	0.00000	0.00000
7	3	1	0.09116	0.00000	0.00000	0.00000
7	4	1	0.36585	0.00010	0.02727	0.00002
7	5	1	0.36583	0.00007	0.02348	0.00002
7	6	1	0.36583	0.00007	0.02298	0.00001
7	7	1	0.36586	0.00012	0.03055	0.00001
7	8	1	0.36586	0.00012	0.03019	0.00001
7	9	1	4.55232	0.00202	0.00986	0.00027
7	10	1	2.31033	0.02352	0.06638	0.00047
7	11	1	3.33429	0.00491	0.02102	0.00029
7	12	1	1.47273	0.00200	0.03035	0.00012
7	13	1	1.47279	0.00231	0.03260	0.00010
7	14	1	1.47243	0.00020	0.00969	0.00003
7	15	1	1.47269	0.00176	0.02850	0.00013
7	16	1	1.47242	0.00010	0.00667	0.00001
7	17	1	2.30852	0.00562	0.03247	0.00021
7	18	1	0.82569	0.00029	0.02064	0.00002

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