A COMPUTER PROGRAM FOR AN EQUATION OF WIND VELOCITY PROFILES FROM ZERO TO THIRTY FEET

by

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INTRODUCTION

The news media and educational facilities of today have made the general public very much aware of the destructive forces of nature. One of these forces is natural wind in the form of hurricanes, tornadoes, and heavy gusts. Each year millions of dollars of damage occurs to man-made structures as a result of high velocities and the turbulent character of the wind.

Davenport (1)* points out that in the past structural design was based on the traditional static, quasisteady approach with the design velocity being the maximum gust speed recorded with some instrument. Safe structures have been built and offer no serious danger at present as long as a generous safety factor is used. The hazard lies in what may occur should either the safety factor be changed or a radical or experimential change in design or material be employed.

Most structures are built in what is considered the lower level of the earth's atmosphere. Research in the turbulence of this lower atmosphere has intensified in recent years due to the interest in space (13). Missiles and high speed aircraft can be severely affected by turbulent motion near the earth's surface. This intensified research is also reflected in the field of structural research where the relationship between the properties of natural wind and their effects on the structure are being studied with the anticipation that a refined design procedure will be forthcoming.

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*Numbers in parenthesis refer to appended references.

A research project involving the measurement of the pressure developed by wind on the surfaces of a prototype building is being conducted by the Agricultural Engineering Department, Virginia Polytechnic Institute, Blacksburg, Virginia. The measurement of the surface pressures has yielded and is expected to continue to yield useful information about the distribution of the pressures over low-profile buildings such as those used in agricultural enterprises. A wind velocity and direction are recorded simultaneously with the surface pressures, but no additional wind properties or characteristics are being taken. If a better description of the impinging wind could be obtained, a correlation between the wind and the distribution of the surface pressures would be valuable in the study.

A significant property of the natural wind structure is the vertical velocity profile (horizontal wind velocity observed in a vertical plane parallel to the wind direction). Extensive studies of the velocity profile of the wind have been made from the ground to the stratosphere, but investigators have concentrated on the winds above thirty feet. It has been from the studies in excess of thirty feet that the most recent concepts for deriving design velocities have been obtained. A velocity profile of the wind approaching the prototype building would allow a correlation between the actual nature and structure of the wind striking the building during a particular windy period and the distribution of the wind-produced pressures. This would provide information as to the aerodynamic response of the building to the varying wind conditions. Since most of the data on velocity profiles have been taken above thirty feet, a need for more basic data is necessary in the lower thirty feet of the earth's atmosphere.

The cost of conducting research becomes more and more expensive with increases in salaries for personnel and the cost of equipment. This cost makes it necessary for the researcher to obtain his desired results in a short period of time. One way of meeting this objective is through the use of automatic data compiling equipment and computers for analyzing the data. Wind profile data contain many variations of velocities over a short period of time and the manual process of extracting these data from charts and performing the necessary computations will be both time consuming and tiring. A computer program which could be used in the study of wind velocity profiles would be a useful tool in the wind study project being conducted by the Agricultural Engineering Department at V.P.I.

In this investigation, an attempt was made to obtain data adequate for the determination of a thirty-foot velocity profile. A computer program was written to process the data, to analyze it statistically, and to read-out an equation for the profile with multiple regression coefficients stated. The program developed was based on velocity data for 30-second periods, but the program is arranged such that if a more detailed analysis of the statistical properties of the velocity data indicates a change of time interval, or any other parameter, then the program can be easily modified.

REVIEW OF LITERATURE

Years of research have been devoted to the understanding of the structure and nature of wind and to the development of theories which can be applied to the design of buildings and other structures. Davenport (1) pointed out that in the mid-eighteenth century John Smeaton fashioned the profile of the Eddystone lighthouse after that of the stoutest oak tree he could find in the belief that nature had developed in this tree a good shape for resisting the onslaught of the wind. Today's structures are built in many shapes and of many different materials and they too must withstand the onslaught of natural wind.

Validity of Model Tests

Structures of many types, such as airplanes, have been tested as models in wind tunnels and the results applied to prototypes with satisfactory results. Davenport (2) in his extensive review of literature on wind loads as applied to buildings came to the conclusion that the results obtained from model buildings tested in wind tunnels and those obtained from the prototype in natural wind were dissimilar due to the variations of the natural wind. Davenport points out that investigations by Stanton showed that although the general form of the pressure was similar between the model and the prototype, that there is up to fifty per cent reduction of pressure on the leeward side of a full-scale building as would be estimated from the model test. It was also shown in a comparison of pressures on the prototype and its wind tunnel model of the Empire State Building (10) that natural wind movements are not at all like those in a wind tunnel.

Although such investigations as those mentioned are few, Davenport (2) noted that practical application has been met by certain assumptions such as: (a) the differences of pressures between prototype structures and their models tested in steady flow are due to turbulence in natural wind which is not significant; and (b) that the increase of velocity with height, which is not normally simulated in the wind tunnel, can be accounted for by an increase of pressure with height on the full-scale structure proportional to the increase in velocity pressure. Experimental evidence indicates that small scale turbulence may have a significant effect on the shape factor describing the distribution of pressure on a structure and that the pressure increase with height on a structure is not simply related to an increase of velocity pressure. Davenport (2) states that it is remarkable that such important factors as those above, upon which the validity of the results of model tests must depend, have received so little attention.

Jensen (8) in his paper on "The Model-Law Phenomena in Natural Wind" arrived at the same conclusions as those made by Davenport and others. Jensen points out that investigations made on models in the past are misleading and the reason the results from these investigations have been accepted for such a long period of time is because they have never been checked by full-scale tests in nature. Jensen stated that the correct model test with phenomena in the wind must be carried out in a turbulent boundary layer and the model-law requires that this boundary layer be to scale as related to the velocity profile. He pointed out that in practically all the model tests that have been carried out in the past the investigators made it a point to keep the model out of the turbulent layer of the air stream.

Jensen relied on the roughness of the surface as the determining factor affecting his velocity profiles although he noted that thermal conditions also produce an effect on velocity profiles. To achieve a similar velocity profile in his model tests, Jensen prepared the tunnel surface to represent the roughness of the surface where the prototype was located. His results between the model and the prototype were very similar as compared to the test where no attempt was made to simulate the surface roughness.

The Atmosphere

Davenport (2) in a review of literature discussed the structure of natural wind. He points out that winds are caused by the atmospheric pressure differentials which arise over the surface of the earth due to differences in the amount of heat that is received from the sun. Acceleration produced by these differentials is affected by another component of acceleration caused by the rotation of the earth. If a parcel of air is moving in the northern hemisphere, it will experience a force to the right of the direction of the wind and proportional to the speed of motion. This force is called a coriolis force. When there is no surface friction affecting the wind and the coriolis forces are just in equilibrium with the force due to the pressure differential, the wind has reached a steady state condition. During this steady state condition, the wind will flow parallel to the isobars (lines of equal barometric pressure). The above conditions are usually satisfied above

1000 or 1500 feet and the velocity of this gradient wind is called the gradient velocity.

Winds below this gradient wind are retarded by frictional forces and obstructions at the earth's surface. Viscous forces are transmitted upward by this turbulence and the wind direction is no longer parallel to the isobars. Since man-made structures are located in this lower turbulent layer, the understanding of wind behavior in this region is important.

Velocity Profile of Natural Wind

The power law. A most important factor to be considered in determining a design wind velocity is the increase of wind velocity with height. Various formulas have been derived in order to calculate the velocity at a particular height. One which has been used for structural design is the exponential profile or power law formula. This law can be stated as:

$$V_z = KZ^{1/\alpha}$$

where: V_z = velocity at height Z,

K = constant,

α = constant.

This law is only applicable from the surface to the layer where the gradient velocity is first obtained.

Davenport (2) found that there were three exponents generally accepted for the power law and they were governed according to the roughness of the surface. For open country, flat coastal belts, and small islands located in large bodies of water $\alpha = 7$; for wooded countrysides, parklands, towns, and outskirts of large cities $\alpha = 3.5$; and for centers of large cities $\alpha = 2.5$.

The constant K in the power law is defined as:

$$K = V_g \left(\frac{1}{Z_g} \right)^{1/\alpha},$$

where: V_g = gradient velocity at height Z_g,

α = constant.

The generally accepted values for height Z_g are also governed by the surface roughness. For flat open country Z_g = 1300 ft.; and for centers of large cities Z_g = 1700 ft.

Ekman's spiral. Another formula which has been used in explaining velocity variation with height was derived by V. W. Ekman in 1905. In Sherlock's (11) discussion of the Ekman spiral, he points out that the theory developed by Ekman originally applied to ocean drift, but by inverting the system of coordinates it is possible to find the resulting movements within a body of air relative to which the underlying water, or land, is apparently moving. The relation between the wind velocity and height in this system is represented graphically by a logarithmic spiral when the velocity vectors are projected onto a plane surface. The Ekman spiral has been used mainly in determining velocity profiles above thirty feet, but could also apply to profiles in the lower thirty feet of the earth's atmosphere.

Halstead's formula. Halstead (5) developed a formula which included both the power law and the logarithmic law. The logarithmic law being:

$$V = a \log h + b,$$

where: V = velocity at height h,

a = constant,

b = constant.

The constants a and b are not universal constants, but only for a given time and place. They are also numerically dependent on the units employed (7). In order to use the logarithmic law, one must have simultaneous velocities of the wind at two appreciably different heights so that the current values of a and b can be determined.

Halstead's objective was to develop an expression for velocity at a particular height without using surface parameters. His final equation was:

$$V = \left(\frac{\tau_o}{a_m} - \frac{b_m A_{mo}}{a^2_m} \right) \ln \left(\frac{a_m}{A_{m_o}} Z + 1 \right) + \frac{b_m}{a_m} Z,$$

where: V = velocity at height Z,

τ_o = shear stress at $Z = 0$,

$b_m = \frac{d\tau}{dZ}$,

A_{m_o} = turbulent exchange coefficient in terms of vertical velocity gradient $\frac{dV}{dZ}$

$a_m = \frac{dA_m}{dZ}$.

Halstead checked his equation using a wide variety of data and found it to be reliable in the very low layers of the earth's atmosphere. He also found that it was very unreliable above 100 meters. It may be that this equation would also be applicable to investigations below thirty feet.

Factors Affecting Velocity Profile

The review of literature by Davenport (2) and the work of others has shown that the velocity profile will change due to the different types of surface roughness, and also that the change will be influenced by local disturbances.

Thunderstorms and frontal squalls are extremely unstable and consequently the increase of mean velocity with height is small. That is to say that due to the intense mixing of the atmospheric layers, the velocity at 500 feet may only be slightly higher than the velocity at 50 feet or even at 20 feet. During this unstable condition, surface roughness has almost no effect on the velocity profile. In contrast to this, large-scale mature storms exhibit nearly neutral stability. Here the dominating influence on the velocity profile is surface roughness and not stability.

Sutton (14) points out that a question of great interest is the type of variation which a velocity profile shows with the temperature gradient. Through experimental data it has been shown that using the power law in relation to temperature instead of surface roughness, that the exponent ranged from 0.01 in high lapse rates to 0.62 in large inversions. Lapse rate is the condition when the sun has warmed the surface of the earth and there is a decrease of temperature with height. During this period there is turbulence in the atmosphere due to the rising of the less dense warm air. The peak of this condition has been found to occur around the noon hours. The condition of inversion occurs in the late afternoon, night, and early morning. During these time periods the earth gives up its heat through long wave radiation to the atmosphere and the surface layers of air become cool. In this condition there is an increase of temperature with height and due to the fact that the dense, cold air is near the surface there is little if any turbulence in the atmosphere. Sutton (16) noted that Thornthwaite and Kaser found that during a 24-hour period in the summer, velocity profiles were concave during lapse periods and convex during inversion periods.

It can be seen from the above statements that the location of the sensing instrument or a change in wind direction will have a large effect on the profile unless the recording site is a level and smooth surface that extends for a long distance in all directions. Jensen (8) found this to be true in his investigations of the model-law phenomena in natural wind. He found a change in velocity profile caused by surface roughness would be reflected in the pressure distribution on a building. He also noted that a change caused by thermal conditions would be reflected in the pressure distribution.

Wind Velocity Analysis

Due to the turbulence near the earth's surface rapid fluctuations occur over a wide range of frequencies and amplitudes; therefore, the velocities in these lower levels are most useful when expressed in terms of mean speed and deviations from the mean speed (15). That is to say, that in order to use wind velocity in the design of structures, it is necessary to find a mean value for velocity because of the many variations in frequencies and amplitudes over a very short period of time.

Sutton (14) and Singer (13) show that it is extremely difficult, if not impossible, to formulate anything except statistical laws for the irregular wind velocities. They point out that concepts pertaining to the random processes have been successfully applied to the statistical properties of wind fluctuations.

Panofsky and Brier (9) point out that a spectrum analysis can be used to indicate the time interval over which winds should be averaged in order to obtain stable values, and also, that the response time required of wind sensing instruments can be determined by this approach. Spectrum analysis can locate the general shape of a spectral curve, but cannot pinpoint particular cycles.

Davenport (1) found that although Ludlam and Scorer state that for many applications it is sufficient to know the average wind speed during a day or an hour, it is necessary to know the mean velocity during the peak of a storm for structural design. Davenport (2) also points out that the time or distance interval used in averaging mean velocities depends upon the purpose for which the velocity is required.

Velocity Sensors

Sensors used in obtaining wind velocity data vary depending on the accuracy required for the intended use of the data. Sherlock and Stout (12) in 1932 used a nine by eight inch pressure plate anemometer in their efforts to obtain a profile picture of the wind.

The standard three cup anemometer is used by most weather stations throughout the country. This sensor gives a mean average velocity over a relatively long period of time (7).

The pitot tube has been used for many years as a means of obtaining the velocities of fluids. It has been used in obtaining the fluid flow in pipes, air speed of aircraft, and variation of wind velocity. The pitot tube is capable of giving an accurate reading within $\pm$ 15 or 20 degrees variation of the direction of flow.(6).

Hot-wire anemometers have been used by researchers as a velocity sensing device in the measuring of very low velocities as well as high velocities. It is a very accurate sensor of small changes due to its electrical connections (7).

A report given at John Hopkins by Frenkiel (3) described the IMFL* anemoclinometer and the possibilities it has in the investigation of atmosphere turbulence. This sensor, which is spherical in shape, can give both velocity magnitude and velocity direction. It has been applied to some aerodynamic and meteorological investigations and has been found to be very easy to use in the field. This sensor, or a similar sensor, might be applicable to an investigation involving the rotational properties of gusts.

*IMFL stands for Institut de Micanique des Fluides de Lille.

O B J E C T I V E S

The objectives of this investigation are twofold:

1. To measure wind velocities at four intervals between zero and thirty feet above the earth's surface, and
2. To develop a computer program for velocity profiles through the analysis of random wind velocities in the lower thirty feet of the earth's atmosphere.

THE INVESTIGATION

Scope

Wind velocity pressure was measured in the lower thirty feet of the earth's atmosphere by means of pitot tubes mounted at four intervals along a thirty-foot mast. The velocity pressures sensed by these pitot tubes were transformed into electrical signals by pressure transducers. These signals were recorded instantaneously by an oscillograph. These pressure data were then converted into velocity in miles per hour by mathematical computer computations, and then analyzed statistically through a computer program, yielding coefficients for the power law equation for a vertical velocity profile.

Apparatus

Thirty-foot mast. The mast used in this investigation is shown in Figure 1. The mast was a thirty-foot television antenna mast anchored to a four-foot-square concrete foundation located fifty feet from the full-scale wind study building. Four thirty-seven inch Teltru pitot tubes (manufactured and distributed by E. Veron Hill and Co.) were mounted on the mast at intervals of eight feet (Figure 2). The bottom pitot tube was located five feet eleven inches above the ground. A Temperature Compensated Pressure Transducer (model No. PM5TC$\pm$0.3-350, pressure range $\pm$0.3 psid, manufactured by Statham Instruments, Inc.) was mounted on the mast at each pitot tube station and connected to the pitot tube by a five-inch piece of plastic tubing (Figure 2). The pitot tubes were directed into the wind during each

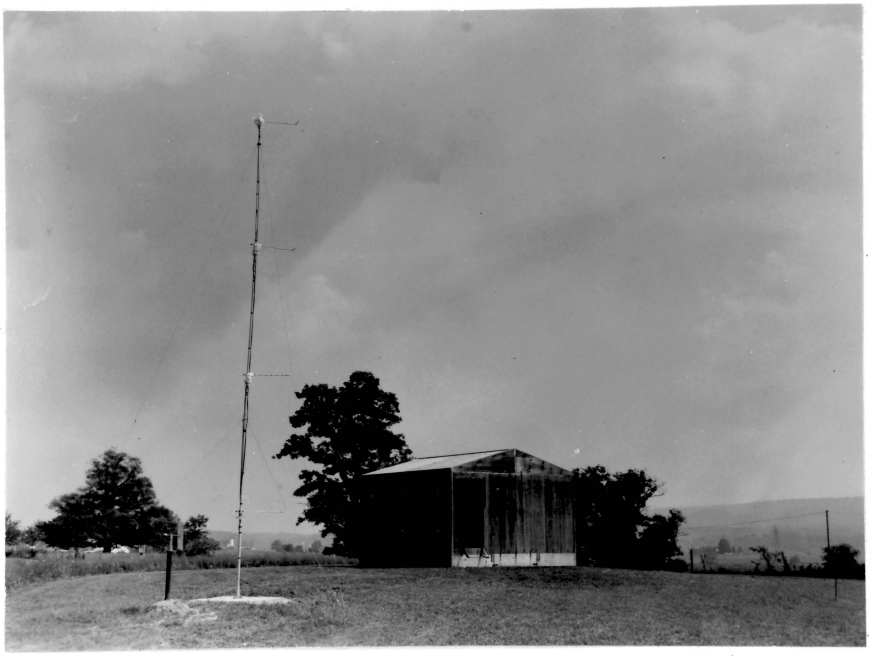

Figure 1. The thirty-foot mast with mounted pitot tubes and transducers. The wind study prototype building is shown in the background. Recording instruments were located in this building.

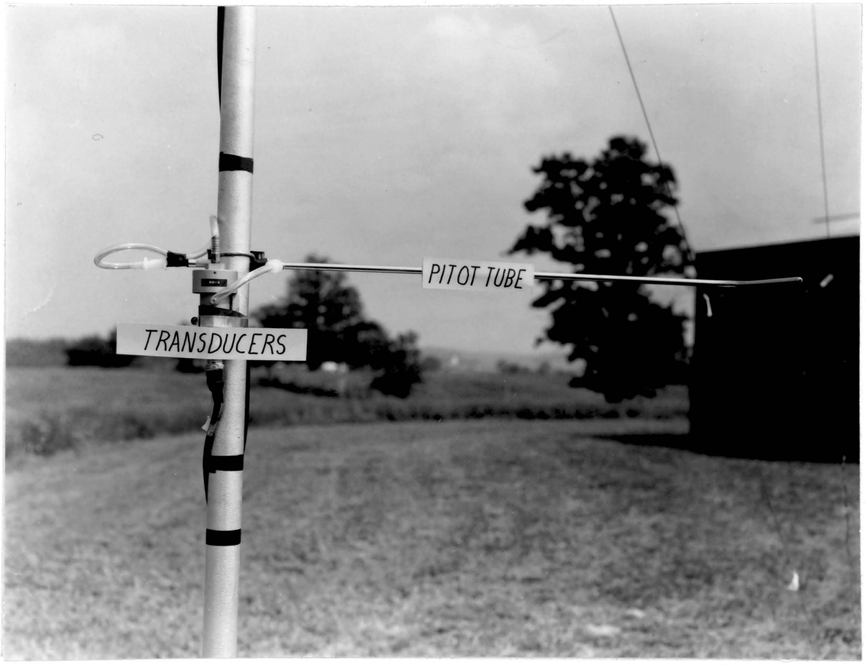

Figure 2. Teltru pitot tube and Temperature Compensated Pressure Transducer mounted on the thirty-foot mast shown in Figure 1.

recording period by loosening a set-screw at the base of the mast and rotating the mast manually.

The original mast used in this investigation is shown in Figure 3. This mast was fourteen feet in height and rotated by means of a wind vane mounted near the top. Pitot tube stations were located at intervals of four feet with the bottom station being two feet above the ground. Data obtained from these stations were found not to be suitable for statistical analysis. It was believed that the unsuitable data were due to the small intervals between the stations and that an extension of these intervals would give a more accurate indication of the velocity variation with height.

Recording equipment. The recording equipment used in this investigation was located in the prototype building and is shown in Figure 4. Each transducer mounted on the mast was connected to a balance control (Honeywell) which in turn was connected to an Accudata 104 D-C Amplifier (Honeywell) by means of an electrical cable. Each amplifier was connected to a Honeywell model M1650 Subminiature galvanometer channel in a Honeywell model 1508 Visicorder oscillograph. The Visicorder recorded the velocity pressure fluctuations at each station simultaneously on No. 200333, eight-inch Honeywell photo-sensitive recording paper.

Temperature was recorded from a shielded thermometer mounted at the bottom station of the mast.

Barometric pressure readings were taken from a No. 5070 Eberbach Mercurial Barometer located inside the prototype structure.

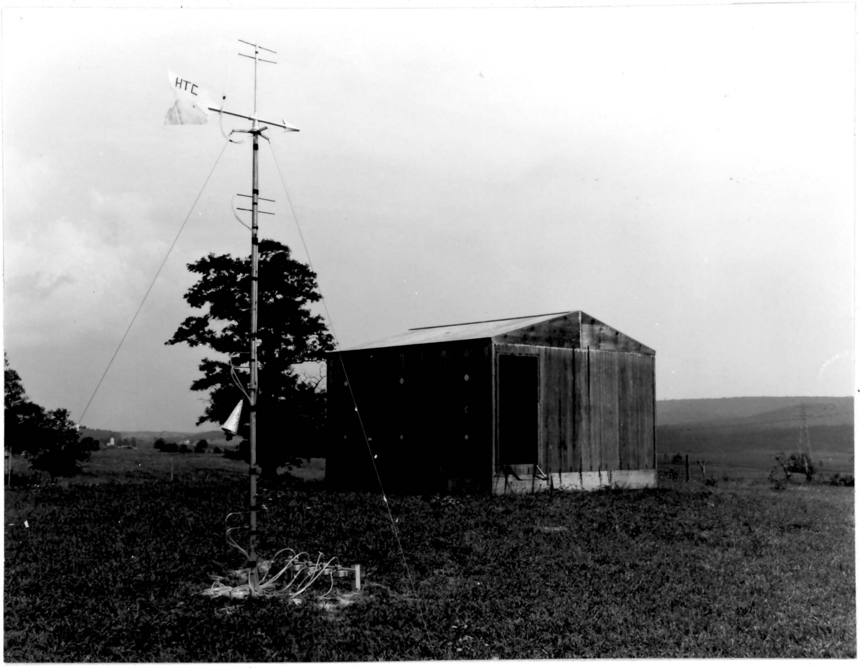

Figure 3. The original mast used in the investigation. It was fourteen feet high with transducers mounted at ground level.

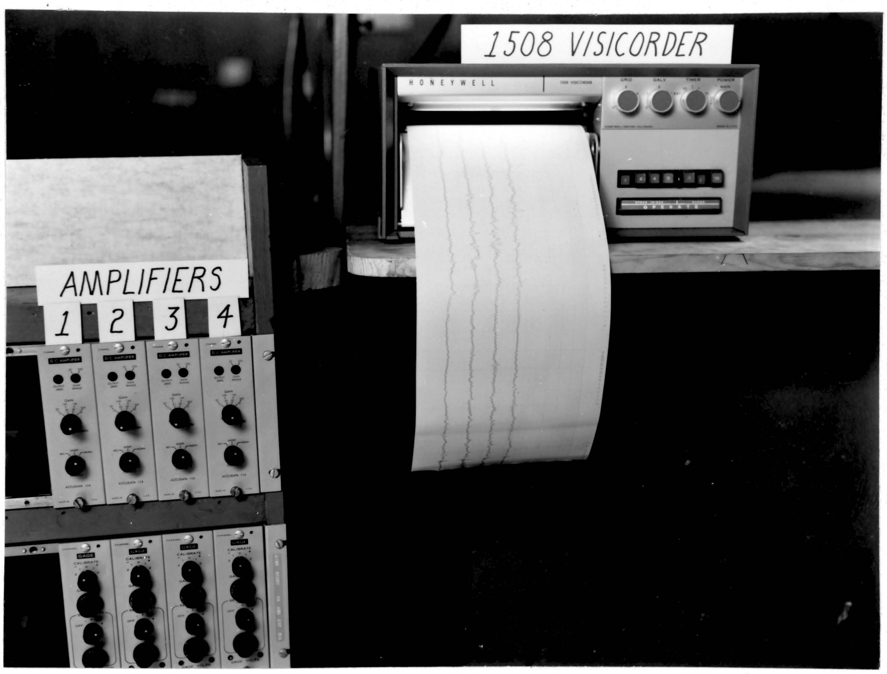

Figure 4. Honeywell model 1508 Visicorder and Accudata 104 D-C Amplifiers used to record velocity pressures in this investigation.

Recording Procedure

Calibration. Each transducer was calibrated to give a two-inch deflection on the Visicorder for one inch of water pressure. This was accomplished by using a column of water in a U-shaped plastic tube. One end of the tube was open to the atmosphere and the other end was connected to a tee-connection. The dynamic side of the transducer was connected to one side of the tee, and a gage indicating pressure in inches of water was connected to the other side of the tee. The static side of the transducer was left open to the atmosphere as a reference. Moving the open end of the tube of water up or down increased or decreased the pressure sensed by the transducer and the gage. A pressure reading of one inch of water on the gage indicated a pressure of one inch of water on the transducer. By adjusting amplifier gain and by an adjustment of the voltage on the transducer, the desired deflection on the Visicorder was obtained. The desired deflection in this case was two inches as mentioned above.

Obtaining data. The zero position of the Visicorder was checked each day before the start of the recording periods. This involved disconnecting the pitot tubes from the transducers and connecting the dynamic and static sides of the transducer together with a short piece of plastic tubing. This put a zero signal on the transducer; and by adjusting the zero setting on the balance control, the zero position on the Visicorder was made. The transducers were reconnected to the pitot tubes after these adjustments were completed.

The speed of the Visicorder chart ranged from one tenth of an inch per second to eighty inches per second. The time indicator ranged from one-hundredth of a second to ten seconds. It was decided, after making test recordings, that a chart speed of one inch per second and a time mark of one tenth of a second would be used. This would simplify the job of transposing the data from the charts. Recorded velocity pressure data from all four transducers at the above Visicorder settings can be seen in Figure 5.

The recordings were made when the wind velocity was ten miles per hour or higher. An indication of this speed was taken from a single anemometer located in the vicinity of the prototype building. Recordings were taken at irregular intervals because of the short duration of the above velocities during this time of the year.

Transposing data. The data were taken from the Visicorder charts in time intervals of thirty seconds. These intervals were selected from the overall data recorded to include the highest velocities. This time interval and its selection from the chart was made necessary because of the short duration of velocities in excess of ten miles per hour.

The data were transposed from the chart manually into tabular form. Two columns of data were tabulated: (a) velocity pressure when the fluctuation of pressure was greater than one half of a chart division; and (b) the time elapsed from the beginning of the thirty-second period to the time of the tabulated pressure fluctuation (See Appendix I-A)*. The transposed data were then punched on IBM data cards in preparation for computer computations (See Appendix I-B).

*The data shown in Appendix I are data of a sample 10-second interval used instead of the large amount of data recorded for the four 30-second intervals.

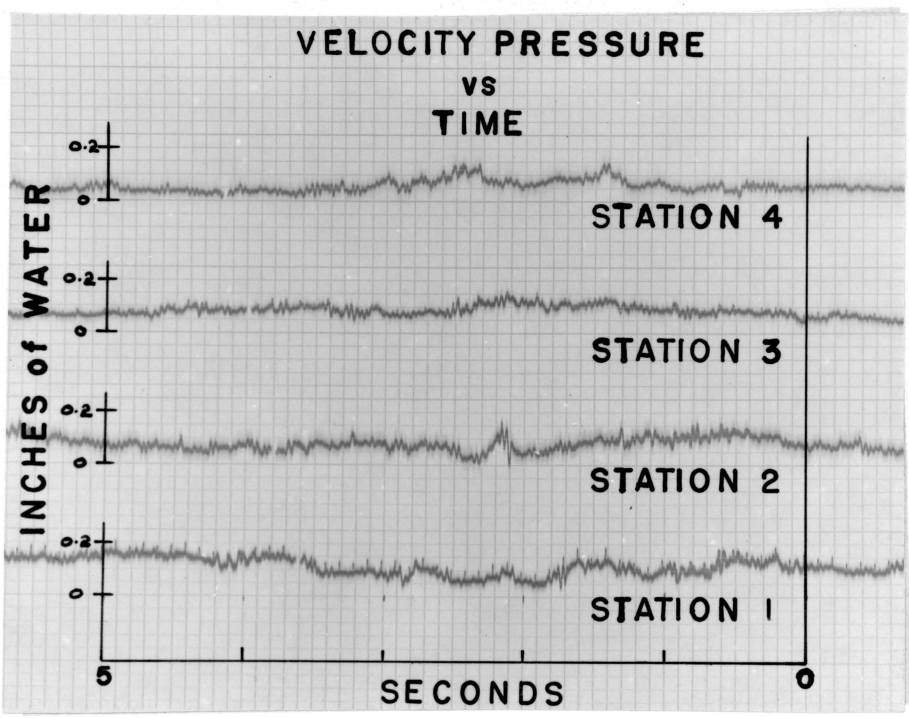

Figure 5. Chart recording from Visicorder in Figure 4 showing a five-second interval of instantaneous velocity pressure obtained from the four pitot tube stations on the thirty-foot mast shown in Figure 1. Station 1 is located at the top of the mast with the others located at intervals of eight feet down the mast.

Analysis of Data

The data were put into a computer program which first performed a weighted mean average over the selected time interval (See Appendix II-A).* This resulted in the weighted mean average of the tabulated chart divisions, each division representing 0.05 inches of water pressure. These four averages, one for each pitot tube station were then converted into velocities in miles per hour by a pitot tube velocity equation (See Appendix III). The computer program for this computation can be seen in Appendix II-B.

Having obtained the velocities for the four stations in miles per hour, the general form of the power law equation,

$$V = KZ^{1/\alpha}$$

Where: V = velocity at height Z

α = constant

K = constant,

was fitted to the points. Another station was added to the data at this time, that of zero ground level, assuming the velocity at this level to be zero. These data were added to the data of the four pitot tube stations giving five points to which to fit the curve.

The data, consisting now of the five heights from ground level to 29.92 feet and the corresponding five velocities, were submitted to a statistical computer program for multiple regression analysis. It

*The outputs of the computer programs in Appendix II are those from the data of the sample 10-second interval.

was necessary at this point to transform the data into logarithmic form, thus putting the power law equation in the logarithmic form of:

$$\log V = \log K + 1/\alpha \log Z.$$

The data were transformed into logrithmic form by the computer program seen in Appendix II-C. This program returned its output data punched in IBM data cards and also in printed form. The punched data were then placed into an execution program (See Appendix II-D) and processed by a statistical computer program for multiple regressions with case combinations. This program (BMD03R) is filed on tapes in the V.P.I. Computing Center. It was developed by Health Sciences Computing Center, Department of Preventive Medicine and Public Health, School of Medicine, University of California, Los Angeles, and modified for use at Virginia Polytechnic Institute Computing Center. The output from program BMD03R consisted of the following:

(a) Sums and sums of squares,

(b) Cross-products of deviations,

(c) Correlation matrix

(d) Inverse of correlation matrix

(e) Means and standard deviations,

(f) Regression coefficients, their standard error and t-values

(g) Sums of squares and mean squares due to regression and the deviation about regression, with degrees of freedom and f-values,

(h) Sums of squares due to regression for each variable,

(i) Standard error of estimate,

(j) Intercept,

(k) Partial correlation coefficients,

(l) Multiple correlation coefficients, R and R^2.

From this output the K value of the equation was the intercept value and the $1/\alpha$ value was the regression coefficient. The output from program BMD03R may be seen in Appendix II-D.

The first three programs described in the processing of the data are shown combined into one program giving all the results described above (See Appendix II-E). This does not include the execution program for program BMD03R but does give the punch data cards for it.

PRESENTATION AND DISCUSSION OF RESULTS

The objectives of this investigation were to obtain wind velocities at four intervals in the vertical distance of zero to thirty feet, and to develop a computer program for an equation for the profile of these velocities.

Measuring Wind Velocities

Sample results from the first of these objectives are shown in Table 1 for four thirty-second recording intervals. This table gives the height of each pitot tube station and the weighted mean velocity of that station for each of the four intervals. The last three intervals were recorded on the same day and the first interval on a different day. This was done because winds from which good data could be obtained were not readily available during the month of August when this investigation was conducted.

Table 1. Wind velocities for four thirty-second intervals.

Pitot Tube Position	Height Ft.	Interval 1 Velocity M.P.H.	Interval 2 Velocity M.P.H.	Interval 3 Velocity M.P.H.	Interval 4 Velocity M.P.H.
Station 1	29.92	18.90	23.43	19.27	19.95
Station 2	21.92	18.57	21.30	17.12	18.41
Station 3	13.92	15.88	18.85	14.88	18.70
Station 4	5.92	12.96	16.29	13.78	15.52

Indications from a single anemometer, located in the vicinity of the thirty-foot mast, were that the velocities obtained from Station 3 were about seven per cent high. If this indication is correct, it could have resulted from the assumption that the coefficient of the pitot tube velocity formula was unity. Herschel (6) pointed out that the coefficient used in the formula for determining velocities from pitot tube readings may be less than unity in turbulent flow. This difference may also have resulted from the fact that pitot tube measurements are often inaccurate for velocities around ten to fifteen miles per hour and below (6) and, therefore, this difference may not occur for velocities of thirty to forty miles per hour and higher.

The Computer Program

The results of the second objective are found in Appendix II-D and Appendix II-E. The computer program in Appendix II-D is the first of two programs required for the calculation of the velocity profile equation. This program starts with the transposed data and results in punched IBM data cards consisting of the heights of the four pitot tube stations and the weighted mean velocity for each station, all in logarithmic form. The program in Appendix II-E is an execution program for program No. BMD03R which is a statistical computer program for multiple regression coefficients. This execution program directs the punched data, from the initial program (Appendix II-D), into program No. BMD03R. The pertinent output from BMD03R for the four recorded time intervals is shown in Table 2.

Table 2. Output of program BMD03R for the four time intervals.

	Interval 1	Interval 2	Interval 3	Interval 4
Multiple Correlation Coefficient	0.9410	0.9510	0.9331	0.9221
Intercept (K - constant)	1.41	1.39	1.43	1.49
Regression Coefficient ($1/\alpha$ slope)	0.87006	0.97357	0.85602	0.87813
F-Value	23.1841	28.3599	20.1841	17.041
Significance	95%	95%	95%	95%

The two computer programs fitted the velocity data to a curve of the general form of the power law equation,

$$V = KZ^{1/\alpha}.$$

The values for this equation which are needed in order for the curve to be fitted to the data are K and $1/\alpha$. The value of $1/\alpha$ is the slope and has a large influence on the profile. The value of K is the velocity intercept.

The equations for the four thirty-second intervals obtained from the computer program are:

(a) Interval 1, $V = 1.41\ Z^{0.87}$;

(b) Interval 2, $V = 1.39\ Z^{0.97}$;

(c) Interval 3, $V = 1.43\ Z^{0.86}$;

(d) Interval 4, $V = 1.49\ Z^{0.88}$.

The F-value test determines the significance of the regression coefficient of the fitted curve. The F-values obtained for the regression coefficients of each of the four thirty-second intervals gave a 95% assurance that the curve would fit the weighted mean velocities computed for each interval.

The multiple correlation coefficient is a measurement of linear relationship between two variables. Recalling that program BMD03R (Appendix II-E) analyzed the logarithms of the weighted mean velocities as a linear regression, the multiple correlation coefficients obtained are an indication of the linear relationship of the logarithmic values of the two variables, height and velocity. Table 2 shows a high value for all four intervals; the value exceeding 0.90.

It can be seen that the exponent of Interval 2 is larger than those of the other three. This relatively large difference indicates that the profile of Interval 2 will be different from the profiles of the other intervals. The profiles of Intervals 1, 3, and 4 are very similar; the spread in their exponential values being only 0.02. This is illustrated graphically in Figure 6.

Davenport (2) pointed out that the exponent of the power law has been found to vary roughly from the value of 0.111 to 1.000, depending on the surface roughness. The exponential values arrived at by the computer program fall within this overall range, but are different from those given for specific surface roughnesses. The specific values given by Davenport (2) as accepted values for surface roughnesses are: 0.143 for open country, 0.286 for wooded countryside or rough coastal lands, and 0.400 for centers of large cities. These values are based on data taken above thirty feet.

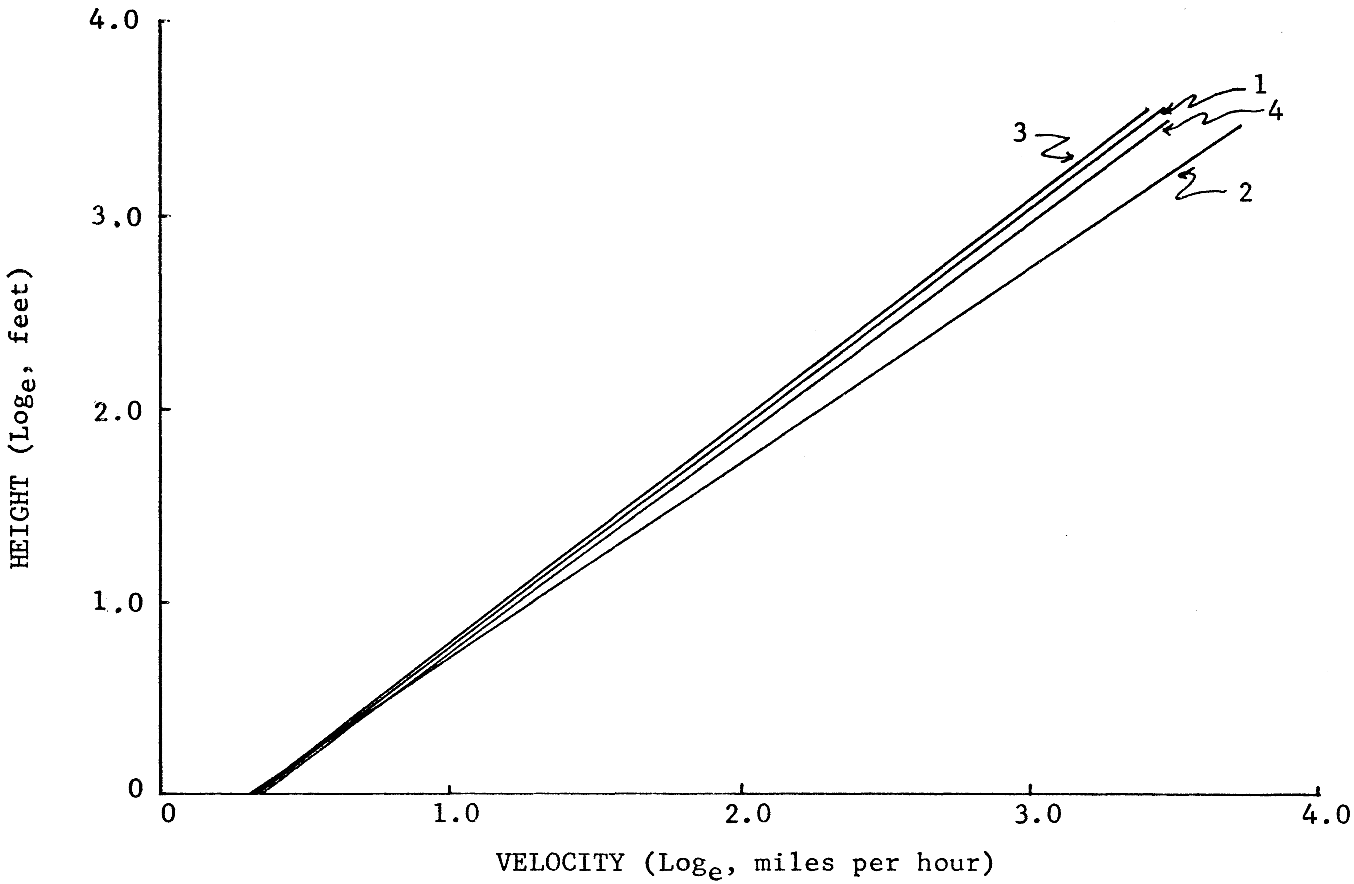

Figure 6. Velocity vs. height for the four thirty-second intervals. Velocity values are those estimated by the computer for the curve.

The location of the thirty-foot mast in this investigation would fall into the second classification which Davenport has found to have an accepted value of 0.286. The exponent found by the computer from the data of this investigation ranged from 0.86 to 0.97 which is significantly larger than 0.286. This may be accounted for due to the fact that the exponent 0.286 was based on data obtained above thirty feet and the data of this investigation was obtained below thirty feet. This difference may also be accounted for due to the stability of the atmosphere within the zero to thirty foot range. Davenport (2) states that the exponent of the power law would increase with an increase of stability. This stability of the atmosphere is the condition where there is no variation of temperature with height, an adiabatic condition. Since the exponent given by Davenport was taken from heights above thirty feet up to heights of 300 feet, the condition of unstable atmosphere is more likely than in the range of heights of this investigation; therefore, the possibility of a stable condition could account for the higher exponents found by the computer.

The objectives of this investigation were not to analyze the values obtained, but to provide a means of obtaining a velocity profile equation through computer computations. The four time intervals in this investigation are not sufficient to provide an analysis of the exponential values and more research will be needed to verify these values.

SUMMARY AND CONCLUSIONS

Wind velocities were measured at four intervals in the lower thirty feet of the earth's atmosphere. This was accomplished by the erection of a thirty-foot mast with pitot tubes mounted on it at intervals of eight feet, the lower pitot tube being five feet eleven inches above the ground. The velocity pressure sensed by the pitot tubes at each station was recorded instantaneously on an oscillograph.

The data taken from the oscillograph recordings were entered into a computer program developed to give an equation for the velocity profile curve of the four pitot tube velocities.

Four thirty-second recording intervals were selected from the available recordings taken and the data were entered into the computer program which yielded an equation for each of the four intervals. Statistical analysis showed that the slope of the curves derived had a significance level of 95%, and the multiple correlation coefficient showed a good fit of the curves to the velocity points.

It is concluded from the results of this investigation that the wind velocities can be measured in the lower thirty feet of the atmosphere with reasonable accuracy, and that this accuracy can be expected to increase in winds of higher velocities than those recorded in this investigation.

It is also concluded that the computer program presented in this investigation can be used with confidence in obtaining an equation for a vertical profile of wind velocities recorded by four pitot tubes approximately equally spaced between ground level and thirty feet.

ACKNOWLEDGEMENTS

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A P P E N D I X I

Data

Appendix I-A

Data transposed from Visicorder charts

Station 1		Station 2		Station 3		Station 4	
Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions
0.00	3.50	0.00	2.50	0.00	2.00	0.00	1.00
0.10	2.25	0.40	1.00	0.15	1.25	1.00	1.00
0.15	3.25	0.50	2.50	0.30	2.00	1.35	1.75
0.50	1.25	0.60	1.00	1.10	0.50	2.70	1.00
0.60	3.00	0.70	2.00	1.80	1.00	3.20	1.25
0.70	1.50	1.00	1.00	2.45	0.25	3.30	0.75
0.80	2.75	1.25	2.00	2.50	2.00	3.90	0.50
1.20	2.00	1.90	0.50	2.60	0.50	4.00	2.00
1.40	2.75	2.40	1.25	2.70	2.00	4.60	1.00
1.50	2.00	2.70	1.00	3.00	0.75	5.15	2.00
1.60	3.00	2.80	2.25	3.25	1.50	5.25	1.00
1.70	1.25	3.00	0.00	4.30	1.00	5.40	2.50
1.80	3.00	3.20	2.00	4.65	0.50	5.70	1.50
2.00	1.75	3.25	1.00	4.70	1.75	5.75	2.50
2.10	3.00	3.40	3.50	4.80	0.50	6.10	1.50
2.20	2.00	3.60	2.00	4.90	2.00	6.60	2.75
2.40	3.50	4.00	3.00	5.10	1.75	6.70	1.50
2.50	2.25	4.20	1.25	5.15	3.00	7.25	2.00
2.60	4.75	4.60	2.50	5.20	2.00	7.60	1.50
2.70	2.25	5.00	0.50	5.30	3.50	7.80	2.50
2.75	3.50	5.20	2.00	5.45	2.25	7.90	1.50
2.80	3.00	5.30	1.25	5.60	3.50	8.10	2.50
2.90	4.00	5.50	2.25	5.70	2.50	8.60	1.75
2.95	2.50	5.60	1.00	6.00	3.00	8.70	3.00
3.30	4.00	5.75	3.00	6.10	3.50	8.90	1.50
3.50	3.00	6.00	2.00	6.20	2.00	8.95	3.00
3.55	4.50	6.10	4.00	6.25	3.75	9.30	1.50
3.60	3.25	6.70	1.50	6.40	2.50	9.80	2.75

Data transposed from Visicorder charts (continued)

Station 1		Station 2		Station 3		Station 4	
Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions
3.70	4.25	6.80	3.00	6.50	3.75	9.90	1.25
3.80	2.25	7.10	2.00	6.90	2.00	10.00	3.00
3.90	4.50	7.30	3.50	7.00	3.00		
4.00	2.50	7.50	1.75	7.15	3.50		
4.10	4.50	8.20	3.75	7.60	1.50		
4.20	1.00	8.30	2.50	7.65	2.50		
4.30	4.00	8.35	4.75	8.30	2.00		
4.40	3.00	8.40	2.50	8.90	2.25		
4.70	2.00	8.45	4.00	9.20	1.00		
4.80	5.00	8.50	2.50	9.30	3.00		
5.00	2.25	8.65	4.50	9.50	2.00		
5.10	5.00	8.75	2.50	9.70	3.25		
5.20	2.00	8.80	4.00	9.90	1.75		
5.30	4.75	9.10	2.00	10.00	3.50		
5.40	2.00	9.20	5.00				
5.50	4.25	9.25	3.50				
5.60	2.00	9.30	5.00				
5.70	3.00	9.40	2.00				
5.80	2.00	9.45	5.00				
5.90	3.50	9.50	3.50				
6.10	2.00	9.55	5.25				
6.30	3.75	9.60	3.75				
6.40	1.75	9.65	5.75				
6.50	3.50	9.80	4.00				
6.90	3.00	9.90	5.50				
7.10	4.75	10.00	6.50				
7.50	3.00						
7.55	5.00						
7.60	3.50						
7.80	4.75						

Data transposed from Visicorder charts (continued)

Station 1		Station 2		Station 3		Station 4	
Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions	Time Seconds	Pressure Chart Divisions
8.00	3.25						
8.10	4.75						
8.20	3.00						
8.40	6.50						
8.50	5.00						
8.60	7.00						
8.70	4.50						
8.80	7.00						
8.85	5.00						
8.90	6.00						
9.00	4.25						
9.05	7.00						
9.10	4.25						
9.15	6.00						
9.20	4.00						
9.25	6.50						
9.60	3.75						
9.70	5.25						
9.80	3.00						
9.90	6.50						
10.00	4.00						

Temperature - 78°F.

Saturated Vapor Pressure - 0.9666 inches of Hg.

Barometric Pressure - 27.85 inches of Hg.

Appendix I-B

Data prepared for IBM data cards

Station 1					Station 2				
Time Seconds		Pressure Chart Division		Control No.	Time Seconds		Pressure Chart Division		Control No.
0.00	0.10	3.50	2.25	1	0.00	0.40	2.50	1.00	1
0.10	0.15	2.25	3.25	1	0.40	0.50	1.00	2.50	1
0.15	0.50	3.25	1.25	1	0.50	0.60	2.50	1.00	1
0.60	0.70	3.00	1.50	1	0.60	0.70	1.00	2.00	1
0.70	0.80	1.50	2.75	1	0.70	1.00	2.00	1.00	1
0.80	1.20	2.75	2.00	1	1.00	1.25	1.00	2.00	1
1.20	1.40	2.00	2.75	1	1.25	1.90	2.00	0.50	1
1.40	1.50	2.75	2.00	1	1.90	2.40	0.50	1.25	1
1.50	1.60	2.00	3.00	1	2.40	2.70	1.25	1.00	1
1.60	1.70	3.00	1.25	1	2.70	2.80	1.00	2.25	1
1.70	1.80	1.25	3.00	1	2.80	3.00	2.25	0.00	1
1.80	2.00	3.00	1.75	1	3.00	3.20	0.00	2.00	1
2.00	2.10	1.75	3.00	1	3.20	3.25	2.00	1.00	1
2.10	2.20	3.00	2.00	1	3.25	3.40	1.00	3.50	1
2.20	2.40	2.00	3.50	1	3.40	3.60	3.50	2.00	1
2.40	2.50	3.50	2.25	1	3.60	4.00	2.00	3.00	1
2.50	2.60	2.25	4.75	1	4.00	4.20	3.00	1.25	1
2.60	2.70	4.75	2.25	1	4.20	4.60	1.25	2.50	1
2.70	2.75	2.25	3.50	1	4.60	5.00	2.50	0.50	1
2.75	2.80	3.50	3.00	1	5.00	5.20	0.50	2.00	1
2.80	2.90	3.00	4.00	1	5.20	5.30	2.00	1.25	1
2.90	2.95	4.00	2.50	1	5.30	5.50	1.25	2.25	1
2.95	3.30	2.50	4.00	1	5.50	5.60	2.25	1.00	1
3.30	3.50	4.00	3.00	1	5.60	5.75	1.00	3.00	1
3.50	3.55	3.00	4.50	1	5.75	6.00	3.00	2.00	1
3.55	3.60	4.50	3.25	1	6.00	6.10	2.00	4.00	1
3.60	3.70	3.25	4.25	1	6.10	6.70	4.00	1.50	1
3.70	3.80	4.25	2.25	1	6.70	6.80	1.50	3.00	1
3.80	3.90	2.25	4.50	1	6.80	7.10	3.00	2.00	1
3.90	4.00	4.50	2.50	1	7.10	7.30	2.00	3.50	1
4.00	4.10	2.50	4.50	1	7.30	7.50	3.50	1.75	1
4.10	4.20	4.50	1.00	1	7.50	8.20	1.75	3.75	1
4.20	4.30	1.00	4.00	1	8.20	8.30	3.75	2.50	1
4.30	4.40	4.00	2.00	1	8.30	8.35	2.50	4.75	1
4.40	4.50	2.00	3.00	1	8.35	8.40	4.75	2.50	1
4.50	4.70	3.00	2.00	1	8.40	8.45	2.50	4.00	1
4.70	4.80	2.00	5.00	1	8.45	8.50	4.00	2.50	1
4.80	5.00	5.00	2.25	1	8.50	8.65	2.50	4.50	1
5.00	5.10	2.25	5.00	1	8.65	8.75	4.50	2.50	1

Data prepared for IBM data cards (continued).

Station 1					Station 2				
Time Seconds		Pressure Chart Division		Control No.	Seconds		Pressure Chart Division		Control No.
5.10	5.20	5.00	2.00	1	8.75	8.80	2.50	4.00	1
5.20	5.30	2.00	4.75	1	8.80	9.10	4.00	2.00	1
5.30	5.40	4.75	2.00	1	9.10	9.20	2.00	5.00	1
5.40	5.50	2.00	4.25	1	9.20	9.25	5.00	3.50	1
5.50	5.60	4.25	2.00	1	9.25	9.30	3.50	5.00	1
5.60	5.70	2.00	3.00	1	9.30	9.40	5.00	2.00	1
5.70	5.80	3.00	2.00	1	9.40	9.45	2.00	5.00	1
5.80	5.90	2.00	3.50	1	9.45	9.50	5.00	3.50	1
5.90	6.10	3.50	2.00	1	9.50	9.55	3.50	5.25	1
6.10	6.30	2.00	3.75	1	9.55	9.60	5.25	3.75	1
6.30	6.40	3.75	1.75	1	9.60	9.65	3.75	5.75	1
6.40	6.50	1.75	3.50	1	9.65	9.80	5.75	4.00	1
6.50	6.90	3.50	3.00	1	9.80	9.90	4.00	5.50	1
6.90	7.10	3.00	4.75	1	9.90	10.00	5.50	6.50	2
7.10	7.50	4.75	3.00	1					
7.50	7.55	3.00	5.00	1					
7.55	7.60	5.00	3.50	1					
7.60	7.80	3.50	4.75	1					
7.80	8.00	4.75	3.25	1					
8.00	8.10	3.25	4.75	1					
8.10	8.20	4.75	3.00	1					
8.20	8.40	3.00	6.50	1					
8.40	8.50	6.50	5.00	1					
8.50	8.60	5.00	7.00	1					
8.60	8.70	7.00	4.50	1					
8.70	8.80	4.50	7.00	1					
8.80	8.85	7.00	5.00	1					
8.85	8.90	5.00	6.00	1					
8.90	9.00	6.00	4.25	1					
9.00	9.05	4.25	7.00	1					
9.05	9.10	7.00	4.25	1					
9.10	9.15	4.25	6.00	1					
9.15	9.20	6.00	4.00	1					
9.20	9.25	4.00	6.50	1					
9.25	9.60	6.50	3.75	1					
9.60	9.70	3.75	5.25	1					
9.70	9.80	5.25	3.00	1					
9.80	9.90	3.00	6.50	1					
9.90	10.00	6.50	4.00	2					

Data prepared for IBM data cards (continued).

Station 3					Station 4				
Time Seconds		Pressure Chart Division		Control No.	Time Seconds		Pressure Chart Division		Control No.
0.00	0.15	2.00	1.25	1	0.00	1.00	1.00	1.00	1
0.15	0.30	1.25	2.00	1	1.00	1.35	1.00	1.75	1
0.30	1.10	2.00	0.50	1	1.35	2.70	1.75	1.00	1
1.10	1.80	0.50	1.00	1	2.70	3.20	1.00	1.25	1
1.80	2.45	1.00	0.25	1	3.20	3.30	1.25	0.75	1
2.45	2.50	0.25	2.00	1	3.30	3.90	0.75	0.50	1
2.50	2.60	2.00	0.50	1	3.90	4.00	0.50	2.00	1
2.60	2.70	0.50	2.00	1	4.00	4.60	2.00	1.00	1
2.70	3.00	2.00	0.75	1	4.60	5.15	1.00	2.00	1
3.00	3.25	0.75	1.50	1	5.15	5.25	2.00	1.00	1
3.25	4.30	1.50	1.00	1	5.25	5.40	1.00	2.50	1
4.30	4.65	1.00	0.50	1	5.40	5.70	2.50	1.50	1
4.65	4.70	0.50	1.75	1	5.70	5.75	1.50	2.50	1
4.70	4.80	1.75	0.50	1	5.75	6.10	2.50	1.50	1
4.80	4.90	0.50	2.00	1	6.10	6.60	1.50	2.75	1
4.90	5.10	2.00	1.75	1	6.60	6.70	2.75	1.50	1
5.10	5.15	1.75	3.00	1	6.70	7.25	1.50	2.00	1
5.15	5.20	3.00	2.00	1	7.25	7.60	2.00	1.50	1
5.20	5.30	2.00	3.50	1	7.60	7.80	1.50	2.50	1
5.30	5.45	3.50	2.25	1	7.80	7.90	2.50	1.50	1
5.45	5.60	2.25	3.50	1	7.90	8.10	1.50	2.50	1
5.60	5.70	3.50	2.50	1	8.10	8.60	2.50	1.75	1
5.70	6.00	2.50	3.00	1	8.60	8.70	1.75	3.00	1
6.00	6.10	3.00	3.50	1	8.70	8.90	3.00	1.50	1
6.10	6.20	3.50	2.00	1	8.90	8.95	1.50	3.00	1
6.20	6.25	2.00	3.75	1	8.95	9.30	3.00	1.50	1
6.25	6.40	3.75	2.50	1	9.30	9.80	1.50	2.75	1
6.40	6.50	2.50	3.75	1	9.80	9.90	2.75	1.25	1
6.50	6.90	3.75	2.00	1	9.90	10.00	1.25	3.00	1
6.90	7.00	2.00	3.00	1	10.00	10.00	3.00	2.00	2
7.00	7.15	3.00	3.50	1					
7.15	7.60	3.50	1.50	1					
7.60	7.65	1.50	2.50	1					
7.65	8.90	2.50	2.25	1					
8.90	9.20	2.25	1.00	1					
9.20	9.30	1.00	3.00	1					
9.30	9.50	3.00	2.00	1					
9.50	9.70	2.00	3.25	1					
9.70	9.90	3.25	1.75	1					
9.90	10.00	1.75	3.50	2					

A P P E N D I X II

Computer Programs

Appendix II-A

```
$JOB                025550629  OGBURN, C. B.
$IBJOB              NODECK,GO
$IBFTC THESIS
C      COMPUTED VELOCITY ON A WEIGHTED AVERAGE (CHART DIVISIONS)
       DIMENSION D(4), VEL(4)
       I = 0
    25 SUMA = 0.
    50 READ (5,100) T1,T2,DIV1,DIV2,K
   100 FORMAT (1X,4F6.2,I3)
       A = (T2-T1)*((DIV1+DIV2)/2.)
       SUMA = SUMA+A
       GO TO (50,150),K
   150 I = I+1
       D(I) = SUMA/10.
       WRITE (6,200) D(I)
   200 FORMAT (1X,F6.2)
       IF(I-4) 25,600,600
   600 STOP
       END
$ENTRY              THESIS
$IBSYS
```

<u>Output from program</u> - weighted average of chart divisions.

STATION 1	STATION 2	STATION 3	STATION 4
3.44	2.26	1.82	1.63

Appendix II-B

```
$JOB                 0.25550629 OGBURN, C.B.
$IBJOB               NODECK,GO
$IBFTC  THESIS
C       VELOCITY EQUATION FOR A PITOT TUBE
C       VELOCITY = 12.46*((D*0.05/R)**.5) M.P.H.
C           WHERE D = CHART DIVISIONS
C                 R = DENSITY (LBS/FT.**3.)
C       DENSITY = (((B-0.376*P)/460.0+T)*1.327)
C           WHERE B = BARMETRIC PRESSURE (INCHES OF HG.)
                  P = SATURATED VAPOR PRESSURE (INCHES OF HG.)
                  T = TEMPERATURE (DEGREES FAHRENHEIT)
        DIMENSION D(4,1), VEL(4,1)
        READ (5,7) T,P,B
      7 FORMAT (3F10.4)
        READ (5,8) D
      8 FORMAT (4F10.4)
        DO 20 I = 1,4
        DO 20 J = 1,1
     200VEL(I,J) = 12.46*(SQRT(ABS((D(I,J)*0.05*(460.0+T))/
       1(1.327*B-0.498952*P))))
        WRITE (6,30)
     300FORMAT (6X,9HSTATION 1,6X,9HSTATION 2,6X9HSTATION 3,
       16X,9HSTATION 4)
        DO 35 J=1,1
     35 WRITE (6,40) VEL(1,J),VEL(2,J),VEL(3,J),VEL(4,J)
     40 FORMAT (1X,//5X,F10.4,F15.4,F15.4,F15.4)
        STOP
        END
$ENTRY          THESIS
$IBSYS
```

<u>Output from program</u> - velocity in miles per hour.

STATION 1	STATION 2	STATION 3	STATION 4
19.8462	16.0862	14.4356	13.6613

Appendix II-C

```
$JOB                  025550629 OGBURN, C. B.
$IBJOB
$IBFTC                NODECK
      1 READ(5,500)A,B
    500 FORMAT(2F10.2)
        IA = ALOG(A)*10000.
        IB = ALOG(B)*10000.
        WRITE(7,7000) IA,IB
   7000 FORMAT(2110)
        WRITE(6,6000) IA,IB
   6000 FORMAT(1X,2I10)
        GO TO 1
        END
$ENTRY
$IBSYS
```

Output from program - Heights of four stations and velocity at each station in logarithmic form, both in printed form and punched IBM data cards.

	Height	Velocity
Station 1	33985	29882
Station 2	30873	27769
Station 3	26333	26700
Station 4	17783	26144

Appendix II-D

```
$JOB                 025550629 OGBURN, C. B.
$IBJOB               NODECK,GO
$IBFTC THESIS
C       VELOCITY EQUATION FOR A PITOT TUBE
C       VELOCITY = 12.46*((D*0.05/R)**.5) M.P.H.
C           WHERE D= CHART DIVISIONS
C                 R = DENSITY (LBS./FT.**3.)
C       DENSITY = (((B-0.376*P)/460.0+T)*1.327)
C           WHERE B = BARMETRIC PRESSURE (INCHES OF HG.)
                  P = SATURATED VAPOR PRESSURE (INCHES OF HG.)
                  T = TEMPERATURE (DEGREES FAHRENHEIT)
C       STATION 1 - 29 FEET 11 INCHES
C       STATION 2 - 21 FEET 11 INCHES
C       STATION 3 - 13 FEET 11 INCHES
C       STATION 4 -  5 FEET 11 INCHES
C       TEST - EXP.
        DIMENSION D(4),VEL(4),IB(4),A(4),IA(4)
        I = 0
     25 SUMA = 0.
     50 READ (5,100) T1,T2,DIV1,DIV2,K
    100 FORMAT (1X,4F6.2,I3)
        A = (T2-T1)*((DIV1+DIV2)/2.)
        SUMA = SUMA + A
        GO TO (50,150),K
    150 I = I+1
        D(I) = SUMA/10.
        WRITE (6,200) D(I)
    200 FORMAT (1X,F6.2)
        IF (I-4) 25,230,600
    230 READ (5,231) T,P,B
    231 FORMAT (3F10.4)
        DO 250 I=1,4
   2500 VEL(I)=12.46*(SQRT(ABS((D(I)*0.05*(460.0+T))/
      1(1.327*B-0.498952*P))))
        WRITE (6,300)
   3000 FORMAT (6X,9HSTATION 1,6X,9HSTATION 2,6X,9HSTATION 3,
      16X,9HSTATION 4)
        WRITE (6,350) VEL(1), VEL(2), VEL(3),VEL(4)
    350 FORMAT (1X,//5X,F10.2,F15.2,F15.2,F15.2)
        READ (5,500) A
    500 FORMAT (4F10.2)
        DO 550 N=1,4
        IA(N) = ALOG(A(N))*10000
        IB(N) = ALOG(VEL(N))*10000
        WRITE (7,7000) IA(N), IB(N)
    550 WRITE (6,6000) IA(N), IB(N)
```

Appendix II-D (continued)

```
  7000 FORMAT (2I10)
  6000 FORMAT (1X,2I10)
   600 STOP
       END
$ENTRY      THESIS
$IBSYS
```

<u>Output from program</u> - The same output as received from Appendix II-A, Appendix II-B, and Appendix II-C.

Appendix II-E

```
$JOB              025550629 OGBURN, C. B.
$EXECUTE          BMD03R
PROBLM 1 2    5
SAMSIZ     5
(2F10.4)
SELECT0102 0 0 1 1
FINISH
$IBSYS
```

Output from program - Regression coefficient, $1/\alpha$, intercept, K, and the statistical analysis of the regression coefficient.

```
SUMS     10.89740     11.04950
SUM OF SQUARES     31.17784     30.60450
CROSS PRODUCT     ROW 1     31.17784     30.40862
                  ROW 2     30.40862     30.60450
CROSS PRODUCT DEVIATIONS     ROW 1     7.42718     6.32646
                             ROW 2     6.32646     6.18621
CORRELATION COEFFICIENTS     ROW 1     1.00000     0.93333
                             ROW 2     9.3333      1.00000
COEFFICIENT OF DETERMINATION     0.8711
MULTIPLE CORR. COEFFICIENT       0.9333
SUM OF SQUARES ATTRIBUTABLE TO REGRESSION     5.38886
SUM OF SQUARES OF DEVIATION FROM REGRESSION     0.79735
INTERCEPT (A VALUE) 0.35342
```

ANALYSIS OF VARIANCE FOR THE MULTIPLE
LINEAR REGRESSION

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARES	F VALUES
DUE TO REGRESSION	1	5.38886	5.38886	20.2754
DEVIATION ABOUT REGRESSION	3	0.79735	0.26578	
TOTAL	4	6.18621		

Appendix II-E (continued)

VARIABLE NO.	MEAN	STD. DEVIATION	REG. COEFF.	STD.ERROR OF REG.COEFF.	COMPUTED T VALUE	PARTIAL CORR.COEFF.
1	2.17948	1.24364	0.85180	0.18917	4.50282	0.9333
2	2.20990	1.24360				

OBSERVATION	Y VALUE	Y ESTIMATE
1	2.98820	3.24826
2	2.77690	2.98318
3	2.67000	2.59646
4	2.61440	1.86818
5	-0.00000	0.35342

A P P E N D I X III

Verification of the Pitot Tube Velocity Equation and the Effects Due to Changes in the Variables of the Equation.

I. Pitot Tube Velocity Formula*

$$V = Y\sqrt{\frac{h}{\rho}}$$

where: V = velocity (M.P.H.)

Y = 12.46

h = Head (inches of H_2O)

ρ = specific weight defined as

$$1.327\left[\frac{B - 0.376\ PH}{460 + t}\right]\ \#/ft^3$$

B = barometric pressure (in. of Hg.)

P = pressure of saturated vapor (in. of Hg.)

H = relative humidity

t = temperature in degrees F.

A. Verification that $\rho = 1.327\left[\frac{B - 0.376\ PH}{460 + t}\right]\ \#/ft^3$ is an exact equation.

$P_m = P_a + P_v$ where P_m = mixture pressure

P_a = air pressure

P_v = vapor pressure

Letting volume = 1 cu. ft. of mixture

For vapor: $1 = \frac{W_v R_v T_v}{P_v}$

$$W_v = \frac{P_v}{R_v T_v}$$

where: W_v = weight of vapor (lb.)

R_v = vapor constant (85.2)

T_v = 460 + t

P_v = vapor pressure

*Herschel, W. H., "The Pitot Tube and Other Anemometers for Aeroplanes," First Annual Report, National Advisory Committee for Aeronautics, 1915.

For air: $1 = \frac{W_a R_a T_a}{P_a}$

$$W_a = \frac{P_a}{R_a T_a}$$

where: W_a = weight of air (lb.)

R_a = air constant (53.3)

T_a = 460 + t

P_a = air pressure

lbs/ft^3 = 70.7 inches of Hg.

$$\rho \text{ of air } (lbs/ft^3) = W_v + W_a$$

$$= \frac{P_v}{R_v T_v} + \frac{P_a}{R_a T_a}$$

$$P_a = P_m - P_v$$

$$\therefore \rho_{air} = \frac{P_v}{R_v T_v} - \frac{P_v}{R_a T_a} + \frac{P_m}{R_a T_a}$$

$$\rho\, air = \frac{P_v\,(\frac{70.7}{53.3})}{T} - \frac{P_v\,(\frac{70.7}{53.3})}{T} + \frac{P_m\,(\frac{70.7}{53.3})}{T}$$

$$\rho\, air = 1.327\left[\frac{0.624\ P_v}{T} - \frac{P_v}{T} + \frac{P_m}{T}\right]$$

$$\rho\, air = 1.327\left[\frac{P_m}{T} - \frac{0.376\ PH}{T}\right]$$

Let $P_m = B$, $P_v = P.H$, $T = 460 + t$

Then $\rho_{air} = 1.327\left[\frac{B - 0.376\ PH}{460 + t}\right]$

B. Verification that $V = Y\sqrt{\frac{h}{\rho}}$ M.P.H. where Y = 12.46.

$V = \sqrt{2gH}$ where: V = velocity (ft/sec)

g = acceleration of gravity (ft/sec^2)

H = head of flowing substance (ft)

$$V = \sqrt{2 \times 32.2 \text{ ft/sec}^2 \times H \text{ ft}}$$

$$H \text{ (ft)} = \frac{h \text{ (inches of Hg)} \times 5.2 \text{ (\#/ft}^2\text{/in. of Hg)}}{\rho \text{ \#/ft}^3}$$

$$H \text{ (ft)} = \frac{5.2h}{\rho} \text{ (ft)}$$

$$V = \sqrt{10.4 \times 32.2 \text{ ft}^2\text{/sec}^2} \left[\frac{3600 \text{ sec/hr}}{5280 \text{ ft/mi}}\right]$$

$$V = 12.46\sqrt{\frac{h}{\rho}} \quad \text{M.P.H.}$$

II. The Effect of Changes in Specific Weight on Velocity

The expected change in the specific weight of air in this investigation is very small. During extreme conditions which occur in the summertime, the greatest change in specific weight between the ground and the top of the thirty-foot mast is less than 0.003 $lbs./ft.^3$. As can be seen from Figure 7, this represents a change of $\pm$ 2.3% in velocity which is less than the expected experimental error. This also reflects an extreme change in the variables of specific weight, temperature, barometric pressure, and relative humidity.

With temperature, barometric pressure held constant and relative humidity varied from 10% to 100%, the change in specific weight is 0.0008 $lb./ft.^3$. It can be seen from Figure 1 that this will reflect

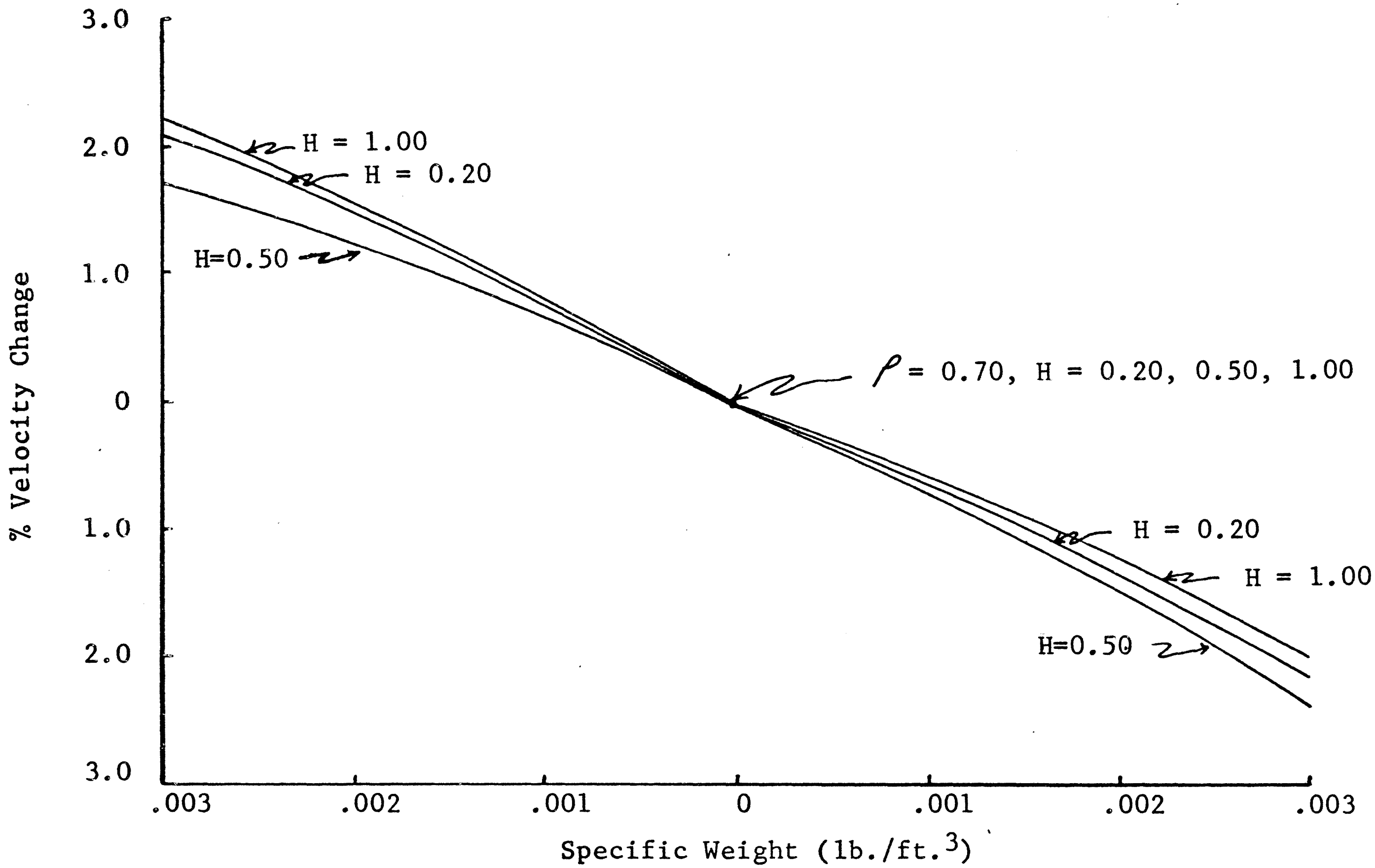

Figure 7. Change in specific weight vs. per cent change in velocity.

a change in velocity of less than 1%; therefore, it is felt that relative humidity can be omitted from the calculations of specific weight without any appreciable effect on velocity.

A COMPUTER PROGRAM FOR AN EQUATION OF

WIND VELOCITY PROFILES FROM ZERO TO THIRTY FEET

by

Charles Brame Ogburn

ABSTRACT

Years of research have been devoted to the understanding of the structure and nature of natural wind and to the development of theories which can be applied to the design of buildings and other structures. Extensive studies of the velocity profile of wind have been made from the ground to the stratosphere, but investigators have concentrated on the winds above thirty feet. It has been from the studies in excess of thirty feet that the most recent concepts for deriving design velocities have been obtained.

Structures used in agricultural enterprises are usually low-profile structures being located in the lower thirty feet of the atmosphere. For this reason, this investigation was undertaken to measure the wind velocities in the lower thirty feet of the atmosphere and to develop a computer program whose output would be an equation for the vertical profile of the measured wind velocities. It was felt that this information would be of great value in the study of wind pressure distributions on a prototype building, and also in the wind tunnel model tests of the prototype.

Velocity measurements were made with four pitot tubes mounted on a thirty-foot mast at intervals of eight feet along the mast. Velocity

pressures were recorded instantaneously from all the pitot tubes by an oscillograph.

The data recorded were entered into a computer program for multiple regression coefficients. The output was the intercept, K, and the slope, $1/\alpha$, for a velocity profile with an equation of the general form,

$$V = KZ^{1/\alpha}$$

Where: V = velocity at height Z,

K = intercept,

$1/\alpha$ = slope.

The statistical analysis on the fit of the profile equation, obtained from the computer, to the velocities recorded for this investigation showed a high significance value.

It was concluded that wind velocity measurements could be obtained by pitot tubes with reasonable accuracy in the lower thirty feet of the atmosphere, and that these velocity data could be entered into a computer program which would yield an output of a velocity profile equation that could be used with confidence.