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EFFECT OF A WIND PROTECTION DEVICE ON VENTILATION FAN PERFORMANCE

by

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INTRODUCTION

Confinement housing has emerged during the last two decades as a very economical method of producing livestock. Confinement housing has helped to overcome predation, monitor disease, moderate effects of weather, and facilitate management. Sufficient ventilation is very important in the management of a confined livestock production system. The ventilation system plays an integral part in confinement housing, as there is a greater need to properly remove excess heat, moisture, gases, and particulates. Exhaust fans are used to dilute the air in most mechanical ventilation systems. Recirculation of inside air is impractical for livestock systems due to high concentrations of pollutants and particulates. This exchange of air is necessary throughout the year to control air quality and humidity within the livestock facility, but lower exhaust airflows are desired during colder weather to conserve heat. These lower exhaust airflows are provided by relatively small single-, multi, or variable-speed fans. The performance of these small fans may be significantly affected when exhausting into a wind. Decreased fan performance will affect livestock growth and productivity due to insufficient ventilation.

A windbreak, a hood, an elbow, or a cone shaped wind diverter located outside the fan outlet may be used to reduce these detrimental wind effects. Two important factors must be considered when evaluating the performance of a wind protection device:

1. Decreased fan performance due to added airflow resistance created

by the wind protection device.

2. Increased fan performance in oncoming winds due to the wind protection device.

A need to thoroughly study the wind effects on ventilation fan performance was identified, as livestock producers have become more aware of detrimental effects of strong winds on the performance of their mechanical ventilation systems. The evaluation and development of wind protection devices is therefore important to the livestock industry. The problems associated with wind effects on ventilation fans were delineated as follows:

1. Wind is detrimental to the performance of ventilation fans, especially variable speed fans.
2. Kansas farmers need efficient ventilation fans.
3. Experimental data on wind protection devices is lacking.
4. The economic benefit of wind protection devices is uncertain.

Since research has not been published on wind protection, this research was initiated to provide experimental data on the performance of a commercially produced wind protector for fans.

A fan testing facility is required to properly evaluate the performance of ventilation fans. Fan performance can be evaluated with a properly designed fan test facility in still ambient air and in various wind velocities created by a wind tunnel. The first part of this thesis describes the development of a fan testing facility. The second part is an investigation of the effects of wind on fan performance, and the evaluation and development of wind protection devices. The specific research objectives were to:

1. Develop a fan testing facility in accordance with the Air Movement Control Association Standard 210-85,
2. Evaluate the effect of a commercially available, cone shaped, wind diverter on the performance of exhaust fans facing into a wind,
3. Evaluate the effects of various design parameters of the wind diverter on fan performance, and
4. Improve the design of the wind diverter.

LITERATURE REVIEW

Ventilation Systems

There are two types of ventilation systems in common use today. One is a negative pressure system and the other is a pressurized system. Fans are used to exhaust air from a building in the negative pressure system, creating a slight negative pressure inside the building. The pressurized system uses fans to force air into the building, thus creating a slight positive pressure inside the building. Mitchell (1975) reports that a negative pressure system is the primary system used in livestock ventilation for the following reasons:

1. A negative pressure system provides for uniform air distribution throughout the building and better mixing of cold incoming air with warm inside air during cold weather than a pressurized system.
2. A pressurized system limits the number and sizes of fans that can be used while a negative pressure system does not.
3. Condensation within the wall sections is less likely to occur with a negative pressure ventilation system.

The fan is the "heart" of a mechanical ventilation system (Shelton and Bodman, 1983a). An understanding of basic fan design and operation is therefore important in the selection and management of a mechanical ventilation system. The most efficient use of energy by a fan and satisfactory overall performance requires that all components of a ventilation system are carefully designed, selected, installed and managed. Livestock ventilation fans operate under severe environmental conditions

(Person et al., 1979). Thus, it is essential that fans be selected carefully, as most modern ventilation systems are designed to meet both winter and summertime airflow requirements. Ventilation is needed during the winter months to exhaust moisture, and prevent the accumulation of odors and dust, without carrying away too much heat. The ventilation system is used in the summer to remove the heat generated by the livestock as well as the solar heat absorbed by the building (Mitchell, 1975). The Midwest Plan Service (1983) explained the importance of proper ventilation in this way: "If air is not replaced in livestock housing, the air composition changes, and the concentration of carbon dioxide and other harmful gases increases to the danger level".

The fan's performance is often impeded by various sources of resistance. The resistance to airflow occurs throughout the entire ventilation system, including exterior air inlets, baffled inlet slots, building space, fan safety screens, fan housing, fan blades, louvered shutters, and exterior weather hoods, with this system resistance typically amounting to about 25 Pa to 31 Pa (0.10 to .125 in wg). Person et al. (1979) examined the effect of dirt, louvers, and other attachments on fan performance. It was found in this study that louvers had the most substantial effect on fan performance, as louvers decreased total fan efficiency and fan discharge. Results of tests also indicated that the collection of dust, moisture, and other contaminants on various fan components resulted in adverse environmental conditions and excessive energy consumption. Thus, an efficient livestock ventilation system must utilize proper types and sizes of fans and be well managed.

Fans

Axial flow, or propeller fans are predominantly used in mechanical ventilation of agricultural buildings. In an axial flow fan, air flows through the fan parallel to the shaft on which the fan blades are mounted. The propeller fan is a subclass of axial flow fans and consists of two or more blades attached to a central hub, usually driven by a motor. Propeller fans are limited to low pressure difference applications and function to move large quantities of air, rather than to generate significant total pressure differences. (Pratt et al., 1983). Osborne (1966) recommended that propeller fans not be used against static pressures greater than 124 Pa (0.5 in of water). The usual field of application is with small units of equipment and simple ventilation systems requiring little or no duct work. Propeller fans are therefore well suited for ventilation of agricultural buildings with static pressures ranging from 12.4 to 31.0 Pascals. The design of propeller fans is very important due to relatively poor pressure characteristics.

An important design consideration is blade tip clearance. A small, uniform clearance is the most desirable (Pratt et al., 1983). Small tip clearances prevent air from short-circuiting back around the propeller. A small back pressure can significantly lower the air flow rate of propeller fans.

Air leaves the blades of a propeller fan in a circular discharge pattern due to the twisting motion imparted by the blades. The propeller fan functions in a way such that the leading edge of the fan blade picks up the air, accelerates it and discharges it from the trailing edge with a helical path advancing in an axial direction. As static pressure on the fan increases, the fan's performance becomes unstable. Baumeister (1935) noted that as static pressure increases, the centrifugal force component of acceleration becomes more pronounced. This centrifugal force effect is evidenced by the tendency of the air to slip out radially along the fan blades. The flow of air through a propeller fan is axial in the higher capacity region, but as the capacity decreases, the centrifugal effect, and consequent radial-flow component, becomes larger. The effect of this increase in the centrifugal force element causes the fan to experience an unstable region of operation, indicated by a point of inflection in the fan characteristic. Eck (1973) provides a detailed explanation of the processes involved in the creation of this unstable region.

Careful design and selection of the propeller fan is imperative due to its unique behavior. Fan efficiency and fan load are among the important parameters. The importance of fan efficiency, the effect of load on input power, and efforts to improve fan motor efficiency were reported by Hoffmeister (1980). One measure of fan efficiency is the volume of air moved per unit of energy input, commonly referred to as the Ventilating Efficiency Ratio (VER). VER ratings for fans range from 5 to 25, with most being in the 10 to 15 range (Shelton and Bodman, 1983b). Fan performance is dependent on fan slippage. All fans have slippage and thus are not completely efficient in transferring energy to air. Propeller fans are about 40 percent efficient. This slippage leads to the necessity for experimentally determining fan characteristic curves (Pratt et al. 1983).

Fan Testing

Fan performance tests are an experimental means of evaluating airflow performance, mechanical characteristics, sound levels, and vibration characteristics (Shahan, 1985). Each of these fan characteristics are important, but airflow performance directly indicates the fan's main function of moving air. The Air Movement and Control Association (AMCA) serves as an authority on fan performance. AMCA is a non-profit trade association made up of manufacturers of fans, louvers, dampers and shutters. The purpose of the AMCA Certified Ratings Program is to assure the buyer, specifier, and user that published ratings of air moving equipment are reliable and accurate (Cruse, 1976). Performance data from an AMCA-certified fan were obtained with a fan test which conformed to facilities and procedures approved by AMCA (Metzger et al., 1981). According to Pratt et al. (1983), the AMCA Certified Ratings Program provides the following features:

1. A published standard that defines procedures and conditions for testing fans. This standard allows different manufacturers to compare ratings of fans.
2. Continuing check tests of licensed products, challenge tests brought by competing manufacturers, and periodic check tests of AMCA-approved fan test facilities.

Following defined procedures and conditions does not in itself guarantee reliable performance data. However, fan installation should be free from significant flow separations and possess approximately axisymmetric flow conditions through the installation. The best experimental procedures will not produce reliable performance data unless this condition is fulfilled (Ruglen, 1973).

Fan Laws

Fan laws express the relationships among the performance variables for any two fans that have similar flow conditions. Jorgenson (1983) reported that the fan laws are a particular version of the more general similarity laws that apply to all classes of turbomachinery. The fan laws can be used to predict the performance of a fan, provided that the performance at the corresponding points of rating for a homologous fan are known. According to Pratt et al. (1983), fan laws can be used to predict air flow rate (Q), power (W), and pressure difference (ΔP) as functions of fan diameter (D), air density (ρ) and rotational speed (RPM). The fan laws have their origin in classical fluid mechanics, and are presented in several references (Jorgenson, 1983; AMCA, 1985; Furse, 1963; Pratt et al., 1983). In general, the three basic equations are as follows:

$$Q_2 = Q_1 \left(\frac{RPM_2}{RPM_1}\right) \left(\frac{D_2}{D_1}\right)^3$$

$$W_2 = W_1 \left(\frac{RPM_2}{RPM_1}\right)^3 \left(\frac{D_2}{D_1}\right)^5 \left(\frac{\rho_2}{\rho_1}\right)$$

$$P_2 = P_1 \left(\frac{RPM_2}{RPM_1}\right)^2 \left(\frac{D_2}{D_1}\right)^2 \left(\frac{\rho_2}{\rho_1}\right)$$

These equations can be used within the following limitations:

1. The fan laws are restricted to homologous fans.
2. The fan laws should only be used to go up in fan blade diameter.
3. The fan laws should not be used to extrapolate results if the diameter ratio (D_2 / D_1) or speed ratio (RPM_2 / RPM_1) is greater than three, or if the product of the two is greater than three.

Furse (1963) reports that two fans are said to be geometrically similar if they are similar in shape with their various dimensions related by a constant of proportionality. Two fans are homologous when they are geometrically similar and when the fluid flow velocity vector diagrams within the fans are similar (corresponding vector magnitudes related by a constant of proportionality). Jorgenson (1983) adds to this definition by stating that two or more homologous fans are said to be operating at corresponding points of rating if the positions of the operating points, relative to shutoff and free delivery, are the same.

Wind Effects on Livestock Ventilation Systems and Fan Performance

The airflow rate for a confined livestock ventilation system must be adjustable to accommodate changes in the wind velocity and direction in addition to the fluctuations in the temperature and humidity of the inside and outside air (Hinrichs and Wolfert, 1977). The wind velocity determines the amount of pressure exerted against the building, with the pressure being positive, negative or neutral. The wind velocity pressure increases with the square of wind speed and is expressed by a modified version of the Bernoulli Equation:

$$H_v = 248.36 * (\frac{V}{2034.54})^2$$

where

H_v = velocity pressure (Pa)

V = mean velocity of flow (cm/s)

The relation of velocity pressures corresponding to several wind speeds were calculated, Table 1.

TABLE 1. Relation of wind speed to velocity pressure

Wind Speed (mps)	Velocity (cm/s)	Pressure (Pa)
2.2	223	3.0
4.4	447	12.0
6.7	671	27.1
8.9	894	47.9
11.2	1118	75.0
13.4	1341	108.0

Frost (1973) has shown that wind speeds can range from zero to maximum in less than one second, thus causing a reversal from positive to negative pressure. Winds in the field are extremely turbulent near the ground with continual and random changes in direction and speed both horizontally and vertically. A wind assessment study by Johnson (1982) has shown that in the central United States the maximum wind speeds near ground level are normally experienced in the early afternoon and the minimum wind speeds sometime after midnight, with the average wind speed between 5.3 and 6.3 mps for a 10 m tower.

Hinrichs and Wolfert (1977) found that the wind is constantly changing direction, with normal time intervals ranging from 2.5 to 6 minutes. They also found that the concept of "prevailing wind" is not compatible with present day confinement housing for the following reasons:

1. The wind is constantly changing directions so that a "prevailing wind" is effective only part of the time, whereas ventilating performance needs to be constant throughout the 24 hour day.
2. Field investigations of ventilating problems have determined that the "prevailing wind" concept was actually responsible for some of the poor performance of the systems studied.

In evaluating the performance of a fan within a ventilation system, the positive or negative pressures produced by the fans are added to or subtracted from the negative or positive pressures exerted by the wind. "Thus, a shift in wind direction or fluctuation in wind velocity can change, substantially, the pressure across a specific vent or fan "(Hinrichs and Wolfert, 1977).

Much of the work already completed on the effect of wind on structures such as a livestock structure has been done in a wind tunnel. Simiu and Scanlon (1986) examined wind loads and their effects on structures, including bluff-body aerodynamics, flow separation, and wakes. Sachs (1972) also has performed extensive work on static and dynamic wind effects on engineering structures. There are some apparent differences between wind tunnel results and actual field conditions. Frost (1973) states "patterns of pressure distributions, although having a general similarity, show some differences from wind tunnel data." It was also reported that "extrapolation of wind tunnel data to extremely turbulent and gusty real winds introduces unavoidable uncertainties in our knowledge of flow around full scale buildings. Nevertheless, wind tunnel tests continue to be the principle source of data and to provide physical insight into the flow near structures."

Weibull Distribution of Wind Speed Frequency Curve

Wind speed fluctuates significantly, thus making it difficult to accurately determine wind effects on structures and fan performance. A frequency curve is often used to describe wind speed. Certain statistical distributions have been shown to fit the wind speed frequency curve fairly well to data collected over an extended time period. Among these statistical distributions is the Weibull distribution. The Weibull distribution is a special case of the Pearson type III or generalized gamma distribution (Johnson, 1985). In general, the wind speed, μ, is distributed as the Weibull distribution if its probability density function is:

$$f(\mu) = \frac{k}{c}\left(\frac{\mu}{c}\right)^{k-1}\exp\left[-\left(\frac{\mu}{c}\right)^{k}\right] \qquad (k > 0,\ \mu > 0,\ c > 1)$$

The Weibull distribution is a two parameter distribution where c and k are the scale and shape parameters, respectively. As k increases, the Weibull density function narrows and peaks with the maximum shifting in the direction of higher wind speeds. The Weibull usually fits the observed data reasonably well for periods of several weeks to a year or more. The Weibull distribution function $F(\mu)$ is:

$$F(\mu) = 1 - \exp[-(\frac{\mu}{c})^k]$$

The variance of the Weibull density function is:

$$\sigma^2 = c^2[\Gamma(1 + \frac{2}{k}) - \Gamma^2(1 + \frac{1}{k})] = \frac{\mu^2\Gamma(1 + 2/k)}{\Gamma^2(1 + 1/k)} - 1$$

The probability of the wind speed, μ, being equal to or greater than μ_a is:

$$P(\mu \geq \mu_a) = \int_{\mu_a}^{\infty} f(\mu)d\mu = \exp[-(\frac{\mu_a}{c})^k]$$

The probability of the wind speed occurring within a 1 mps interval centered on the wind speed μ_a is:

$$P(\mu_a - 0.5 \leq \mu \leq \mu_a + 0.5) = \begin{cases} \displaystyle\int_{\mu_a-0.5}^{\mu_a+0.5} f(\mu)d\mu \\ = \exp[-(\frac{\mu - 0.5}{c})^k] - \exp[-(\frac{\mu + 0.5}{c})^k] \end{cases}$$

For the central United States, Johnson (1982) has shown that the average Weibull shape parameter, k, for 10 m high towers, was 2.10.

DEVELOPMENT OF A VENTILATION FAN TESTING FACILITY

Introduction

Confinement housing for livestock requires either natural or mechanical ventilation. In the case of mechanical ventilation, fans provide the primary means of exhausting excess heat, moisture, gases, and particulates. A properly designed ventilation system is a necessity for the management of the system. An understanding of how the fan performs is a major requirement to good design. Fans are less than 100% efficient in transferring energy to air, due to fan slippage. Fan characteristics are unique for each type of fan, thus leading to the need for experimentally determining fan performance. The first part of this study is the development of a fan testing facility for experimentally determining fan performance.

A fan testing facility provides an experimental means of determining fan performance. Fan manufacturers do not know how well their fans perform without having fan performance experimentally determined in a laboratory facility. Results based only on the performance of the fan blade are often reported.. The fan blade performance is not truly indicative of how the total fan system will operate. The overall fan performance is also dependent on fan housing and shape, fan blade tip clearance, and motor specifications and performance.

This report describes the steps that were necessary to construct a fan testing facility for use in testing axial flow fans used for exhaust ventilation, ranging in size from 20.3 cm (8 in) to 61.0 cm (24 in) in diameter. The design of the Kansas State University fan test chamber followed the standards set forth in the AMCA Standard 210-85 of the Air Movement and Control Association (AMCA, 1985). This standard establishes uniform methods for laboratory testing of fans to determine their performance in terms of flow rate, pressure, power, air density, speed of rotation, and efficiency. The objective of this portion of the study was to develop a fan testing facility which is:

1. In accordance with AMCA Standard 210-85,
2. Capable of becoming a certified fan testing laboratory, and
3. Convenient for use in wind tunnel studies.

Research Facilities and Procedure

Procedure

Fan Test Chamber Standards.

An inlet chamber design was selected from the AMCA Standard 210-85 for Laboratory Methods of Testing Fans (AMCA, 1985), Figure 1.

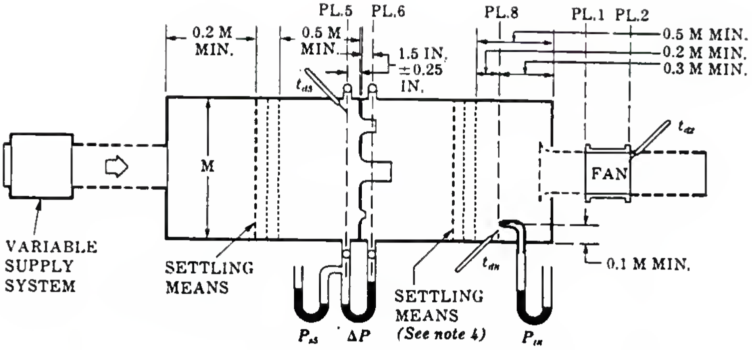


Figure 1. Inlet chamber setup - multiple nozzles in chamber.

The selection of an inlet chamber employing nozzles to measure fan airflow rate was based on the fact that this study involved only exhaust fans. Burkhardt (1976) reported that multi-nozzle inlet chambers were considered to simulate an installation of a fan exhausting air from a duct system or building. AMCA standards require that certain specifications and dimensions be observed. The cross sectional area of the inlet chamber must be at least five times the fan inlet area. The remaining dimensions for a rectangular inlet chamber are then calculated on the basis of an equivalent diameter, M:

$$M = \sqrt{4ab/\pi}$$

where a = height (cm)

b = width (cm)

Flow settling means must be installed within the inlet chamber to provide proper airflow patterns. Settling means are any combinations of screens or perforated plates that will insure uniform airflow patterns. The air velocity profile throughout a cross section of the chamber must be fairly uniform with a small variance between the velocities. In the case where a measuring plane is located downstream of the settling means, the settling means are provided to insure a substantially uniform air flow ahead of the measuring plane. The maximum velocity at a distance of 0.1 M (approximately 18 cm) downstream of the screen, Figure 1, shall not exceed the average velocity by more than 25% unless the maximum velocity is less than 2.03 mps (400 fpm). When a measuring plane is located upstream of the settling means, the settling means are provided to absorb the kinetic energy of the upstream jet and allow its normal expansion as if in an unconfined space. The maximum reverse velocity shall not exceed 10% of the calculated mean jet velocity. AMCA suggests settling means consist of several screens of square mesh round wire with open areas of 50% to 60%.

The flow rate is calculated from the pressure differential generated across a bank of nozzles. Nozzles are selected so that the average velocity at the nozzle discharge corresponding to the flow rate at free delivery is at least 14.2 mps (2800 fpm). AMCA Standard 210-85 also specified that the centerline of each nozzle shall be at least 1.5 nozzle throat diameters from the chamber wall and the minimum distance between centers of any two nozzles in simultaneous use shall be three times the throat diameter of the larger nozzle.

KSU Fan Test Chamber.

The KSU fan test chamber was built according to the standards specified by AMCA along with additional project constraints. The largest fan to be tested was Agri-Aide's 61.0 cm (24 in) axial flow fan with a fan inlet area of 5058 cm^2 (784 in^2). The cross sectional area of the chamber must be greater than 5 X 5058 $cm^2 = 25290$ cm^2 (3920 in^2). A rectangular cross section was preferred. Nearly square dimensions were desired to create a more uniform airflow throughout the cross section. The inlet chamber was selected to have inside dimensions of width = 167.6 cm (66 in) and height = 152.4 cm (60 in) giving an overall cross sectional area of 25548 cm^2, which is greater than the required 25290 cm^2 (3960 $in^2 > 3920$ in^2). The equivalent diameter, M, for the KSU inlet chamber was calculated as follows:

$$M = \sqrt{4ab/\pi} = \sqrt{4(152.4)(167.6)/\pi} = 180.4 \text{ cm. } (71.0 \text{ inches})$$

where a = height (cm)
b = width (cm)

The desire to conduct wind effects studies using a wind tunnel at the USDA Wind Erosion Laboratory raised additional concerns. Other restrictions besides fan inlet area were considered in determining the size of the inlet chamber. The length of the chamber could not exceed about 4.9 m (16 ft). This limitation on length was imposed by the physical dimensions of the "dust room" at the USDA Wind Erosion Laboratory, where the later study on wind protection devices would take place. Another factor to be considered was that it was desired to construct a chamber with manageable dimensions in order to keep the cost down and facilitate physical maneuvering of the chamber. Portability and the ability to adjust the height of the fan test chamber were also considered to be important for the testing at the wind tunnel. Adjustable jacks and wheels were employed to aid in these measures.

The number of settling means was also a factor to be considered prior to determining the overall chamber dimensions. It was decided that there would be five settling screens or perforated plates in front of the nozzle bank (closest to the supply fan) with the percent open area to be 60% in the first screen, 55% in the second screen, 50% in the third and fourth screens, and 45% in the fifth screen. The settling means in front of the test fan would consist of three screens or perforated plates with the percent open area to be 60% in the first screen, 50% in the second screen, and 45% in the third screen.

The number and sizes of nozzles was also considered prior to determining the dimensions of the inlet chamber. The fan test chamber was to be used to test fans over a range of airflows from 0 to 3070 Lps (0 to 6500 cfm) and static pressures up to 620 Pa (2.5 in wg). Nine nozzles were selected on the basis of these criteria. In an effort to minimize cash outlay, three aluminum nozzles and six fiberglass nozzles were obtained from the inventory of the Agricultural Engineering Department at Kansas State University and Osborne Industries, respectively. The nozzles selected were four 2.07 cm (5.25 in) and two 2.31 cm (5.87 in) diameter fiberglass nozzles, one 0.79 cm (2.0 in), one 1.18 cm (3.0 in), and one 1.57 cm (4.0 in) diameter aluminum nozzles. Each of these nozzles were then positioned in accordance with AMCA Standard 210-85 as symmetrically as possible, giving a total nozzle discharge area open for airflow of .1055 m^2 (1.135 ft^2). The remaining dimensions of the chamber were then determined using the equivalent diameter, M, and by AMCA specifications and project imposed constraints.

Construction.

The Kansas State University fan test chamber was constructed with plywood, using angle iron spaced every 6.30 cm (16 inches) to provide rigidity. The interior of the chamber was painted to seal tiny holes and cracks and to provide a professional appearance, and plexiglass windows were installed for viewing the interior. An adjustable roof was also added to simulate actual field conditions and aerodynamics. Details of the construction and materials are given in Figures 2 and 3.

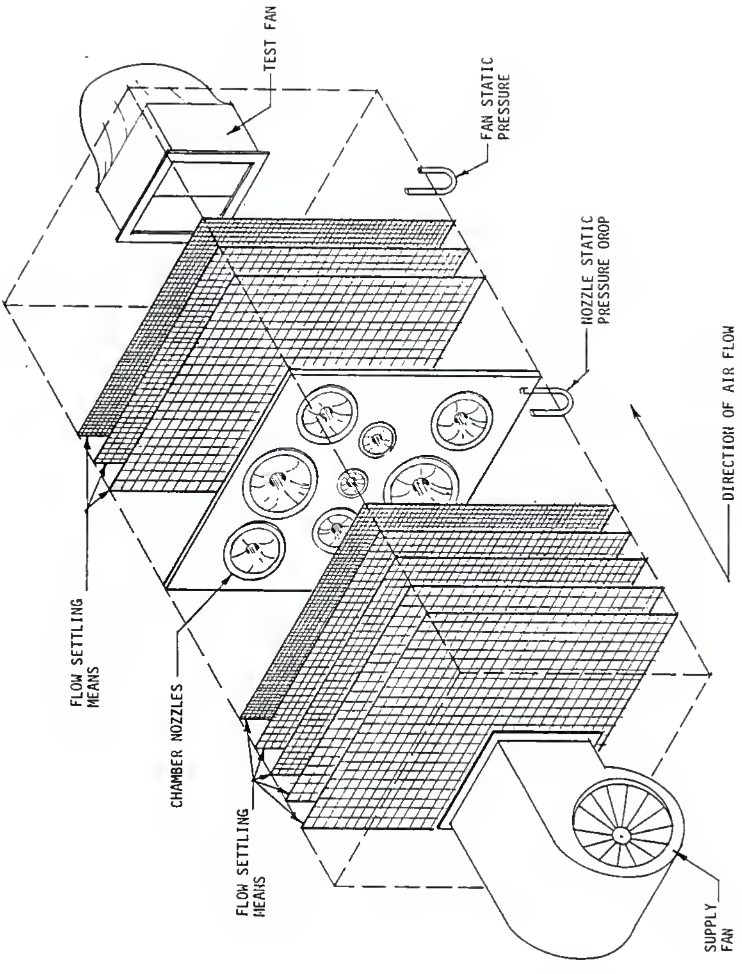


Figure 2. Detail of KSU fan test chamber components

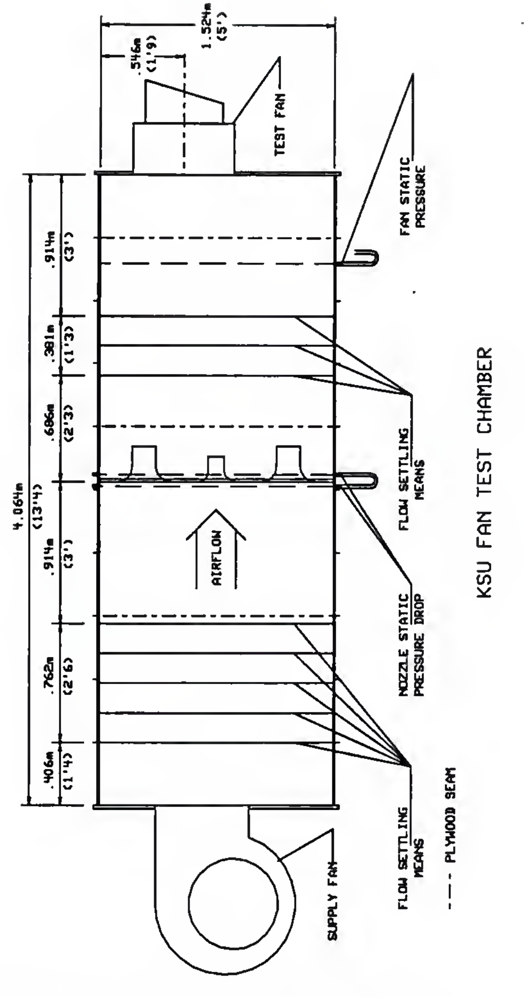


Figure 3. KSU fan test chamber dimensions

Instrumentation.

The chamber was instrumented upon completion of the chamber's construction. A Buffalo Forge Belted Vent Set (Model 375B) centrifugal fan was used as the supply system for the chamber. Since the output from the centrifugal supply fan must cover a wide range of airflows for the various testing conditions, there was a need for some means of controlling the amount of air supplied. Therefore, a set of variable inlet vanes was purchased for the inlet of the supply fan. These variable inlet vanes throttled and controlled the airflow by means of opening or closing the vanes. An adjustable sliding gate was installed on the chamber wall, over a slot beside the supply fan, to allow excess airflow to escape. The gear motor used to operate the gate was slow enough to provide a more precise control of the supply air, as the variable inlet vanes were a rough control mechanism.

Three piezometer rings were installed around the cross-sectional perimeter of the chamber in accordance with AMCA standards (AMCA, 1985). The AMCA standard specifies the dimensions and construction of static pressure taps, Figure 4. Figure 5 is a cross-sectional view of one of the twelve static pressure taps constructed for the KSU fan test chamber. Each of the static pressure taps were constructed of oak and the pores in the wood sealed with a varnish.

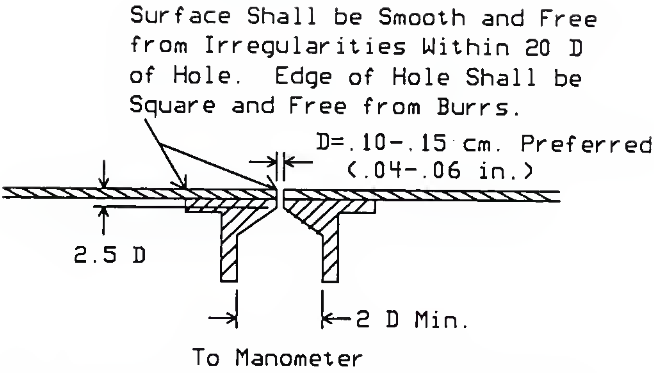


Figure 4. AMCA specifications for static pressure taps

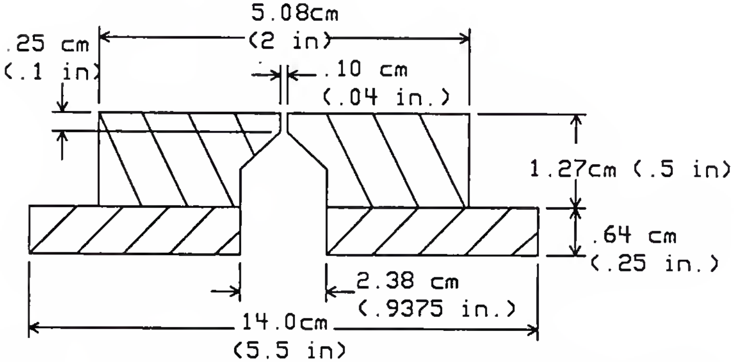


Figure 5. Static pressure taps employed in the KSU fan test chamber

Each piezometer ring consisted of four static pressure taps, one on each side of the chamber, to obtain an average static pressure across the cross section of the chamber. The pressure differentials were measured with a micromanometer on each piezometer ring. Power measurements of the test fan motor were also very important, particularly for the Ventilating Efficiency Ratio (VER). The VER is a ratio of what comes out of the fan (airflow) compared to what goes into the fan (electricity). A digital volt-amp-watt meter (Clarke-Hess Model 256) was purchased for these power measurements. An Ametek Model 1736 photoelectric tachometer was employed for the measurement of fan rotational speed. The photoelectric tachometer measured fan rotational speed using a reflected beam of light. A 0-240 volt variac was used to supply a constant voltage to the test fan.

Testing of Chamber Performance.

The performance of the fan testing facility was evaluated following full instrumentation of the inlet chamber. Many small leaks around joints and through small cracks in the chamber walls were found using smoke candles and soap bubbles and were sealed with silicone sealant.

Settling Means. Two main concerns surfaced upon arrival of the completed chamber to the Agricultural Engineering Department at KSU. The first concern centered on the settling means, as the installed perforated plates consisted of large punched holes with large solid areas between the holes, Figure 6.

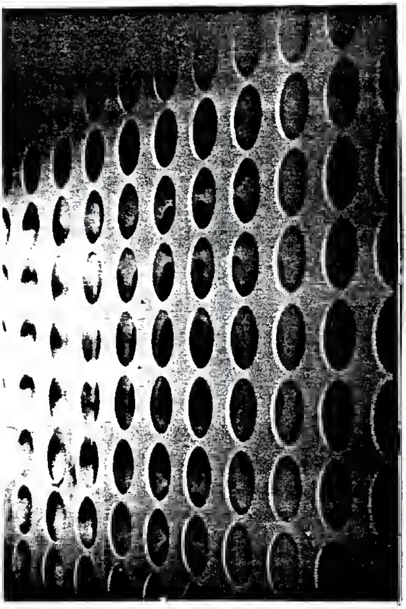


Figure 6. Initial settling means - perforated plates

The performance of such plates was a particular concern downstream of the nozzle discharge. Due to the relatively high air velocities at the nozzle discharge, there was some question as to whether these perforated plates would be able to provide a uniform air velocity profile across the chamber cross section. Even though the maximum velocity anticipated for this study was below the 2.03 mps velocity specified in AMCA Standard 210-85, AMCA recommended that the air velocity profile still be tested (Bhatt, 1987). Velocity profiles taken across the chamber substantiated the failure of the plates to properly distribute the airflow.

A wide discrepancy in the air velocities was observed across the chamber, thus establishing that the perforated plates did not meet standards established by AMCA.

The velocities collected in the initial profile were point velocities and did not represent equal areas. Therefore, the resultant mean for the profile was calculated by weighting the results according to the area represented. The resultant means, variance between samples, and number of violations for the initial air velocity profile and subsequent profiles are summarized in Table 2, following discussion of all of the velocity profiles collected, while Appendix A contains the test results in tabular form.

Additional settling means constructed of fine, round wire, square mesh, aluminum, window screening were added in an effort to correct the problem and properly distribute the air flow. A thorough examination of the flow nozzles was undertaken while the chamber was disassembled, due to some question concerning their conformity to AMCA standards. The investigation revealed that eight of the nine initial flow nozzles failed to meet standards established by AMCA. A set of new nozzles meeting AMCA Standards were obtained and installed in place of the original nozzles. An air velocity profile with the new nozzles and without any additional screens (Run #1) was collected. This data again showed that the air was not being dispersed across the chamber in a uniform manner (high velocities directly in front of the nozzles and lower velocities elsewhere), Table 2.

One set of additional screens was installed upstream and downstream of the settling means closest to the supply fan, while one set downstream and three sets upstream of the settling means closest to the test fan were installed for Run #2. The analysis of this data indicated a marked improvement as the air velocities were more evenly distributed, but still indicated some high velocity points (especially at the measuring plane downstream of the settling means closest to the test fan). One additional profile test was conducted with all of the additional screens installed (four additional screens upstream of the settling means closest to the test fan). These results (Run #3) were similar to Run #2, as there still existed some high velocity points, but it was felt that this combination gave the "best" results, Table 2.

Velocity profiles were also collected at the measurement plane downstream of the settling means closest to the supply fan and at the measurement plane upstream of the settling means closest to the test fan. The initial results obtained at these two measurement planes indicated that the violations were few and small in magnitude. Therefore, extensive velocity profiles were not collected at these two measurement planes, as the velocity distributions were considered to be satisfactory. Figure 7 illustrates the location of each sampling point and a key to the notation employed to designate each collection point.

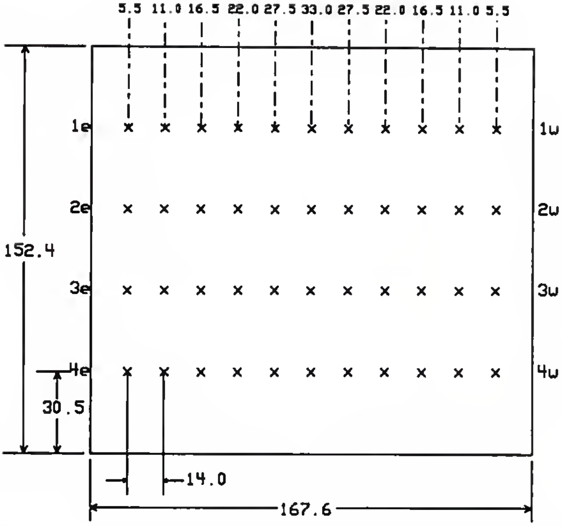


Figure 7. Location of sampling points for air velocity profiles

Key to Notation of Sampling Points:

tf - measuring plane downstream of settling means closest to test fan.

nd - measuring plane upstream of settling means closest to test fan.

nu - measuring plane downstream of settling means closest to supply fan.

le-4e - vertical location of sampling point from east side of chamber.

lw-4w - vertical location of sampling point from west side of chamber.

5.5-33.0 - horizontal location of sampling point from east and west.

The improvements made to the settling means were satisfactory, but were considered to be only a temporary solution. New settling means, constructed of a round wire square mesh screen, with varying percent open area, were purchased, Figure 8.

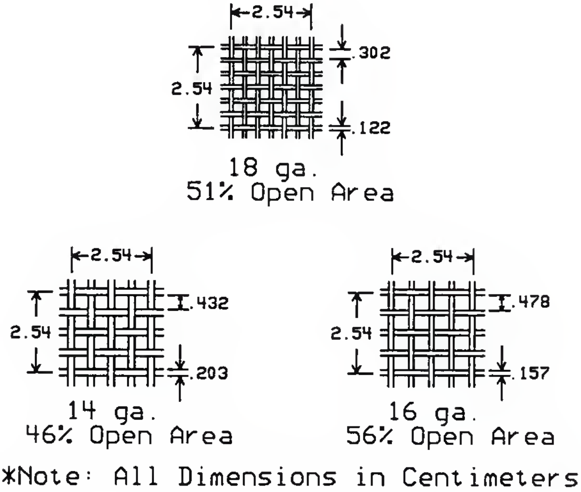


Figure 8. Details of round-wire square-mesh settling means

The initial settling means were removed and replaced with the new settling means and the measurement of air velocity profiles were repeated. The results indicated a large variance in air velocities across the chamber, with the highest velocities occurring directly in front of the open nozzles. Screen patches were attached to the settling means directly in front of the nozzles and one full-size window screen was reinstalled. The velocity profiles showed a marked improvement, but still indicated a fairly large variance. Therefore, round screen patches were attached to the screen directly in front of each nozzle and additional full-size window screens were installed. These conditions provided greater uniformity across the chamber, as the variance in the air velocity profile and the number of points exceeding AMCA limits were small. It was felt that these modifications and additions created an environment that was suitable for obtaining accurate test results. One velocity profile was also obtained at measuring plane "nu", downstream of the settling means closest to the test fan. The results indicated a few minor violations, so a rectangular screen patch was attached to the screen directly in front of the supply fan, to distribute the incoming air. Additional air velocity profiles were not collected at measuring planes "nu" and "nd", upstream of the settling means closest to the test fan, due to time constraints.

TABLE 2. Means and variance of air velocities at the three measurement planes within the KSU fan test chamber.

Settling Means	Measurement Plane								
	tf			nd			nu		
Initial	μ	σ^2	n	μ	σ^2	n	μ	σ^2	n
Perf. Plates	.422	.048	13	.246	.007	0	.444	.004	2
New Nozzles	.422	.013	6	.240	.006	0	.392	.005	4
6 Added Screens	.422	.017	8	-	-	-	.405	.006	3
8 Added Screens	.422	.014	8	-	-	-	.378	.006	5
New									
Wire Mesh Only	.480	.643	18	-	-	-	.396	.010	7
1 Added Screen & Downstream Patches	.418	.038	17	-	-	-	-	-	-
2 Added Screens & Additional Patches	.387	.006	8	-	-	-	-	-	-

where:

\------

tf - measuring plane downstream of settling means closest to test fan

nd - measuring plane upstream of settling means closest to test fan

nu - measuring plane downstream of settling means closest to supply fan

μ - mean velocity when weighted by area

σ^2 - variance of point velocities

n - number of violations according to AMCA Standard 210

Flow Nozzles. The next concern to arise centered on the set of nozzles in the chamber. The nozzles chosen were never properly examined in accordance with AMCA standards. In order to calculate the airflow through nozzles, as presented in AMCA Standard 210-85, the nozzles must conform to certain specifications, as illustrated in Figure 9.

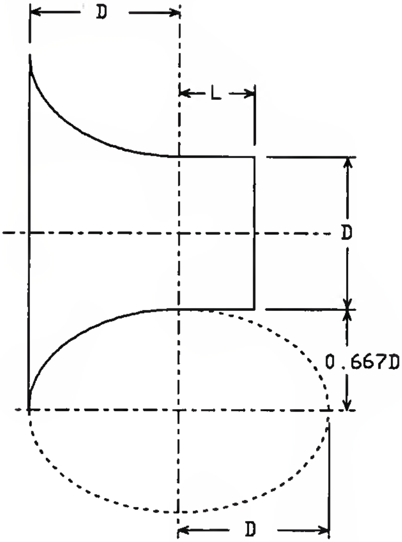


Figure 9. AMCA nozzle specifications

All of the fiberglass nozzles and two of the aluminum nozzles failed to meet the standards. Seven aluminum spun nozzles, designed in accordance with AMCA standards, were purchased and repositioned to meet the spacing requirements. The total nozzle discharge area open for airflow was now adjusted to .105 m^2 (1.131 ft^2), Figure 10.

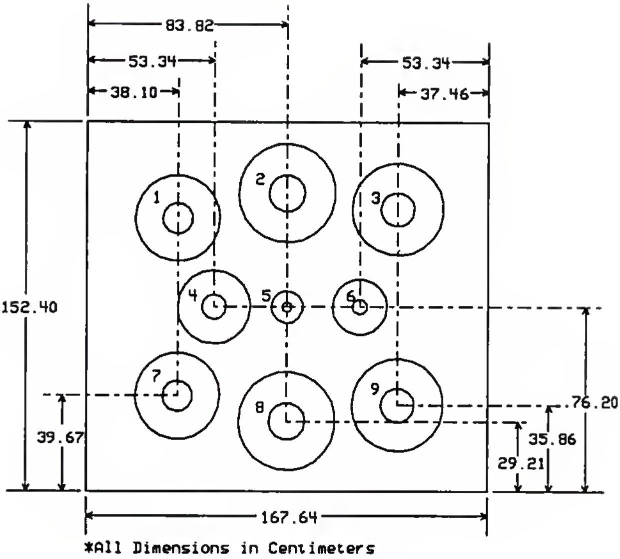


Figure 10. Nozzle dimensions and locations

Nozzle Dimensions

Nozzle Number	Throat Diameter (cm)	Outside Diameter (cm)	L/D Ratio
1	12.70 (5.0")	35.56 (14.0")	.6
2	15.24 (6.0")	40.64 (16.0")	.5
3	13.97 (5.5")	38.10 (15.0")	.6
4	10.16 (4.0")	30.48 (12.0")	.6
5	4.06 (1.6")	13.33 (5.25")	.6
6	6.35 (2.5")	22.86 (9.0")	.6
7	12.70 (5.0")	35.56 (14.0")	.6
8	15.24 (6.0")	40.64 (16.0")	.5
9	13.97 (5.5")	38.10 (15.0")	.6

Data Acquisition System.

A Zenith Z150 personal computer (IBM compatible) was selected to be the core of the data acquisition system. A personal computer and data acquisition program were a necessity, as the calculation of fan airflow was dependent on many inputs. These inputs included atmospheric conditions, pressure measurements, and nozzle selection information. The atmospheric conditions necessary included dry-bulb temperature, wet-bulb temperature, and barometric pressure. The pressure measurements necessary were the static pressure differential across the nozzle bank, which lead to the calculation of airflow, and the static pressure differential across the test fan, thus providing a reference to the test fan's point of operation. Finally, the number and sizes of nozzles open for airflow must also be known. The calculation of airflow was based upon the pressure differential across the nozzles and was calculated through the use of equations presented in AMCA Standard 210-85. These equations are presented below.

$$Q_0 = Q_5 = 1096Y\sqrt{\Delta P/\rho_0}\;\Sigma(CA_6) \qquad \text{[ref 9.3.2.8]}$$

$$Y = 1 - (0.548 + 0.71\beta^4)(1 - \alpha) \qquad \text{[ref 9.3.2.3]}$$

$$\alpha = 1 - \frac{5.187\Delta P}{\rho_0 R(t_{d0} + 459.7)} \qquad \text{[ref 9.3.2.1]}$$

$$\rho_0 = \frac{70.73(p_b - 0.378p_p)}{R(t_{d0} + 459.7)} \qquad [\text{ref } 9.2.1]$$

$$p_e = 2.96 \times 10^{-4} t_{w0}^{2} - 1.59 \times 10^{-2} t_{w0} + 0.41 \qquad [\text{ref } 9.2.1]$$

$$p_p = p_e - p_b\left(\frac{t_{d0} - t_{w0}}{2700}\right) \qquad [\text{ref } 9.2.1]$$

$$\Sigma(CA_6) = \begin{cases} 0.013963N_{1.6}C_{1.6} + 0.034088N_{2.5}C_{2.5} \\ \quad + 0.087266N_4C_4 + 0.136354N_5C_5 \\ \quad + 0.164988N_{5.5}C_{5.5} + 0.196349N_6C_6 \end{cases}$$

$$C_{1.6} = 0.9986 - \frac{7.006}{\sqrt{Re_{1.6}}} + \frac{134.6}{Re_{1.6}} \qquad [\text{ref } 9.3.2.6]$$

$$Re_{1.6} = \frac{1096}{60\mu_6} C_{1.6}(0.133333)Y\sqrt{\Delta P/\rho_0} \qquad [\text{ref } 9.3.2.5]$$

$$C_{2.5} = 0.9986 - \frac{7.006}{\sqrt{Re_{2.5}}} + \frac{134.6}{Re_{2.5}} \qquad [\text{ref } 9.3.2.6]$$

$$Re_{2.5} = \frac{1096}{60\mu_6} C_{2.5}(0.208333)Y\sqrt{\Delta P/\rho_0} \qquad [\text{ref } 9.3.2.5]$$

$$C_4 = 0.9986 - \frac{7.006}{\sqrt{Re_4}} + \frac{134.6}{Re_4} \qquad [\text{ref } 9.3.2.6]$$

$$Re_4 = \frac{1096}{60\mu_6} C_4(0.333333)Y\sqrt{\Delta P/\rho_0} \qquad [\text{ref } 9.3.2.5]$$

$$C_5 = 0.9986 - \frac{7.006}{\sqrt{Re_5}} + \frac{134.6}{Re_5}$$ [ref 9.3.2.6]

$$Re_5 = \frac{1096}{60\mu_6} C_5(0.416667)Y\sqrt{\Delta P/\rho_0}$$ [ref 9.3.2.5]

$$C_{5.5} = 0.9986 - \frac{7.006}{\sqrt{Re_{5.5}}} + \frac{134.6}{Re_{5.5}}$$ [ref 9.3.2.6]

$$Re_{5.5} = \frac{1096}{60\mu_6} C_{5.5}(0.458333)Y\sqrt{\Delta P/\rho_0}$$ [ref 9.3.2.5]

$$C_6 = 0.9986 - \frac{6.688}{\sqrt{Re_6}} + \frac{131.5}{Re_6}$$ [ref 9.3.2.6]

$$Re_6 = \frac{1096}{60\mu_6} C_6(0.500000)Y\sqrt{\Delta P/\rho_0}$$ [ref 9.3.2.5]

Symbols Used

$A_{1.6}$ = Nozzle discharge cross sectional area (ft^2)

$C_{1.6}$ = 1.6 in (4.1 cm) nozzle discharge coefficient (dimensionless)

$C_{2.5}$ = 2.5 in (6.4 cm) nozzle discharge coefficient (dimensionless)

C_4 = 4 in (10.2 cm) nozzle discharge coefficient (dimensionless)

C_5 = 5 in (12.7 cm) nozzle discharge coefficient (dimensionless)

$C_{5.5}$ = 5.5 in (14.0 cm) nozzle discharge coefficient (dimensionless)

C_6 = 6 in (15.2 cm) nozzle discharge coefficient (dimensionless)

D_6 = Nozzle discharge diameter (ft^2)

$N_{1.6}$ = Number of 1.6 in (4.1 cm) nozzles open for airflow (dimensionless)

$N_{2.5}$ = Number of 2.5 in (6.4 cm) nozzles open for airflow (dimensionless)

N_4 = Number of 4 in (10.2 cm) nozzles open for airflow (dimensionless)

N_5 = Number of 5 in (12.7 cm) nozzles open for airflow (dimensionless)

$N_{5.5}$ = Number of 5.5 in (14.0 cm) nozzles open for airflow (dimensionless)

N_6 = Number of 6 in (15.2 cm) nozzles open for airflow (dimensionless)

p_b = corrected barometric pressure (in. Hg)
p_e = saturated vapor pressure at t_w (in. Hg)
p_p = partial vapor pressure (in. Hg)
$Re_{1.6}$ = Reynolds Number for 1.6 in (4.1 cm) nozzle (dimensionless)
$Re_{2.5}$ = Reynolds Number for 2.5 in (6.4 cm) nozzle (dimensionless)
Re_4 = Reynolds Number for 4 in (10.2 cm) nozzle (dimensionless)
Re_5 = Reynolds Number for 5 in (12.7 cm) nozzle (dimensionless)
$Re_{5.5}$ = Reynolds Number for 5.5 in (14.0 cm) nozzle (dimensionless)
Re_6 = Reynolds Number for 6 in (15.2 cm) nozzle (dimensionless)
Q_0 = Fan flow rate (cfm)
Q_5 = Nozzle flow rate (cfm)

t_{d0} - Atmospheric dry-bulb temperature (°F)

t_{w0} - Atmospheric wet-bulb temperature (°F)

Y - Nozzle expansion factor (dimensionless)

α - Static pressure ratio for nozzles (dimensionless)

ΔP - Static pressure differential across nozzles (in. wg)

ρ_0 - Atmospheric air density (lbm/ft^3)

$\Sigma(CA_6)$ - Summation of nozzle coefficients times nozzle discharge cross sectional areas (ft^2)

Constants Used

β - ratio of nozzle exit diameter (D_6) to approach duct diameter (D_5). For chamber, $\beta = 0$

R - Gas constant (53.35 ft-lb/lbm-°R)

D_6 - Nozzle discharge diameter (ft)

= .133333 (1.6 in (4.1 cm) nozzle)

= .208333 (2.5 in (6.4 cm) nozzle)

= .333333 (4 in (10.2 cm) nozzle)

= .416667 (5 in (12.7 cm) nozzle)

= .458333 (5.5 in (14.0 cm) nozzle)

= .500000 (6 in (15.2 cm) nozzle)

A_6 - Nozzle discharge cross sectional area (ft^2)

= .013963 (1.6 in (4.1 cm) nozzle)

= .034088 (2.5 in (6.4 cm) nozzle)

= .087266 (4 in (10.2 cm) nozzle)

= .136354 (5 in (12.7 cm) nozzle)

= .164988 (5.5 in (14.0 cm) nozzle)

= .196349 (6 in (15.2 cm) nozzle)

μ_6 = Air viscosity (1.222×10^{-5} lbm/ft-s)

Equation Limitations

1. The static pressure at the test fan must be always less than 4 inches w.g. (993 Pa). In this case, the chamber air density may be considered equal to the atmospheric air density and the gases can be assumed to be incompressible. [Ref 9.2.2]
2. The saturated vapor pressure equation employed is applicable over the temperature range of 40 to 90° F (4.4 to 32.2° C).
3. The nozzle discharge coefficients equations are valid for Re > 12000.

These equations, along with the additional inputs required, were used in a computer program to calculate the fan airflow. This program employed English units of measurement, as all of the inputs were based on the English system. The program was written in the C language to allow for future automation of inputs via a Tekmar board data acquisition unit. The equations above calculate the flow rate based on test conditions. In order to standardize the results, allowing for comparison at other test conditions and locale, the results were converted to nominal results based on standard atmospheric conditions and nominal fan rotational speed. The equations below illustrate the conversions involved:

$$Q_c = Q_0\left(\frac{N_c}{N}\right)\left(\frac{K_p}{K_{pc}}\right) \qquad \text{[ref 9.9.1]}$$

$$\frac{K_p}{K_{pc}} = \left(\frac{Z}{Z_c}\right)\left(\frac{X_c}{X}\right) \qquad \text{[ref 9.9.1]}$$

$$\frac{Z}{Z_c} = \left(\frac{P_{t1c} + 13.63p_{bc}}{P_{t1} + 13.63p_b}\right)\left(\frac{\rho}{\rho_c}\right)\left(\frac{N}{N_c}\right)^2 \qquad \text{[ref 9.9.1]}$$

$$Z_c = \frac{Z}{Z/Z_c} \qquad \text{[ref 9.9.1]}$$

$$Z = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{6362H/Q_0}{P_{t1} + 13.63p_b}\right) \qquad \text{[ref 9.8.2]}$$

$$\ln(1 + X_c) = \ln(1 + X)\left[\frac{\ln(1 + Z_c)}{\ln(1 + Z)}\right] \qquad \text{[ref 9.9.1]}$$

$$X = \frac{P_t}{P_{t1} + 13.63p_b} \qquad \text{[ref 9.8.2]}$$

$$X_c = e^{\ln(1 + X_c)} - 1 \qquad \text{[ref 9.9.1]}$$

$$P_{tc} = P_t\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right)\left(\frac{K_p}{K_{pc}}\right) \qquad \text{[ref 9.9.2]}$$

$$P_{vc} = P_v\left(\frac{N_c}{N}\right)^2\left(\frac{\rho_c}{\rho}\right) \qquad \text{[ref 9.9.2]}$$

$$P_{sc} = P_{tc} - P_{vc} \qquad \text{[ref 9.9.2]}$$

Symbols Used

H - Fan power input (hp)

K_p - Compressibility coefficient for air at test conditions (dimensionless)

K_{pc} - Compressibility coefficient for air for nominal conditions (dimensionless)

N - Speed of fan rotation at test conditions (rpm)

N_c - Speed of fan rotation at nominal conditions (rpm)

p_b - Corrected barometric pressure at test conditions (in. Hg)

p_{bc} - Corrected barometric pressure for standard atmospheric conditions (in Hg)

p_{sc} - Fan static pressure for nominal conditions (in. wg)

p_t - Fan total pressure (in. wg)

p_{tc} - Fan total pressure for nominal conditions (in. wg)

p_{t1} - Total pressure at test fan inlet at test conditions (in. wg)

p_{t1c} - Total pressure at test fan inlet for nominal conditions (in. wg)

p_v - Fan velocity pressure at test conditions (in. wg)

p_{vc} - Fan velocity pressure for nominal conditions (in. wg)

Q_c - Fan flow rate converted to nominal conditions (cfm)

Q_0 - Fan flow rate at test conditions (cfm)

X - Function used to determine K_p for air at test conditions (dimensionless)

X_c - Function used to determine K_{pc} for air at nominal conditions (dimensionless)

Z - Function used to determine K_p for air at test conditions (dimensionless)

Z_c - Function used to determine K_{pc} for air at nominal conditions (dimensionless)

ρ - Fan air density at test conditions (lbm/ft^3)

ρ_c - Fan air density for nominal conditions (lbm/ft^3)

Constants Used

γ - Ratio of specific heats; for air - 1.400 (dimensionless)

Standard atmospheric conditions:

ρ_c - Standard air density - .075 lbm/ft^3 (1.20 kg/m^3)

t_{d0} - 68°F (20° C)

P_{bc} - 29.92 in Hg (101.3 Pa)

Equation Limitations

1. Nominal conditions refers to nominal constant density and nominal constant speed.
2. Nominal constant density must be within 10% of the actual density and nominal constant speed within 5% of the actual speed.

The computer program thus proceeded to calculate the fan airflow rate, and nominal fan airflow rate from the various atmospheric, pressure, and motor power inputs, all entered via the standard input (keyboard). The source code for the program is contained in Appendix B.

Results and Discussion

A minimum of eight points of operation were taken for each fan tested in an effort to fully establish the fan's performance over the range from shut off to free delivery. Initially, several tests were performed on two fan models that had previously been tested in laboratories established in accordance with AMCA Standard 210-85. The results obtained with the Kansas State University fan test chamber were slightly below the published results, but within 5%. This indicated a slight leakage within the chamber. These leaks were found to be through joints, walls, and through the nozzle plugs. At this time, one of Agri-Aide's flush mount series 40.6 cm (16 in) fans was shipped to the AMCA laboratories to be performance tested. Meanwhile, the remainder of Agri-Aide's flush mount series of axial fans were performance tested in the Agricultural Engineering Department with the fan test chamber. The results of tests for all fans were not part of the thesis requirements.

Two full performance tests were made on each fan to show the repeatability of the laboratory chamber. Each performance test required approximately one hour to complete, and one additional hour to prepare the results in a presentable manner. A Zenith personal computer was employed adjacent to the fan test chamber for calculation of the fan's performance via the data acquisiton program. These results were then passed over to a Microvax II computer within the Agricultural Engineering Department, where the fan's performance was displayed graphically (fan static pressure in Pa versus fan airflow in Lps) and in tabular form through the capabilities of the Microvax.

The Agri-Aide fan was tested on the KSU fan test chamber following its performance test at the AMCA laboratories. These results compared very favorably with the results obtained by AMCA, with only slight discrepancies at free air delivery and near the shut off point. A comparison of the results obtained can be seen in Figure 11 and Tables 3-5.

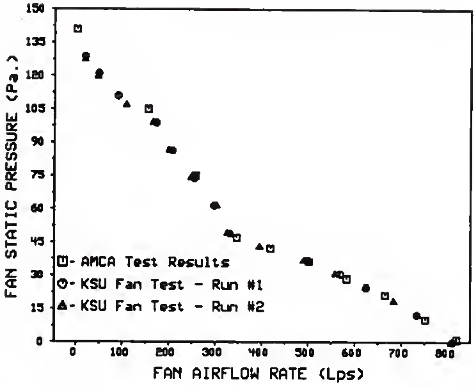


Figure 11. Fan performance curves for the Agri-Aide FM-1619-1 fan from results obtained at the AMCA laboratories versus results obtained with the KSU fan test chamber.

TABLE 3. Fan performance results obtained at the AMCA laboratories for the Agri-Aide FM-1619-1 fan.

FAN : Agri-Aide FM-1619-1 at 1725 RPM (nominal)
DATE: 10-9-87

TEST AIR		STANDARD AIR		MOTOR PERFORMANCE			VER
STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.99	831.6	0.99	817.9	1754	1.1	142	5.8
10.18	763.6	10.18	751.8	1752	1.1	145	5.2
21.11	675.8	21.11	665.4	1752	1.1	145	4.6
28.31	591.8	28.56	582.4	1753	1.1	144	4.0
36.01	509.2	36.26	501.2	1754	1.1	142	3.5
42.47	426.2	42.47	419.1	1754	1.1	141	3.0
47.19	352.1	47.19	346.4	1753	1.1	143	2.4
74.51	261.0	75.00	257.7	1748	1.1	150	1.7
104.06	157.2	105.06	154.8	1747	1.1	150	1.0
139.58	0.0	141.07	0.0	1744	1.1	154	0.0

TABLE 4. Fan performance results obtained with the KSU fan test chamber in run #1 on the Agri-Aide FM-1619-1 fan.

FAN : Agri-Aide FM-1619-1 at 1725 RPM (nominal)
DATE: 10-28-87

TEST AIR		STANDARD AIR		MOTOR PERFORMANCE			VER
STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	822.3	0.00	809.2	1753	0.81	140	5.9
12.37	744.4	12.22	733.1	1752	0.82	142	5.2
24.81	633.9	24.51	624.3	1752	0.81	142	4.5
31.02	577.6	30.62	568.6	1753	0.81	140	4.1
37.23	507.1	36.73	498.9	1753	0.80	137	3.7
49.67	336.2	49.00	330.8	1753	0.80	137	2.4
62.09	301.6	61.52	297.4	1749	0.82	143	2.1
74.51	258.4	73.91	255.0	1748	0.82	145	1.8
86.93	210.2	86.28	207.4	1748	0.82	145	1.4
99.34	175.5	98.75	173.2	1747	0.83	146	1.2
111.76	90.7	111.04	89.5	1748	0.82	144	0.6
121.94	48.5	121.16	47.8	1748	0.82	144	0.3
129.15	18.4	128.75	18.2	1746	0.83	146	0.1

TABLE 5. Fan performance results obtained with the KSU fan test chamber in run #2 on the Agri-Aide FM-1619-1 fan.

FAN : Agri-Aide FM-1619-1 at 1725 RPM (nominal)
DATE: 10-29-87

TEST AIR		STANDARD AIR		MOTOR PERFORMANCE			VER
STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	822.5	0.00	808.8	1754	0.80	139	5.9
12.37	745.8	12.27	734.2	1752	0.81	141	5.3
18.58	694.1	18.43	683.6	1752	0.81	141	4.9
24.81	632.3	24.59	622.5	1752	0.81	140	4.5
31.02	567.2	30.72	558.1	1753	0.81	138	4.1
37.23	498.4	36.83	490.1	1754	0.80	137	3.6
43.44	402.1	42.94	395.3	1755	0.80	136	3.0
49.67	330.8	49.17	325.5	1753	0.80	138	2.4
62.09	307.0	61.69	302.6	1750	0.82	142	2.2
74.51	251.1	74.21	247.7	1748	0.82	144	1.7
86.93	202.6	86.63	200.0	1748	0.83	146	1.4
99.34	168.0	99.17	165.9	1747	0.83	147	1.1
107.54	109.2	107.19	107.8	1748	0.82	144	0.8
120.21	47.0	119.91	46.4	1747	0.83	145	0.3
127.66	18.2	127.48	18.0	1747	0.83	146	0.1

There evidently was still some slight leakage through the chamber causing these discrepancies. These leaks were very small, though, as they only manifested themselves at the point of highest airflow and when the test fan was operating under a relatively high static pressure differential. Exhaust fans normally operate against a partial vacuum from 12.4 to 31.0 Pa (.05 to .125 in) water of static pressure, and over this range, the KSU fan test chamber accurately repeated the AMCA laboratories results. Thus, since the majority of manufacturers published results report the fan's performance over this range, the performance tests on Osborne's fans were felt to be satisfactory. Nevertheless, additional steps were taken to provide better sealing of leaks, and the Osborne 40.6 cm (16 in) fan was retested. The results of these tests closed the discrepancies considerably, with differences between 1 and 2%. There was still some small leakage through the chamber walls, though, as the results at free air delivery were still slightly lower than AMCA's, Figure 12 and Table 6.

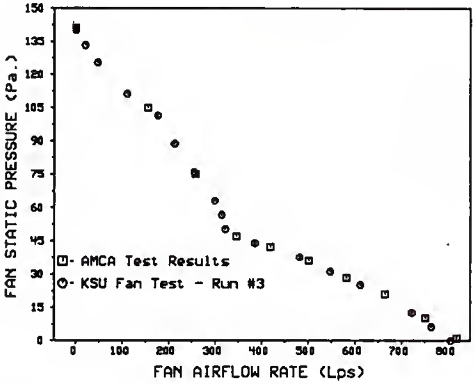


Figure 12. Fan performance curves for the Agri-Aide FM-1619-1 fan comparing results obtained in the AMCA laboratories with run #3 obtained with the KSU fan test chamber.

TABLE 6. Fan performance results obtained with the KSU fan test chamber in run #3 on the Agri-Aide FM-1619-1 fan.

FAN : Agri-Aide FM-1619-1 at 1725 RPM (nominal)
DATE: 3-9-88

TEST AIR		STANDARD AIR		MOTOR PERFORMANCE			VER
STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	818.7	0.00	804.9	1754	0.85	143	5.7
6.16	776.5	6.23	763.9	1754	0.85	144	5.4
12.37	734.4	12.57	722.8	1753	0.85	146	5.0
24.81	622.5	25.16	612.3	1754	0.85	144	4.3
31.02	555.9	31.42	546.6	1754	0.85	142	3.9
37.23	489.8	37.68	481.3	1755	0.85	140	3.5
43.44	392.4	43.98	385.7	1755	0.85	140	2.8
49.67	326.8	50.37	321.5	1753	0.85	143	2.3
55.88	318.8	56.75	313.9	1752	0.85	144	2.2
62.09	303.4	63.13	299.0	1751	0.85	146	2.1
74.51	258.0	75.90	254.4	1749	0.85	148	1.7
86.93	215.4	88.66	212.5	1748	0.86	149	1.4
99.34	178.4	101.38	176.0	1748	0.86	150	1.2
109.28	110.7	111.36	109.2	1749	0.86	148	0.7
122.94	47.4	125.45	46.8	1748	0.86	149	0.3
130.39	20.2	133.32	20.0	1747	0.87	152	0.1
136.60	0.0	139.93	0.0	1745	0.87	153	0.0

Summary and Conclusions

This study investigated the development of a fan testing facility. The development of the KSU fan test chamber proved to be an arduous task, as performance problems arose throughout the development and testing. Improvements were implemented as the shortcomings became evident and the chamber's performance improved with each new implementation. The problems encountered during the development phase provided a great learning experience and a greater understanding of all that is involved in accurately determining fan performance. With all of the additional improvements, the results obtained with the KSU fan test chamber are felt to be repeatable and accurate in comparison with an AMCA laboratory performance test. This study, therefore, accomplished all of its initial objectives by developing a fan testing facility in accordance with AMCA Standard 210-85 and which is capable of accurately repeating results previously obtained in the AMCA laboratories.

The development and instrumentation of a fan testing facility requires careful planning and preparation. It is important to determine the intended use of the fan test facility and overdesign its construction. The proper choice of settling means to insure a uniform airflow is essential, as is the correct selection of nozzles. The sealing of the chamber proved to be an arduous task, due to the use of 1.27 cm (0.5 in) plywood, especially along joints. Constructing the chamber in sections, though, was essential to allow for access into the various components of the chamber.

Despite its performance, there remain many possible improvements to the KSU fan test chamber. Additional automation of the the fan test chamber would be one possible improvement. Automation would aid in the elimination of any human measurement errors and potentially lessen the time required for testing a fan's performance. The use of pressure transducers to measure the various static pressures would eliminate the need to manually read these pressures, while automation of the fan speed and power measurements could be attained through use of a data acquisition board. In addition, thermocouples could be employed to sense the temperatures and a barocell pressure transducer could measure the barometric pressure. The use of various sport balls to plug the nozzles proved to be adequate, but the search continues for more effective means of sealing those nozzles which are not needed during testing. The development a fan testing facility seems to be a never ending process, as there always remain possible improvements.

EFFECT OF CONE SHAPED WIND DIVERTERS ON VENTILATION FANS

Introduction

The performance of exhaust ventilation fans decreases when the fan is forced to blow into a wind. Strong winds may even cause a net reverse flow through small, unprotected fans. Variable speed fans operated at low speeds are particularly vulnerable. The proper management of livestock ventilation systems should include solutions to this problem so that livestock growth and productivity can be maintained.

Several types of wind protection devices have been implemented in attempts to minimize the detrimental effects of the wind. There are three principle types of wind protection devices, or techniques, with two of the three being placed directly on the fan exhaust. A windbreak, though, is located a reasonable distance from the fan exhaust, and consists of a row of trees or shrubs, or a solid barrier. The other two devices mount directly in front of the outlet of the fan. The main purpose of each of these devices is to negate the effect of the wind without increasing the load on the fan in a drastic manner.

The design and location of all wind protection devices must address two main concerns. The first concern is the extra load placed on the fan by the device during normal operation with no wind. Pratt et al. (1983) explained that anything on the discharge side of the fan which impedes the swirling motion acts to degrade the fan's performance. The second concern is whether such wind protection actually improves the performance of the fan when exhausting into a wind. There is a lack of published research on this problem, thus creating a great need for experimentally examining the performance of wind protection devices. Exhaust fans normally operate against a partial vacuum from 12.4 to 31.0 Pa (.05 to .125 in wg) of static pressure. When a fan is subjected to this pressure, it is not uncommon for the airflow delivered by the fan to decrease by 25% to 30%. Variable speed fans especially have poor pressure ratings at low fan speeds and may not deliver enough air against wind (MWPS, 1983). Wind protection devices have been employed to combat the effects of wind, but the design of such equipment generally has not been based on research data. Experimental testing and research has not been conducted to gather the necessary data to evaluate the benefits/costs of the wind protection device. Because of the lack of experimental and design data, this project was established with the following objectives:

1. To test the effect of a commercially available, cone shaped, wind diverter on the performance of ventilation fans exhausting directly into winds ranging from 0 to 10 mps,
2. To compare the effects of using a wind diverter, and using a hood, on the performance of a fan exhausting into a wind,
3. To evaluate the effect of wind diverter position on fan performance,
4. To evaluate the effect of wind diverter angle on fan performance and,
5. To improve the design of the cone shaped wind diverter.

Research Facilities and Procedure

Existing Wind Diverter

The Osborne Wind Diverter is a 30° inverted fiberglass cone supported directly in front of the fan outlet by means of aluminum struts. The performance of the wind diverter has not been evaluated, thus creating the need to experimentally test its performance. Two parameters of the wind diverter were examined in this study. The first parameter examined was the position of the wind diverter relative to the fan outlet. The other parameter studied was wind diverter angle and its effect on fan performance. Figure 13 illustrates the Osborne 30° wind diverter, its attachment to the fan, and the determination of the parameter hereby denoted as area ratio. The area ratio was defined as the ratio of circumferential area open for flow over the fan outlet area. The equation used to calculate the area ratio required only the radius of the fan outlet and the perpendicular distance from the edge of the fan outlet (along its horizontal centerline) to the wind diverter.

$$\text{ratio} = \frac{2\pi r(x)}{\pi r^2}$$

where r = radius of fan outlet (cm)

x = perpendicular distance from the fan outlet to the wind diverter.

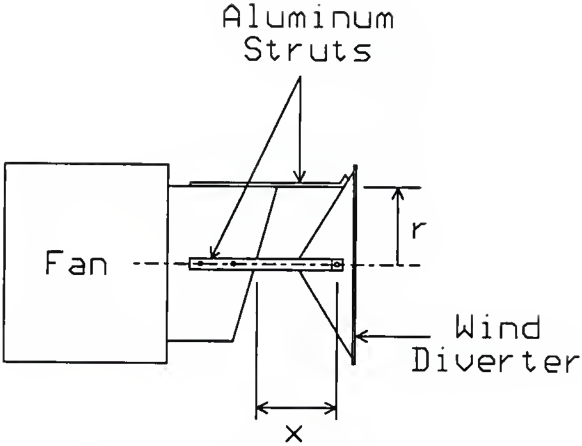
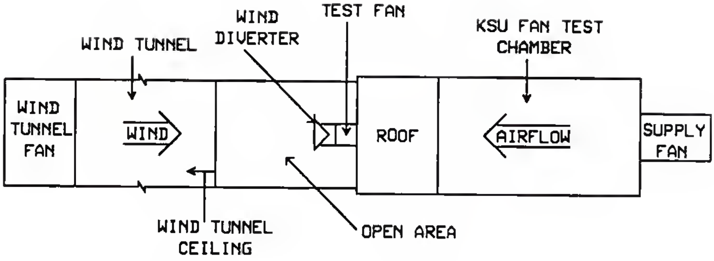


Figure 13. Osborne 30° wind diverter

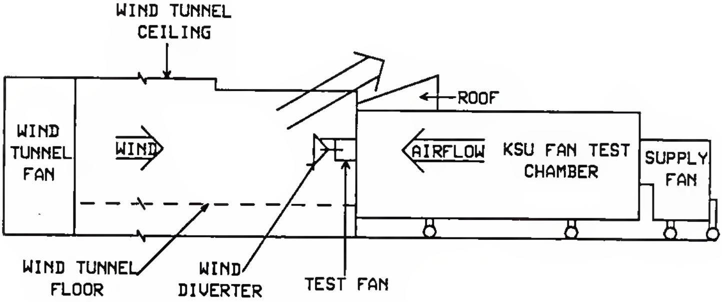
The problem with experimentally testing wind protection devices is how to establish a controlled wind. The wind was simulated in this study with a 15.24 m (50 ft) long wind tunnel at the USDA Wind Erosion Laboratory at Kansas State University. The wind tunnel was 152.4 cm (60 in) wide and 198.1 cm (78 in) high, giving a cross sectional area of 3.0 m^2 (32.5 ft^2). The wind tunnel was capable of generating wind velocities from 0 to 18 meters per second (mps), but for this study the maximum wind velocity used was 10 mps.

Test Setup

The KSU fan test chamber was transported to the USDA Wind Erosion Laboratory from the Agricultural Engineering Department. The chamber was then positioned at the exit of the wind tunnel in a 6.2 m long by 5.5 m wide "dust" room. The chamber was positioned so that the test fan would exhaust into the wind tunnel and against the oncoming wind. The wind tunnel walls and floor were extended 1.22 m (4 ft) to the front wall of the inlet chamber, Figure 14. The extension of the tunnel's walls and floor allowed the air to flow over the top of the chamber through an area approximately equal to the cross sectional area of the wind tunnel. A flow constriction would cause an excessive pressure buildup. This "escape" area was at least equal to the wind tunnel cross sectional area so that a constriction of airflow would be avoided.



TOP VIEW



SIDE VIEW

Figure 14. Setup of the KSU fan test chamber in the wind tunnel.

Instrumentation and Control

The USDA Wind Erosion Laboratory was equipped with all of the necessary equipment to monitor and control the wind tunnel. The wind was generated by a Joy Axivane (Series 1000) fan, with a maximum speed of 1300 rpm, and powered by a 125 hp, 240 V, DC motor. The wind velocity was adjusted from the instrumentation room with a Cutler-Hammer Control Unit. A pitot tube was employed to sense the pressure inside the tunnel. This pressure was converted to a voltage by means of a Datametrics Transducer. This signal was then processed by an Ectron Differential DC Amplifier (Model 687) and a Hewlett Packard 3497A Data Acquisition/Control Unit for input into a Basic program, which converted the signal to a wind velocity in mps. Barometric pressure and required temperatures were also collected and entered into the wind velocity program.

Development of Test Procedure

The effect of wind upon fan airflow with/without the presence of wind diverters was to be investigated on three sizes of Osborne's flush mount series of axial flow fans. The fan sizes selected were 20.3 cm (8 in) diameter, 30.5 cm (12 in) diameter, and 40.6 cm (16 in) diameter. Initially, the fan's airflow with/without a wind diverter was to be evaluated at wind velocities of 0, 2.5, 5, 7.5, 10, and 12.5 mps. The fan tests were performed over the range from free air delivery to shut-off static pressure at each of the six wind speeds. It was soon realized, however, that full performance tests were very time-consuming and gave more information than was needed. Normal fan operation is at building static pressures from 12.4 to 31.0 Pa (.05 to .125 in water). Performance tests outside this range were not as important. Therefore, it was determined that the fan tests would be performed at only one building static pressure. A 31.0 Pa (.125 in wg) static pressure was used for the 30.5 cm (12 in) fan operated at high speed, and the 40.6 cm (16 in) fan. A 12.4 Pa (.05 in wg) static pressure was selected for the 20.3 cm (8 in) fan, and the 30.5 cm (12 in) fan operated at low speed. It was also determined at this time that the wind velocities would be 0 to 10 mps, with an interval of 2 mps between each wind velocity. Each fan test would consist of the fan airflow measurement at each of the six wind speeds and with the static pressure inside the chamber (building) held constant throughout. The static pressure inside the chamber was considered to simulate a controlled environment and not the actual static pressure felt by the fan. The actual fan static pressure was difficult to measure and included the wind velocity pressure. The tests could proceed quickly using a constant building static pressure, allowing additional time for testing the effect of wind diverter position. The ratio of circumferential area open for flow to fan outlet area was used for establishing the position of the wind diverter relative to the fan outlet. For example, an area ratio of 1.0 indicated that the circumferential area open for flow was equal to the fan outlet area.

Wind Speed Frequency

It was felt that the naturally occurring frequency of wind speeds should be considered in the evaluation of fan and wind diverter performance. For example, a 4 mps wind is much more common than a 10 mps wind. It was therefore desired to sum the weights of fan airflows at each wind speed to obtain one "time weighted airflow" for each experimental condition or treatment. Two main techniques are used to obtain wind speed frequency. One technique uses actual field data to establish a wind speed frequency curve and equation. This technique is best where the data is available for the particular region being investigated. The second technique employs a statistical distribution of Pearson Type III, called the Weibull distribution, to describe the wind speed frequency. This statistical distribution describes the wind speed frequency curve on the basis of the scale and shape parameters. The scale parameter (c) describes the approximate median wind speed. The shape parameter (k) describes the relative shape of the frequency curve. A scale parameter of 4.47 mps (10 mph) and a shape parameter of 2.0 were selected for this particular application (agricultural ventilation systems, 3.1 to 6.1 m (10 to 20 ft) high buildings). The Weibull distribution of the wind speed frequency curve was obtained using these two parameters, Figure 15.

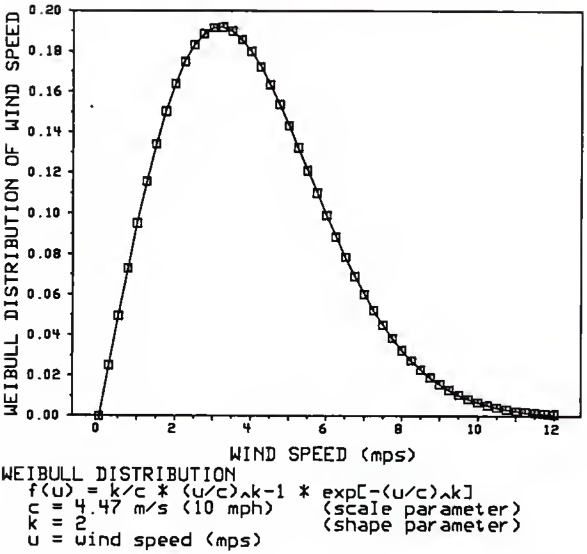


Figure 15. Weibull distribution of wind speed frequency curve

This distribution was used to weight the results obtained at the one static pressure and the six wind velocities from 0 to 10 mps (0 to 22.4 mph) at intervals of 2.0 mps. The weighted airflow for an experimental treatment at each wind velocity was obtained by multiplying the measured fan airflow by the area under the Weibull distribution over an interval of the wind velocity minus one mps to the wind velocity plus one mps. The time weighted airflow was then obtained by summing the weighted airflows at each wind velocity. The overall performance of each experimental treatment could be compared on the basis of one weighted value using this approach.

Experimental Treatments

Experiment 1.

The purpose of Experiment 1 was to test the performance of the Osborne 30° inverted cone wind diverter and observe the effect of wind diverter position. For each of the three fan sizes, tests were performed with/without a wind diverter and with the wind diverter at different positions. In addition, two variations of the Osborne 30° cone were tested. Figure 16 illustrates the three types of 30° cone shaped wind diverters tested in this phase. One variation was a wind diverter without a flange. The other variation involved placing two wind diverters back to back, essentially forming a double cone.

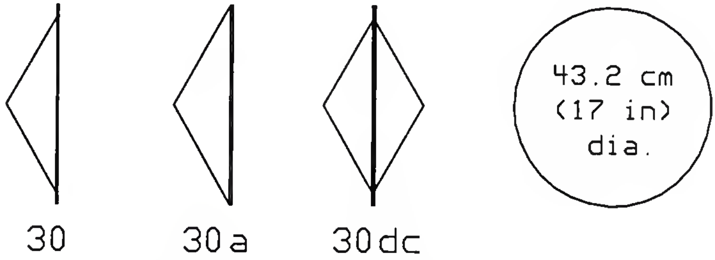


Figure 16. 30° cone shaped wind diverters

Table 7 illustrates the use of the Weibull distribution and weighted airflows with a sample of data for the 40.6 cm fan.

TABLE 7. Determination of weighted airflow for the Agri-Aide single speed 40.6 cm fan with a 30° wind diverter at an area ratio of 3.0.

FAN : Agri-Aide FM-1624-1 at 1725 RPM (nominal)
DATE: 11-3-87

WIND SPEED (mps)	STATIC PRESSURE (Pa)	FAN AIRFLOW (Lps)	PROB. OF WIND SPEED	WEIGHTED AIRFLOW (Lps)
0.00	31.17	842.2	0.0489	41.2
2.00	31.24	832.6	0.3146	261.9
4.01	31.22	782.4	0.3520	275.4
6.00	31.00	488.4	0.2005	97.9
7.99	31.19	418.8	0.0689	28.8
9.99	31.37	275.3	0.0150	4.1
				TWA=709.3

Experiment 2.

The purpose of Experiment 2 was to determine the effect of wind diverter angle on fan airflow. Osborne Industries constructed four new cone shaped wind diverters with angles of 0°, 15°, 45°, and 60°, Figure 17.

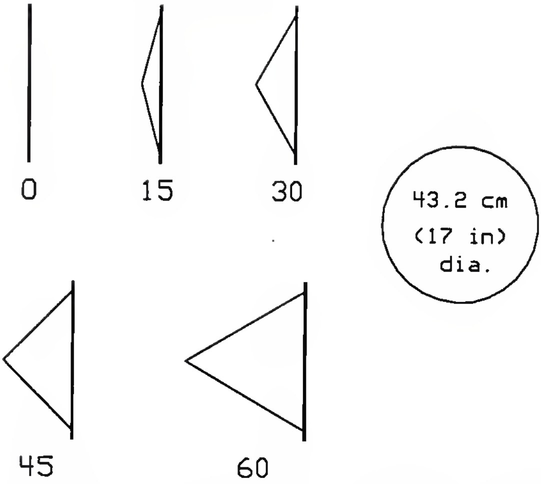


Figure 17. 0°, 15°, 30°, 45°, and 60° wind diverters for the Agri-Aide FM-1211-2 fan.

The effect of wind diverter angle was tested on the 30.5 cm (12 in) diameter fan, operated at high speed (1725 rpm) and low speed (1140 rpm). In addition, three wind diverter positions (area ratios) were tested for each wind diverter angle and fan speed. The effect of wind diverter angle and position could thus be evaluated. The relationship between the fan airflow rate and the wind was also examined in a visual manner. Visual display of the effects of wind on fan airflow was achieved by using a set of string streamers attached to the wind diverter. The streamers were photographed at each wind velocity during a performance test. In addition, averaging of the results over the wind diverter angles and positions tested was performed in an effort to summarize the overall results.

Various statistical techniques were applied to the test results. Statistics can be a powerful tool for modeling when the proper steps are taken, and when the database is large enough. This study did not lend itself well for statistical analysis for a variety of reasons. The study embarked into an area with very little, if any, previous experimentation, and thus, no initial database to build on. The purpose of the testing was to gain an understanding of how the wind and wind diverters affect fan airflow. Since a good portion of the study was spent in trying to evaluate the effects of wind diverter angles and positions, the testing was not completely randomized. In order to properly develop a statistical model, the variables involved and procedures required should be understood prior to testing. Since no previous work had been performed in this area of research, a proper understanding of all of the variables and inputs was not available. One final limitation on any statistical modeling was the fact that only one manufacturer's fans were tested and only three sizes of fans tested. Any model developed was very limited in scope and can best be considered only a preliminary model.

The results obtained in the testing of wind diverter angles and area ratios were used as the base data for the statistical model. The model was developed for the two-speed 30.5 cm fan, with wind diverter angle and area ratio serving as the independent variables and time weighted airflow being the dependent variable. In addition, the results obtained with the 30° wind diverter without a flange were not used in the model, in order to maintain a degree of uniformity between the wind diverters. A regression model was felt to be the best choice of models to use in fitting the data. The Statistical Analysis System (SAS, 1987) was employed as an aid in developing a regression model. Various regression models were used in the development of a "best" model and included linear, quadratic, and response surface models. The main factor used in comparing the different models was the coefficient of determination, R^2, which measured the portion of the variation in the response that was attributed to the model rather than to random error. The effect of each parameter in the model was also evaluated by use of the F-ratio and the probability of obtaining at least as great an F ratio given that the parameter tested was equal to zero (at $P < .05$). If the significance probability for a particular parameter was less than .05, that parameter was considered significant in the model. Three regression models were examined for both high and low speed operation of the two-speed, 30.5 cm fan.

Results and Discussion

Experiment 1

20.3 cm Fan.

The effect of wind diverter position on the time weighted airflow of the 20.3 cm (8 in) fan was evaluated for area ratios of 1.5 to 3.5, Figure 18. The presence of a wind diverter improved the time weighted airflow from 39 Lps for the exposed fan to between 62 and 65 Lps for the protected fan, an increase of 57% to 65%, with the greatest airflow occurring at a 2.5 area ratio. The effect of wind diverter position was relatively low, as indicated by small differences in time weighted airflow (4.7% difference between minimum and maximum).

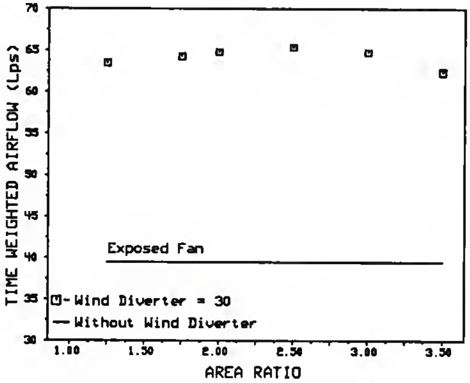


Figure 18. Time weighted airflow (Lps) versus area ratio for the single-speed 20.3 cm fan.

The presence of a wind diverter enabled the fan to operate up to the 8 mps wind velocity, while the exposed fan was only able to operate up to a 6 mps wind velocity, Figure 19. The wind diverter improved fan airflow at wind velocities above 2 mps, with a 300% increase at the 6 mps wind velocity. In windless conditions, there was a 6.8% difference between the results collected at area ratios of 1.25 and 3.5, with the larger area ratios yielding higher fan airflows. The effect of wind diverter position changed as wind velocities increased. At a wind velocity of 10 mps, an area ratio of 3.5 caused a decrease of 53.4% in fan airflow from the airflow attained at an area ratio of 1.25. Small area ratios increased the load on the fan at wind velocities below 4 mps, resulting in lower fan airflows. This phenomena was reversed at wind velocities above 6 mps, as the small area ratios created a chimney effect. The chimney effect was created when the wind included the airflow from the exhaust fan, thereby accelerating its velocity and aiding in its exhaust flow. The fan's airflow was easily entrained into the wind at the small area ratios, while the larger area ratios caused the fan to exhaust more directly into the wind.

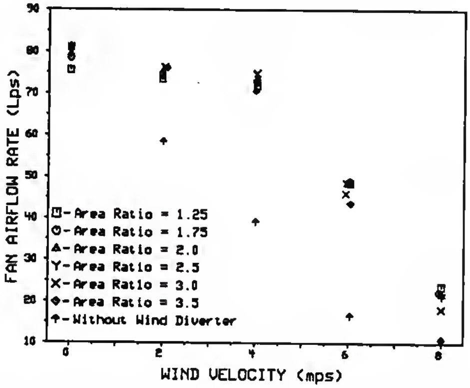


Figure 19. Fan airflow (Lps) versus wind velocity (mps) for the single-speed 20.3 cm fan.

Single-Speed 30.5 cm Fan.

Tests performed on the single speed 30.5 cm (12 in) fan, with area ratios ranging from 1.0 to 3.0, exhibited larger differences in fan airflow, Figures 20 and 21. These figures also exhibit one of the problems encountered in the testing. The same wind diverter position resulted in several different airflows at area ratios between 1.5 and 2.5. This scatter was due to the unstable region typical of axial flow fans, as reported by Baumeister (1935) and Eck (1973). This unstable region was very difficult to avoid, as the wind pressure caused the fan's static pressure to cross through this region as wind velocity was increased from 0 to 10 mps. The only fan to avoid this unstable region was the 20.3 cm fan, as its initial static pressure in windless conditions was already above the range of instability. The presence of this unstable operating region made it difficult to determine the optimum wind diverter position. It appears, however, that a 2.125 area ratio produced the best results with time weighted airflow increases of 23.4% to 32.5%, Figure 20. The position of the wind diverter appeared to have a significant effect on fan airflow, as fan airflow generally improved as the distance from the fan outlet increased up to 2.125 and gradually decreased beyond 2.125. The presence of a wind diverter improved the time weighted airflow from 194 Lps for the exposed fan to airflows between 224 and 257 Lps for the protected fan, depending on the area ratio.

The plot of fan airflow and wind velocity, Figure 21, showed the effects of wind at various area ratios. In windless conditions, fan airflow was 11% to 19% higher while exposed than while protected, but immediately dropped from 280 to 231 Lps with only a 2 mps wind, and continued decreasing to 14 Lps as wind velocity increased to 9.4 mps (10 mps was not attainable). The presence of a wind diverter enabled the fan to operate up to the 10 mps wind, and improved fan airflow by 120% to 158% at the 8 mps wind. The chimney effect was evident at the 4 mps wind velocity, as fan airflow improved from 253 Lps at the 2 mps wind to

263 Lps for area ratios of 2.0 to 3.0. The effect of wind diverter position at various wind velocities was also exhibited in the plot of fan airflow rate versus wind velocity, Figure 21. The fan's airflow was up to 10% higher for larger area ratios at wind velocities up to 6 mps, but 37% lower in the 10 mps wind.

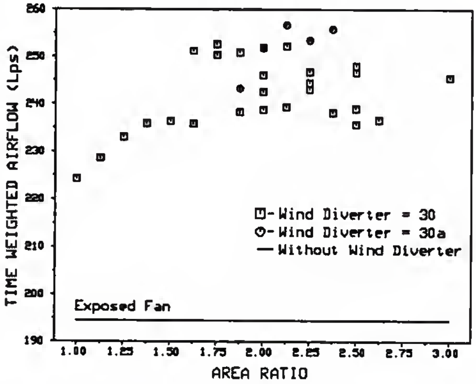


Figure 20. Time weighted airflow (Lps) versus area ratio for the single-speed 30.5 cm fan.

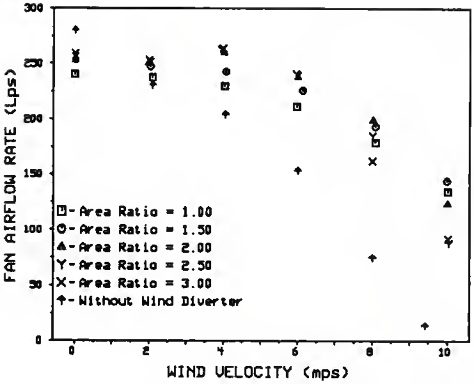


Figure 21. Fan airflow (Lps) versus wind velocity (mps) for the single-speed 30.5 cm fan.

Two-Speed 30.5 cm Fan.

High Speed. Effects of wind protection on the two-speed, 30.5 cm fan operated at 1725 rpm are presented in Figures 22 and 23. This fan delivered a larger capacity of air than the single-speed, 30.5 cm fan (574 Lps as compared to 280 Lps in windless conditions) during operation of the fan without a wind diverter. The unstable region was again evident at area ratios between 1.5 and 2.5. A large jump in the time weighted airflow from 264 Lps to 337 Lps occurred at a ratio of 2.5, as higher airflows were recorded within the unstable region. The effect of wind diverter position was very important for the two-speed fan, as time weighted airflow was greater than that without a wind diverter only for area ratios above 2.5. The optimum position was 4.0, with the time weighted airflow improving from 316 Lps to between 346 and 350 Lps, an increase of 10% to 11%.

The effect of wind diverter position was evident in the plot of fan airflow against wind velocity, Figure 23. The effect of the unstable operating region was especially evident at a ratio of 2.5 and at winds below 2 mps. Two different results were obtained due to this region of instability, with the difference amounting to 155 Lps (48% increase) in windless conditions. The unstable region affects the fan airflow up to the 4 mps wind, where the increase in static pressure has caused the fan's airflow to cross completely through the region of instability. At wind velocities below 4 mps, the fan's airflow was considerably higher with area ratios above 2.5. The fan's airflow improved from 312 Lps to 519 Lps (67% increase) in windless conditions as the area ratio increased from 2.0 to 4.0. The chimney effect was again evident at the optimum position of 4.0, as fan airflow increased from 519 to 523 Lps at the 4 mps wind, while the fan airflow for an area ratio of 2.0 dropped to 305 Lps. In contrast, area ratios above 2.5 provided the lowest airflows at wind velocities above 8 mps, with a 70% decrease in airflow between results at ratios of 1.5 to 2.0 and results at a ratio of 5.5. The presence of any wind diverter, though, enabled the fan to operate up to the 10 mps wind, improved fan airflow for winds above 4 mps, and provided for up to a 130% increase in airflow over that of the exposed fan.

Two additional wind protection devices were tested on the two-speed fan. The existing 30° wind diverter was modified by eliminating the outer flange surrounding the wind diverter, while maintaining the same outside diameter. The hypothesis for removing the flange was based on the theory that any directional change imposed on the air exiting the fan will cause the fan to work harder. This hypothesis proved to be well founded, as the fan's time weighted airflow with the wind diverter without a flange was from 3 to 13 Lps higher (1% to 13% increase), depending on the area ratio. This effect was greater at smaller area ratios, with the increase being 13% at 2.5, and 1% at ratios of 4.0 and 5.5.

The other wind protection device tested was a hood placed over the exhaust of the fan. The hood was a severe restriction on the fan, Figure 22. The effect of the hood decreased time weighted airflow by 81 Lps (25% decrease) in comparison to the exposed fan, and by 115 Lps (33% decrease) in comparison to the fan with the wind diverter at the optimum position. The fan airflow attained with the hood was 270 Lps in windless conditions, while a wind diverter at a ratio of 4.0 yielded an airflow of 519 Lps, a 92% improvement, Figure 23. The results attained with the hood improved slightly (in relation to wind diverter results) as wind velocities increased above 4 mps, but were always less than the results at the 4.0 ratio.

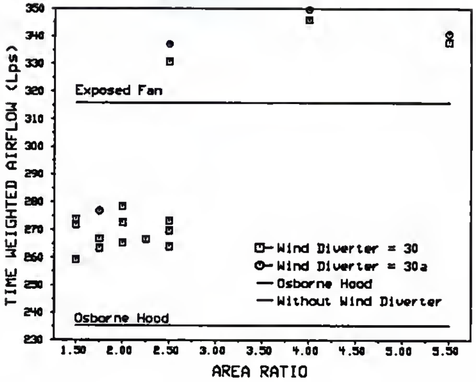


Figure 22. Time weighted airflow (Lps) versus area ratio for the two-speed 30.5 cm fan operated at 1725 rpm.

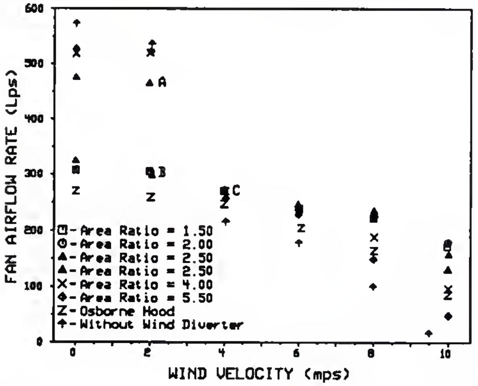


Figure 23. Fan airflow (Lps) versus wind velocity (mps) for the two-speed 30.5 cm fan operated at 1725 rpm.

The two-speed 30.5 cm fan was tested under windless conditions with a 30° wind diverter at an area ratio of 2.5 in order to document the region of instability. Test points were collected around 31.0 Pa (.125 in wg) static pressure, Figure 24 and Table 8. The effect of this unstable operating region is evident in Figures 23 and 24. Although the test of instability was in windless conditions, this unstable region affects fan airflow at either a 2 or 4 mps wind at an area ratio of 2.5. Fan airflow dropped from 477 Lps (point A) to 278 Lps (point C) as wind velocities increased from 2 to 4 mps, Figure 23. Static pressure across the fan increases as the wind velocity increases, causing this drop in airflow. The change in wind velocity from 2 to 4 mps raised the effective fan static pressure through the unstable region from point A to point C, Figure 24. In contrast, at a 2 mps wind, the unstable region also yielded a fan airflow of 307 Lps at the top end of the region of instability, point B, Figures 23 and 24. Fan airflow decreased to 278 Lps for both point A and B with the increase in wind velocity from 2 to 4 mps. The 4 mps wind thus caused the fan to operate as if at a higher static pressure (34.8 Pa), point C, Figure 24.

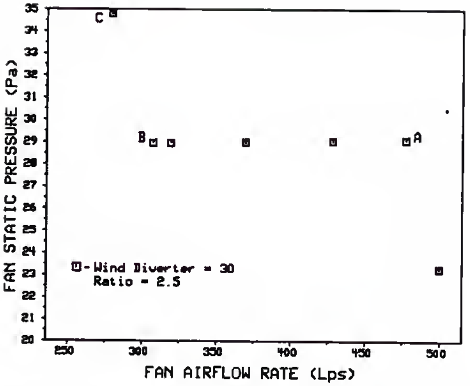


Figure 24. Performance of two-speed 30.5 cm fan operated at 1725 rpm under windless conditions with a 30° wind diverter located at an area ratio of 2.5.

TABLE 8. Fan performance test on the two-speed 30.5 cm fan documenting the unstable operating region.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 1-6-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	24.81	514.5	23.27	500.2	24.5	1775	2.24	221	2.3
0.00	24.81	513.6	23.27	499.2	24.4	1775	2.26	223	2.3
0.00	31.05	316.7	28.96	307.1	15.0	1779	2.24	202	1.6
0.00	31.05	329.0	28.96	319.0	15.6	1779	2.24	202	1.6
0.00	31.02	380.6	28.98	369.4	18.1	1778	2.24	208	1.8
0.00	31.02	440.6	29.03	427.9	20.9	1776	2.26	214	2.1
0.00	31.02	491.0	29.08	477.2	23.4	1775	2.26	221	2.2
0.00	37.25	287.4	34.80	278.8	13.6	1778	2.21	203	1.4
0.00	37.25	287.9	34.77	279.3	13.7	1778	2.24	206	1.4

Low Speed. Test results from the two-speed, 30.5 cm fan, operated at 1140 rpm, with three types of wind protection devices are shown in Figures 25 and 26. Fan airflow improved with a wind diverter, but wind diverter position had minor effects. The presence of a wind diverter improved the time weighted airflows from 90 Lps for the exposed fan to between 129 and 140 Lps, an increase of 43% to 55%, depending on the area ratio. The greatest improvement occurred at a 1.375 ratio, where the time weighted airflow was 140 Lps, a 55% increase over the exposed fan's airflow. The effect of a flange on the wind diverter was not apparent, as the results were almost identical. The presence of a hood improved the time weighted airflow from 90 Lps for the exposed fan, to 117 Lps, an increase of 30%, which was still 23 Lps or 16% less, than the airflow attained with a wind diverter at a 1.375 ratio.

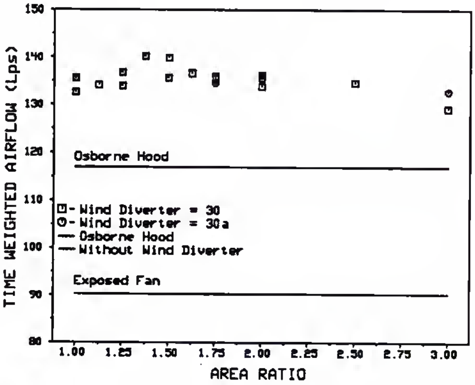


Figure 25. Time weighted airflow (Lps) versus area ratio for the two-speed 30.5 cm fan operated at 1140 rpm.

The effect of wind on fan airflow was readily exhibited, Figure 26. A one mps wind decreased the airflow of the exposed fan by 59%, from 364 to 151 Lps. The use of a wind diverter produced a more stable airflow and allowed for operation up to about 7.5 mps wind velocity as compared to only about 5.5 mps without a wind diverter. Area ratios greater than 1.5 allowed operation in winds up to only 6 mps though, while area ratios below 1.5 enabled the fan to operate in up to a 8 mps wind.

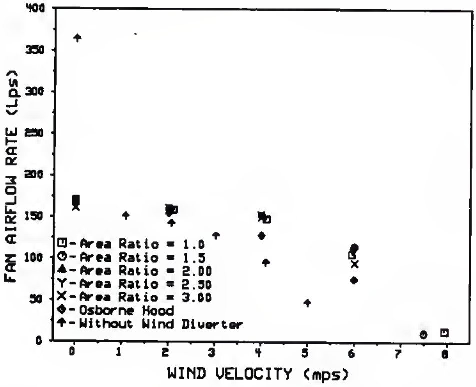


Figure 26. Fan airflow (Lps) versus wind velocity (mps) for the two-speed 30.5 cm fan operated at low speed (1140 rpm).

40.6 cm Fan.

Wind diverter position exhibited the most apparent effect in tests of the single-speed, 40.6 cm (16 in) fan, Figures 27 to 30. Time weighted airflow steadily increased as the distance from the fan outlet increased from 11.4 cm (4.5 in) to 50.8 cm (20 in), at which point the airflow leveled off. The highest airflow of 752 Lps, occurring at an area ratio of 5.0, was 27% higher than the exposed fan airflow of 591 Lps. Three types of 30° wind diverters were employed with this fan. A 30° cone without an outer flange yielded 1% to 2% higher time weighted airflows than the 30° cone with a flange, indicating the negative effect of a flange. A double cone, formed by placing two wind diverters back to back, had no apparent effect on fan airflow.

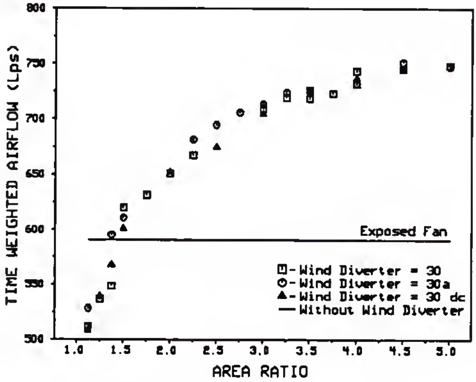


Figure 27. Time weighted airflow (Lps) versus area ratio for the single-speed 40.6 cm fan.

Plots of fan airflow rate versus wind velocity exhibited the effects of wind diverter position and wind diverter design modifications, Figures 28 to 30. The effect of wind diverter position was readily apparent for wind velocities below 4 mps. In windless conditions, the airflow increased by up to 41% as the area ratios increased, Figure 29. The airflows remained 27% to 70% higher, up to a 6 mps wind, for an area ratio of 5.0 in comparison to airflows attained at ratios of

1.125 and 1.5. The effect of position essentially disappeared at wind velocities from 6 to 8 mps. At 10 mps, larger area ratios yielded 33% to 38% lower airflows than the smaller area ratios, but still 76% to 80% higher airflows than for the exposed fan. The graphs also illustrate that the presence of a wind diverter was not beneficial until winds exceeded 3 mps. The fan airflow decreased from 837 to 477 Lps, a 43% decrease, at a 3.5 mps wind velocity for the fan operated without a wind diverter. This large decrease in fan airflow was caused by the wind pressure raising the effective fan static pressure above the region of instability. The presence of a wind diverter at any position enhanced fan airflow for winds above 3.5 mps and provided a more stable airflow. Small area ratios (below 3.5) did decrease the airflow by up to 34% at winds below 2 mps, but area ratios greater than 3.5 only decreased the airflow by 7.7% to 8.2% in windless conditions, and by less than one percent at the 2 mps wind.

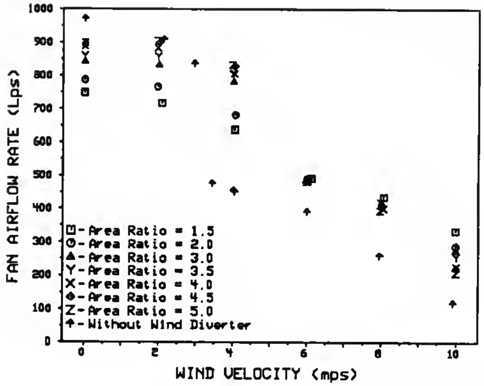


Figure 28. Fan airflow (Lps) versus wind velocity (mps) for the single-speed 40.6 cm fan with the 30 degree wind diverter.

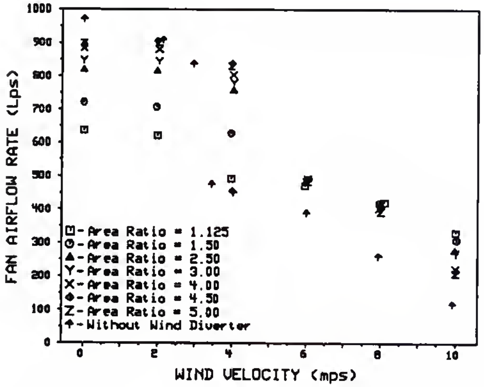


Figure 29. Fan airflow (Lps) versus wind velocity (mps) for the single-speed 40.6 cm fan with the 30 degree wind diverter without a flange.

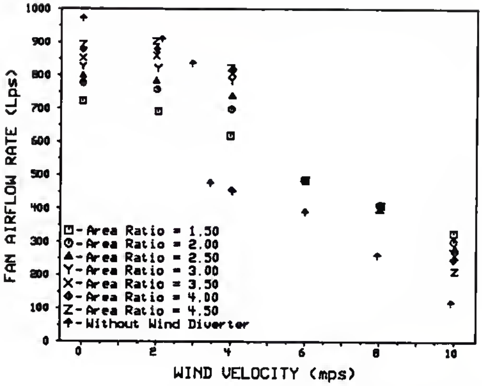


Figure 30. Fan airflow (Lps) versus wind velocity (mps) for the single-speed 40.6 cm fan with the 30 degree double cone wind diverter.

The results gathered in Experiment 1 illustrated the importance of wind diverter position in relation to fan airflow. In general, the presence of a wind diverter did decrease the fan's airflow when the oncoming wind velocity was below 2 mps, but improved the airflow for winds above 4 mps. Based on the use of time weighted airflows, the wind diverter was an aid to overall fan airflow. The position of the wind diverter was also shown to be very important, especially for larger fans. The overall fan airflow increased to a maximum as the wind diverter was moved farther away from the fan outlet, and then leveled off or decreased slightly as the distance was increased.

One problem encountered in the testing of all of the fan sizes except the 20.3 cm fan was the unstable region of fan operation. Small changes in pressure can cause large changes in fan airflow when a fan is operating in this region. In normal operation, this unstable region should be avoided if at all possible. Wind heightens the problem as added wind pressure causes the fan to operate at a higher actual static pressure than indicated by the measured building static pressure. The addition of a wind protection device also increased the load on the fan, causing the fan to work harder and operate at a higher static pressure. It was therefore impossible to avoid the region of instability during tests involving wind, as the fan's airflow follows its designated fan performance curve and inevitably crosses through the unstable region. The test procedures in Experiment 2 considered the careful acquisition of the test data so that results could be compared. Many test conditions in Experiment 1 were repeated in an attempt to verify the results. Some of the discrepancies were due to the unstable region of the fan. The other discrepancies were possibly due to measurement errors, particularly in the static pressure measurement, as higher wind velocities caused the pressure to fluctuate, making readings difficult.

Experiment 2

Experiment 1 showed an apparently significant effect of the wind diverter and wind diverter position on fan airflow in an oncoming wind. The second experiment examined the effect of wind diverter angle on the airflow of the 30.5 cm fan operated at 1725 rpm and 1140 rpm. Three wind diverter positions were examined for each of five wind diverter angles and two fan speeds. Experiment 2 thus evaluated the effects of wind diverter angle, position, and fan speed using a 5x3x2 factorial design.

High Speed Operation.

Wind Tunnel Tests. The effects of wind velocity on fan airflow for the various wind diverter angles and positions are shown in Figures 31 through 34. At an area ratio of 1.75, the effect of wind diverter angle was most apparent at winds below 2 mps, Figure 31. In windless conditions, fan airflow attained with the 45° wind diverter was 22% higher than with the 0° wind diverter, as airflow improved from 284 Lps to 346 Lps. The effect of wind diverter angle decreased as wind velocity increased up to 10 mps, where there was no apparent effect. The presence of a wind diverter decreased the fan airflow at winds equal to or below 2 mps, with a decrease of 40 to 50% in windless conditions. In contrast, the wind diverter aided airflow for winds above 2 mps, with up to a 115% improvement at a wind velocity of 8 mps. The exposed fan's airflow dropped from 537 to 216 Lps (60% decrease) as wind velocity increased from 2 to 4 mps. The use of a wind diverter created a more stable operating condition allowing the fan to operate in up to a 10 mps wind, while the exposed fan was only able to operate up to a 9.5 mps wind.

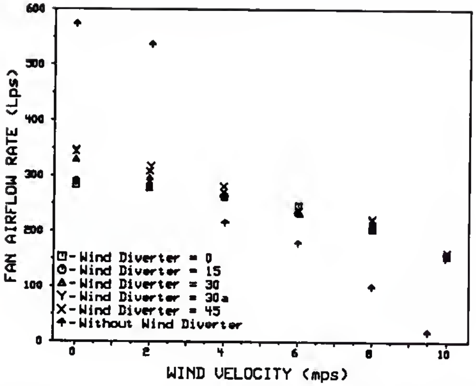


Figure 31. Effect of wind velocity on fan airflow rate (Lps) for high speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 1.75

The effect of wind diverter angle was more apparent at an area ratio of 2.5, especially for wind velocities at or below 2 mps, Figure 32. In windless conditions, a 45° or 60° wind diverter improved airflow from 286 Lps (for the 0° wind diverter) to between 498 and 502 Lps, an increase of 75%. The effect of the flange was also apparent, as the presence of an outer flange impeded the airflow by 2%. The effect of wind diverter angle again decreased at wind velocities of 4 mps and higher. At a wind velocity of 10 mps, though, the effect of wind diverter position was exhibited, as the 0° wind diverter yielded results 20% higher than the airflow attained with a 60° wind diverter. The effect of area ratio was even more graphic at winds of 2 mps and below, as the airflow attained with the 60° wind diverter was only 12% lower than the exposed fan's airflow in windless conditions, and 8% lower at a

2 mps wind. The use of a wind diverter again stabilized the airflow, and improved the airflow from 100 Lps to 230 Lps, a 130% increase, at a wind velocity of 8 mps.

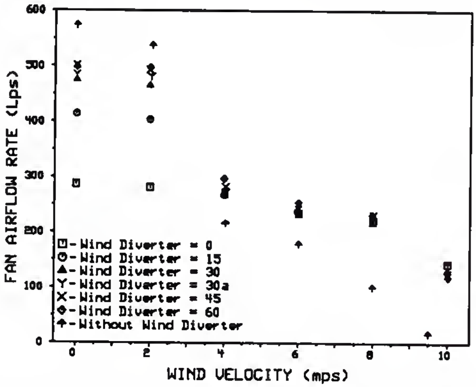


Figure 32. Effect of wind velocity on fan airflow rate (Lps) for high speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 2.5

The effect of wind diverter angle was again diminished at an area ratio of 4.0, Figure 33. At windless conditions, there was only a 4% difference between airflows, with the 60° angle providing 532 Lps and the 0° angle yielding 510 Lps. A small chimney effect was exhibited at a wind velocity of 2 mps, as the airflows improved by 1%. The effect of wind diverter position also became more pronounced at a ratio of 4.0. The use of a wind diverter only decreased the fan airflow by 7% to 11% as compared to the exposed fan's airflow at windless conditions, and by 1 to 4% at the 2 mps wind. In contrast, the use of a wind diverter increased the airflow from 100 Lps to 160 to 185 Lps, a 60% to 85%

increase, at a wind velocity of 8 mps. At a wind velocity of 10 mps, the 0° wind diverter now yielded results 30% higher than the airflow attained with a 60° wind diverter.

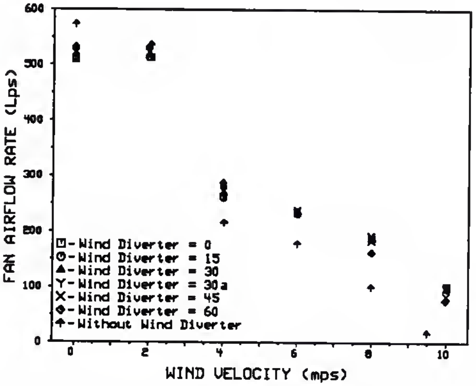


Figure 33. Effect of wind velocity on fan airflow rate (Lps) for high speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 4.0

This same trend was apparent at an area ratio of 5.5, Figure 34. In windless conditions, there was again a 4% difference between airflows, with the 60° angle providing 544 Lps and the 0° angle yielding 522 Lps. The airflow obtained with the 60° wind diverter angle did improve from 544 to 546 Lps at a 2 mps wind, thus exceeding the exposed fan's airflow of 537 Lps at that wind velocity. At an area ratio of 5.5, the effect of wind diverter position was readily apparent. The use of a wind diverter decreased the fan airflow by only 5% to 8.5% in relation to the exposed fan's airflow at windless conditions, but only improved the airflow at a wind of 8 mps from 100 Lps to between 130 and

160 Lps (30% to 60% increase). The effect of wind diverter angle was also evident at the 10 mps wind, as the airflow improved from 34 Lps for the 60° wind diverter to 62 Lps for the 0° wind diverter, an improvement of 82%.

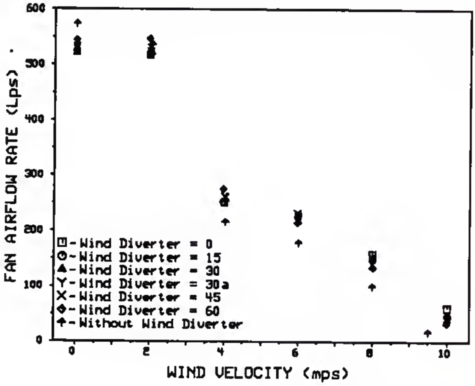


Figure 34. Effect of wind velocity on fan airflow rate (Lps) for high speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 5.5

The effect of wind diverter position was even more apparent when the results presented in Figures 31 through 34 were examined together. At wind velocities of 2 mps and below, the wind diverter position had an apparently large effect on fan airflow. At an area ratio of 1.75, the wind diverter restricted the airflow quite severely, with airflows ranging from 284 to 346 Lps in windless conditions. Subsequent area ratios resulted in less restriction, increasing the airflow to between 522 and 544 Lps at an area ratio of 5.5 in windless conditions. The opposite effect was exhibited for wind velocities above 4 mps. The largest benefit for use of a wind diverter was exhibited at an area ratio of 1.75, where the airflow was 157 Lps at a wind velocity of 10 mps. Subsequent area ratios yielded a decrease in airflows over the range of winds from 4 to 10 mps, with an area ratio of 5.5 only yielding airflows from 34 to 62 Lps at the 10 mps wind.

Effect of Wind on the Fan Performance Curve. The effects of wind on fan airflow can also be seen when plotted against the fan's performance curve under windless conditions. The fan airflows for the two-speed 30.5 cm fan (1725 rpm) without a wind diverter (at all possible static pressures) and with the 30° wind diverter at various positions and at constant building static pressure are presented in Figures 35 through 39. The results from the wind effects study were all collected at 31.0 Pa building static pressure, with the airflows obtained at each wind velocity proceeding from right to left as the wind velocity increased. The initial load placed on the fan by the wind diverter was most readily evident at an area ratio of 1.75. This initial load caused the fan's performance curve to shift horizontally to the left and down. The initial airflow was decreased from 573 to 328 Lps, a 43% decrease, at this area ratio. Subsequent wind velocities caused the fan airflow to continue to decrease, with an airflow of only 154 Lps at a wind velocity of 10 mps. The vertical differences between the two performance curves (windless conditions versus varying wind velocities) was due to the pressure created by the wind, and is theoretically related to the square of the wind velocity. This theoretical relationship appears to be verified in the graphs, as the distance between the two performance curves appears to increase according to the square of the wind velocity as the wind velocity increases from 0 to 10 mps. The wind thus causes the fan to operate against a larger static pressure than the average static pressure inside the chamber (building).

The initial load placed on the fan by the wind diverter decreased as the distance between the wind diverter and the fan outlet increased. Wind velocities less than 2 mps resulted in the fan airflow approaching the fan performance curve under windless conditions. At an area ratio of 2.5, the fan airflow improved to 475 Lps in windless conditions, a decrease of 17% from the fan performance curve obtained without a wind diverter in windless conditions. The airflow in windless conditions continued to improve as the area ratio increased, with 519 Lps being attained at a ratio of 4.0 and 528 Lps at a ratio of 5.5. This 528 Lps airflow was only an 8% decrease from the fan performance curve obtained without a wind diverter and in windless conditions. The fan airflow also increased steadily at the 2 mps wind as the area ratio increased. At a wind velocity of 2 mps, the airflow was 296 Lps at a ratio of 1.75, 465 Lps at 2.5, 519 Lps at 4.0, and 523 Lps at 5.5. In contrast, the airflow decreased steadily for winds of 4 mps and above as the area ratio increased above 2.5. At an area ratio of 1.75, though, the wind diverter was a large enough restriction that for wind velocities between 4 and 8 mps, the airflows were 2% to 4% lower than the airflows determined at a ratio of 2.5. At area ratios of 2.5 and larger, the fan airflows did steadily decrease as the area ratio increased, with the largest subsequent decreases occurring at wind velocities of 8 mps and 10 mps. For example, at a wind velocity of 10 mps, the airflow was 154 Lps at a ratio of 1.75, 131 Lps at 2.5, 97 Lps at 4.0, and 48 Lps at 5.5.

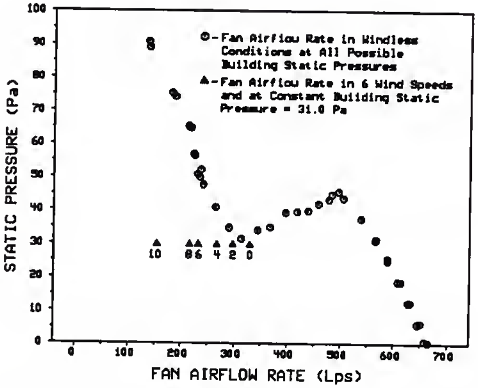


Figure 35. Fan airflow in windless conditions without a wind diverter and with a wind diverter (area ratio = 1.75) in 6 wind speeds at a constant building static pressure

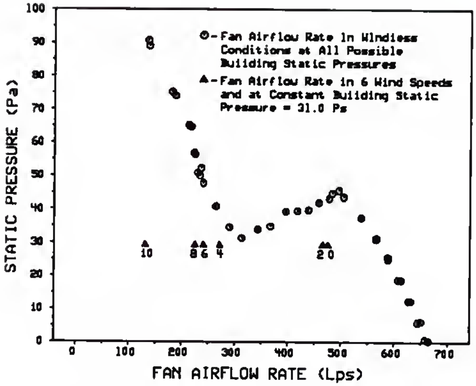


Figure 36. Fan airflow in windless conditions without a wind diverter and with a wind diverter (area ratio = 2.5) in 6 wind speeds at a constant building static pressure

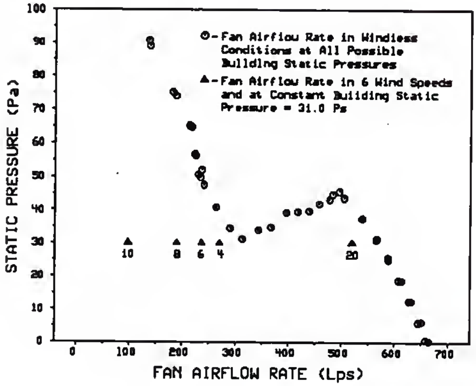


Figure 37. Fan airflow in windless conditions without a wind diverter and with a wind diverter (area ratio = 4.0) in 6 wind speeds at a constant building static pressure

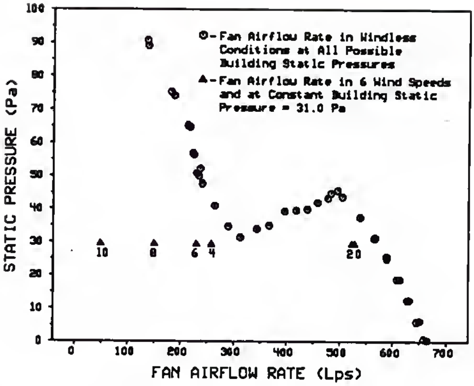


Figure 38. Fan airflow in windless conditions without a wind diverter and with a wind diverter (area ratio = 5.5) in 6 wind speeds at a constant building static pressure

The fan airflow without a wind diverter yielded a wide spread of results, Figure 39. In windless conditions, the exposed fan's airflow was 573 Lps, falling directly on the performance curve of the fan. At a wind velocity of 2 mps, the airflow remained high at 537 Lps, but dropped sharply to 216 Lps at the 4 mps wind. The airflow continued to drop sharply as the wind velocity increased, with the fan only able to produce 17 Lps at a wind velocity of 9.5 mps. The calculated wind velocity pressure was added to the 31.0 Pa building static pressure, Figure 39. The calculated fan static pressures were not equal to the fan static pressures obtained in windless conditions. Possibilities for the remaining differences include turbulence at the fan, increased wind velocity as the wind "escapes" over the chamber, and difficulty in measuring the "true" wind velocity at the fan, as the measurement of the wind velocity was at a distance of approximately 2.5 m (8 ft) upstream from the fan.

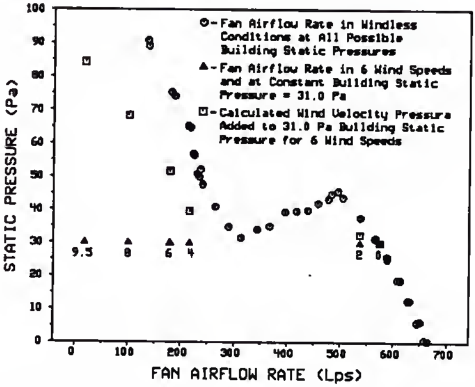


Figure 39. Fan airflow in windless conditions without a wind diverter and in 6 wind speeds at a constant building static pressure

Wind and Fan Airflow Interaction. A wind velocity of 4 mps was a critical wind for all of the testing conditions, as the wind pressure raised the effective fan static pressure through the region of instability for the fan. The fan operated below the unstable region for wind velocities of 0 and 2 mps, while it operated at the upper edge of the region for a wind of 4 mps. The interaction between wind velocity and fan airflow was visualized with streamers made of string and attached to the wind diverter. The streamers were 7.6 cm (3 in) long and were attached at 2.5 cm (1.0 in) increments, along a length of string that ran from the fan outlet to the edge of the diverter and over to the wind tunnel wall.

The behavior of these streamers was photographed at each wind velocity during the tests in an effort to visualize the processes taking place during operation of the fan facing a wind. The pictures serve to show the location of the diverter, its attachment to the fan (aluminum struts) and the behavior of the streamers (wind tunnel wall as background). The plywood background and poor lighting prohibited optimal visualization, but the effect of increased wind velocity was identified. The behavior of the streamers over the range of wind velocities from 0 to 10 mps for the 60° wind diverter at an area ratio of 5.5 are exhibited in Figures 40 through 45. These figures and graphs illustrate the relationships between wind velocity and diverter angle and position.

Figure 40. Interaction between a 0 mps wind and fan airflow with the 60° wind diverter

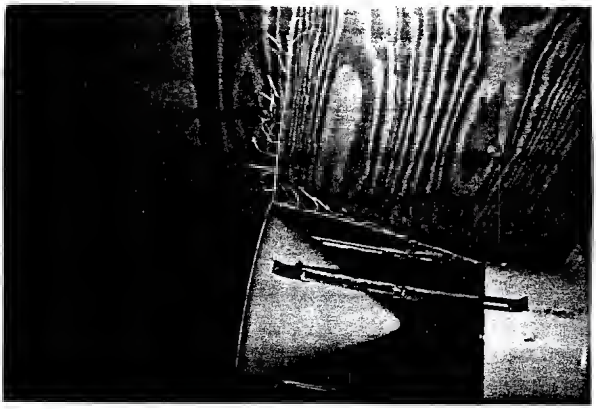


Figure 41. Interaction between a 2 mps wind and fan airflow with the 60° wind diverter

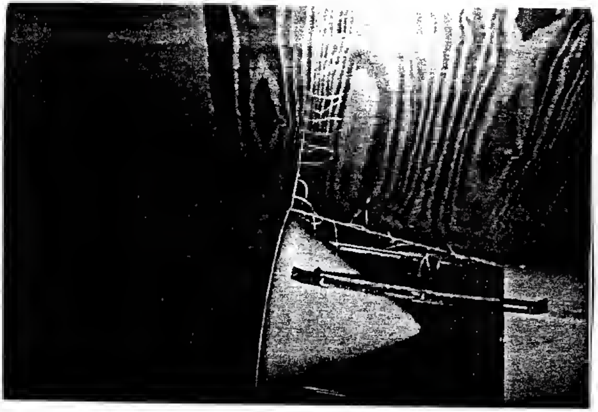


Figure 42. Interaction between a 4 mps wind and fan airflow with the 60° wind diverter

Figure 43. Interaction between a 6 mps wind and fan airflow with the 60° wind diverter

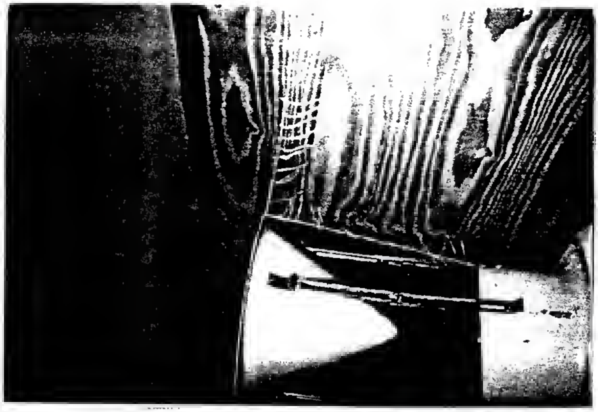


Figure 44. Interaction between a 8 mps wind and fan airflow with the 60° wind diverter

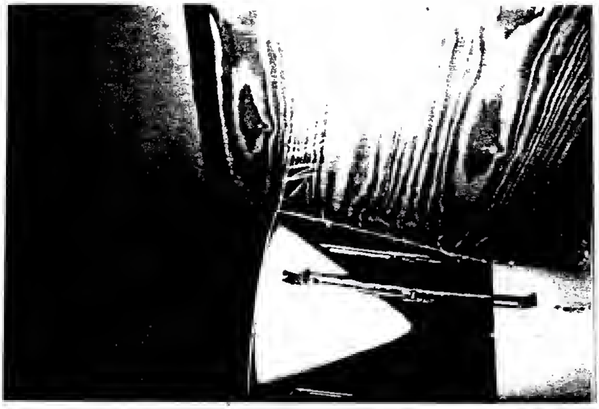


Figure 45. Interaction between a 10 mps wind and fan airflow with the 60° wind diverter

Time Weighted Airflow. The combined effect of wind diverter angle and position are presented in Figure 46. At an area ratio of 1.75, the time weighted airflow was from 260 to 278 Lps, a decrease of 12 to 16% from the 316 Lps obtained with the exposed fan. The effect of wind diverter angle was most apparent at an area ratio of 2.5. The two 30°, 45°, and 60° wind diverters exhibited time weighted airflows ranging from 331 Lps to 354 Lps, a 5% to 12% improvement over the exposed fan's 316 Lps. In contrast, the 0° and 15° wind diverters only yielded 83% to 97% of the time weighted airflows obtained without a wind diverter. An area ratio of 4.0 yielded time weighted airflows of 339 to 355 Lps, an improvement of 7% to 12% over the exposed fan's 316 Lps, with the 60° wind diverter yielding the largest airflow. The time weighted airflows at an area ratio of 5.5 were all higher than those obtained without a wind diverter, but the improvement was decreased to only 6% to 11%. The optimum wind diverter angle and position appeared to be a 60° angle at an area ratio of either 2.5 or 4.0. An area ratio of 2.5 may be a better choice than 4.0, though, due to the inconsequential difference between the time weighted airflows, and the disadvantage of longer brackets needed for a ratio of 4.0. Additional information is presented in Appendix C, where the various test conditions and results are exhibited in tabular form.

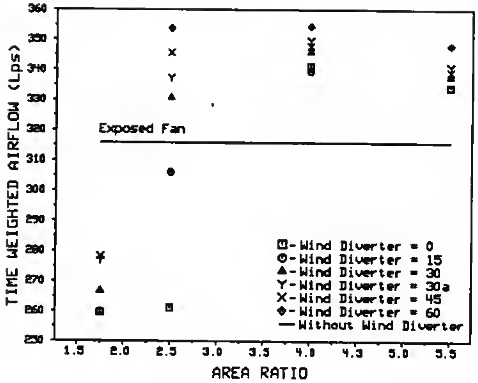


Figure 46. Effect of area ratio and wind diverter angle on time weighted airflow for high speed operation of the two-speed 30.5 cm fan

Low Speed Operation.

Wind Tunnel Tests. The effect of wind diverter angle and position on fan airflow were not as apparent for the two-speed 30.5 cm fan operated at 1140 rpm. Plots of fan airflow rate versus wind velocity for three wind diverter positions are presented in Figures 47 through 49. At an area ratio of 1.0, and in windless conditions, the use of a wind diverter decreased the fan airflow from 364 Lps for the exposed fan, to between 156 and 163 Lps, a decrease of 55% to 57%, depending on the wind diverter angle, Figure 47. The use of a wind diverter was beneficial for wind velocities of one mps and beyond, as the exposed fan's airflow dropped from 364 Lps to 151 Lps, a 58% decrease, at a wind of 1 mps. The use of a wind diverter also provided a more stable airflow and enabled the fan to operate up to a wind of 8 mps, while the exposed fan was only able to operate up to a 5 mps wind. At a wind velocity of 4 mps, the wind diverter increased the airflow by 52% to 57%, from 96 Lps for the exposed fan to between 146 and 150 Lps for the 45° wind diverter. The effect of wind diverter angle on fan airflow was relatively small over the entire range of wind velocities. In windless conditions, the airflow was improved by 4.5% with the use of a 45° wind diverter over the 0° wind diverter, while at a 6 mps wind, the 45° wind diverter improved the airflow by 6%. The relatively small distance between the wind diverter and the fan outlet also prohibited the use of the 60° wind diverter at this ratio, due to its length.

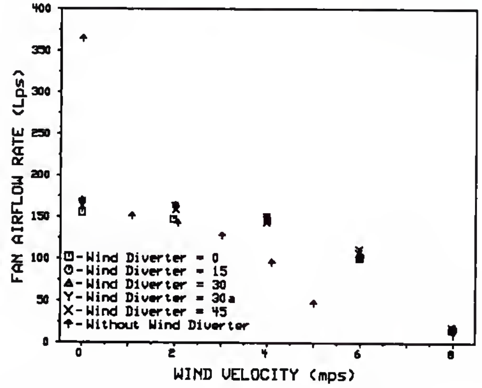


Figure 47. Effect of wind velocity on fan airflow rate (Lps) for low speed operation of the two-speed 30.5 cm fan with five wind diverter angles at an area ratio of 1.0

At an area ratio of 2.0, the airflow in windless conditions improved from 156 to 163 Lps for a ratio of 1.0 to between 163 and 176

Lps, which still was a 51% to 55% decrease in airflow as compared to the exposed fan (364 Lps), Figure 48. The use of a wind diverter was again beneficial for wind velocities of one mps and beyond, enabling the fan to operate up to a wind velocity of 6 to 7 mps. The beneficial use of a wind diverter at a wind velocity of 4 mps increased, as the airflow improved to between 145 and 155 Lps, an increase of 51% to 61% over the exposed fan's airflow (96 Lps). The effect of wind diverter position was also evident, as the larger distance between the diverter and the fan outlet resulted in the fan only being able to operate up to a 6 mps wind.

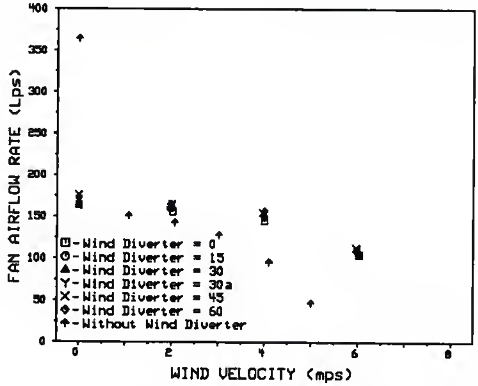


Figure 48. Effect of wind velocity on fan airflow rate (Lps) for low speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 2.0

In windless conditions, the effect of wind diverter angle increased at an area ratio of 3.0, Figure 49. The fan airflow improved over the 2.0 area ratio from 176 to 181 Lps for the 45° wind diverter while the airflow decreased from 163 to 160 Lps for the 0° wind diverter. The use of a wind diverter also improved the benefit at a wind velocity of 4 mps, as the airflow increased to between 147 and 159 Lps, a 53% to 65% increase over the exposed fan's airflow of 96 Lps. The effect of wind diverter position was evident at the 6 mps wind. The fan airflow decreased from between 105 and 113 Lps at a ratio of 2.0 to between 92 and 100 Lps for a ratio of 3.0. The relatively large distance between the wind diverter and the fan outlet again prohibited the fan from operating in winds above 6 mps.

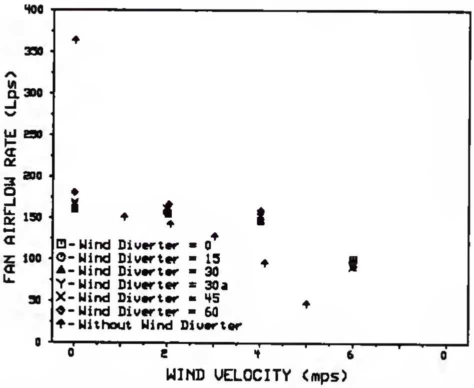


Figure 49. Effect of wind velocity on fan airflow rate (Lps) for low speed operation of the two-speed 30.5 cm fan with six wind diverter angles at an area ratio of 3.0

Time Weighted Airflow. The effects of wind diverter angle and position are presented in Figure 50. The presence of a wind diverter improved the fan airflow from 90 Lps to between 127 and 138 Lps, an increase of

41% to 53%, depending on area ratio and wind diverter angle. The results also indicated that wind diverter position had very little effect on time weighted airflows. The effect of wind diverter angle had a relatively small effect on time weighted airflow. The 45° wind diverter yielded the highest time weighted airflows at area ratios of 1.0 and 2.0, with airflows of 131 and 138 Lps, respectively. These results were 6.3% and 7% higher, respectively, than the 0° wind diverter at these two ratios. At an area ratio of 3.0, the 60° wind diverter yielded an airflow of 136 Lps, which was 5.4% higher than the airflow obtained with the 0° wind diverter, and 3.8% higher than the airflow obtained with the 45° wind diverter. Based on the small differences exhibited with wind diverter angle, and the length limitations of the 60° wind diverter, the 30° wind diverter without a flange, or the 45° wind diverter appear to be the best choice. The effect of wind diverter position was very small, but, based on the data collected, it appeared that an area ratio of 2.0 yielded results that were 1% higher than area ratios of 1.0 and 2.0.

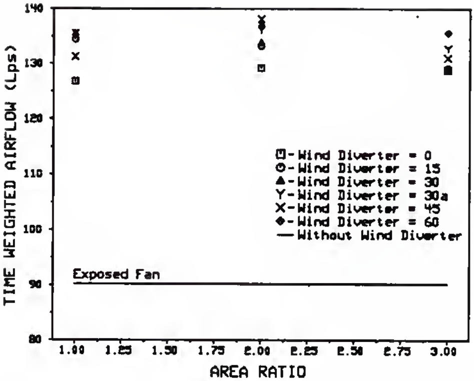


Figure 50. Effect of area ratio and wind diverter angle on time weighted airflow for low speed operation of the two-speed 30.5 cm fan

Overall Effects of Angle and Area Ratio.

In an effort to summarize the results obtained for all tests, the time weighted airflows were averaged for each wind diverter angle and area ratio, Figures 51 and 52.

The overall effect of wind diverter angle was apparently significant for high speed operation, but less significant at low speed operation, Figure 51. At both fan speeds, the 60° wind diverter provided the highest average time weighted airflow, with a more pronounced effect exhibited with high speed operation. This effect amounted to an increase in average time weighted airflow of 2.3%, 2.6%, 4.1%, 8.0%, and 13.0%, over wind diverter angles of 45°, 30° without a flange, 30°, 15°, and 0°, respectively. For low speed operation, the 60° wind diverter improved the average time weighted airflow by 0.7%, 1.5%, 3.0%, 3.7%, and 5.5%, over wind diverter angles of 45°, 30° without a flange, 30°, 15° and 0°, respectively. The effect of the flange was also exhibited, as the presence of an outer flange on the wind diverter decreased the average time weighted airflow by 1.5% for both high and low speed operation. This difference may not appear to be significant, but over an extended period of operation, and in a large livestock ventilation system, these improvements may mean a significant savings in operating costs.

The effect of wind diverter position on fan airflow is presented in Figure 52. The effect of wind diverter position was apparently significant for high speed operation, but relatively insignificant for low speed operation. The optimum area ratio for high speed operation was 4.0, with an average time weighted airflow of 346 Lps, which was 2% higher than for a ratio of 5.5, and 29% higher than for a ratio of 1.75. The optimum area ratio for low speed operation appeared to be 2.0, as the average time weighted airflow of 135 Lps was 1.5% higher than for a ratio of 1.0, and 3% higher than for a ratio of 3.0.

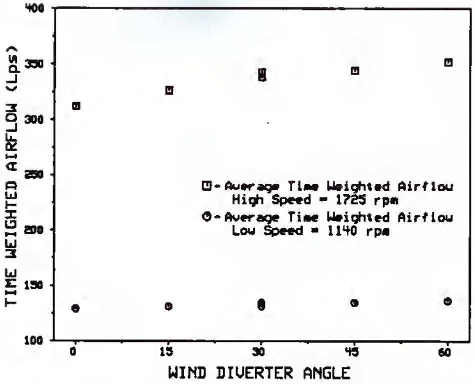


Figure 51. Time weighted airflow (Lps) versus wind diverter angle, averaged over the tested range of area ratios, for the two-speed 30.5 cm fan.

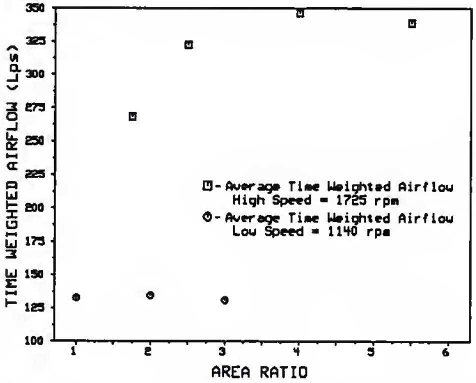


Figure 52. Time weighted airflow (Lps) versus area ratio, averaged over the tested range of wind diverter angles, for the two-speed 30.5 cm fan.

The determination of an optimum wind diverter position for all fans was very difficult. The determination of wind diverter position was dependent on fan airflow. In general, the larger the fan, the greater the airflow, and the greater the distance between the wind diverter and the fan outlet. The position of the wind diverter should be located to yield high fan airflow at low wind velocities, and maintain reasonable fan airflow at higher wind velocities. The effect of wind diverter position was not as apparent for smaller fans, or fans operated at low speeds. It therefore appears best to locate the wind diverter for medium to high speed operation for variable speed fans. The wind speed frequency curve must also be considered, as it is site dependent. The wind speed frequency curve, the fan's airflow, and the normal operating conditions must all be considered in the location of the optimum position for the wind diverter.

Statistical Models.

Various regression techniques were employed in an effort to develop a model to fit the data collected. The lack of a large data base was a slight hindrance in determining the "best" model, as a truly representative model requires a fairly large data base with replications. The models determined are thus preliminary at best, as much research still remains. Three regression models, of varying complexity, were developed for the two-speed 30.5 cm fan operated at high speed. These models are presented below, with their respective R^2 value and parameter estimates, while Appendix D contains additional statistical results on the three models.

Model 1: $TWA = \beta_0 + \beta_1 * Angle + \beta_2 * Ratio + \beta_3 * Ratio^2$

Coefficient	Parameter Estimate	R-Squared
β_0	119.9547	0.8467
β_1	0.6347	
β_2	97.4244	
β_3	-11.1584	

Model 2: $TWA = \beta_0 + \beta_1 * Angle + \beta_2 * Ratio + \beta_3 * Ratio^2 + \beta_4 * Angle * Ratio$

Coefficient	Parameter Estimate	R-Squared
β_0	100.8647	0.8952
β_1	1.6235	
β_2	100.1497	
β_3	-10.5257	
β_4	-0.2696	

Model 3: $$TWA = \begin{cases} \beta_0 + \beta_1 * Angle + \beta_2 * Ratio + \beta_3 * Angle^2 \\ + \beta_4 * Ratio^2 + \beta_5 * Angle * Ratio \end{cases}$$

Coefficient	Parameter Estimate	R-Squared
β_0	101.7584	0.8954
β_1	1.5473	
β_2	99.9141	
β_3	0.0015	
β_4	-10.4869	
β_5	-0.2727	

The three models above exhibit that a regression model can be fit fairly well to the data obtained, with R^2 ranging from approximately .85 to .90. Since model 2 contains one less parameter than model 3 and yields approximately the same R^2, it would be chosen as the "best" model. This model was not conclusive, though, as there was no repetition of data and the database was small.

Various regression models were developed from the data from tests on the two-speed 30.5 cm fan operated at low speed. Unfortunately, these models did not fit the data very well, as R^2 was approximately .67 for all three models. There are a couple of possible reasons for this poor fit. One reason for the poor fit could be that the tips of the 45° and 60° wind diverters were cut off for the small area ratios. The stub-nose resulted in lower airflows for those two wind diverters instead of the anticipated higher values. This effect was even more magnified in that the differences between results for wind diverter angle and area ratio were not very significant. Thus, when these two factors are combined, an accurate regression model was difficult to obtain. The three models are presented below with their parameter estimates and respective R^2, while Appendix D contains the statistical results in further detail.

Model 1: $\text{TWA} = \beta_0 + \beta_1{*}\text{Angle} + \beta_2{*}\text{Ratio} + \beta_3{*}\text{Ratio}^2$

Coefficient	Parameter Estimate	R-Squared
β_0	123.1374	
β_1	0.1141	0.6634
β_2	8.7555	
β_3	-2.4487	

Model 2: $\text{TWA} = \beta_0 + \beta_1{*}\text{Angle} + \beta_2{*}\text{Ratio} + \beta_3{*}\text{Ratio}^2 + \beta_4{*}\text{Angle}{*}\text{Ratio}$

Coefficient	Parameter Estimate	R-Squared
β_0	123.0397	
β_1	0.1196	
β_2	8.7743	0.6635
β_3	-2.4374	
β_4	-0.0025	

Model 3: $\text{TWA} = \beta_0 + \beta_1{*}\text{Angle} + \beta_2{*}\text{Ratio} + \beta_3{*}\text{Angle}^2 + \beta_4{*}\text{Ratio}^2$

Coefficient	Parameter Estimate	R-Squared
β_0	122.4712	
β_1	0.1638	
β_2	9.0494	0.6722
β_3	-0.0009	
β_4	-2.5075	

In addition to fitting regression models to the data obtained during testing of the effect of wind diverter angle and position ratio, a model predicting the optimum wind diverter position ratio was attempted. Since the results obtained from this study indicated that a 60° wind diverter was the best choice of angles, a means of obtaining the optimum wind diverter position would be helpful. A prediction equation for this purpose was not obtained, due to several limitations. The test results did seem to indicate an optimum position for each fan tested, but there was no single model that could be used to estimate the optimum position for any size fan. The optimum wind diverter position did seem to be function of fan output (Lps), but there was no single relation that could be applied to all the fan sizes. Since only three sizes of fans were tested, and from only one manufacturer, the database from which to work was very small. The effect of wind speed also was a detriment, as it affected each fan's operation differently, depending on the capacity of the fan. In conclusion, much additional research and experimentation remains before a model to predict optimum wind diverter position can be properly developed.

Summary and Conclusions

A greater understanding of fan performance was gained in this study. The study illustrated the effect of the wind and wind diverters upon fan airflow. The use of the Weibull distribution to weight the fan's airflows at each test wind speed enabled the results from each tested parameter to be compared on the basis of one weighted airflow. The comparison of time weighted airflows thus provided an evaluation of the fan's performance, under particular test conditions, over an extended period of time. The Weibull distribution used with these tests included two parameters specific for the anticipated normal operating conditions of ventilation fans in Kansas. These specific parameters must be kept in mind when observing and applying the results presented in this study.

The presence of a wind diverter was very beneficial to fan performance overall. For operation over an extended time period, the use of a wind diverter was shown to improve fan airflow up to 65%. The presence of wind diverters yielded significantly higher airflows (over 100% improvement over fan airflow without a wind diverter in some cases) and maintained positive fan airflow at higher wind velocities. The addition of a wind diverter did create a load on the fan, but this load was only evident at wind velocities below 2 mps, and was fairly insignificant (only 2% to 3% reduction in some cases). The airflows attained with wind diverters were 33% and 16% higher, for high and low speed operation, respectively, than the airflows attained with the Osborne hood.

Two parameters were investigated in the study on wind effects. The effect of wind diverter position appeared significant, as the optimum wind diverter position increased the fan's time weighted airflow by up to 65% over the fan's airflow without a wind diverter. The optimum wind diverter position was difficult to determine, and was directly related to the fan diameter and rotational speed.

The effect of wind diverter angle was readily apparent. From the test results, it was found that the 60° angle yielded the highest time weighted airflow, while the flat plate yielded the lowest results. This overall result indicated that a larger angle aided the fan in exhausting its airflow, or in essence created less of a restriction upon the fan. When the results were broken down further, it was discovered that the 60° cone angle improved the fan airflow by up to 75% in relation to other cone angles, but diminished the airflow by up to 60% at a wind velocity of 10 mps. It was also found that the use of a 60° angle may be somewhat restricted. This restriction is due to the overall length of the 60° wind diverter, as its length necessitates that the area ratio be fairly large. The ratio for the 30.5 cm (12 in) fan must be at least 2.5, and even at that position, the tip of the wind diverter must be cut off. Therefore, for larger capacity fans, the 60° wind diverter was the proper choice when the area ratio was at or above 2.5. For smaller capacity fans, though, the 60° wind diverter would not be the best choice, and either a 30° or 45° angle wind diverter should be considered. Based on the test results obtained, it would be recommended that the wind diverters be constructed without a flange. The effect of a flange on the outer edge of the wind diverter lowered the fan's overall airflow by 1% to 3%.

This study effectively illustrated the effect of wind upon fan performance and examined two different wind diverter parameters in some detail. The results obtained are not conclusive, as additional research is needed, but the results clearly indicate the detrimental effects of wind and, consequentially, the need for a wind protection device. This study concentrated particularly on the cone shaped wind diverter as a wind protection device and clearly exhibited the benefits of using a wind diverter and the effects of cone angle and diverter position.

RECOMMENDATIONS FOR FUTURE RESEARCH

Prior to labeling the KSU fan test chamber as a viable fan testing facility, verification of its performance must be obtained. This verification should entail a thorough evaluation of the instrumentation employed, and whether it can be improved, and a re-evaluation of the air velocity profiles to some deeper extent, along with a thorough examination for leaks. Further automation of the fan testing procedure by means of a data acquisition system would be recommended. This automation may require various instrumentation changes including temperature and barometric pressure acquisition, and pressure measurement. A switch from a basically manually operated system to one that is more automatically controlled should reduce the sources for error as well as lessen the time required for testing.

A further study on the effect of various fan parameters and attachments would be very beneficial. Efforts in this area would particularly benefit manufacturers, as they are constantly searching for any means of improving their fans' performance, and, thus, their fans' marketability. Further study into the components of a fan may also prove beneficial by providing a better understanding of the region of unstable performance exhibited by axial flow fans.

Further research into the effect of wind upon fan performance is also needed. The results obtained are fairly preliminary, and are really an introductory study into understanding wind effects. This particular study was very specific and is not conclusive for other fans. The effect of wind angle was not examined in this study, but will be examined in a subsequent study. Additional experimentation in a wind tunnel is also needed in order to form a larger data base from which operational theory of fan performance with/without wind protection devices may be developed. This study concentrated on the use of a cone shaped wind diverter and virtually ignored alternative wind protection devices. Thus, further research is needed on the performance of alternative wind protection devices, thus allowing for comparison between the different devices and means of protection. The Weibull distribution was also employed to simplify the analysis of the results. Thus, an examination of the applicability of the Weibull distribution to describe wind speed frequency would be in order. Determination of fan performance with/without some means of wind protection within a wind tunnel is not truly indicative of field conditions and installations. Therefore, field tests of fans exhausting into a wind would be of particular interest, albeit difficult to obtain.

Finally, diligent preparation and design must be observed prior to initiating any research. It is far more beneficial to spend extra time in the design and preparation stage to insure that the proper steps in development and evaluation are followed. Prior to initiating any research, it is important to determine the projects goals, examine any potential problems, and determine what variables are involved and how to treat them so as to simplify the research and experimentation.

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APPENDIX A

Summary of Air Velocity Profiles

Air Velocity Profiles for the Initial Settling Means

The point velocities (mps) obtained in the air velocity profiles are presented in Tables 9 through 11. Since the sampling points did not represent equal areas within the chamber, the resultant mean was calculated based on the percentage of the total area that each area around the point represented. Data points exceeding the resultant mean by more than 25% (AMCA Standard 210, 1985) are indicated by an asterik (*).

TABLE 9. Average point velocity (mps) at measuring plane downstream of settling means closest to the test fan.

Probe Loc.	Initial	Run #1	Run #2	Run #3
tf1e5.5	.25	.464	.451	.366
tf1e11.0	.5	.609*	.454	.412
tf1e16.5	.6*	.465	.431	.463
tf1e22.0	.6*	.349	.192	.249
tf1e27.5	.3	.411	.463	.430
tf1e/1w33.0	.3	.388	.388	.474
tf2e5.5	.25	.511	.513	.492
tf2e11.0	.65*	.636*	.498	.442
tf2e16.5	.4	.390	.363	.333
tf2e22.0	.4	.199	.188	.289
tf2e27.5	.9*	.372	.495	.430
tf2e/2w33.0	.55*	.472	.525	.482
tf3e5.5	.2	.504	.406	.456
tf3e11.0	1.0*	.731*	.492	.486
tf3e16.5	.2	.380	.384	.494
tf3e22.0	.3	.175	.170	.174
tf3e27.5	.9*	.607*	.430	.460
tf3e/4e33.0	.3	.420	.438	.424
tf4e5.5	.25	.449	.359	.331
tf4e11.0	.8*	.456	.394	.346
tf4e16.5	.8*	.430	.393	.389
tf4e22.0	.8*	.229	.152	.146
tf4e27.5	.5	.367	.352	.363
tf4e/4w33.0	.35	.364	.388	.380
tf1w5.5	.2	.445	.552*	.582*
tf1w11.0	.2	.454	.299	.335
tf1w16.5	.2	.336	.313	.362
tf1w22.0	.3	.319	.426	.503
tf1w27.5	.25	.388	.511	.511
tf2w5.5	.35	.513	.593*	.534*
tf2w11.0	.3	.487	.451	.354
tf2w16.5	.5	.464	.412	.391
tf2w22.0	.5	.522	.663*	.557*
tf2w27.5	.35	.458	.488	.486
tf3w5.5	.2	.547*	.582*	.554*
tf3w11.0	.3	.343	.373	.381
tf3w16.5	.55*	.352	.194	.221
tf3w22.0	.55*	.311	.652*	.656*
tf3w27.5	.4	.569*	.534*	.574*
tf4w5.5	.4	.441	.532*	.528*
tf4w11.0	.25	.406	.265	.348
tf4w16.5	.7*	.212	.256	.231
tf4w22.0	.3	.306	.714*	.726*
tf4w27.5	.4	.355	.371	.389
mean	.422	.422	.422	.422
1.25*mean	.528	.528	.528	.528

TABLE 10. Average point velocity at measuring plane upstream of settling means closest to the test fan

Probe Loc.	Initial	Run #1
nd1e5.5	.45	.389
nd1e11.0	.3	.468
nd1e16.5	.2	.183
nd1e22.0	.45	.264
nd1e27.5	.3	.257
nd1e/1w33.0	-	-
nd2e5.5	.45	.286
nd2e11.0	.3	.183
nd2e16.5	.3	.206
nd2e22.0	.25	.197
nd2e27.5	.25	.258
nd2e/2w33.0	.25	.270
nd3e5.5	.3	.169
nd3e11.0	.25	.152
nd3e16.5	.25	.203
nd3e22.0	.25	.244
nd3e27.5	.25	.262
nd3e/3w33.0	-	-
nd4e5.5	.5	.240
nd4e11.0	.3	.232
nd4e16.5	-	.216
nd4e22.0	-	.260
nd4e27.5	-	.308
nd4e/4w33.0	-	-
nd1w5.5	.2	.143
nd1w11.0	.2	.15
nd1w16.5	.4	.266
nd1w22.0	.3	.170
nd1w27.5	.3	.264
nd2w5.5	.3	.159
nd2w11.0	.3	.194
nd2w16.5	.25	.207
nd2w22.0	.2	.266
nd2w27.5	.15	.322
nd3w5.5	.2	.325
nd3w11.0	.3	.223
nd3w16.5	.25	.275
nd3w22.0	.25	.221
nd3w27.5	.15	.198
nd4w5.5	.3	.446
nd4w11.0	.15	.459
nd4w16.5	.2	.258
nd4w22.0	.3	.223
nd4w27.5	.2	.277
mean jet vel	14.38	14.38
.10*mean jet vel	1.44	1.44

TABLE 11. Average point velocity at measuring plane downstream of settling means closest to the supply fan

Probe Loc.	Initial	Run #1	Run #2	Run #3
nu1e5.5	.5	.421	.463	.315
nu1e11.0	.45	.277	.276	.268
nu1e16.5	.4	.447	.470	.464
nu1e22.0	.4	.282	.312	.276
nu1e27.5	.35	.377	.320	.266
nu1e/1w33.0	.5	.362	.374	.370
nu2e5.5	.6*	.333	.429	.342
nu2e11.0	.5	.318	.309	.397
nu2e16.5	.5	.435	.424	.415
nu2e22.0	.4	.314	.285	.287
nu2e27.5	.4	.427	.422	.436
nu2e/2w33.0	.45	.344	.358	.321
nu3e5.5	.7*	.354	.389	.381
nu3e11.0	.5	.425	.388	.433
nu3e16.5	.45	.473	.486	.514*
nu3e22.0	.35	.309	.292	.298
nu3e27.5	.4	.531*	.481	.531*
nu3e/3w33.0	.4	.386	.353	.363
nu4e5.5	.45	.454	.418	.214
nu4e11.0	.45	.338	.337	.357
nu4e16.5	.4	.252	.301	.286
nu4e22.0	.4	.348	.265	.283
nu4e27.5	.4	.434	.440	.439
nu4e/4w33.0	.4	.391	.340	.356
nu1w5.5	.4	.481	.538*	.547*
nu1w11.0	.4	.391	.444	.353
nu1w16.5	.4	.412	.455	.485*
nu1w22.0	.55	.370	.399	.336
nu1w27.5	.55	.465	.503	.438
nu2w5.5	.45	.455	.444	.423
nu2w11.0	.4	.384	.408	.428
nu2w16.5	.4	.427	.389	.389
nu2w22.0	.4	.318	.359	.299
nu2w27.5	.45	.452	.445	.439
nu3w5.5	.45	.515*	.510*	.515*
nu3w11.0	.4	.344	.373	.366
nu3w16.5	.4	.494*	.445	.455
nu3w22.0	.4	.315	.271	.283
nu3w27.5	.4	.359	.366	.358
nu4w5.5	.4	.448	.587*	.443
nu4w11.0	.4	.347	.398	.367
nu4w16.5	.45	.529*	.450	.443
nu4w22.0	.5	.327	.289	.291
nu4w27.5	.45	.354	.453	.421
mean	.444	.392	.405	.378
1.25*mean	.556	.490	.506	.473

Summary of Air Velocity Profile for New Settling Means

The results from the air velocity profiles collected with the new settling means and additional configurations are presented in Tables 12 and 13. The results within the tables are again point velocities and the resultant mean is a weighted mean according to the area represented.

TABLE 13. Average point velocity at measuring plane downstream of new settling means closest to test fan

Probe Location	New Screens	+1 Add. Screen	+2 Add Scr + Patc.
tf1e5.5	.407	.542*	.424
tf1e11.0	.825*	.509	.452
tf1e16.5	2.280*	.600*	.426
tf1e22.0	.827*	.696*	.441
tf1e27.5	2.535*	.428	.407
tf1e/1w33.0	.715*	.373	.352
tf2e5.5	.264	.264	.405
tf2e11.0	.596	.555*	.497*
tf2e16.5	.810*	.572*	.498*
tf2e22.0	.844*	.735*	.518*
tf2e27.5	.631*	.577*	.495*
tf2e/2w33.0	.393	.558*	.500*
tf3e5.5	.466	.373	.325
tf3e11.0	.178	.299	.354
tf3e16.5	.268	.573*	.379
tf3e22.0	.481	.687*	.439
tf3e27.5	.286	.560*	.448
tf3e/4e33.0	.338	.420	.316
tf4e5.5	.665*	.158	.320
tf4e11.0	.378	.104	.248
tf4e16.5	.271	.400	.277
tf4e22.0	.281	.402	.367
tf4e27.5	2.442*	.110	.257
tf4e/4w33.0	.859*	.137	.272
tf1w5.5	.343	.197	.384
tf1w11.0	.270	.158	.256
tf1w16.5	.410	.191	.282
tf1w22.0	.546	.347	.310
tf1w27.5	2.527*	.140	.314
tf2w5.5	.288	.340	.408
tf2w11.0	.245	.379	.377
tf2w16.5	.390	.518	.431
tf2w22.0	.550	.503	.482
tf2w27.5	.268	.501	.512*
tf3w5.5	.350	.451	.431
tf3w11.0	.586	.629*	.434
tf3w16.5	.635*	.952*	.465
tf3w22.0	.604*	.634*	.490*
tf3w27.5	.557	.660*	.542*
tf4w5.5	.377	.361	.405
tf4w11.0	1.559*	.517	.376
tf4w16.5	3.447*	.665*	.370
tf4w22.0	.959*	.585*	.309
tf4w27.5	2.802*	.265	.428
mean	.480	.418	.387
1.25*mean	.600	.522	.484

TABLE 14. Average point velocity at measuring plane downstream of new settling means closest to supply fan

Probe Location	New Screens
nu1e5.5	.292
nu1e11.0	.263
nu1e16.5	.268
nu1e22.0	.282
nu1e27.5	.279
nu1e/1w33.0	.275
nu2e5.5	.377
nu2e11.0	.317
nu2e16.5	.304
nu2e22.0	.323
nu2e27.5	.323
nu2e/2w33.0	.306
nu3e5.5	.437
nu3e11.0	.381
nu3e16.5	.373
nu3e22.0	.381
nu3e27.5	.398
nu3e/3e33.0	.386
nu4e5.5	.481
nu4e11.0	.459
nu4e16.5	.453
nu4e22.0	.465
nu4e27.5	.486
nu4e/4w33.0	.477
nu1w5.5	.304
nu1w11.0	.260
nu1w16.5	.261
nu1w22.0	.274
nu1w27.5	.277
nu2w5.5	.427
nu2w11.0	.395
nu2w16.5	.387
nu2w22.0	.374
nu2w27.5	.354
nu3w5.5	.533*
nu3w11.0	.499*
nu3w16.5	.481
nu3w22.0	.447
nu3w27.5	.431
nu4w5.5	.605*
nu4w11.0	.588*
nu4w16.5	.559*
nu4w22.0	.525*
nu4w27.5	.519*
avg	.396
1.25*avg	.495

APPENDIX B

Data Acquisition Program for Fan Testing

The data acquisition program for the fan test chamber was written in the C language for use on a Zenith Z150 personal computer. The main program (fanperf2.c) included various functions which were called into the main program.

```
#define LINT_ARGS

#include <stdio.h>
#include "fandef.h"

/* This program is used to write initial constant fan parameters */
/* to a headerfile. When a new fan is to be tested a new      */
/* headerfile is needed.  Once a headerfile is created, proceed     */
/* to execution of the main program, fanperf.c. The main program */
/* is executed in the following format:                          */
/*             fanperf2 -h headerfile -f outputfile        */

main(argc,argv)
int argc;
char **argv;
{
    int    c;             /* used for getopt routine */
    extern char    *optarg;
    extern int    optind;
    char    *optstring = "f:?";
    void    usage(char **);

    if (argc < 2)
        usage(argv);

    while ( ( c = getopt(argc,argv,optstring) ) != EOF ) {
        switch (c) {
            case 'f':
                if ( (outfile = fopen(optarg,"w")) == NULL) {
                    fprintf(stderr,"cannot open file %s\n",
                        optarg);
                    exit(1);
                }
                break;
            case '?':
```

```
            default:
                usage(argv);
                break;
        }
    }
    /* sets up headerfile with constant information    */
    /* for each particular fan                        */

    printf("Enter the date of the test (mm-dd-yy) \n");
    scanf("%d-%d-%d",&month,&day,&year);
    fflush(stdin);
    printf("Enter the name of test operator (first and last names)\n");
    scanf("%s%s",firstname,lastname);
    fflush(stdin);
    printf("Enter the fan manufacturer \n");
    scanf("%s",manufacturer);
    fflush(stdin);
    printf("Enter the fan model number \n");
    scanf("%s",modelno);
    fflush(stdin);

    fprintf(outfile,"%2.2d-%2.2d-%2.2d %10s %10s %s %s Agr Eng-KSU\n",
        month,day,year,firstname,lastname,manufacturer,modelno);

    printf("Enter the fan blade diameter in inches \n");
    scanf("%lf",&fanbladediam);
    fflush(stdin);
    printf("Enter the fan motor hp in decimal form \n");
    scanf("%lf",&motorhp);
    fflush(stdin);
    printf("Enter the nominal speed (rpm) of the fan \n");
    scanf("%lf",&nominalfanspeed);
    fflush(stdin);
    printf("Enter the rated capacity (cfm) of the fan");
    printf(" at 1/8 inch static pressure \n");
    scanf("%d",&ratedcfmfan);
    fflush(stdin);
    printf("Enter the fan's rated voltage \n");
    scanf("%d",&ratedvolts);
    fflush(stdin);
    printf("Enter the fan motor efficiency in decimal form \n");
    scanf("%lf",&motoreff);
    fflush(stdin);

    fprintf(outfile,"%lf\n%lf\n%lf\n%d\n%d\n%lf\n",
        fanbladediam,motorhp,nominalfanspeed,
        ratedcfmfan,ratedvolts,motoreff);

}

void
```

```
usage(argv)
char    **argv;
{
    fprintf(stderr,"usage:  %s -f outfile\n",argv[0]);
    exit (1);
}


**************************************************************************

#define LINT_ARGS

#include <stdio.h>
#include <math.h>
#include <string.h>
#include "fandef.h"

/* This is the main program for execution and calculation    */
/* of fan air performance parameters.  Before using, a        */
/* headerfile must be created via header_w.  The same        */
/* headerfile can be used while that particular fan is        */
/* being tested. Execution of the program follows the        */
/* following format : fanperf -h headerfile -f outfile        */
/* where the headerfile is the header_w file that contains the    */
/* desired fans specifications and the outfile is the filename    */
/* where the output is written to                  */

main(argc,argv)
int argc;
char **argv;
{
    int     c;                  /* used for getopt routine */
    extern char    *optarg;
    extern int    optind;
    char    *optstring = "h:f:?";
    void    usage(char **);
    char    line[LINESIZE];
    char    dfile_str0[LINESIZE],dfile_str1[LINESIZE];
    char    dfile_str2[LINESIZE];
    char    hfile_str[LINESIZE];
    char    date[LINESIZE];
    char    namefirst[LINESIZE];
    char    namelast[LINESIZE];
    char    manuf[LINESIZE];
    char    modno[LINESIZE];

    double  exp_fac[20];          /* expansion factor */
    double  sumcarea[20];        /* sum of coeff of disc x noz area*/
    double  chamairdens[20];     /* chamber air density */
    double    nozflowrate[20];      /* nozzle flow rate */
    double  fanflowrate[20];     /* fan flow rate */
```

```
if (argc < 2)
    usage(argv);

while ( ( c = getopt(argc,argv,optstring) ) != EOF ) {
    switch (c) {
        case 'f':
            strncpy(dfile_str0,optarg,LINESIZE);
            strncpy(dfile_str1,optarg,LINESIZE);
            strncpy(dfile_str2,optarg,LINESIZE);
            strncat(dfile_str0,".pwr",4);
            strncat(dfile_str1,".air",4);
            strncat(dfile_str2,".psy",4);

            if ( (dfile_pwr=fopen(dfile_str0,"a"))==NULL) {
                fprintf(stderr,"cannot open file %s\n",
                    dfile_str0);
                exit(1);
            }
            if ( (dfile_air=fopen(dfile_str1,"a"))==NULL) {
                fprintf(stderr,"cannot open file %s\n",
                    dfile_str1);
                exit(1);
            }
            if ( (dfile_psy=fopen(dfile_str2,"a"))==NULL) {
                fprintf(stderr,"cannot open file %s\n",
                    dfile_str2);
                exit(1);
            }
            break;
        case 'h':
            strncpy(hfile_str,optarg,LINESIZE);
            if ((headerfile = fopen(optarg,"r")) == NULL) {
                fprintf(stderr,"cannot open file %s\n",
                    optarg);
                exit(1);
            }
            break;
        case '?':
        default:
             usage(argv);
            break;
    }
}

/* read in information previously entered in the header file */

fgets(line,LINESIZE,headerfile);
 fscanf(headerfile,"%lf%lf%lf%d%d%lf",
    &fanbladediam,&motorhp,&nominalfanspeed,
    &ratedcfmfan,&ratedvolts,&motoreff);
```

```
    sscanf(line,"%s%s%s%s%s", date,namefirst,namelast,manuf,modno);

    getdata();            /* get info on test */
    airdens();
    exp_factor();
    coefdisch();
    nozzleflow();
    fanflow();
    fanpress();
    fanpwr();
    datafile(hfile_str,namefirst,namelast);
    screenout(namefirst,namelast,manuf,modno);
}

void
usage(argv)
char    **argv;
{
    fprintf(stderr,"usage:  %s -h headerfile -f outfile\n",argv[0]);
    exit (1);
}


*******************************************************************

/* This function accesses the needed inputs from the user */

#define LINT_ARGS


#include <stdio.h>
#include <math.h>
#include "fanperf.h"

double
getdata()
{

double pe, pp;
int i, j, k, pt, n, runno, nozzlechanges;

sumbp = 0;
sumdbtemp = 0;
sumwbtemp = 0;
sumatmo = 0;
j = 0;
k = 0;

printf("Enter the date of the test (mm-dd-yy) \n");
```

```
scanf("%d-%d-%d", &mm,&dd,&yy);
fflush(stdin);
printf("Enter the wind diverter angle \n");
scanf("%lf", &angle);
fflush(stdin);
printf("Enter the wind diverter location (ratio) \n");
scanf("%lf", &ratio);
fflush(stdin);

do {
    pt = k + 1;
    printf("\n\n");
    printf("Test point number %d\n", pt);
    printf("-----------------------\n");
    if(k == 0){
        printf("Enter the average wind velocity in m/s \n");
        scanf("%lf", &windvel);
        wind[k] = windvel;
        fflush(stdin);
         printf("Enter the ambient wet bulb temperature (F) \n");
        scanf("%lf", &wbtemp);
        tempwb[k] = wbtemp;
        fflush(stdin);
        printf("Enter the ambient dry bulb temperature (F) \n");
        scanf("%lf", &dbtemp);
        tempdb[k] = dbtemp;
        fflush(stdin);
        printf("Enter the corrected barometric pressure (in Hg) \n");
        scanf("%lf", &bp);
        bptemp = bp;
        bpgrav = bptemp;
        barometricpressure[k] = bpgrav;
        fflush(stdin);
        pe = .000296 * wbtemp * wbtemp - .0159 * wbtemp + 0.41;
        pp = pe - bpgrav * ((dbtemp - wbtemp)/2700);
        atairdens[k] = (70.73 * (bpgrav - .378*pp))/(R*(dbtemp + TK));
    }
    if(k != 0){
        printf("Has the wind speed, temperatures,");
        printf(" or barometric pressure changed?\n");
        printf("Enter 0 if no, 1 if yes <cr>\n");
        scanf("%d", &psychanges);
        fflush(stdin);
        if(psychanges == 0){
            wind[k] = wind[k - 1];
            tempwb[k] = tempwb[k - 1];
            tempdb[k] = tempdb[k - 1];
            barometricpressure[k] = barometricpressure[k - 1];
            atairdens[k] = atairdens[k -1];
        }
        if(psychanges == 1){
```

```
         printf("Enter the average wind velocity in m/s \n");
         scanf("%lf", &windvel);
         wind[k] = windvel;
         fflush(stdin);
          printf("Enter the ambient wet bulb temperature (F)\n");
         scanf("%lf", &wbtemp);
         tempwb[k] = wbtemp;
         fflush(stdin);
         printf("Enter the ambient dry bulb temperature (F)\n");
         scanf("%lf", &dbtemp);
         tempdb[k] = dbtemp;
         fflush(stdin);
         printf("Enter the corrected barometric pressure");
         printf(" (in Hg) \n");
         scanf("%lf", &bp);
         bptemp = bp;
         bpgrav = bptemp;
         barometricpressure[k] = bpgrav;
         fflush(stdin);
         pe = .000296 * wbtemp * wbtemp - .0159 * wbtemp + 0.41;
         pp = pe - bpgrav * ((dbtemp - wbtemp)/2700);
         atairdens[k] = (70.73 * (bpgrav - .378 * pp))
                 /(R * (dbtemp + TK));

    }
}
printf("Enter the pressure drop across the nozzles (in. wg)\n");
scanf("%lf", &deltaP);
deltapressure[k] = deltaP;
fflush(stdin);
printf("Enter the static pressure at plane 8(test fan)[in. wg]\n");
scanf("%lf", &Ps8);
Pstatic8[k] = Ps8;
fflush(stdin);
printf("Enter the fan speed measured (rpm)\n");
scanf("%lf", &fanrpm);
fanspeed[k] = fanrpm;
fflush(stdin);
printf("Enter the power input to the fan motor (watts) \n");
scanf("%lf", &watt);
watts[k] = watt;
fflush(stdin);
printf("Enter the fan voltage measured\n");
scanf("%lf", &volt);
volts[k] = volt;
fflush(stdin);
printf("Enter the fan current measured (amps)\n");
scanf("%lf", &amp);
amps[k] = amp;
fflush(stdin);
i = 0;
```

```
n = 0;
if(k != 0){
    printf("Did you change the nozzle selection?\n");
    printf("Enter 0 if no, 1 if yes <cr>\n");
    scanf("%d", &nozzlechanges);
    fflush(stdin);
    if(nozzlechanges == 0){
        do{
            number[i][j] = number[i][j - 1];
            nozdiam[i][j] = nozdiam[i][j - 1];
            nozzlearea[i][j] = nozzlearea[i][j - 1];
            LoverD[i][j] = LoverD[i][j - 1];
            i++;
            n++;
        }while(diamno[n] != 0);
    }
}
if(k == 0 || nozzlechanges == 1){
    printf("Enter the corresponding nozzle numbers open");
    printf(" during the test, one at a time <cr>.\n");
    printf("When all of the open nozzles have been entered,");
    printf(" enter a 0 <cr>\n");
    do {
        scanf("%lf", &diam);
        diamno[n] = diam;
        if(diam == 1){
            number[i][j] = 1;
            nozdiam[i][j] = 5.0;
            ddiam = 5.0;
            }
        if(diam == 2){
            number[i][j] = 2;
            nozdiam[i][j] = 6.0;
            ddiam = 6.0;
            }
        if(diam == 3){
            number[i][j] = 3;
            nozdiam[i][j] = 5.5;
            ddiam = 5.5;
            }
        if(diam == 4){
            number[i][j] = 4;
            nozdiam[i][j] = 4.0;
            ddiam = 4.0;
            }
        if(diam == 5){
            number[i][j] = 5;
            nozdiam[i][j] = 1.6;
            ddiam = 1.6;
            }
        if(diam == 6){
```

```
            number[i][j] = 6;
            nozdiam[i][j] = 2.5;
            ddiam = 2.5;
            }
        if(diam == 7){
            number[i][j] = 7;
            nozdiam[i][j] = 5.0;
            ddiam = 5.0;
            }
        if(diam == 8){
            number[i][j] = 8;
            nozdiam[i][j] = 6.0;
            ddiam = 6.0;
            }
        if(diam == 9){
            number[i][j] = 9;
            nozdiam[i][j] = 5.5;
            ddiam = 5.5;
            }
        nozzlearea[i][j] = PI * ddiam * ddiam / (4 * 144);
        if(nozdiam[i][j] != 6.0) {
            LoverD[i][j] = 0.6;
        }
        if(nozdiam[i][j] == 6.0) {
            LoverD[i][j] = 0.5;
        }
        i++;
        n++;
    }while(diam != 0);
    if(diam == 0) {
        ddiam = 0;
        LoverD[i][j] = 0;
    }
}
printf("\n");
printf("Are the data all entered correctly?\n");
printf("\n");
printf("Test Point Number = %d\n", pt);
printf("wind velocity = %f m/s\n", wind[k]);
printf("wet bulb temp = %f F\n", tempwb[k]);
printf("dry bulb temp = %f F\n", tempdb[k]);
printf("corrected barometric pressure = %f in. Hg\n", bp);
printf("pressure drop across the nozzles = %f in. wg\n",
    deltapressure[k]);
printf("static pressure at plane 8 (test fan) = %f in. wg\n",
    Pstatic8[k]);
printf("fan speed measured = %f rpm\n", fanspeed[k]);
printf("power input to the fan motor = %f watts\n", watts[k]);
printf("fan voltage measured = %f volts\n", volts[k]);
printf("fan current measured = %f amps\n", amps[k]);
printf("nozzle numbers entered = ");
```

```
    i = 0;
    do {
        numb = number[i][j];
        printf("%d", numb);
                i++;
    }while(i < 9);
    printf("\n\n");
    printf("Enter 0 if the data are correct, or 1 if they are");
    printf(" incorrect <cr>\n");
    scanf("%d", &datachanges);
    fflush(stdin);
    if(datachanges == 0){
        sumwbtemp = sumwbtemp + tempwb[k];
        sumdbtemp = sumdbtemp + tempdb[k];
        sumbp = sumbp + barometricpressure[k];
        sumatmo = sumatmo + atairdens[k];
        j++;
        k++;
        printf("\n");
        printf("Do you wish to collect another data point?");
        printf(" Enter 1 if yes, 0 if no <cr>\n");
        scanf("%d", &runno);
        fflush(stdin);
        if(runno == 1){
            testpoints = k + 1;
        }
        if(runno == 0){
            testpoints = k;
        }
    }
    if(datachanges == 1)
        testpoints = k + 1;
}while(k < testpoints);
wetbulbtemp = sumwbtemp/testpoints;
drybulbtemp = sumdbtemp/testpoints;
avgbaropress = sumbp/testpoints;
atmoairdens = sumatmo/testpoints;
return;
}


**********************************************************************

#define LINT_ARGS

#include <stdio.h>
#include <math.h>
#include "fanperf.h"

double
```

```
 airdens()

 {
   /* This function calculates the chamber air density    */
   /* in lbm/cu ft, from the static pressure (in wg) at    */
   /* the nozzle inlet, the barometric pressure (in Hg),    */
   /* and the atmospheric air density            */

     int k;

     k = 0;
     do{
         chamairdens[k]=atairdens[k];
         k++;
     }while(k < testpoints);
     return;
 }
```

```
*******************************************************************
```

```
#define LINT_ARGS

#include <stdio.h>
#include <math.h>
#include "fanperf.h"

double
exp_factor()                /* expansion factor */
{
    double alpha;            /* alpha ratio */
    int k;

    /* This function calculates the alpha ratio and expansion    */
    /* factor necessary for determining the Reynolds number and    */
    /* the coefficients of discharge for the nozzles          */

    k = 0;
    do{
        alpha = 1 - ((5.187 * deltapressure[k])/((chamairdens[k] * R)
            * (tempdb[k] + TK)));
        exp_fac[k] = 1 - (0.548 * (1 - alpha));
        k++;
    }while(k < testpoints);
    return;
}
```

```
double
coefdisch()
{
    /* This function calculates the Reynolds number and        */
    /* coefficients of discharge for each nozzle open and     */
    /* sums the products of the coefficients times the         */
    /* area of the nozzle for each of the nozzles open         */

    double coeffA;       /* initial coeff of discharge for nozzle*/
    double coeffB;       /* final coeff of discharge for nozzle  */
    double Re;           /* Reynolds number                      */
    double sumcoeffarea; /* sum of noz coeff of disc x noz areas */
    int i, flag, j, k;


    coeffA = 0.95;        /* initial assignment for coeff of dis. */
    flag = 0;
    j = 0;
    k = 0;
    do {
        i = 0;
        sumcoeffarea = 0;
        do {
            do {
                if(flag !=0)
                      coeffA = coeffB;
                Re =124568.1033*coeffA*nozdiam[i][j]*exp_fac[k]
                 * sqrt(deltapressure[k] * chamairdens[k]);
                if(nozdiam[i][j] != 0) {
                    if(LoverD[i][j] == 0.6){
                          coeffB = .9986-(7.006/sqrt(Re))
                       + 134.6/Re;
                    }
                    if(LoverD[i][j] == 0.5){
                          coeffB = .9986-(6.688/sqrt(Re))
                       +. 131.5/Re;
                    }
                }
                flag = 1;
            } while(fabs(coeffA - coeffB) >= 0.0001);
            coeff[i][j] = coeffA;
            flag = 0;
            sumcoeffarea=sumcoeffarea+nozzlearea[i][j]*coeff[i][j];
            sumcarea[k] = sumcoeffarea;
            i++;

        } while(nozdiam[i][j] != 0);
        j++;
        k++;
    }while(k < testpoints);
    return;
```

```
}

double
nozzleflow()
{
    /* This function calculates the nozzle flow rate in cfm */

    int k;

    k = 0;
    do {
        nozflowrate[k] = 1096 * exp_fac[k] *
        sqrt(deltapressure[k]/chamairdens[k]) * sumcarea[k];
        k++;
    }while(k < testpoints);
    return;
}

double
fanflow()
{
    /* This function calculates the fan flow rate in cfm */

    double volflowrate_fan;  /* air flow rate at plane 8 (cfm) */
    double airvel_fan;       /* air velocity at plane 8 (fpm) */
    double d81;              /* initial air density at fan */
    double massflowrate_noz; /* mass flow rate at nozzles */
    double sumPtot8;
    int flag, k;

    sumPtot8 = 0;
    k = 0;
    do {
        massflowrate_noz = nozflowrate[k] * chamairdens[k];
        d81 = chamairdens[k];
        flag = 0;
        do {
            if(flag != 0)
                d81 = fanairdens[k];
            volflowrate_fan = massflowrate_noz / d81;
            airvel_fan = volflowrate_fan / AREACHAM;
            Pvel8 = (airvel_fan / 1096)*(airvel_fan / 1096) * d81;
            Ptot8[k] = Pstatic8[k] + Pvel8;
            fanairdens[k] = atairdens[k] *
            ((Ptot8[k] + 13.63 * barometricpressure[k])
            /(13.63 * barometricpressure[k]));
            flag = 1;
        } while(fabs(d81 -fanairdens[k]) >= 0.0001);
        fanflowrate[k] = nozflowrate[k]*(chamairdens[k]/fanairdens[k]);
        sumPtot8 = sumPtot8 + Ptot8[k];
        k++;
```

```
    }while(k < testpoints);
    nom_Ptot8 = sumPtot8/testpoints;
    return;
}

double
fanpress()
{
    /* This function calculates the fan velocity pressure, */
    /* the fan total pressure, and the fan static pressure */

    double fanarea;          /* area at the fan outlet (sq ft) */
    double fandens_out;      /* air density at fan outlet (lbm/cu ft) */
    int k;

    k = 0;
    do {
        fanarea = (PI * fanbladediam * fanbladediam)/(4 * 144);
        fandens_out = atmoairdens;
        Pvel[k] = (fanflowrate[k] * fanairdens[k])/(1096 * fanarea)
            * (fanflowrate[k] * fanairdens[k])/(1096 * fanarea)
            * (1 / fandens_out);
         Ptot[k] = Pvel[k] - Ptot8[k];
        Pstat[k] = Ptot[k] - Pvel[k];
        k++;
    }while(k < testpoints);
    return;
}

double
fanpwr()
{
    /* This function calculates the fan power input (H), the    */
    /* fan power output (Ho), the fan total efficiency, and the    */
    /* fan static efficiency.                            */
    /* This function also calculates the weighted airflows for    */
    /* the various wind velocities tested, by use of the    */
    /* Weibull distribution.                          */

    double x, z;
    double kp;     /* compressibility coefficient */
    int k;

    k = 0;
    sum_Qweighted = 0;
    do {
        powerinput[k] = (watts[k] * motoreff)/745.7;
        x = Ptot[k] / (Ptot8[k] + 13.63 * barometricpressure[k]);
        z = (.400/1.400) * (((6362 * powerinput[k])/fanflowrate[k])
            /(Ptot8[k] + 13.63 * barometricpressure[k]));
        kp = (log(1 + x)/x) * (z/log(1 + z));
```

```
if(Ptot[k] <= 12)
     kp = 1.0;
poweroutput[k] = (fanflowrate[k] * Ptot[k] * kp)/6362;
eff_tot[k] = poweroutput[k] / powerinput[k];
eff_stat[k] = eff_tot[k] * (Pstat[k] / Ptot[k]);
Z = (nom_Ptot8 + 13.63 * baropress)
   /(Ptot8[k] + 13.63 * barometricpressure[k])
   * (fanairdens[k]/nom_fanairdens) * (fanspeed[k]
   /nominalfanspeed) * (fanspeed[k]/nominalfanspeed);
z_nom = z/Z;
Y = log(1 + x) * (log(1 + z_nom)/log(1 + z));
x_nom = exp(Y) - 1;
 K_nom = (z/z_nom) * (x_nom/x);
if(0.99 <= K_nom && K_nom <= 1.01)
     K_nom = 1.0;
Ptot_nominal[k] = Ptot[k] * (nominalfanspeed/fanspeed[k])
        * (nominalfanspeed/fanspeed[k])
        * (nom_fanairdens/fanairdens[k]) * K_nom;
nom_fanflowrate[k] = fanflowrate[k] * (nominalfanspeed
        /fanspeed[k]) * K_nom;
Pvel_nominal[k] = Pvel[k] * (nominalfanspeed/fanspeed[k])
                    * (nominalfanspeed/fanspeed[k])
        * (nom_fanairdens/fanairdens[k]);
Pstat_nominal[k] = Ptot_nominal[k] - Pvel_nominal[k];
nom_powerinput[k] = powerinput[k]*(nominalfanspeed/fanspeed[k])
        *(nominalfanspeed/fanspeed[k])
        *(nominalfanspeed/fanspeed[k])
        *(nom_fanairdens/fanairdens[k]) * K_nom;
nom_eff_stat[k] =eff_tot[k]*(Pstat_nominal[k]/Ptot_nominal[k]);
if(wind[k] == 0.0) {
    Qweighted[k] = nom_fanflowrate[k] * 0.04893075;
}
if(1.8 <= wind[k] && wind[k] <= 2.2) {
    Qweighted[k] = nom_fanflowrate[k] * 0.31456746;
}
if(3.8 <= wind[k] && wind[k] <= 4.2) {
    Qweighted[k] = nom_fanflowrate[k] * 0.35201649;
}
if(5.8 <= wind[k] && wind[k] <= 6.2) {
    Qweighted[k] = nom_fanflowrate[k] * 0.20054106;
}
if(7.8 <= wind[k] && wind[k] <= 8.2) {
    Qweighted[k] = nom_fanflowrate[k] * 0.06889818;
}
if(9.8 <= wind[k] && wind[k] <= 10.20) {
    Qweighted[k] = nom_fanflowrate[k] * 0.01504606;
}
if(7.3 <= wind[k] && wind[k] <= 7.7) {
    Qweighted[k] = nom_fanflowrate[k] * 0.04556083;
}
if(9.3 <= wind[k] && wind[k] <= 9.7) {
```

```
            Qweighted[k] = nom_fanflowrate[k] * 0.01067426;
        }
        sum_Qweighted = sum_Qweighted + Qweighted[k];
        k++;
    }while(k < testpoints);
    tot_Qweighted = sum_Qweighted;
    return;
}
```

```
****************************************************************************
```

```
/* This function writes the calculated outputs to the    */
/* various output files, denoted by outfilename and     */
/* one of three extensions: .air, .pwr, and .psy    */

#define LINT_ARGS

#include <stdio.h>
#include <math.h>
#include "fanperf.h"

void
datafile(hfile_str,namefirst,namelast)
{
double Q_per_w;             /* VER - cfm per watt    */
int i, j, k;
j = 0;
k = 0;

do {
    Q_per_w = fanflowrate[k]/watts[k];

/*write headerfile name, date of test and operator name to outfile.air*/

    fprintf(dfile_air, "%s %2.2d-%2.2d-%2.2d", hfile_str,mm,dd,yy);
    fprintf(dfile_air, " %s%s ",namefirst,namelast);
    fprintf(dfile_air, "AGE-KSU ");

    /* write nozzle numbers open for flow to outfile.air */
    i=0;
    do {
        numb = number[i][j];
        fprintf(dfile_air, "%d", numb);
        i++;
    }while(i < 9);
```

```
    /* write pressure and flow rate values to outfile.air */
    fprintf(dfile_air," %2.4f %2.4f %2.4f %2.4f %2.4f %4.4f %4.4f",
        deltapressure[k],Pstatic8[k],Ptot[k],
        Pvel[k],Pstat[k],nozflowrate[k],fanflowrate[k]);

    fprintf(dfile_air," %2.4f %2.4f %2.4f %4.4f %2.2f", Ptot_nominal[k],
        Pvel_nominal[k],Pstat_nominal[k],nom_fanflowrate[k],wind[k]);

    fprintf(dfile_air," %2.2f %2.2f %4.4f %4.4f\n", angle,ratio,
        Qweighted[k],tot_Qweighted);


/*write headerfile name, date of test and operator name to outfile.psy*/
    fprintf(dfile_psy, "%s %2.2d-%2.2d-%2.2d", hfile_str,mm,dd,yy);
    fprintf(dfile_psy, " %s%s ",namefirst,namelast);
    fprintf(dfile_psy, "AGE-KSU");

    /* write wet bulb and dry bulb temperatures to outfile.psy */
    fprintf(dfile_psy," %3.2f %3.2f %3.2f %3.2f",
              tempwb[k],wetbulbtemp,tempdb[k],drybulbtemp);
    /* write barometric pressure and air densities to outfile.psy */
    fprintf(dfile_psy," %3.2f %3.2f %2.4f %2.4f %2.4f %2.4f\n",
              barometricpressure[k],baropress,atairdens[k],atmoairdens,
        chamairdens[k],fanairdens[k]);

/*write headerfile name, date of test and operator name to outfile.pwr*/
    fprintf(dfile_pwr, "%s %2.2d-%2.2d-%2.2d", hfile_str,mm,dd,yy);
    fprintf(dfile_pwr, " %s%s ",namefirst,namelast);
    fprintf(dfile_pwr, "AGE-KSU");

    /* write power relations and fan speed to outfile.pwr */
    fprintf(dfile_pwr," %3.4f %2.4f %3.4f",
        volts[k],amps[k],watts[k]);

/*write fan speed, power relations, and efficiency to outfile.pwr*/
    fprintf(dfile_pwr," %4.4f %2.4f %2.4f %1.4f %1.4f %1.4f %3.4f\n",
        fanspeed[k],powerinput[k],poweroutput[k],eff_tot[k],
        eff_stat[k],nom_eff_stat[k],Q_per_w);
    j++;
    k++;
}while(k < testpoints);
}
```

```
*****************************************************************

#define LINT_ARGS

#include <stdio.h>
#include <math.h>
#include "fanperf.h"

void
screenout(namefirst,namelast,manuf,modno)
{
double Q_per_w;
int i, j, k, r, s, t;

/* This function is responsible for sending the output to the screen */

printf("\n\n\n\n\n\n\n\n\n\n");
printf("Test Facility and Location:AGRICULTURAL ENGINEERING DEPT,KSU\n");
printf("Date of test: %d-%d-%d \n", mm, dd, yy);
printf("Name of test operator: %s %s \n", namefirst, namelast);
printf("Fan Model Information: \n");
printf("    Fan Manufacturer: %s \n", manuf);
printf("    Fan Model No.: %s \n", modno);
printf("    Fan Blade Diameter: %f inches \n", fanbladediam);
printf("    Fan Motor Horsepower: %f hp \n", motorhp);
printf("    Nominal Speed of the Fan: %f rpm \n", nominalfanspeed);
printf("    Rated Capacity of the Fan: %d cfm \n", ratedcfmfan);
printf("    Fan's Rated Voltage: %d volts \n", ratedvolts);
printf("    Fan's Motor Efficiency: %f \n", motoreff);
printf("\n");
printf("Hit x and then return to continue \n");
do {
}
while(getchar() != 'x');
printf("\n\n\n\n");
printf("PSYCHROMETRIC PROPERTIES: \n");
printf("-------------------------\n");
printf("test\twetbulb\tdrybulb\t baro.\tatmo\tcham\tfan \n");
printf(" no.\t temp\t  temp\t press\tdens\tdens\tdens \n");
printf("\t  (F)\t  (F)\t(in Hg)\t ( lbm / cu. ft )\n");
printf("--------------------------------------------------\n");
r = 0;
k = 0;
do {
    r = k + 1;
    printf("%2.2d\t", r);
    printf("%3.2f\t%3.2f\t%3.2f\t%2.4f\t%2.4f\t%2.4f\n",
        tempwb[k],tempdb[k],barometricpressure[k],atairdens[k],
                chamairdens[k],fanairdens[k]);
    k++;
}while(k < testpoints);
```

```
printf("avg\t%3.2f\t%3.2f\t%3.2f\t%2.4f\n",
    wetbulbtemp,drybulbtemp,avgbaropress,atmoairdens);
printf("\n");
printf("Hit x and then return to continue \n");
do {
}
while(getchar() != 'x');
printf("\n\n\n\n\n\n\n");
printf("AIRFLOW MEASUREMENTS \n");
printf("--------------------\n");
printf("test\tNozzles\t\tdeltaP\tPstatic\n");
printf(" no.\t open\t\tnozzles\tplane8\n");
printf("\t\t\t(in wg)\t(in wg)\n");
printf("-------------------------------------------------\n");
k = 0;
j = 0;
do {
    i = 0;
    s = k + 1;
    printf("%2.2d\t", s);
    do {
        numb = number[i][j];
        printf("%d", numb);
        i++;
    } while(i < 9);
    printf("\t%2.4f\t%2.4f\n",
        deltapressure[k],Pstatic8[k]);
    j++;
    k++;
}while(k < testpoints);
printf("\n");
printf("Hit x and then return to continue \n");
do {
}
while(getchar() != 'x');
printf("\n\n\n\n\n\n\n\n\n\n");
printf("test\t Ptot\t Pstat\t Pvel\tNozzle\t\t  Fan\n");
printf(" no.\t fan\t fan\t fan\tAirflow\t\tAirflow\n");
printf("\t(in wg)\t(in wg)\t(in wg)\t (cfm)\t\t (cfm)\n");
printf("--------------------------------------------------\n");
k = 0;
do {
    s = k + 1;
    printf("%2.2d\t", s);
    printf("%2.4f\t%2.4f\t%2.4f\t%4.4f\t%4.4f\n",
        Ptot[k],Pstat[k],Pvel[k],nozflowrate[k],fanflowrate[k]);
    k++;
}while(k < testpoints);
printf("\n");
printf("Hit x and then return to continue \n");
do {
```

```
}
while(getchar() != 'x');
printf("\n\n\n\n");
printf("RESULTS CONVERTED TO NOMINAL CONSTANT VALUES #\n");
printf("---------------------------------------------\n");
printf("test\t Ptot\tPstat\t Pvel\t  Fan\t\t Wind\tWeight\n");
printf(" no.\t fan\t fan\t fan\tAirflow\t\tVeloc\tAirflow\n");
printf("\t(in wg)\t(in wg)\t(in wg)\t (cfm)\t\t (m/s)\t (cfm)\n");
printf("------------------------------------------------------\n");
k = 0;
do {
    s = k + 1;
    printf("%2.2d\t%2.4f\t%2.4f\t%2.4f\t%4.4f\t%2.2f\t%4.4f\n",
        s,Ptot_nominal[k],Pstat_nominal[k],Pvel_nominal[k],
        nom_fanflowrate[k],wind[k],Qweighted[k]);
    k++;
}while(k < testpoints);
printf("Sum of weighted airflows (cfm) = %4.4f\n", tot_Qweighted);
printf("\n");
printf("# Nominal Constant Density and Nominal Constant Speed\n");
printf("\n");
printf("Hit x and then return to continue \n");
do {
}
while(getchar() != 'x');
printf("\n\n\n\n\n\n\n");
printf("FAN EFFICIENCY \n");
printf("---------------\n");
printf("test\t fan\t  fan\t watts\t  fan\n");
printf(" no.\tvolts\tcurrent\t\t speed\n");
printf("\t\t(amps)\t\t (rpm)\n");
printf("------------------------------------------------------\n");
k = 0;
do {
    t = k + 1;
    printf("%2.2d\t%3.3f\t%2.4f\t%3.3f\t%4.4f\n",t,volts[k],
        amps[k],watts[k],fanspeed[k]);
        k++;
}while(k < testpoints);
printf("\n");
printf("Hit x and then return to continue \n");
do {
}
while(getchar() != 'x');
printf("\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n\n");
printf("test\tpower\tpower\t fan\t fan\tnom fan\t cfm\n");
printf(" no.\tinput\toutput\ttotal\tstat\t stat\t per\n");
printf("\t(hp)\t (hp)\t eff\t eff\t  eff\t watt\n");
printf("------------------------------------------------------\n");
k = 0;
do {
```

```
    t = k + 1;
    Q_per_w = fanflowrate[k]/watts[k];
    printf("%2.2d\t%2.4f\t%2.4f\t%1.4f\t%1.4f\t%1.4f\t%3.4f\n",
t,powerinput[k],poweroutput[k],eff_tot[k],eff_stat[k],
nom_eff_stat[k],Q_per_w);
        k++;
}while(k < testpoints);

}
```

```
**************************************************************************

/* Constants used in the program    */

# ifndef FANCONST_H
#define    FANCONST_H

#define LINESIZE    132


#define R 53.35                 /* gas constant (ft-lb/lbm-R) */
#define TK 459.7                /* conversion from F to R */
#define PI 3.1416               /* value for pi */
#define AREACHAM 27.5           /* cross-sect area of chamber */
#define baropress 29.92         /* baro press at stand air cond */
#define nom_fanairdens .075     /* air density at stand air cond */

# endif    /* FANCONST_H */
```

```
**********************************************************************

/*This function defines the various inputs and variables employed*/

# ifndef FANDEF_H
#define    FANDEF_H

#include "fanconst.h"

                /* pressure measurements */
```

```
double deltaP,              /*press change across nozzles(in. wg)*/
       deltapressure[20],   /* array to store deltaP readings */
       Psnoz,               /*static press at nozzles (in. wg) */
       nozstatpressure[20], /* array to store Psnoz readings */
       Ps8,                 /*stat pressure at plane 8 (in. wg)*/
       Pstatic8[20],        /* array to store Ps8 readings */
       Pvel8,               /*vel pressure at plane 8 (in. wg)*/
       Ptot8[20],           /*total press at plane 8 (in. wg)*/
       Ptot[20],            /* fan total pressure (in. wg) */
       Pvel[20],            /* fan velocity pressure (in. wg) */
       Pstat[20],           /* fan static pressure (in. wg) */
       nom_Ptot8,           /*nominal total pressure at plane 8*/
       Ptot_nominal[20],    /* nominal fan total pressure */
       Pvel_nominal[20],    /* nominal fan velocity pressure */
       Pstat_nominal[20];   /* nominal fan static pressure */

                /* psychrometric measurements */

double wetbulbtemp,                /*avg wet bulb temperature (F)*/
       wbtemp,                     /*wet bulb temp reading*/
       tempwb[20],                 /*array to store wet bulb temps*/
       sumwbtemp,                  /*summation of wet bulb temps*/
       drybulbtemp,                /*avg dry bulb temp (F) */
       dbtemp,                     /*dry bulb temp reading */
       tempdb[20],                 /*array to store dry bulb temps*/
       sumdbtemp,                  /*summation of dry bulb temps */
       sumbp,                      /*summation of baro pressures */
       bp,                         /*uncorrected baro press reading*/
       bptemp,                     /*baro press corrected for temp*/
       bpgrav,                     /*baro press corrected for grav*/
       barometricpressure[20],     /*array for corrected baro pres*/
       avgbaropress,               /*avg barometric pressure */
       sumatmo,                    /*summation of atmo air densities*/
       atairdens[20],              /*array for atmo air densities */
       atmoairdens,                /*atmo air density (lbm/cu ft) */
       chamairdens[20],            /*chamber air density (lbm/cu ft)*/
       fanairdens[20],             /*fan air density (lbm/cu ft) */
       windvel,                    /*average wind velocity (m/s) */
       wind[20];                   /*array for avg wind velocities*/

                /* fan and fan motor measurements */

double watts[20],          /* array for the power input */
       watt,               /* power input (watts) */
       motoreff,           /* eff of fan motor (decimal) */
       motorhp,            /* fan motor horsepower */
       powerfactor[20],    /* array to store powerfactor*/
       pf,                 /* measured power factor */
       fanspeed[20],       /* array for fan speed (rpm) */
       nominalfanspeed,    /* nom speed of the fan (rpm) */
       fanrpm,             /* fan speed reading */
```

```
       fanbladediam,       /* fan blade diameter (inches) */
       volts[20],          /* array for fan motor voltage */
       volt,               /* fan motor voltage reading */
       amps[20],           /* array for fan motor amperage */
       amp,                /* fan motor amperage reading */
       powerinput[20],     /* fan power input (hp) */
       poweroutput[20],    /* fan power output (hp) */
       eff_tot[20],        /* fan total efficiency */
       eff_stat[20],       /* fan static efficiency */
       nom_powerinput[20], /* nom power input to fan motor */
       nom_eff_stat[20];   /* nom static efficiency */

                /* airflow measurements */

double nozflowrate[20],     /*airflow rate at the nozzles(cfm)*/
       fanflowrate[20],     /*airflow rate at the fan (cfm)*/
       nozdiam[10][20],     /*array to store nozzle diameters*/
       diamno[20],          /*array to store nozzle numbers*/
       ddiam,               /*nozzle diameters (inches)*/
       diam,                /*nozzle # corresponding to noz open*/
       LoverD[10][20],      /*length/diameter ratio for nozzles*/
       nozzlearea[10][20],  /*array for nozzle areas*/
       exp_fac[20],         /*array for expansion factors*/
       sumcarea[20],        /*coeff * nozzlearea array*/
       coeff[10][20],       /*array for nozzle coeff of disch*/
       nom_fanflowrate[20], /*nominal fan airflow rate*/
       Z,                   /*z/zc*/
       z_nom,               /*nominal zc*/
       Y,
       x_nom,               /*nominal xc*/
       K_nom,               /*nominal compressibility ratio*/
       angle,               /*wind diverter angle*/
       ratio,               /*wind diverter position ratio*/
       Qweighted[20],       /*array for weighted airflows*/
       sum_Qweighted,       /*sum of weighted airflows*/
       tot_Qweighted;       /*total weighted airflow*/

int    month,          /*month the fan headerfile created*/
       day,            /*day the fan headerfile created*/
       year,           /*year the fan headerfile created*/
       mm,             /*month the fan test was performed*/
       dd,             /*day the fan test was performed*/
       yy,             /*year the fan test was performed*/
       ratedcfmfan,    /*fan flow rate at 1/8" sp(cfm)*/
       ratedvolts,     /*rated voltage of the fan motor*/
       testpoints,     /*number of test points collected*/
       psychanges,     /*indicator of psych changes*/
       datachanges,    /*indicator of data input changes*/
       number[10][20], /*array to store the nozzle number*/
       numb;           /*nozzle diameter number*/
```

```
char    firstname[10], lastname[10],     /*operator name*/
        manufacturer[10], modelno[10];     /*fan manu & model no*/


double exp_factor(),               /* functions */
       airdens(),
       coeffdisch(),
       nozzleflow(),
       fanflow(),
       fanpress(),
       fanpwr(),
       getdata();

FILE    *outfile, *headerfile;
FILE    *dfile_pwr, *dfile_air, *dfile_psy;

# endif    /* FANDEF_H */
```

```
******************************************************************
```

```
/*This function defines the various inputs and variables globally*/

# ifndef FANPERF_H
#define    FANPERF_H

#include "fanconst.h"

                /* pressure measurements */

extern double deltaP,               /*press drop across noz(in. wg)*/
              deltapressure[20],    /*array for deltaP readings*/
              Psnoz,                /*static press at noz(in. wg)*/
              nozstatpressure[20],  /*array for Psnoz readings*/
              Ps8,                  /*stat press at plane 8(in. wg)*/
              Pstatic8[20],         /*array to store Ps8 readings*/
              Pvel8,                /*vel press at plane 8(in. wg)*/
              Ptot8[20],            /*tot press at plane 8(in. wg)*/
              Ptot[20],             /*fan total pressure (in. wg)*/
              Pvel[20],             /*fan vel pressure (in. wg)*/
              Pstat[20],            /*fan static pressure (in. wg)*/
              nom_Ptot8,            /*nom tot pressure at plane 8*/
              Ptot_nominal[20],     /*nom fan total pressure*/
              Pvel_nominal[20],     /*nom fan velocity pressure*/
              Pstat_nominal[20];    /*nom fan static pressure*/
```

```
                    /* psychrometric measurements */

extern double wetbulbtemp,                 /*avg wet bulb temp (F)*/
              wbtemp,                      /*wet bulb temp reading*/
              tempwb[20],                  /*array for wet bulb temps*/
              sumwbtemp,                   /*sum of wet bulb temps*/
              drybulbtemp,                 /*avg dry bulb temp (F)*/
              dbtemp,                      /*dry bulb temp reading*/
              tempdb[20],                  /*array for dry bulb temps*/
              sumdbtemp,                   /*sum of dry bulb temps*/
              sumbp,                       /*sum of baro pressures*/
              bp,                          /*uncorrected baro press*/
              bptemp,                      /*bp corrected for temp*/
              bpgrav,                      /*bp corrected for gravity*/
              barometricpressure[20],      /*array for corrected bp*/
              avgbaropress,                /*avg barometric pressure*/
              sumatmo,                     /*sum of atmo air densities*/
              atairdens[20],               /*array for atmo air dens*/
              atmoairdens,                 /*atmo air dens(lbm/cu ft)*/
              chamairdens[20],             /*chamber air dens(lbm/cu ft)*/
              fanairdens[20],              /*fan air density (lbm/cu ft)*/
              windvel,                     /*avg wind velocity (m/s)*/
              wind[20];                    /*array for avg wind vel*/

                    /* fan and fan motor measurements */

extern double watts[20],              /*array for the power input*/
              watt,                   /*power input (watts)*/
              motoreff,               /*eff of fan motor (decimal)*/
              motorhp,                /*fan motor horsepower*/
              powerfactor[20],        /*array to store powerfactor*/
              pf,                     /*measured power factor*/
              fanspeed[20],           /*array for fan speed (rpm)*/
              nominalfanspeed,        /*nom speed of the fan (rpm)*/
              fanrpm,                 /*fan speed reading*/
              fanbladediam,           /*fan blade dia (inches)*/
              volts[20],              /*array for fan motor volts*/
              volt,                   /*fan motor voltage reading*/
              amps[20],               /*array for fan motor amps*/
              amp,                    /*fan motor amperage*/
              powerinput[20],         /*fan power input (hp)*/
              poweroutput[20],        /*fan power output (hp)*/
              eff_tot[20],            /*fan total efficiency*/
              eff_stat[20],           /*fan static efficiency*/
              nom_powerinput[20],     /*nom power input to fan motor*/
              nom_eff_stat[20];       /*nom static efficiency*/

                    /* airflow measurements */

extern double nozflowrate[20],         /*airflow rate at noz(cfm)*/
              fanflowrate[20],         /*airflow rate at fan (cfm)*/
```

```
             nozdiam[10][20],      /*array for nozzle dia*/
             diamno[20],           /*array for nozzle #'s*/
             ddiam,                /*nozzle diameters (inches)*/
             diam,                 /*noz # corresp to noz open*/
             LoverD[10][20],       /*length/dia ratio for noz*/
             nozzlearea[10][20],   /*array for nozzle areas*/
             exp_fac[20],          /*array for exp factors*/
             sumcarea[20],         /*coeff * nozzlearea array*/
             coeff[10][20],        /*array for noz coef of dis*/
             nom_fanflowrate[20],  /*nominal fan airflow rate*/
             Z,                    /*z/zc*/
             z_nom,                /*nominal zc*/
             Y,
             x_nom,                /*nominal xc*/
             K_nom,                /*nom compressibility ratio*/
             angle,                /*wind diverter angle*/
             ratio,                /*wind div position ratio*/
             Qweighted[20],        /*array -weighted airflows*/
             sum_Qweighted,        /*sum of weighted airflows*/
             tot_Qweighted;        /*total weighted airflow*/

extern int month,           /*month the fan headerfile created*/
           day,             /*day the fan headerfile created*/
           year,            /*year the fan headerfile created*/
           mm,              /*month the fan test was performed*/
           dd,              /*day the fan test was performed*/
           yy,              /*year the fan test was performed*/
           ratedcfmfan,     /*fan flow rate at 1/8" sp(cfm)*/
           ratedvolts,      /*rated voltage of the fan motor*/
           testpoints,      /*number of test points collected*/
           psychanges,      /*indicator of psych changes*/
           datachanges,     /*indicator of data input changes*/
           number[10][20],  /*array for the nozzle number*/
           numb;            /*nozzle diameter number*/

extern char firstname[10], lastname[10],    /*operator name*/
            manufacturer[10], modelno[10];    /*manu & model no*/


extern double   exp_factor(),            /* functions */
            airdens(),
            coeffdisch(),
            nozzleflow(),
            fanflow(),
            fanpress(),
            fanpwr(),
            getdata();

extern FILE    *outfile, *headerfile;
extern FILE    *dfile_pwr, *dfile_air, *dfile_psy;
```

```
# endif    /* FANPERF_H */
```

```
*****************************************************************
```

```
# makefile for header_w.c

GETOPT=c:

header_w.exe:    $*.c fandef.h
    cc $*.c $(GETOPT)
    rm $*.obj

header_r.exe:    $*.c fandef.h
    cc $*.c $(GETOPT)
    rm $*.obj

# The following statements compile the various components
# of the main program (fanperf2.c) and make it executable.

FAN_OBJ=getdata2.obj airdens.obj airflow.obj
    datfile2.obj scrnout2.obj

getdata2.obj:    $*.c fanperf.h fanconst.h
    cc -c $*.c

airdens.obj:    $*.c fanperf.h fanconst.h
    cc -c $*.c

airflow.obj:    $*.c fanperf.h fanconst.h
    cc -c $*.c

datfile2.obj:    $*.c fanperf.h fanconst.h
    cc -c $*.c

scrnout2.obj:    $*.c fanperf.h fanconst.h
    cc -c $*.c

fanperf2.exe:    $*.c fandef.h fanconst.h $(FAN_OBJ)
    cc  -F4fff $*.c $(GETOPT) $(FAN_OBJ)
```

APPENDIX C

Tabular Results of Study Investigating Wind Diverter Position and Angle

TABLE 15. Two-speed 30.5 cm fan (high speed) with a 0° wind diverter at an area ratio of 1.75 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	292.5	29.68	283.7	13.9	1779	2.22	197	1.5
1.98	31.05	286.9	29.73	278.3	87.5	1779	2.22	198	1.4
4.01	31.05	270.6	29.83	262.5	92.4	1778	2.22	199	1.4
6.01	31.05	253.2	29.80	245.8	49.3	1777	2.22	203	1.2
8.00	31.05	209.9	29.80	203.9	14.0	1776	2.23	208	1.0
10.00	31.05	161.8	29.80	157.2	2.4	1775	2.23	211	0.8

TIME WEIGHTED AIRFLOW - 259.5

TABLE 16. Two-speed 30.5 cm fan (high speed) with a 15° wind diverter at an area ratio of 1.75 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	299.7	29.68	290.6	14.2	1779	2.22	196	1.5
1.98	31.05	292.2	29.75	283.4	89.1	1779	2.22	197	1.5
3.98	31.05	272.2	29.78	264.0	92.9	1778	2.22	198	1.4
5.98	31.05	240.3	29.80	233.3	46.8	1777	2.22	203	1.2
8.00	31.05	214.6	29.83	208.4	14.4	1776	2.23	208	1.0
9.99	31.05	163.7	29.83	159.1	2.4	1776	2.23	212	0.8

TIME WEIGHTED AIRFLOW - 259.8

TABLE 17. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter at an area ratio of 1.75 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	339.0	29.70	328.6	16.1	1779	2.21	193	1.8
1.99	31.05	305.8	29.78	296.4	93.2	1780	2.21	194	1.6
4.02	31.05	274.9	29.78	266.5	93.8	1779	2.21	197	1.4
6.03	31.05	238.6	29.83	231.6	46.5	1777	2.22	201	1.2
8.00	31.05	222.1	29.83	215.6	14.9	1777	2.22	206	1.1
10.00	31.05	158.4	29.85	153.9	2.3	1775	2.22	212	0.7

TIME WEIGHTED AIRFLOW - 266.8

TABLE 18. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter without a flange at an area ratio of 1.75 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEICHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	357.2	29.75	346.4	16.9	1779	2.21	195	1.8
2.02	31.05	327.3	29.75	317.3	99.8	1780	2.21	193	1.7
3.99	31.05	278.8	29.78	270.4	95.2	1778	2.21	197	1.4
6.02	31.05	243.9	29.78	236.7	47.5	1778	2.21	200	1.2
7.98	31.05	227.0	29.80	220.4	15.2	1777	2.22	205	1.1
9.97	31.05	156.6	29.88	152.2	2.3	1775	2.23	215	0.7

TIME WEIGHTED AIRFLOW - 276.9

TABLE 19. Test of two-speed 30.5 cm fan (high speed) with a 45° wind diverter at an area ratio of 1.75 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	354.5	29.60	343.7	16.8	1780	2.22	195	1.8
2.00	31.05	317.8	29.58	308.0	96.9	1780	2.22	194	1.6
3.99	31.05	290.0	29.75	281.2	99.0	1779	2.22	197	1.5
6.01	31.05	246.0	29.75	238.7	47.9	1778	2.22	202	1.2
8.00	31.05	229.3	29.78	222.7	15.3	1777	2.23	207	1.1
10.01	31.05	165.8	29.80	161.1	2.4	1775	2.24	214	0.8

TIME WEIGHTED AIRFLOW = 278.3

TABLE 20. Test of two-speed 30.5 cm fan (high speed) without a wind diverter in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-12-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	590.4	29.85	573.7	28.1	1775	2.23	214	2.8
2.03	31.02	552.4	29.90	536.8	168.8	1775	2.24	214	2.6
4.03	31.05	222.1	29.90	215.7	75.9	1776	2.22	211	1.1
6.00	31.05	183.8	29.95	178.7	35.8	1774	2.24	219	0.8
7.99	31.05	103.1	30.03	100.4	6.9	1771	2.26	233	0.4
9.49	31.05	18.0	30.10	17.6	0.2	1769	2.27	244	0.1

TIME WEIGHTED AIRFLOW = 315.8

TABLE 21. Test of two-speed 30.5 cm fan (high speed) with a 0° wind diverter at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.05	295.4	29.36	286.5	14.0	1778	2.22	200	1.5
2.00	31.05	289.3	29.43	280.7	88.3	1778	2.23	200	1.4
4.01	31.05	276.9	29.43	268.8	94.6	1777	2.22	199	1.4
6.00	31.05	241.1	29.41	234.1	46.9	1777	2.23	206	1.2
8.00	31.05	225.3	29.43	218.8	15.1	1776	2.23	211	1.1
10.00	31.05	147.0	29.48	143.0	2.2	1774	2.24	221	0.7

TIME WEIGHTED AIRFLOW = 261.1

TABLE 22. Test of two-speed 30.5 cm fan (high speed) with a 15° wind diverter at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	426.6	29.31	414.2	20.3	1777	2.23	208	2.1
1.98	31.02	415.7	29.33	403.5	126.9	1777	2.23	207	2.0
3.99	31.05	275.2	29.31	267.0	94.0	1778	2.22	201	1.4
5.97	31.05	244.7	29.33	237.6	47.6	1777	2.22	205	1.2
8.01	31.05	226.4	29.31	219.9	15.1	1776	2.23	210	1.1
10.00	31.05	144.6	29.41	140.7	2.1	1774	2.24	223	0.6

TIME WEIGHTED AIRFLOW = 306.1

TABLE 23. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	489.2	29.28	475.4	23.3	1775	2.24	217	2.3
1.97	31.02	479.1	29.38	465.6	146.5	1775	2.24	216	2.2
3.99	31.05	279.4	29.26	271.0	95.4	1778	2.23	200	1.4
5.97	31.05	247.9	29.28	240.6	48.3	1777	2.23	205	1.2
8.00	31.05	231.2	29.28	224.6	15.5	1776	2.23	212	1.1
9.99	31.05	134.7	29.36	131.0	2.0	1773	2.25	227	0.6

TIME WEIGHTED AIRFLOW = 330.8

TABLE 24. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter witout a flange at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	498.7	29.38	484.7	23.7	1775	2.24	216	2.3
2.01	31.02	495.0	29.43	481.2	151.4	1775	2.24	216	2.3
4.03	31.05	282.2	29.33	273.7	96.4	1778	2.22	199	1.4
5.99	31.05	249.8	29.36	242.5	48.6	1777	2.22	204	1.2
8.00	31.05	228.3	29.36	221.8	15.3	1776	2.23	212	1.1
10.00	31.05	124.7	29.46	121.4	1.8	1773	2.25	226	0.6

TIME WEIGHTED AIRFLOW = 337.2

TABLE 25. Test of two-speed 30.5 cm fan (high speed) with a 45° wind diverter at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	516.2	29.48	501.6	24.5	1775	2.25	218	2.4
1.97	31.02	507.9	29.53	493.6	155.3	1775	2.25	217	2.3
4.03	31.05	291.1	29.41	282.3	99.4	1779	2.23	198	1.5
5.99	31.05	249.9	29.43	242.6	48.6	1777	2.23	205	1.2
8.01	31.05	238.4	29.46	231.5	16.0	1776	2.23	210	1.1
10.01	31.05	129.6	29.53	126.1	1.9	1773	2.25	227	0.6

TIME WEIGHTED AIRFLOW = 345.7

TABLE 26. Test of two-speed 30.5 cm fan (high speed) with a 60° wind diverter at an area ratio of 2.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	512.9	29.26	498.4	24.4	1775	2.24	216	2.4
1.98	31.02	511.2	29.38	496.8	156.3	1775	2.24	215	2.4
3.99	31.05	306.2	29.21	296.8	104.5	1780	2.22	195	1.6
5.99	31.05	261.5	29.23	253.7	50.9	1778	2.22	201	1.3
7.98	31.05	238.3	29.26	231.4	15.9	1777	2.23	207	1.2
10.01	31.05	122.6	29.41	119.3	1.8	1773	2.25	225	0.5

TIME WEIGHTED AIRFLOW = 353.8

TABLE 27. Test of two-speed 30.5 cm fan (high speed) with a 0° wind diverter at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	525.0	30.05	510.0	25.0	1776	2.23	215	2.4
2.02	31.02	528.9	30.13	513.9	161.7	1775	2.23	213	2.5
4.01	31.05	271.8	30.00	263.6	92.8	1779	2.22	201	1.4
5.99	31.05	241.7	30.05	234.6	47.1	1777	2.22	206	1.2
8.00	31.05	194.1	30.10	188.6	13.0	1775	2.24	216	0.9
10.02	31.05	104.9	30.15	102.1	1.5	1773	2.26	228	0.5

TIME WEIGHTED AIRFLOW = 341.0

TABLE 28. Test of two-speed 30.5 cm fan (high speed) with a 15° wind diverter at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	527.0	30.00	512.0	25.1	1776	2.25	216	2.4
1.98	31.02	528.5	30.05	513.4	161.5	1776	2.24	214	2.5
4.01	31.05	268.7	29.98	260.6	91.7	1778	2.22	200	1.3
6.01	31.05	239.9	29.98	232.9	46.7	1777	2.23	208	1.2
7.99	31.05	193.6	30.03	188.1	13.0	1775	2.24	216	0.9
10.03	31.05	100.9	30.15	98.2	1.5	1773	2.26	228	0.4

TIME WEIGHTED AIRFLOW = 339.4

TABLE 29. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	533.6	30.15	518.6	25.4	1775	2.23	214	2.5
2.00	31.02	535.6	30.20	520.5	163.7	1775	2.23	214	2.5
4.02	31.05	278.3	30.13	270.0	95.1	1778	2.22	199	1.4
5.99	31.05	242.8	30.13	235.8	47.3	1776	2.23	206	1.2
8.02	31.05	194.6	30.15	189.1	13.0	1775	2.24	216	0.9
10.00	31.05	100.1	30.23	97.4	1.5	1772	2.26	230	0.4

TIME WEIGHTED AIRFLOW - 345.9

TABLE 30. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter witout a flange at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	536.6	30.13	521.3	25.5	1776	2.25	216	2.5
1.98	31.02	539.7	30.20	524.3	164.9	1776	2.24	215	2.5
4.01	31.05	284.1	30.05	275.6	97.0	1779	2.22	199	1.4
6.00	31.05	243.8	30.08	236.7	47.5	1777	2.23	207	1.2
7.99	31.05	198.2	30.10	192.6	13.3	1775	2.24	217	0.9
10.00	31.05	100.8	30.18	98.1	1.5	1772	2.25	230	0.4

TIME WEIGHTED AIRFLOW - 349.7

TABLE 31. Test of two-speed 30.5 cm fan (high speed) with a 45° wind diverter at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	539.7	30.15	524.4	25.7	1775	2.24	216	2.5
1.98	31.02	538.0	30.25	522.7	164.4	1775	2.24	216	2.5
4.01	31.05	281.1	30.08	272.6	96.0	1779	2.22	200	1.4
6.00	31.05	245.9	30.10	238.7	47.9	1777	2.23	206	1.2
8.00	31.05	188.9	30.15	183.6	12.7	1775	2.24	218	0.9
10.00	31.05	86.4	30.23	84.1	1.3	1772	2.26	234	0.4

TIME WEIGHTED AIRFLOW = 347.8

TABLE 32. Test of two-speed 30.5 cm fan (high speed) with a 60° wind diverter at an area ratio of 4.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	547.5	30.18	532.2	26.0	1775	2.25	215	2.5
1.98	31.02	547.8	30.18	532.3	167.5	1775	2.25	215	2.5
4.00	31.05	296.3	30.03	287.3	101.1	1779	2.22	196	1.5
6.00	31.05	243.2	30.08	236.2	47.4	1777	2.23	208	1.2
8.00	31.05	167.5	30.20	162.9	11.2	1774	2.24	220	0.8
9.98	31.05	78.3	30.28	76.3	1.1	1771	2.26	235	0.3

TIME WEIGHTED AIRFLOW = 354.4

TABLE 33. Test of two-speed 30.5 cm fan (high speed) with a 0° wind diverter at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	537.8	29.41	522.7	25.6	1775	2.24	218	2.5
1.98	31.02	532.1	29.48	517.1	162.7	1775	2.23	217	2.5
4.01	31.05	259.2	29.38	251.5	88.5	1778	2.23	206	1.3
5.99	31.05	233.5	29.41	226.8	45.5	1776	2.24	216	1.1
8.00	31.05	163.4	29.51	159.0	11.0	1773	2.25	225	0.7
10.00	31.05	63.8	29.60	62.2	0.9	1770	2.26	239	0.3

TIME WEIGHTED AIRFLOW - 334.2

TABLE 34. Test of two-speed 30.5 cm fan (high speed) with a 15° wind diverter at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	541.4	29.41	526.0	25.7	1775	2.24	218	2.5
1.98	31.02	534.0	29.46	518.9	163.2	1775	2.25	217	2.5
3.97	31.05	260.0	29.38	252.3	88.8	1777	2.22	206	1.3
5.99	31.05	232.8	29.41	226.2	45.4	1775	2.24	216	1.1
8.00	31.05	152.8	29.51	148.7	10.2	1772	2.26	229	0.7
10.02	31.05	47.1	29.55	45.9	0.7	1769	2.28	244	0.2

TIME WEIGHTED AIRFLOW - 334.1

TABLE 35. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	542.4	29.46	527.4	25.8	1774	2.25	217	2.5
2.01	31.02	537.8	29.48	522.8	164.4	1775	2.24	217	2.5
4.03	31.05	265.2	29.41	257.5	90.6	1777	2.23	205	1.3
5.98	31.05	235.2	29.43	228.6	45.8	1775	2.24	214	1.1
8.00	31.05	154.1	29.51	150.0	10.3	1773	2.25	227	0.7
10.00	31.05	49.7	29.63	48.5	0.7	1769	2.28	243	0.2

TIME WEIGHTED AIRFLOW = 337.8

TABLE 36. Test of two-speed 30.5 cm fan (high speed) with a 30° wind diverter without a flange at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	543.5	29.41	528.4	25.9	1775	2.24	217	2.5
2.00	31.02	539.1	29.46	524.1	164.9	1774	2.24	216	2.5
4.01	31.05	270.2	29.38	262.2	92.3	1777	2.21	203	1.3
5.97	31.05	238.6	29.43	231.8	46.5	1776	2.24	213	1.1
8.00	31.05	157.3	29.53	153.1	10.5	1772	2.25	226	0.7
10.00	31.05	50.6	29.60	49.3	0.7	1769	2.27	243	0.2

TIME WEIGHTED AIRFLOW = 340.8

TABLE 37. Test of two-speed 30.5 cm fan (high speed) with a 45° wind diverter at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	548.2	29.43	532.9	26.1	1775	2.24	216	2.5
1.99	31.02	546.2	29.48	530.8	167.0	1775	2.23	216	2.5
4.02	31.05	267.5	29.41	259.6	91.4	1777	2.23	206	1.3
6.00	31.05	227.4	29.46	221.0	44.3	1775	2.24	215	1.1
7.99	31.05	144.4	29.53	140.5	9.7	1772	2.24	227	0.6
10.00	31.05	44.7	29.60	43.6	0.7	1769	2.27	245	0.2

TIME WEIGHTED AIRFLOW = 339.1

TABLE 38. Test of two-speed 30.5 cm fan (high speed) with a 60° wind diverter at an area ratio of 5.5 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1725 RPM (nominal)
DATE: 11-18-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	31.02	559.9	29.41	544.1	26.6	1775	2.24	218	2.6
1.97	31.02	562.3	29.48	546.4	171.9	1775	2.23	216	2.6
3.97	31.05	283.3	29.43	274.9	96.8	1778	2.22	204	1.4
5.97	31.05	220.3	29.46	214.1	42.9	1775	2.24	217	1.0
8.01	31.05	138.1	29.53	134.4	9.3	1772	2.25	231	0.6
9.99	31.05	34.7	29.65	33.9	0.5	1768	2.28	246	0.1

TIME WEIGHTED AIRFLOW = 348.0

TABLE 39. Test of two-speed 30.5 cm fan (low speed) with a 0° wind diverter at an area ratio of 1.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	161.5	11.55	155.7	7.6	1182	1.33	114	1.4
1.97	12.42	153.2	11.60	147.7	46.5	1183	1.33	114	1.3
3.99	12.42	151.3	11.62	145.9	51.4	1182	1.33	116	1.3
5.98	12.42	104.6	11.62	100.9	20.2	1181	1.34	117	0.9
7.97	12.42	16.5	11.60	15.9	1.1	1182	1.33	116	0.1

TIME WEIGHTED AIRFLOW = 126.8

TABLE 40. Test of two-speed 30.5 cm fan (low speed) with a 15° wind diverter at an area ratio of 1.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	175.2	11.60	168.9	8.3	1182	1.33	113	1.6
2.01	12.42	169.5	11.62	163.5	51.4	1182	1.33	114	1.5
3.98	12.42	155.2	11.62	149.8	52.7	1182	1.33	115	1.3
6.00	12.42	107.5	11.62	103.7	20.8	1181	1.34	117	0.9
8.00	12.42	18.7	11.62	18.0	1.2	1181	1.33	116	0.2

TIME WEIGHTED AIRFLOW = 134.4

TABLE 41. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter at an area ratio of 1.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	176.3	11.57	169.9	8.3	1183	1.33	113	1.6
2.01	12.42	170.1	11.62	163.9	51.6	1183	1.33	113	1.5
4.00	12.42	155.6	11.62	150.0	52.8	1182	1.33	115	1.4
5.98	12.42	111.3	11.62	107.4	21.5	1181	1.33	116	1.0
8.00	12.42	19.0	11.62	18.4	1.3	1182	1.33	116	0.2

TIME WEIGHTED AIRFLOW = 135.5

TABLE 42. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter without a flange at an area ratio of 1.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	174.6	11.55	168.0	8.2	1185	1.35	111	1.6
1.99	12.42	169.2	11.57	163.0	51.3	1184	1.35	112	1.5
3.97	12.42	155.9	11.60	150.2	52.9	1183	1.34	111	1.4
5.97	12.42	116.0	11.60	111.9	22.4	1182	1.34	115	1.0
8.00	12.42	10.3	11.62	10.0	0.7	1181	1.33	117	0.1

TIME WEIGHTED AIRFLOW = 135.5

TABLE 43. Test of two-speed 30.5 cm fan (low speed) with a 45° wind diverter at an area ratio of 1.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-20-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	168.9	11.57	162.7	8.0	1183	1.34	113	1.5
2.02	12.42	164.8	11.60	158.8	49.9	1183	1.33	113	1.5
3.98	12.42	149.2	11.60	143.9	50.7	1182	1.33	114	1.3
5.96	12.42	110.9	11.62	107.0	21.5	1182	1.33	115	1.0
7.97	12.42	19.1	11.62	18.4	1.3	1182	1.34	115	0.2

TIME WEIGHTED AIRFLOW - 131.4

TABLE 44. Test of two-speed 30.5 cm fan (low speed) without a wind diverter in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 10-16-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.39	377.4	11.67	364.3	4.5	1181	1.33	117	3.2
1.07	12.42	156.7	11.72	151.3	14.3	1181	1.33	116	1.4
2.06	12.42	148.0	11.70	142.8	23.2	1182	1.33	116	1.3
3.02	12.42	132.5	11.77	128.1	24.4	1180	1.34	119	1.1
4.09	12.42	99.0	11.77	95.8	17.2	1179	1.34	122	0.8
5.00	12.42	48.7	11.82	47.1	6.7	1178	1.34	124	0.4

TIME WEIGHTED AIRFLOW - 90.3

TABLE 45. Test of two-speed 30.5 cm fan (low speed) with a 0° wind diverter at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	169.4	11.60	163.3	8.0	1183	1.33	112	1.5
2.02	12.42	162.0	11.62	156.1	49.1	1183	1.33	112	1.4
4.00	12.42	150.6	11.62	145.2	51.1	1183	1.33	115	1.3
6.03	12.42	108.8	11.62	104.9	21.0	1182	1.33	116	0.9

TIME WEIGHTED AIRFLOW - 129.2

TABLE 46. Test of two-speed 30.5 cm fan (low speed) with a 15° wind diverter at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEICHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	171.8	11.57	165.6	8.1	1183	1.33	112	1.5
1.97	12.42	166.4	11.62	160.3	50.4	1183	1.33	112	1.5
3.99	12.42	155.4	11.62	149.8	52.7	1183	1.33	114	1.4
5.98	12.42	113.7	11.62	109.7	22.0	1182	1.33	116	1.0

TIME WEIGHTED AIRFLOW - 133.2

TABLE 47. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	173.4	11.57	167.1	8.2	1183	1.33	113	1.5
2.01	12.42	166.4	11.60	160.3	50.4	1183	1.33	113	1.5
4.00	12.42	157.0	11.62	151.4	53.3	1182	1.33	115	1.4
6.01	12.42	113.6	11.62	109.6	22.0	1182	1.33	116	1.0

TIME WEIGHTED AIRFLOW - 133.9

TABLE 48. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter without a flange at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	177.2	11.57	170.7	8.4	1183	1.33	112	1.6
2.00	12.42	169.2	11.65	163.1	51.3	1183	1.33	112	1.5
4.00	12.42	159.5	11.62	153.7	54.1	1182	1.33	114	1.4
5.98	12.42	115.7	11.62	111.6	22.4	1182	1.34	116	1.0

TIME WEIGHTED AIRFLOW - 136.2

TABLE 49. Test of two-speed 30.5 cm fan (low speed) with a 45° wind diverter at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	183.0	11.57	176.2	8.6	1184	1.33	113	1.6
2.00	12.42	172.0	11.62	165.6	52.1	1184	1.33	112	1.5
3.96	12.42	161.1	11.62	155.3	54.7	1183	1.33	114	1.4
5.96	12.42	117.4	11.65	113.3	22.7	1182	1.33	116	1.0

TIME WEIGHTED AIRFLOW = 138.1

TABLE 50. Test of two-speed 30.5 cm fan (low speed) with a 60° wind diverter at an area ratio of 2.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-19-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	179.2	11.57	172.6	8.4	1184	1.33	111	1.6
1.98	12.42	171.5	11.62	165.2	52.0	1184	1.33	111	1.5
4.00	12.42	163.1	11.62	157.2	55.3	1183	1.33	114	1.4
6.01	12.42	109.5	11.62	105.6	21.2	1182	1.33	116	0.9

TIME WEIGHTED AIRFLOW = 136.9

TABLE 51. Test of two-speed 30.5 cm fan (low speed) with a 0° wind diverter at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	166.6	11.77	160.6	7.9	1183	1.33	113	1.5
2.01	12.42	161.8	11.82	155.9	49.0	1183	1.33	113	1.4
4.00	12.42	152.8	11.82	147.3	51.8	1183	1.33	115	1.3
6.00	12.42	103.8	11.85	100.3	20.1	1180	1.33	119	0.9

TIME WEIGHTED AIRFLOW = 128.8

TABLE 52. Test of two-speed 30.5 cm fan (low speed) with a 15° wind diverter at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	167.9	11.77	161.8	7.9	1183	1.33	113	1.5
1.98	12.42	163.2	11.82	157.3	49.5	1183	1.33	113	1.4
4.00	12.42	153.8	11.82	148.3	52.2	1182	1.33	115	1.3
5.98	12.42	101.3	11.85	97.8	19.6	1180	1.34	119	0.9

TIME WEIGHTED AIRFLOW = 129.2

TABLE 53. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	167.7	11.77	161.6	7.9	1183	1.33	113	1.5
2.00	12.42	163.4	11.80	157.5	49.5	1183	1.33	113	1.4
4.00	12.42	155.6	11.80	150.0	52.8	1183	1.33	115	1.4
6.00	12.42	97.8	11.82	94.5	19.0	1180	1.34	119	0.8

TIME WEIGHTED AIRFLOW = 129.2

TABLE 54. Test of two-speed 30.5 cm fan (low speed) with a 30° wind diverter without a flange at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	172.3	11.77	166.0	8.1	1183	1.34	113	1.5
2.00	12.42	166.2	11.80	160.2	50.4	1183	1.33	113	1.5
4.00	12.42	161.6	11.82	155.8	54.9	1182	1.33	115	1.4
5.99	12.42	100.2	11.87	96.8	19.4	1180	1.33	120	0.8

TIME WEICHTED AIRFLOW = 132.8

TABLE 55. Test of two-speed 30.5 cm fan (low speed) with a 45° wind diverter at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	175.2	11.77	168.8	8.3	1183	1.33	112	1.6
1.98	12.42	167.9	11.82	161.8	50.9	1183	1.33	113	1.5
4.00	12.42	157.7	11.85	152.1	53.5	1182	1.33	115	1.4
5.98	12.42	94.7	11.87	91.4	18.3	1180	1.33	120	0.8

TIME WEIGHTED AIRFLOW - 131.0

TABLE 56. Test of two-speed 30.5 cm fan (low speed) with a 60° wind diverter at an area ratio of 3.0 in 0 to 10 mps straight on wind.

FAN : Agri-Aide FM-1211-2 at 1140 RPM (nominal)
DATE: 11-17-87

	TEST AIR		STANDARD AIR			MOTOR PERFORMANCE			VER
WIND SPEED (mps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	STATIC PRESS (Pa)	FAN AIRFLOW (Lps)	WEIGHTED AIRFLOW (Lps)	FAN SPEED (rpm)	MOTOR CURRENT (amps)	MOTOR POWER (watts)	(Lps per watt)
0.00	12.42	187.7	11.80	180.7	8.8	1184	1.34	112	1.7
2.03	12.42	172.9	11.82	166.5	52.4	1184	1.34	112	1.5
4.01	12.42	165.1	11.82	159.1	56.0	1183	1.34	114	1.4
6.00	12.42	95.1	11.87	91.8	18.4	1180	1.34	120	0.8

TIME WEIGHTED AIRFLOW - 135.6

APPENDIX D

Tabular Results of the Statistical Modeling

The following tables present the full statistical results obtained through use of various regression models to fit the data obtained on the two-speed 30.5 cm fan, operated at high speed, during testing with five wind diverter angles at four area ratios.

Model 1: $TWA = \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Ratio^2$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	3	19250.146	6416.715	27.614	0.0001	0.8467
Error	15	3485.580	232.372			
C Total	18	22735.726				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	119.955	29.039
β_1	1	0.635	0.171
β_2	1	97.424	17.888
β_3	1	-11.158	2.410

Model 2: $TWA = \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Ratio^2 + \beta_4*Angle*Ratio$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	4	20352.383	5088.096	29.888	0.0001	0.8952
Error	14	2383.343	170.239			
C Total	18	22735.726				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	100.865	25.963
β_1	1	1.623	0.415
β_2	1	100.150	15.349
β_3	1	-10.526	2.078
β_4	1	-0.270	0.106

Model 3: $TWA = \begin{cases} \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Angle^2 \\ + \beta_4*Ratio^2 + \beta_5*Angle*Ratio \end{cases}$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	5	20358.069	4071.614	22.262	0.0001	0.8954
Error	13	2377.657	182.897			
C Total	18	22735.726				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	101.758	27.384
β_1	1	1.547	0.610
β_2	1	99.914	15.965
β_3	0.001	0.008	
β_4	1	-10.487	2.165
β_5	1	-0.273	0.111

The following tables are statistical results for low speed operation of the two-speed 30.5 cm fan with five wind diverter angles and at three area ratios.

Model 1: $TWA = \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Ratio^2$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	3	104.483	34.828	6.570	0.0099	0.6634
Error	10	53.012	5.301			
C Total	13	157.495				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	123.137	4.752
β_1	1	0.114	0.031
β_2	1	8.756	5.288
β_3	1	-2.449	1.292

Model 2: $TWA = \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Ratio^2 + \beta_4*Angle*Ratio$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	4	104.503	26.126	4.437	0.0296	0.6635
Error	9	52.992	5.888			
C Total	13	157.495				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	123.040	5.284
β_1	1	0.120	0.100
β_2	1	8.774	5.582
β_3	1	-2.437	1.376
β_4	1	-0.002	0.043

Model 3: $TWA = \beta_0 + \beta_1*Angle + \beta_2*Ratio + \beta_3*Angle^2 + \beta_4*Ratio^2$

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob > F	R-Square
Model	4	105.865	26.466	4.614	0.0266	0.6722
Error	9	51.630	5.737			
C Total	13	157.495				

Parameter Estimates

Coefficient	DF	Parameter Estimate	Standard Error
β_0	1	122.471	5.126
β_1	1	0.164	0.106
β_2	1	9.049	5.533
β_3	1	-0.001	0.002
β_4	1	-2.507	1.350

EFFECT OF A WIND PROTECTION DEVICE ON VENTILATION FAN PERFORMANCE

by

STEVEN EDWARD COLE

B.S., Colorado State University, 1985

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ABSTRACT

A laboratory facility to test exhaust fans with capacities up to 3070 Lps (6500 cfm) was designed and constructed in the first phase of this study. The fan test chamber performs according to the standards of the Air Movement and Control Association. It reproduced the results of a fan tested by AMCA to within 1 to 2%. Development efforts to attain this performance involved the replacement of inadequate nozzles and settling screens and the location and sealing of air leaks in the plywood, the test fan housing, and the flow nozzle plugs.

The effect of wind on the performance of 20.3 to 40.6 cm (8 to 16 in) diameter ventilation fans and potential benefits of a fan-mounted wind protection device were evaluated during the second phase of the project. The wind protection device evaluated was a commercial cone shaped wind diverter constructed of fiberglass with a 30° cone angle. The effect of cone angle, diverter position and alternative configurations were also evaluated. A 15.2 m (50 ft) long, 2 m (6.5 ft) high, and 1.5 m (5 ft) wide wind tunnel was used to simulate 0 to 10 mps winds in 2 mps intervals for each test. Fan airflow was weighted according to the probability of occurrence for each wind velocity, as described by the Weibull distribution. Although the wind diverter hindered fan airflow by 5 to 55% in windless conditions, the weighted airflow was improved by up to 65% with an optimally designed unit. A 60° cone angle improved the fan airflow by 2 to 10% over fan airflow using the 30° cone angle. The optimum distance of the wind diverter from the fan housing was influenced by fan diameter and rotational speed. The overall

benefit of fan-mounted wind protection devices was greater at low fan speeds and for small fans. Design parameters of the wind diverter were more important with large fan diameters and high fan speeds. Further work is needed, particularly for variable speed fans which are especially vulnerable at low speeds.