This is to certify that the

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AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
UTILIZING INTERACTIVE COMPUTER GRAPHICS

presented by

DENNIS GENE WATSON

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Agricultural Engineering Technology, Department of Agriculture Engineering

Roger C. Brook
Major professor

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AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES UTILIZING INTERACTIVE COMPUTER GRAPHICS

By

Dennis Gene Watson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in

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ABSTRACT

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES UTILIZING INTERACTIVE COMPUTER GRAPHICS

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Dennis Gene Watson

The goal of this research was to study aeration system design for flat grain storages and implement and evaluate an aeration system design program utilizing interactive computer graphics.

A set of software tools was synthesized for development of agricultural engineering design programs. This development system was modeled after an expert's problem solving process for design applications and divides a computer program into components of interview, calculations, design drawing and management recommendations. A group of software tools suitable for implementing each component of the development system was presented and the tools used to implement the aeration system design program were described.

Based on user responses to questions about a grain storage, the program prepares paper copy of a floor plan of the duct layout, a list of component specifications and a list of management recommendations for the user. Aeration system design guidelines and recommendations from various sources were consolidated into a set of guidelines for use in the computer program. The placement of ducts was accomplished with a modified air path ratio method. A higher air path ratio was used to place a duct from an outer wall of a storage compared to placement in the center of a storage. This method results in duct placement similar to methods which base the number and placement of ducts on the size of the storage.

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Dennis Gene Watson

A structured review process was used to evaluate the aeration system design program. Nine extension specialists and industry representatives evaluated technical and usability aspects of the program. Technical content was evaluated for concurrent validity, construct validity, content validity and sensitivity. Usability evaluation centered on ease of use, information conveyance, pertinence of illustrations and usefulness of the design drawing and management recommendations.

Differences were found between results generated by the computer program and the reviewers. The difference in problem solutions is a function of variation in the reviewers' preferred guidelines. Two areas of difference are the distance to offset a perforated duct from the edge of a storage and the maximum length of duct to allow from an air source.

Results of the usability evaluation were very favorable. The user interface was rated very easy to use and was recommended for use by beginning microcomputer users, county extension agents and farmers.

Approved [signature]
Major Professor

Approved [signature]
Department Chairperson

To my wife and childen

ACKNOWLEDGMENTS

Several people have contributed to this work and I would like to take this opportunity to express my appreciation and acknowledge their efforts. I would like to express appreciation to Dr. Roger Brook, my major professor, for his guidance, encouragement and support throughout my graduate studies. His experience and suggestions were especially beneficial during development of the aeration system design program

I am grateful to Drs. Mary Andrews, William Bickert, Erik Goodman and Steve Harsh for agreeing to serve on my graduate committee. Their assistance and professional review throughout this project have been of great value.

I would like to express my appreciation to the W. K. Kellogg Foundation staff for providing the resources needed to conduct this study. Their foresight in funding a project to demonstrate computer graphics as a vehicle for providing human services is to be commended.

Gary Peterson was very instrumental throughout this project. His diligence in providing and maintaining the computer equipment, willingness to discuss any aspects of the project on a moment's notice, and friendship are especially appreciated.

Ken Kuck was very helpful in developing and testing many of the algorithms for the calculations component of the aeration system design program.

The participation of George Foster and Bruce McKenzie of Purdue University; Marvin Hall, William Peterson and Gene Shove of University of Illinois; Bill

Altermatt and Joe McNall of Hancor, Inc. and Dan Hansen and Stephanie Ganser of Aerovent Fan and Equipment, Inc. during the technical and usability evaluation process is greatly appreciated.

I would also like to express great appreciation to my wife, Marva, and children for their perseverance, understanding and support during the long hours of my graduate program.

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CHAPTER I

INTRODUCTION

The recent grain surplus has resulted in a shortage of storage facilities and a program of government incentives for producers who store grain. Grain producers have responded by preparing new and existing structures for grain storage. Adequate preparation includes the installation of aeration systems to maintain the quality of stored grain. If aeration systems are not properly designed, grain spoilage and economic loss can occur.

Design recommendations for aeration systems are readily available in handbooks, bulletins and other reference materials. These materials provide specific recommendations for some parts of an aeration system. Other recommendations are necessarily general and are often not applicable to a producer's specific problem.

The knowledge and experience of an expert in aeration system design is needed to adapt general recommendations to specific situations. Unfortunately, the availability of these experts--agricultural engineering extension specialists and consultants--is often limited. As a result, aeration systems are installed without the benefit of an expert's knowledge. To remedy this situation, a computer program has been developed to simulate the role of an expert in aeration system design in an interactive session with a client (a producer storing grain).

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Increased availability of microcomputers for agricultural purposes has led to development of microcomputer application programs for agricultural education, research and extension purposes. Many quality programs of sound technical content have emerged. However, most microcomputer programs rely on textual information to communicate with users, whereas experts in aeration system design rely on visual aids to communicate with clients. In particular they prepare design drawing for clients to use when implementing designs.

To supply this visual component, interactive computer graphics technology was used to develop this program. Effective use of computer graphics enhances information transfer between a computer program and client. Computer controlled illustrations communicate concepts when asking questions and custom design drawings are generated as solutions to design problems.

Although commercial software products for IBM-compatible microcomputers are available to implement various portions of an agricultural engineering design program, they do not interact directly. To complement the development of computer-aided engineering applications for educational and extension purposes, a software system based on interactive computer graphics was needed. The system had to be flexible enough to incorporate new commercial software products as they become available.

A set of suitable software tools was synthesized, to facilitate development of design applications that appear as one program from the user's perspective. The aeration system design program was selected for development and demonstration as a computer-graphics-based design program.

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GOAL AND OBJECTIVES

The research goal was to study aeration system design for flat grain storages and implement an aeration system design program utilizing interactive computer graphics. Specifically, the objectives were as follows:

1) consolidate design concepts and recommendations for aeration systems in flat grain storages
2) synthesize a set of tools for developing agricultural engineering design programs such as an aeration system design program
3) develop a program to design aeration systems for flat grain storages
4) evaluate the aeration system design program.

CHAPTER II

AERATION SYSTEM DESIGN GUIDELINES

The purpose of this chapter is to review aeration system design literature to determine appropriate guidelines for the design of aeration systems for flat grain storages. Flat storages are defined as any storage where the height of grain is less than the diameter or width (Holman, 1960).

Aeration systems are designed to distribute an appropriate volume of air in a reasonably uniform manner throughout a grain mass. Uniformity of airflow is a key design concern. In typical aeration systems for upright storages, the lowest airflow rate in any part of the storage usually is not less than 90 percent of the selected rate. In contrast, in well-designed systems for flat storages, the lowest airflow rate in some portions of the grain may be less than 50 percent of the selected rate (Holman, 1960). This difference in uniformity is due to the lower ratio of duct surface area to floor area common in flat storages. Aeration system design for flat storages is a compromise between airflow uniformity and reasonable costs.

This review of aeration system design guidelines is divided into four sections: first, a review of aeration equipment; second, system design considerations; third, a discussion of aeration system design procedure; and fourth, guidelines for sizing components.

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AERATION EQUIPMENT

The principal parts of an aeration system and their functions are 1) fans to provide airflow; 2) ducts to distribute air throughout a grain mass and 3) supply tubes to connect fans and ducts.

FANS

Axial and centrifugal fans are commonly used in aeration systems. Fans should be selected based on the manufacturers' performance ratings. Typical performance ratings specify the volume of air delivered by a fan over a range of static pressures. The unique features of axial and centrifugal fans should be considered to determine which type of fan to use.

An axial fan houses the fan and motor within the airstream. Generally, an axial fan will deliver more air than a centrifugal fan at static pressures less than about 1 kPa (4 in. H_2O) (Brook, 1979; Foster and Tuite, 1986; Midwest Plan Service (MWPS), 1987). Axial fans are usually less expensive than centrifugal fans. They can be easily mounted in circular ducts and are widely used for aeration in farm bins and flat storages.

On a centrifugal fan, the motor is mounted outside the air stream. Centrifugal fans are recommended for static pressures above 1 kPa (4 in. H_2O) (Brook, 1979; Foster and Tuite, 1986; Holman, 1960). They are quieter than axial fans and are used where lower noise levels are desired (Foster and Tuite, 1986).

DUCTS

Flat storages are usually temporary grain storages and aeration ducts are placed directly on the floor. Ducts facilitate air distribution through a grain mass. Perforations in ducts allow air to pass from the duct through the grain. Common types of on-floor ducts are round metal, half-round metal and plastic aeration tubing.

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A duct material must have enough perforations to allow sufficient air to reach grain while preventing grain from entering the duct (Foster and Tuite, 1986). Uniformly spaced perforations equal to seven to ten percent of the duct surface area were recommended by Cloud and Morey (1980), Foster and Tuite (1986), Holman (1960) and Noyes (1967). Perforated metal aeration ducts are available which have up to twice this percentage of perforations, whereas plastic tubing typically has less open area.

Plastic drainage pipe has been used for aeration ducts. Manufacturers are now supplying plastic pipe specifically for this purpose. Plastic drainage pipe typically has perforated areas as small as one percent of the surface area (Brook, 1986), but some perforated plastic aeration tubing has up to six percent open area (Hancor, 1985). Plastic ducts must have enough open area in the pipe wall to allow air to pass through easily (Midwest Plan Service, 1987). Midwest Plan Service (1987) recommended that if the openings are in the bottom of the corrugations and evenly distributed, plastic pipes can be covered with a screen or mesh. The total area of the openings in the pipe wall should at least equal the pipe's cross-sectional area. If the openings in the duct are narrow slots in the bottom of the corrugations (as in plastic drain tile), Midwest Plan Service (1987) did not recommend covering the pipe with screen or mesh. The area of the wall openings should be about three times the duct cross-sectional area (MWPS, 1987).

At present, insufficient research data exists to determine how the smaller percentage of open surface area and the corrugated construction of plastic ducts affects airflow through grain as compared to metal ducts. Metal ducts are generally preferred for air distribution in grain storages because at least seven percent of their surface area is open. However, plastic ducts are popular for use in flat storages due to their lower cost and ease of handling.

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SUPPLY TUBES AND CONNECTORS

Supply tubes and connectors connect a fan, on the outside of a storage, to a perforated duct, which is offset from the edge of the storage. Supply tubes are ducts without perforations and are usually of the same type as the perforated ducts.

Optimal performance of an aeration system will not be achieved unless the fan is properly connected to the duct. Holman (1960) estimated that a poor fan connection may reduce the airflow by 25 percent or more. Air entering a fan should approximate a straight line. Upright storages usually have one fan per duct and the fan can be mounted on the end of the duct without any elbows.

Flat storages usually require low airflow per duct and it is cost efficient to connect one fan to multiple ducts. In this case, a fan is often attached to an aeration tube via a tee or elbow fitting. Tees and elbows should be selected to minimize flow restriction. An elbow with a radius of at least 1.5 times the duct diameter is recommended (Holman, 1960).

SYSTEM DESIGN CONSIDERATIONS

Two primary considerations in the design and operation of an aeration system are the direction of airflow and the rate of airflow.

AIRFLOW DIRECTION

Aeration distribution systems are classified as either pressure or suction systems. A pressure system pushes air through the grain; a suction system pulls air through the grain. Airflow is generally upward in a pressure system and downward in a suction system. Although one system may be more appropriate in a particular application, either can be used effectively for aeration if equipment is properly installed and managed (Brook and Watson, 1986). Brook and

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Watson (1986), Foster and Tuite (1986) and Holman (1960) discussed the advantages and disadvantages of both system types.

Pressure systems have the following advantages for flat storages: (1) positive pressure tends to keep openings in plastic aeration pipe from plugging (MWPS, 1987); (2) upward airflow permits more uniform air distribution than suction systems (Steele and Shove, 1969; Burrell, 1974); (3) heat is moved out of the top of the storage, permitting warm grain to be added to storage without pulling heat through previously cool grain (Brook and Watson, 1986; Foster and Tuite, 1986); (4) completion of an aeration cycle is easily monitored by temperature measurement of the grain near the top surface (Brook and Watson, 1986; Foster and Tuite, 1986) and (5) heat from the fan raises the air temperature and lowers its humidity, thus permitting aeration to proceed at times when the air would otherwise be too cold or humid (Brook and Watson, 1986; Foster and Tuite, 1986).

A suction system expels air at a high enough velocity to prevent moisture condensation, which can be a problem with pressure systems (Brook and Watson, 1986; Foster and Tuite, 1986). Aeration can be started in partially filled storages with downward airflow by covering the exposed duct and shallow depths of grain with plastic sheets. Likewise air can be directed to hot spots in the grain mass (Foster and Tuite, 1986).

AIRFLOW RATE

Uniform airflow is desirable and relates directly to uniform conditioning of grain. However, in most flat storages, some grain is aerated at a higher airflow rate than other portions of the grain mass. Careful consideration must be given to the lowest rate that can be permitted in any portion of the stored grain, as the time required for aeration is determined by the lowest airflow rate. For design purpo

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purposes, small portions of the grain mass which cool by conduction or other means may be disregarded in determining the lowest airflow rate (Holman, 1960).

Airflow rates measured in grain soon after storage usually will be higher than those measured after several months. An airflow rate of 0.08 $m^3/min/m^3$ (0.1 $ft^3/min/bu$) is widely used to aerate shelled corn and soybeans stored in farm bins and in flat storages (Foster and Tuite, 1986; Noyes, 1967). Foster and Tuite (1986) recommended an airflow of 0.04 $m^3/min/m^3$ (0.05 $ft^3/min/bu$) for wheat and other smaller seeded crops.

For flat storages, Cloud and Morey (1980) suggested airflow rates of 0.10 to 0.16 $m^3/min/m^3$ (0.125 to 0.2 $ft^3/min/bu$) to compensate for less uniform airflow. Brook (1979) recommended a delivered airflow of 0.08 to 0.16 $m^3/min/m^3$ (0.1 to 0.2 $ft^3/min/bu$) for dry farm-stored grains. An airflow of 0.08 $m^3/min/m^3$ (0.1 $ft^3/min/bu$) is acceptable for clean, dry grain. Grain stored with fines or at a moisture content above the recommended values requires a higher airflow of 0.16 $m^3/min/m^3$ (0.20 $ft^3/min/bu$).

DESIGN PROCEDURE

Aeration systems have often been designed for upright storages. Some published procedures for aeration system design reflect this fact as the number of ducts is a foregone conclusion. The following design procedure described by Peterson (1985) is typical of methods which assume duct placement based upon storage size:

1) determine storage capacity and profile
2) calculate total airflow required
3) determine fan size
4) calculate duct size
5) place duct

The above procedure is adequate for upright storages and some flat storages. When used for flat storages, the designer must have good rules of thumb for the appropriate number of ducts and placement of ducts with various grain profiles. This procedure has the potential of resulting in extremely non-uniform airflow unless adjustments are made for the grain depths in the storage.

A different procedure is needed for use in a computer program where a wide range of problems will be solved. Burrell (1974) described the following aeration system design procedure:

1) determine storage profile and volume
2) select airflow rate and calculate total airflow
3) determine number and placement of ducts
4) divide total airflow by number of ducts
5) size duct
6) estimate static pressure
7) size fan

The design procedure described by Holman (1960) was:

1) determine storage dimensions and capacity
2) select airflow rate
4) estimate volume of grain served by each duct
5) calculate air volume needed for each duct
6) size fan
7) size duct
8) size supply tubes

Two major differences exist between the Burrell and Holman methods. Holman estimated the amount of grain served by each duct to determine the airflow required by the duct. Burrell divided the total airflow of the storage evenly among the ducts. Dividing the airflow evenly among the ducts can result in a considerable difference in delivered airflow per unit of grain when the volume served by ducts in the same storage varies considerably.

Burrell also advocated sizing the duct first and then the fan, which is the reverse of Holman's method. If airflow velocity is indeed the determining factor in sizi

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in sizing a duct, then the fan must be sized first to determine the actual airflow in the duct.

SIZING COMPONENTS

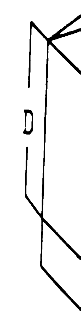
Sizing aeration system components requires determining storage capacity, duct placement, fan sizes, duct sizes, supply tube sizes and exhaust area.

STORAGE CAPACITY

Grain in flat storage is typically peaked to increase capacity. Due to doorways and other limitations in buildings, the grain depth may vary among the four walls which retain the grain. Calculation of grain volume can be accomplished by dividing the grain mass into simple shapes. Midwest Plan Service (1987) suggested a typical peaked flat storage building volume can be calculated by dividing it into three volumes of level fill area, triangular peak and both end peaks (Figure 1). The constant of 1.244 ft^3/bu is used to determine grain capacity in traditional units (bushels). This procedure is suitable in most cases and provides a quick approximation.

Other means of calculating grain volume are available. Holligan (1982) presented equations for free flowing materials stored in rectangular containers with open or closed ends. The side walls were assumed to be at the same depth. Hunter (1985) proposed equations for calculating the volume of various conical piles.

The information required to calculate the volume of grain in a rectangular flat storage is width and length of the storage, depth of grain at walls, and either maximum grain depth or angle of repose. The angle of repose determines the slope of the grain from a wall to the peak and is a key factor in determining grain volume, but it is seldom measured in a storage. Angle of repose depends on grain type, moisture content, amount of fines and foreign material and height of



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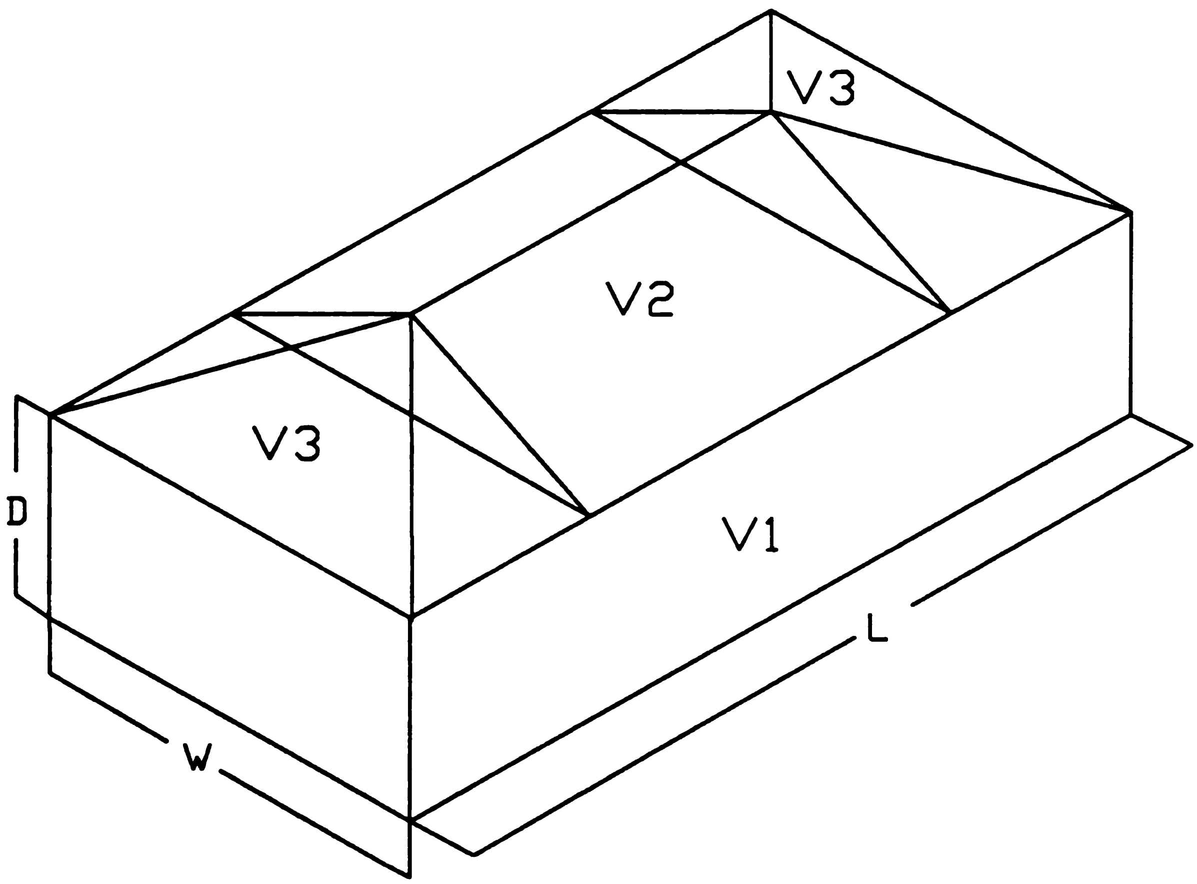

W = storage width, m (ft)
L = storage length, m (ft)
D = grain depth at side walls, m (ft)
V1 = level fill volume, m^3 (ft^3)
V2 = triangular peak volume, m^3 (ft^3)
V3 = end peak volume, m^3 (ft^3)

Figure 1. Typical flat grain storage divided into areas for volume calculation.

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drop (MWPS, 1987). Midwest Plan Service (1987) published average, minimum and maximum filling angles for common grains (Table 1).

Table 1. Average, minimum and maximum angles of repose for some grains.[1]

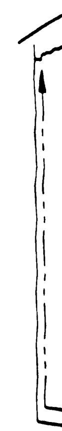
Crop	Angle of Repose (deg) average	minimum	maximum
Corn	25	22	28
Barley	28	24	34
Sunflower	28	20	40
Oats	28	24	32
Durum wheat	23	22	25
Spring wheat	25	19	38
Overall	27	18	40

[1]Midwest Plan Service (1987).

Brooker et al. (1974) listed the angle of repose for barley at 30 degrees; rice at 36 degrees; shelled corn at 27 degrees; soybeans at 30 degrees; and wheat at 31 degrees. Pierce and Bodman (1987) conducted a field study to determine the piling angles for shelled corn and milo in flat grain storages. They found the average angle of repose for shelled corn and milo to be 23 and 29 degrees, respectively. These angles are approximately 4 degrees lower than repose angles appearing in current references.

DUCT PLACEMENT

Duct placement in flat storages is governed by the grain profile and the desired minimum air path ratio. Air path ratio is the ratio of the longest distance air travels through the grain compared to the shortest distance (Figure 2). As



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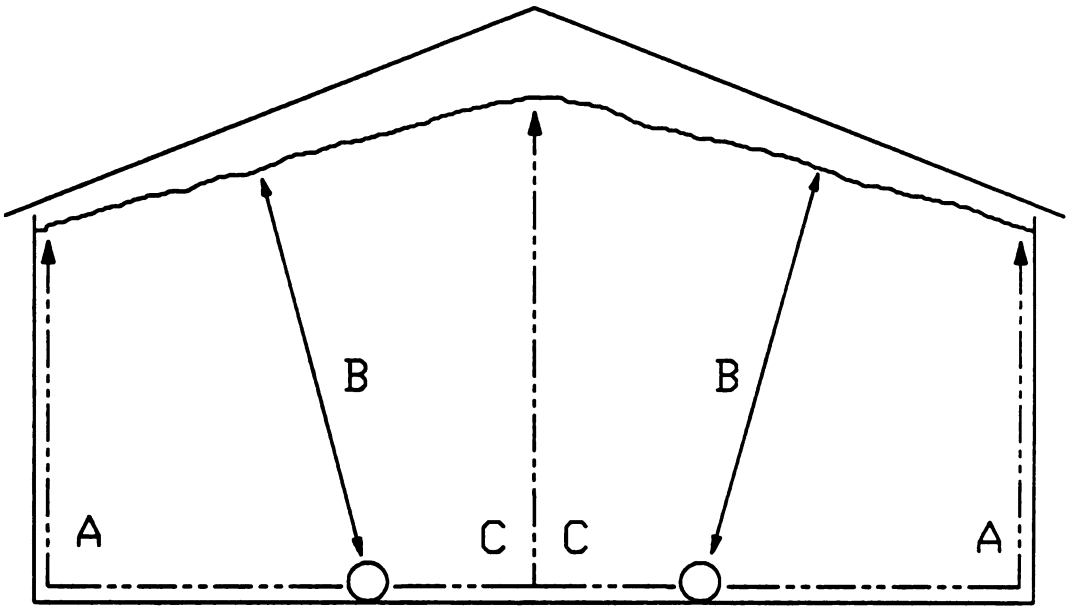

A -- air path from duct to grain surface along outside wall
B -- shortest distance or air path from duct to grain surface
C -- air path from duct to center grain surface

Air paths A and C are less than or equal to 1.5 * B

Figure 2. Cross section of grain storage with duct placement to achieve maximum air path ratio of 1.5.

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discussed in the previous section, the grain profile is determined by building dimensions, grain depth at walls, peak grain depth and angle of repose. Variations in duct spacing may be required to accommodate doorways, framing members and equipment limitations.

The principle for duct placement in flat storages is to maintain air paths through the grain as equal as possible, with no place where the air can 'short circuit' to the edge of the storage. The layout of a duct system becomes more important in flat storages, due to varying grain depths, compared to upright storages (Foster and Tuite, 1986). Holman (1960) noted that ducts must be carefully spaced since the amount of poorly aerated grain increases with an increase in distance between ducts.

The design procedure for placement of ducts in flat storages includes determining the location of ducts in the storage cross-section and the end points of the perforated ducts. Locating ducts in the storage cross-section (as described in the following sections), depends on whether the ducts are to be installed lengthwise or crosswise to the storage and whether the storage is level filled or peaked.

Level Filled Storages

In level filled storages, ducts should be placed as far apart as the grain is deep (Cloud and Morey, 1980; Foster and Tuite, 1986; Holman, 1960). The distance from the storage wall to the nearest duct should not exceed one-half the grain depth (Foster and Tuite, 1986). This design guideline for level filled storages results in an air path ratio of 1.5:1.

These guidelines for level filled storages apply regardless of whether the ducts run lengthwise or crosswise. Generally, running ducts lengthwise reduces the number of ducts and fans required for an aeration system. Duct systems

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designed for level loaded storages are seldom adequate for peak loaded storages.

Peak Loaded Storages

General guidelines for peak loaded flat storages with lengthwise ducts dictate that the air path ratio should not exceed 1.5:1 (Cloud and Morey, 1980; Foster and Tuite, 1986; Holman, 1960; MWPS, 1987) and the distance between ducts should not exceed the average grain depth (Brook and Harmsen, 1982; MWPS, 1987; Peterson, 1985). Burrell (1974) reported that air path ratios of 1.8:1 were satisfactory and that ratios as high as 2.7:1 had been reported to achieve adequate cooling in shallow level loaded stores in the United Kingdom. Burrell (1974) considered a ratio of 2:1 adequate for small stores where grain depth on side walls is 1.5 m (5 ft) or less.

Besides the general guidelines, Holman (1960) reported that performance has been satisfactory with one lengthwise duct in storages up to 12.2 m (40 ft) wide and grain 3.7 to 4.6 m (12 to 15 ft) deep. Recommendations for storages less than 12.2 m (40 ft) wide are one lengthwise duct in the center of the storage (Cloud and Morey, 1980; Foster and Tuite, 1986; MWPS, 1987; Peterson, 1985). These guidelines, which conflict with the previously stated general guidelines of maintaining an air path ratio of 1.5:1, were adopted to economize equipment costs in aeration systems.

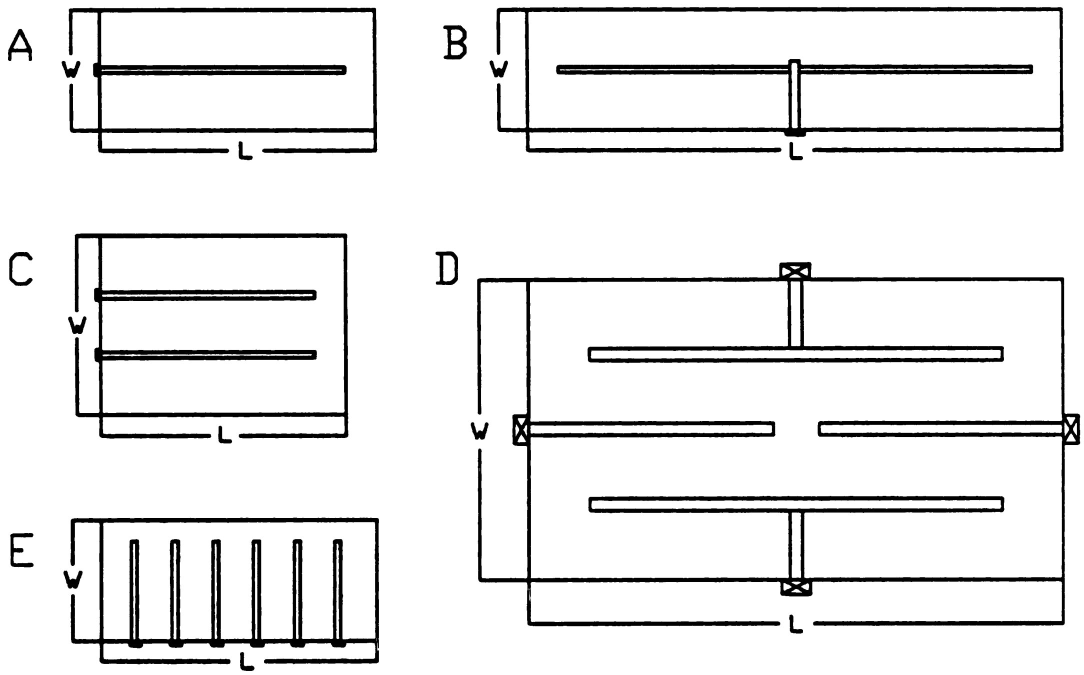
The maximum length of duct allowable from a fan is a limitation in aeration system design. Recommendations range from 22.9 m (75 ft) (Holman, 1960) to 24.4 m (80 ft) (Cloud and Morey, 1980; MWPS, 1987) to 30.5 m (100 ft) (Foster and Tuite, 1986). For plastic ducts Brook (1983) recommended a maximum length of 18.3 m (60 ft).

Widthwise ducts in peaked grain storages generally should not be spaced wider than the least depth of grain (Holman, 1960). Holman (1960) suggested that when a large difference exists between the grain depth at the wall and at the peak, some deviation from this recommendation may be warranted to hold the cost of the duct system to a practical limit. Too much deviation, however, can result in considerable additional hours of fan operation to completely aerate the grain receiving the lowest airflow. Cloud and Morey (1980), Foster and Tuite (1986), Holman (1960) and MWPS (1987) recommended that widthwise ducts spacing be equal to average grain depth.

Specific recommendations for duct placement in flat storages by Cloud and Morey (1980), Foster and Tuite (1986), Holman (1960) and Midwest Plan Service (1987) are depicted in Figure 3. These recommendations are somewhat vague. Although ranges of storage width and length dimensions are given, no range of suitable grain depths on walls or at the peak are given. Storage profiles with shallow grain depths at walls will result in air path ratios exceeding 2:1.

Duct End Points

In flat storages, the perforated aeration duct usually does not start at the end of the storage, but is offset into the grain profile. Air paths through grain should be as equal as possible with no place where the air can 'short circuit' to the storage surface (Foster and Tuite, 1986). Burrell (1974) recommended the distance of the perforated duct from the end of the storage plus the grain depth at the end be equal to the longest air path elsewhere in the storage. Peterson (1985) suggested that the perforated duct should generally be the same distance from the end of the storage as the first duct is from the side of the storage.



Recommended width (W) and length (L) of storages is as follows:

In A:	W = up to12.2 m (40 ft)	(Cloud and Morey, 1980; Foster and Tuite, 1986; MWPS, 1987)
	L = up to 24.4 m (80 ft)	(Cloud and Morey, 1980; MWPS, 1987)
	30.5 m (100 ft)	(Foster and Tuite, 1986)
In B:	W = up to 12.2 m (40 ft)	(Cloud and Morey, 1980; MWPS, 1987)
	L = up to 53.3 m (175 ft)	(Cloud and Morey, 1980; MWPS, 1987)
In C:	W = 12.2 to18.3 m (40 to 60 ft)	(Cloud and Morey, 1980; MWPS, 1987)
	L = 24.4 m (80 ft)	(Cloud and Morey, 1980; MWPS, 1987)
In D:	W = 21.3 to 30.5 m (70 to 100ft)	(Holman, 1960)
	up to 36.6 m (120 ft)	(Foster and Tuite, 1986)
	L = up to 53.3 m (175 ft)	(Foster and Tuite, 1986; Holman, 1960)
In E:	W = up to 24.4 m (80 ft)	(Cloud and Morey, 1980; MWPS, 1987)
	up to 30.5 m (100 ft)	(Foster and Tuite, 1986)
	L = up to 24.4 m (80 ft)	(Cloud and Morey, 1980; MWPS, 1987)
	up to 30.5 m (100 ft)	(Foster and Tuite, 1986)

Figure 3. Aeration duct arrangements for flat storages recommended by Cloud and Morey (1980), Foster and Tuite (1986), Holman (1960) and Midwest Plan Service (1987).

FAN SIZING

Fan sizing is based on the volume of air required for a duct and the static pressure. Static pressure in an aeration system is a measure of the power required from a fan to force air against frictional resistance caused by ducts and grain and is usually measured in kPa (in. H_2O) (Brook, 1979). Static pressure increases with increasing grain depths and increasing airflow rates and varies with grain type, concentration of fines and bin filling method (MWPS 1987). Airflow delivered by a fan decreases as static pressure increases.

Airflow required for each duct is calculated by multiplying the volume of grain aerated by the duct times the desired airflow per unit. For example, if the volume aerated by a duct equals 176 m^3 (5,000 bu) and the desired airflow rate is 0.08 $m^3/min/m^3$ (0.1 $ft^3/min/bu$), then the airflow required is 14.2 m^3/min (500 ft^3/min). Static pressure is estimated on the basis of grain type and grain depth.

The airflow resistance equation in the American Society of Agricultural Engineers standard D272.1 (ASAE, 1987) is:

$$\frac{\Delta P}{L} = \frac{a\,Q^2}{\log_e (1+bQ)} \qquad (1)$$

where: ΔP = pressure, Pa (in. H_2O)
L = bed depth, m (ft)
a = constant for particular grain
Q = airflow rate, $m^3/s \cdot m^2$ ($ft^3/min/ft^2$)
b = constant for particular grain

The constants a and b used in the airflow equation for selected grains are listed in Table 2.

Table 2. Values for constants a and b used in airflow resistance equation.[1]

Grain	Value of a Pa s^2m^3	Value of b m^2s/m^3	Value of a in. H_2O min^2/ft^3	Value of b $ft^2/ft^3/min$
Shelled corn	2.07×10^4	30.4	6.54×10^{-4}	15.44×10^{-2}
Soybeans	1.02×10^4	16.0	3.22×10^{-4}	8.13×10^{-2}
Wheat	2.70×10^4	8.77	8.53×10^{-4}	4.46×10^{-2}
Sorghum	2.12×10^4	8.06	6.70×10^{-4}	4.09×10^{-2}

[1]American Society of Agricultural Engineers data: D272.1 (ASAE, 1987).

This equation is suitable for estimating static pressure through clean, dry, loose-fill grain. In practice, static pressures are further increased to compensate for pressure losses in ducts, fines, and packing (Brook, 1979; Foster and Tuite, 1986; Holman, 1960). Holman (1960) compensated for packed fill by increasing static pressures by 30 percent for corn and wheat; 40 percent for grain sorghum, rice and soybeans; and 50 percent for oats. Holman (1960) increased static pressures by another 20 percent to compensate for pressure loss through supply pipes, ducts and surrounding grain. Typically, static pressure for clean, loose grain is calculated and then increased by a factor specific to each grain. Midwest Plan Service (1987) listed the following factors for adjusting static pressure determined by the airflow resistance equation (1) to reflect field conditions: 1.5 for shelled corn, 1.3 for soybeans, 1.3 for wheat and 1.5 for grain sorghum.

Once the required airflow and estimated static pressure are known, the power requirement of a fan can be calculated in traditional units as follows, assuming an installed static efficiency of 47 percent (Foster and Tuite, 1986; Holman, 1960):

Fan HP = airflow, ft^3/min * static pressure, in. H_2O / 3,000 (2)

Manufacturers' fan specification charts should be consulted to select a fan. Required airflow at a static pressure must be known and the estimated fan horsepower can be used as a starting point. Brook and Harmsen (1982) used manufacturer's fan performance charts to generate 'A' and 'B' values for fans. These values were used in a computer program to estimate fan airflow (in traditional units) given a static pressure. The equation is:

Airflow, ft^3/min = A - B * (static pressure, in. $H_2O)^2$ (3)

DUCT SIZING

After the actual airflow to be delivered to a duct is known, the duct can be sized. The important dimensions of a duct are (1) the cross-sectional area, which influences air velocity within a duct and (2) perforated surface area, which affects velocity of air exiting a duct (Cloud and Morey, 1980; Holman, 1960).

Diameter

Duct diameter is determined by required duct cross-sectional area. Midwest Plan Service (1987) stated that a duct cross-sectional area should be large enough to insure that static pressure and air velocity are not excessive. High air velocities increase fan power requirements and can cause non-uniform airflow from the duct (MWPS, 1987).

Duct diameter is therefore based on allowable air velocity within the duct. Maximum recommended air velocities in ducts for flat storages with suction systems, as given by Holman (1960) (in traditional units), are listed in Table 3.

Table 3. Recommended maximum allowable air velocities within ducts installed in flat storages with suction system aeration.[1]

	Air velocity within ducts (ft/min) for various grain depths									
	corn, soybeans, large grains					wheat, grain sorghum, small grains				
ft³/min /bu	10 ft	20 ft	30 ft	40 ft	50 ft	10 ft	20 ft	30 ft	40 ft	50 ft
1/20	----	750	1000	1250	1250	----	1000	1500	1750	2000
1/10	750	1000	1250	1500	1750	750	1500	2000	----	----
1/5	1000	1250	----	----	----	1000	2000	----	----	----

[1]Calculated for suction systems with ducts up to 100 ft in length. Assumes duct with rough inner surface and corrugations or inside framing. Duct friction loss calculated using a roughness coefficient of 2.5; velocity head loss equal to 1.7 hv (Shove, 1959).

Grain type, depths and airflow rates were considered in the development of this table. With long ducts in flat storages it is beneficial to make the fan connection near the mid-point of the duct (Holman, 1960). This permits a 50 percent reduction in the cross-sectional area of a duct.

Other sources recommended one value or a range of values for the maximum airflow. The recommendations are summarized in Table 4.

Table 4. Recommendations for maximum airflow velocity in ducts.

Velocity m/min (ft/min)	Source	Restrictions
457 (1500)	Brook 1979; MWPS 1987	
457 (1500)	Cloud and Morey 1980	open flow areas
610 (2000)	Cloud and Morey 1980	lengths up to 9 m (30 ft) in bins deeper than 4.3 m (14 ft)
305-457 (1000-1500)	Noyes 1967	lengths 7.6-18.3 m (25-60 ft)
457-610 (1500-2000)	Noyes 1967	lengths up to 7.6 m (25 ft)
457-610 (1500-2000)	McKenzie 1978	

Midwest Plan Service (1987) listed the maximum design velocity for plastic ducts at 457 m/min (1500 ft/min).

The equation commonly used for determining the required cross sectional area of a duct is (Brook, 1979; Cloud and Morey, 1980; Holman, 1960; McKenzie, 1978; MWPS, 1986; Noyes, 1967):

$$\text{cross-sectional area, } m^2\ (ft^2) = \text{airflow, } m^3/min\ (ft^3/min)\ /\ \text{design air velocity, } m/min\ (ft/min) \qquad (4)$$

Length

Minimum duct length is determined by the required duct surface area. There must be enough perforated area to insure that air leaving the duct is not constricted nor the velocity too high. The effective surface area of a round duct is reduced by 20 percent due to contact with the floor (Foster and Tuite, 1986; Holman, 1960).

Required duct surface area is determined based on the maximum airflow velocity at the duct surface. Various recommendations for airflow velocity at the duct surface are summarized in Table 5.

Table 5. Recommendations for maximum airflow velocity at duct surface.

Velocity m/min (ft/min)	Source
6.1 (20)	Holman 1960
7.6 (25)	Cloud and Morey 1980
9.1 (30)	Brook 1979; Foster and Tuite 1986; MWPS 1987
7.6-9.1 (25-30)	McKenzie 1978; Noyes 1979

Duct surface area requirement is commonly calculated as follows (Brook, 1979; Cloud and Morey, 1980; Holman, 1960; McKenzie, 1978; Noyes, 1967):

duct surface area, m^2 (ft^2) = airflow, m^3/min (ft^3/min) / duct surface velocity, m/min (ft/min) (5)

SUPPLY TUBE SIZING

Supply tubes are ducts without perforations. Supply tubes are required to connect fans to perforated ducts. The factor for sizing supply tubes is the maximum allowable airflow velocity in ducts. Foster and Tuite (1986) suggested a design airflow of 457 to 762 m/min (1500 to 2500 ft/min), with velocities above 610 m/min (2000 ft/min) for deep bins or short duct lengths. Holman (1960) also limited airflow velocity to 762 m/min (2500 ft/min) with a recommended range of 457 to 610 m/min (1500 to 2000 ft/min). Equation 4 is used to determine the minimum cross sectional area of a supply tube.

EXHAUST AREA SIZING

An air exchange opening must be provided in the storage structure for intake (suction systems) or exhaust (pressure systems) air. Midwest Plan Service (1987) recommended at least 0.09 m^2 (1 ft^2) of opening in the roof or eaves for each 28.3 m^3/min (1,000 ft^3/min) of airflow. This allows air to exit at a velocity of 305 m/min (1,000 ft/min).

The previously discussed recommendations are required to design an aeration system. The aeration system design program described in Chapter IV incorporates these guidelines into the placement and sizing calculations.

CHAPTER III

DEVELOPMENT SYSTEM FOR AGRICULTURAL DESIGN PROGRAMS

Computer graphics technology has provided tools for computer programs to display information in graphic form. This technology is currently available on microcomputers and can be utilized for development of computer programs. Advantages of graphic display for agricultural engineering design applications are two-fold. First, illustrations can expedite information conveyance when a new concept is being described to a user or a choice involving unfamiliar terminology is requested. Second, design drawings can be presented.

This chapter presents a development system for agricultural engineering application programs. Discussion of the system includes components of the problem-solving process for agricultural engineering design problems and the software tools used to implement each component. Concepts for this development system were previously presented (Watson et al., 1986).

COMPONENTS OF DEVELOPMENT SYSTEM

A system for developing agricultural engineering design programs should represent the problem-solving process used in design problems. The solution to design problems is a design drawing with specifications and related recommendations. Some aspects of the design drawing are predetermined, while others must be obtained by querying the client or through calculations.

The interactive process with a client begins by asking questions. When sufficient information has been acquired, calculations are performed, a design drawing with specifications is rendered and recommendations are made. The design expert controls the progression of these steps and may reiterate them to test alternatives.

A computer program to simulate the role of an expert in an interactive session with a client should include five basic components. These components, and their purposes are

-- **interview** -- questions the client to obtain information about the design problem and educates client as needed.

-- **calculations** -- utilizes problem information obtained from the interview session to determine appropriate size and component characteristics for the design drawing.

-- **design drawing** -- utilizes size and component calculations to generate a customized plan with specifications to meet the client's needs.

-- **management recommendations** -- prescribes appropriate recommendations for successful implementation and usage of customized design.

-- **framework** -- controls operation of the interview, calculations, design drawing and management recommendations components.

INTERVIEW

An interactive computer application, by definition, requires input from a client. Clients are prompted with a question and requested to respond with an appropriate answer. This process is referred to as the interview. The purposes of the interview process are

-- to display questions and educational information to a client.

-- to control the order of questions and educational information presented to a client.

-- to receive client responses and check for reasonable values.

Computer graphics are an important part of the interview process just as visual aids are important tools of an expert when working with a client. A computer directed interview session can incorporate graphics by displaying

-- drawings and illustrations developed with graphics software.

-- video tape and video disc stills and sequences.

-- images captured from a video camera or video tape.

One or more of these methods are suitable for design programs.

Many questions asked of a client benefit from graphic representation. An example from a dairy free-stall barn design application illustrates this point (Figure 4). A client has the option of choosing among wood, suspended, and MSU suspended free stall partitions. Drawings minimize the amount of text needed to communicate clearly with a client.

CALCULATIONS

Engineering problems often require calculations to reach a solution. The goal of the calculations component is to complete all calculations necessary for a design problem. The purposes of the calculations component are

-- to read client responses and reference data from a data file.

-- to perform all calculations necessary to complete the design process.

-- to store the calculated results in a data file for use by the other components of the development system.

The calculations component comprises calculations for all possible entities of a design. Some calculations may be used several times when the finished plan consists of several of the same entities. For example, an aeration system plan

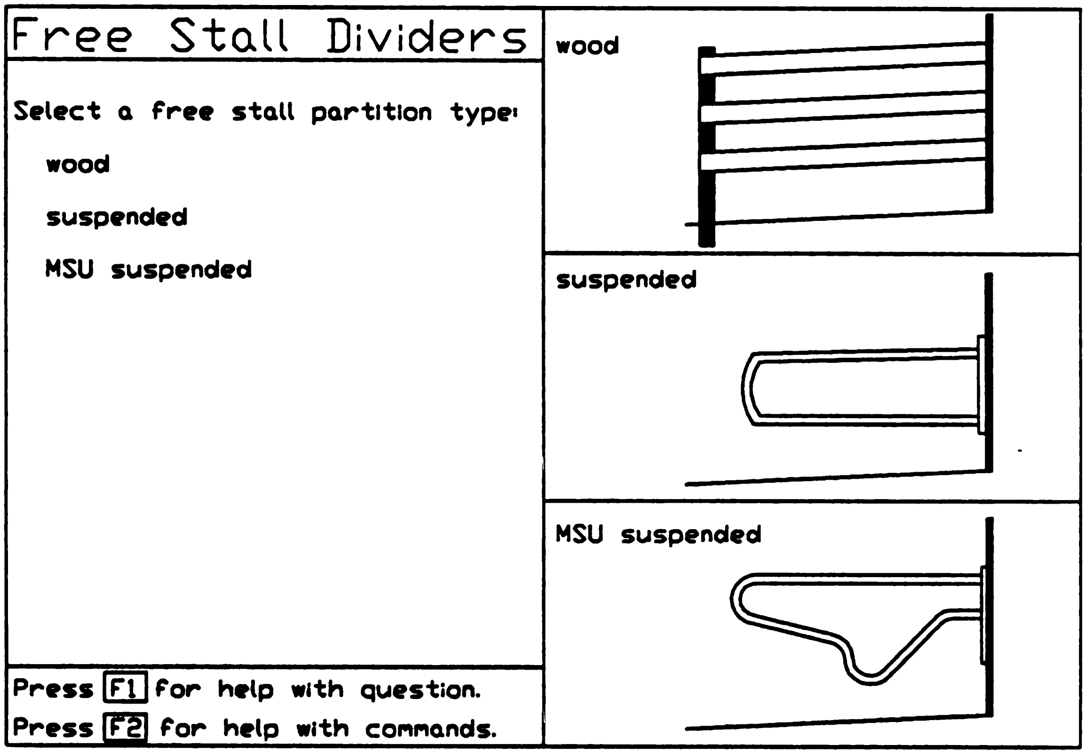


Figure 4. Sample question from interview component, illustrating the necessity of graphics to communicate effectively with a client.

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may consist of 1, 3, or 9 ducts. The same duct sizing calculations are performed to size each duct.

The calculations component may be a program that is separate from the other components. The calculation program must adhere to the data exchange procedure defined by the framework component. The developer can define any practical data organization within the calculations program as long as the program can read and write a data file in the format specified by the framework component.

For example, as part of an aeration system design program, the peak grain depth is calculated. After the interview component acquires storage dimensions, grain depth at side walls and angle of repose information, a data file is written containing the client responses and the framework executes the calculations program. The calculations component executes three functions. First, client responses from the interview session are read from the data file. Second, the calculations are performed. Third, the resulting value for peak grain depth is written in an output data file for use by the other components. When the calculations component terminates, the framework component reads the calculations output data file and passes the value for peak grain depth data to the interview component for display.

DESIGN DRAWING

Once the calculations to size components have been completed, a drawing of the customized design is generated for the client. The role of the design drawing component is to generate a unique plan based on client-specified and calculated values. The application developer must be able prepare a generic design drawing that can be customized to meet a wide range of client needs. This is accomplished with a parametric computer aided drafting processor which allows a developer to

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-- use variable quantities to define lines, circles and arcs which are the primitives of a drawing.

-- use the elements to draw any entities which may be needed to produce a unique plan.

-- determine which components are needed in a specific plan.

-- assign client-specified and calculated values to variable quantities of the primitives of each entity.

-- place the entity drawings in the plan.

-- provide a paper copy of the final plan.

During application development, the design entities are drawn with variables representing dimensions that the developer may need to change for a custom design. During execution of the application program, the design drawing component uses available data to assign values to the custom drawing and displays the drawing.

Design problems typically consist of common elements, even though many possible variations exist. For example, design of an aeration system involves ducts. Diameters and lengths of ducts vary with the required grain storage profile. A parametric duct drawing for a plan view could simply be a rectangle. The width and length of the rectangle are assigned variable names. During execution of the application, the required duct diameter and length are calculated. The design drawing component reads the diameter and length values, assigns the values to the variables, and displays the plan view of the duct with dimensions. Although, this is a simple example, complex drawing can be broken into entities and blocks in a similar manner to generate custom drawings (Figure 5).

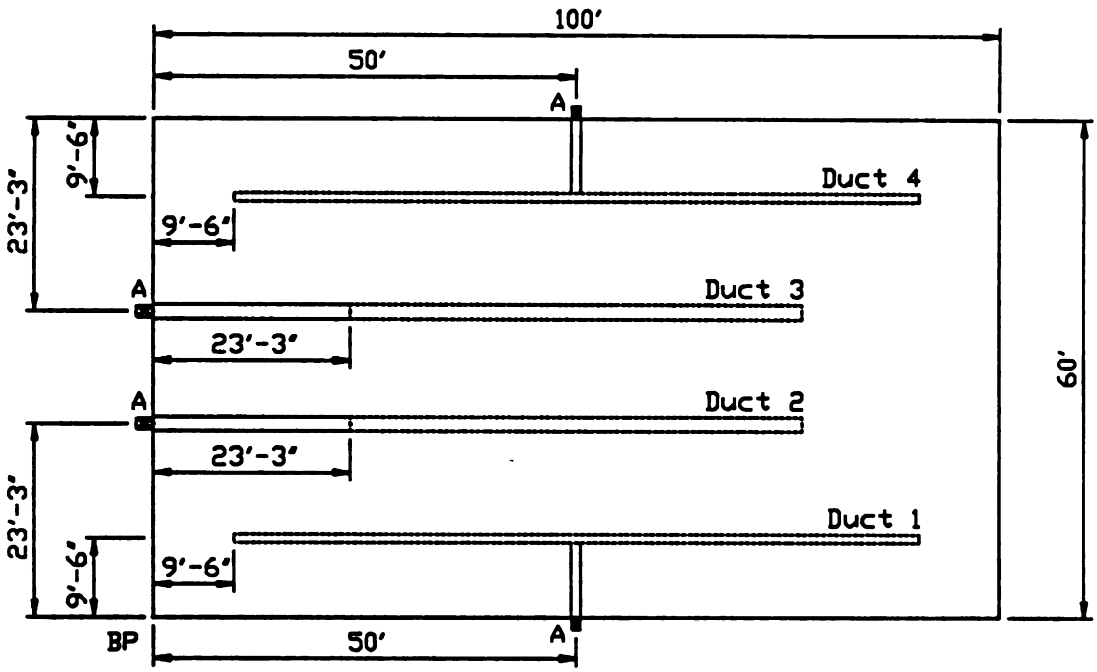


Figure 5. Sample customized plan view drawing of an aeration system, representing a design drawing to be provided to a client.

MANAGEMENT RECOMMENDATIONS

An expert's work is not complete once a customized drawing is prepared, but also includes providing the client with a set of management recommendations relative to the design. In fact, effective communication of management recommendations is often critical to successful implementation and usage of a new design. Management recommendations are often dependent upon specific options employed in a customized design. The roles of the management recommendations processor are

-- to process management recommendation rules to determine which recommendations are relevant to client responses and design decisions.

-- to prepare paper copy of the management recommendations.

For example, a client might request assistance with an aeration system for an existing building. The aeration system expert recommends placing a vapor barrier on the floor of existing buildings and under the concrete for new buildings. The appropriate recommendation should be printed for the client (in this case, putting a vapor barrier on the floor). Questions such as "How often should I run the fans?" and, "How do I know the grain is cool enough?" should be either in the recommendations list or a reference should be provided to an appropriate source.

In a thoroughly developed application, many of the management recommendations may already be incorporated into the educational material of the interview. The recommendations should still be prepared in printed form for the client to take home. This is a crucial point for computer based applications and can prevent problems during implementation and usage of the design. When a question arises, a client can refer to his files for the pertinent recommendation instead of relying on his judgment until an expert is available for consultation.

The amount and content of management recommendations should be tailored to the general needs of the client group. Generally, the least common denominator of client knowledge should be the guiding factor.

FRAMEWORK

The fifth component is needed to supervise interaction with a client. A client should not interact with each of the other four components independently. The supervising component is referred to as the framework. The roles of the framework are

- -- to tie the independent components together into a cohesive application, from a client's perspective.
- -- to manage data exchange among the components.
- -- to provide supplemental flow control during the interview.
- -- to activate the calculations component.
- -- to supervise operation of the design drawing process.
- -- to activate the management recommendations component.
- -- to facilitate client 'what-if' scenarios.

For example, a simple application to determine the profile of a grain storage requires a framework to activate the components. First, the interview is initiated to request length, width and depth values. Second, the calculations process is performed to calculate the grain depth at pertinent points. Third, the design drawing processor is called to display a grain profile drawing with dimensions. Fourth, the management recommendations process is initiated to search for and print pertinent recommendations. Once these processes are complete, the framework offers the client an opportunity to change values and reinitiate the same processing sequence.

Each software product which comprises a component is used for application development. A client interacts with an application via the framework and execution of other software products is transparent (Figure 6).

The selected method of implementing the framework component was to make it an integral part of the interview component. By definition, the framework controls the interaction of the client with the other components. Since the interview component requires the most interaction, integrating the interview and framework components was a logical step. The framework consists of additional capabilities added to the interview processor and a set of guidelines for data exchange among the components.

SOFTWARE TOOLS FOR DEVELOPMENT SYSTEM

Various software tools are currently available to implement each component of the development system. In this section the types of software tools available to implement each component and the tools used in the aeration system design program are discussed.

The set of software tools synthesized for developing the aeration system design application included commercial software and software developed in the Interactive Computer Graphics Laboratory of the Agricultural Engineering Department at Michigan State University. Documentation of the commercial software is available from the manufacturers. The Interactive Computer Graphics Laboratory maintains documentation of software developed in that facility and instructions for developing other engineering design applications with the same set of software tools.

New versions of software tools are being developed which will better facilitate the use of computer graphics. These new tools will serve to simplify a program

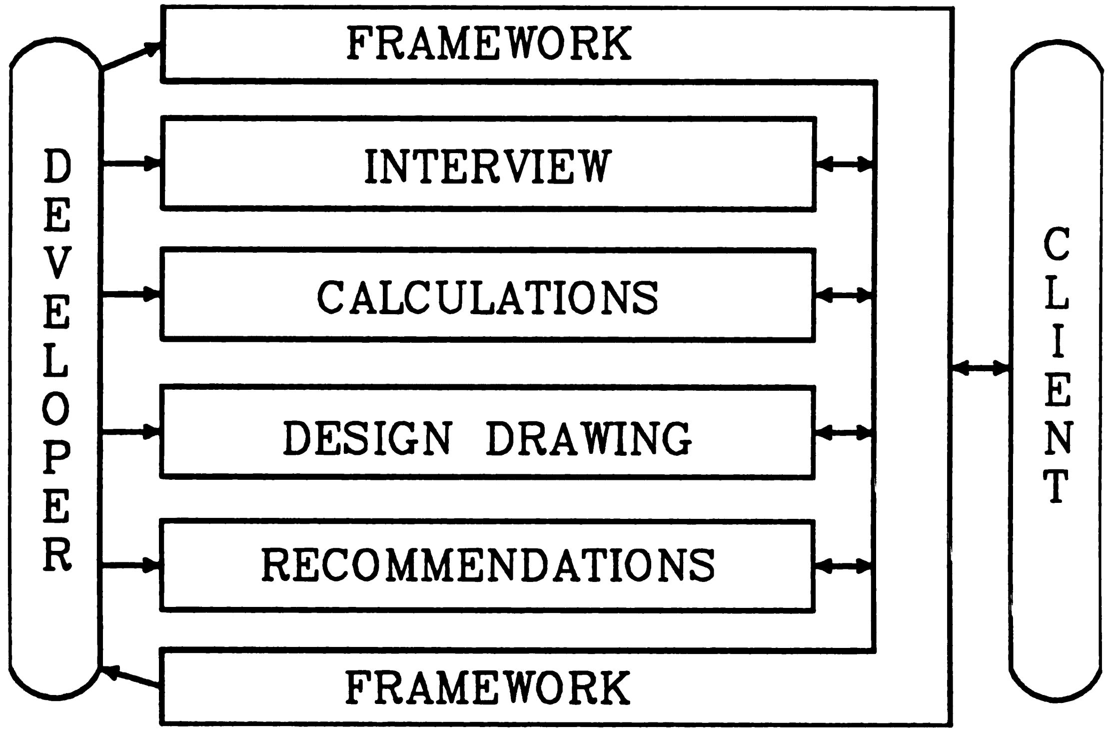


Figure 6. Conceptual relationship of program developer and client with the development system software components.

development process. Due to the modular design of the software system, new software tools can be utilized without redoing an entire application.

INTERVIEW

The interview session should be tailored to a client group. Generally, as the experience level of the client group increases, fewer graphics are needed to supplement information transfer during an interview.

Many commercial software products are available for implementation of an interview session. Computer-aided instruction or authoring programs fulfill the basic roles of the interview component and facilitate display of graphical images and control of video tape or disc. Incorporation of captured video images and high-resolution painted images requires specialized software routines. Manufacturers of image capture adapters for microcomputers typically provide software tools for their products. These software routines can be used to display video images which are stored on magnetic media. Other products allow a developer to design interview screens and generate source code in one or more common computer languages. This source code can be incorporated into a program.

A computer program referred to as the interview processor was written in the 'C' programming languages to meet the requirements of the interview component. Existing computer aided instruction programs did not provide capabilities of simultaneously displaying video quality images and text. The interview processor provides a standard user interface for all applications developed with it and greatly reduces the amount of computer programming by an application developer. The organization of information on the display screen is controlled by the interview processor, and the developer determines the text and graphical images to be displayed.

The interview component of the aeration system design application was implemented by preparing an ASCII (American Standard Code for Information Interchange) file which defined each item to be displayed on the screen, including the title, question, prompts, text, names by which to reference responses, default values, range limits of responses, graphic images and the next screen for display.

Two 'C' functions were written to provide additional features needed by the framework (see Appendices B and C). One function performed consistency checks to verify that a response was consistent with previous responses. The second function provided capabilities of running external programs before exiting a screen. This latter function was used to execute the calculations, design drawings, and management recommendations components.

CALCULATIONS

The calculations component could be a stand-alone program that reads and writes input and output data via data files. In most cases, the calculations component must be coded by the developer. Any programming language which can produce an executable file can be used, allowing the developer to work with a familiar language.

The calculations for the aeration system design application were coded in the 'C' programming languages. The code was compiled with a commercial 'C' compiler for microcomputers. The calculation module was linked with the interview processor to produce one program. The details of the calculations algorithms and procedures are in Chapter IV.

DESIGN DRAWING

Parametric computer-aided drafting (CAD) programs have existed on mainframes and specialized computer systems for several years. At this time, very few products exist to do this type of work on microcomputers. AutoCAD, a commercial (CAD) program, and Synthesis, a commercial parametric CAD extension for AutoCAD, when used together, bring many features of parametric CAD to microcomputers (Figure 7).

Following the aeration system example, the program developer uses AutoCAD to draw aeration system components (called master drawing files in Figure 7). Variable dimensions are added and assigned variable names. During initial processing of the design drawing component, a specification file must be written or updated. (A developer-written program must perform this task.) The specification file contains drawing file names of entities and values assigned to variables. Synthesis is invoked and processes the specification file to define the customized drawing. The customized drawing is routed to AutoCAD for display and paper copy.

Carroll, Peterson and Watson (1987) described the procedure for using AutoCAD and Synthesis in an aeration system design application. Detailed documentation of the features and usage of AutoCAD and Synthesis may be found in the respective user's manuals.

Development of the design drawing component of the aeration system design program consisted of drawing the master drawing files for each component and writing a program which creates a specification file for Synthesis to use in preparing the custom drawing. The master component drawings were drawn with AutoCAD using the Synthesis command set. The program which writes the specification file for Synthesis takes into account each possible arrangement of the components.

MANAGEMENT RECOMMENDATIONS

Searching for and printing management recommendations can be accomplished with a data base query routine or an expert system. A data base

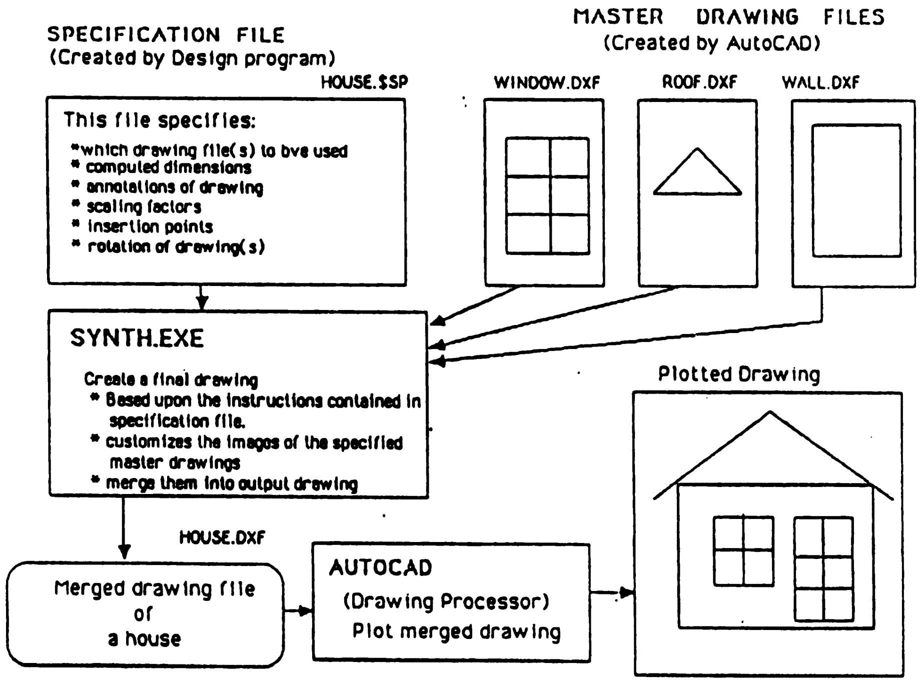


Figure 7. Functional description of Synthesis and AutoCAD usage to produce a parameterized design drawing.
Copied with permission. (c) 1985, TransformerCAD, Bellingham, WA.

of management recommendation files can be established corresponding to available client responses. A data base query routine would search the data base for recommendations which match client responses and prepare a paper copy. An expert system of possible management recommendations can be developed and initiated by supplying the list of client responses.

The management recommendations component was implemented with a relatively simple data base technique. An application developer must prepare a file of all possible management recommendations. The file may be written with any commercial product that will write an ASCII file. The file must contain a specified set of character sequences to identify the separate recommendations.

A program was written to process the file of management recommendation text into a 'keyed' data file of specific format. Information at the beginning of the file relates each management recommendation to a file location for random access file processing.

The keyed data file is used by a program called the recommendations processor. The recommendations processor is written in the 'C' programming language. For the aeration system design application a 'C' function was written to use data from the interview processor and calculations component to determine which recommendations to print. The recommendations processor inserts actual values in the place of variable names when printing the recommendations.

FRAMEWORK

The framework's primary function is to provide logical flow control for an application. Various levels of programming tools can be used to accomplish this task. In some cases, a batch command file may be sufficient. Any programming language which allows execution of external programs with control returning to the original program will work. Expert system development tools which can activate external programs to provide information or accomplish goals are another alternative.

The framework was implemented as an integral part of the interview component. The interview processor was enhanced to allow execution of external programs. Data is transferred to and retrieved from an external program by a data file. The format of the data file is documented by the Interactive Computer Graphics Laboratory and any external program may access the data by interpreting the file correctly. The implementation of the framework allows program users to try one set of input data and then to change one or more data items to determine the effect upon the design.

CHAPTER IV

AERATION SYSTEM DESIGN PROGRAM

An aeration system design application was developed using the development system described in Chapter III. Aeration system design is a good example of an agricultural engineering problem that is encountered by field staff of the extension service but is usually referred to the state specialist. The process of designing an aeration system can take several hours as similar calculations may be performed many times before a suitable design is achieved. The aeration system design program described in this chapter eliminates the need for time-consuming calculations for most farm-sized grain storages.

The aeration system design program is intended for use by aeration system experts in designing systems for farm-sized grain storages. The description of the aeration system design program is divided into the four components of interview, calculations, design drawing and management recommendations.

INTERVIEW

The interview component of the aeration system design program consists of 15 main screens which request information about the design problem. These screens with their titles and descriptions are listed in Table 6. Besides information required to size and place aeration equipment, information about the structure is requested to verify post size requirements for the user's storage structure. Appendix A is a listing of the interview text file which the interview processor uses to display the screens.

Table 6. Response screens for aeration system design program.

#	Screen Title	Description
1	client information	name and address information for contacting person for whom the design is prepared
2	grain type	grain to be stored: shelled corn, soybeans, wheat or grain sorghum
3	new structure	new structure for storage (yes or no) used for making recommendations
4	construction type	post-frame construction (yes or no), if yes post size is calculated
5	post-spacing	If post-frame construction, used to calculate post size
6	structure liner	asks if information needed on grain liners, if yes, a source of plans is provided
7	storage size	length and width of storage
8	grain depth on walls	grain depth may be entered for each of 4 walls
9	maximum piling height	limiting height for piling grain used to calculate peak grain depth
10	number of ducts	may be computer selected or user selected
11	duct type	duct type used: plastic aeration, spiral-lok metal, round metal or half-round metal
12	duct direction	lengthwise or widthwise duct placement
13	fan type	axial or centrifugal fans
14	fan arrangement	fan placement options; end, middle or combination of end and middle of duct
15	airflow rate	aeration airflow rate

The screens are presented to the user in the same order as they appear in Table 6 except as described below. If the response to screen four is a non-post frame building then screen five is not displayed. If the response to screen four is a post frame building then a screen is displayed after screen eight which gives the minimum post size for the storage structure. After screen nine, a screen is displayed which lists the capacity and peak height of the grain in the storage. If the response to screen ten is 'user selected' number of ducts then an additional screen is displayed which asks how many ducts to use.

After screen fifteen, the main calculations are performed and a screen is displayed listing the number of ducts used in the design or describing an error condition that prevented completion of a satisfactory design. If the calculations were successful the next screen displays the design drawing. The design drawing is printed and the following screen asks if the user is ready for the management recommendations. If the user responds affirmatively, the management recommendations are printed and the final screen gives instructions about quitting the program or changing responses. The user can terminate the program or return to previous screens to change responses and generate a different design.

A graphic illustration is displayed with each response screen. The graphics are based on line drawing and digitized slides. The illustrations were prepared using a commercial software program called 'ICBTIPS' (AT&T, 1985) which was obtained from AT&T for use with their image capture video board. Each illustration was developed to convey additional information about the response screen with which it was displayed.

As discussed in Chapter III, two functions were written to provide the additional features needed by the framework. These functions are specific to the aeration system design application. One function is used to to verify that a user's response is consistent with previous responses (see Appendix B for source code). Consistency checks are initiated when the user completes a screen. If an inconsistency occurs, a message is displayed to the user and the user is prevented from moving forward until the inconsistency is corrected.

Table 7 describes the consistency checks for the aeration system design program.

Table 7. Consistency checks for aeration system design program.

#	Screen Title	Consistency Check
7	storage size	storage width must not be greater than storage length
8	grain depth on walls	grain depth at the lower side (end) wall must not be greater than the higher side (end) wall
9	maximum piling height	grain depth at the higher side or end wall must not be greater than maximum piling height

The second function was written to provide supplemental flow control for the application. This function is used if the next screen to be displayed can vary or if a special procedure (such as calculations) is needed (see Appendix C for source code). Table 8 describes the use of this function.

Table 8. Supplemental flow control for aeration system design program.

#	Screen Title	Description of supplemental flow control
8	grain depth on walls	if not post-frame construction display screen 9. If post-frame construction run post sizing calculation and display screen listing post size or warning if the largest post size is not suitable.
9	maximum piling height	run storage capacity calculation and display results or message that storage is too small for program to design an aeration system.
10	number of ducts	if 'computer selected' is the response set desired number of ducts to zero
15	airflow rate	run component placement and sizing calculations and display number of ducts used or error message run design drawing processor run management recommendations processor

CALCULATIONS

The calculations component of the aeration system design program contains all of the calculations necessary to specify a customized aeration system for a grain storage. Results of the calculations module are used in the design drawing processor to define dimensions of the parametric drawing and in the recommendations module to describe the storage and aeration equipment.

The calculations module begins processing with the assumption that all necessary information about the client's grain storage is available and valid. All checks for valid responses must be performed before the calculations module is executed.

The aeration system design procedure described by Holman (1960) is employed. For program development and description, the calculations module was divided into the following seven procedures:

post sizing
storage capacity
duct placement
duct length
fan placement and size
duct size
connector placement and size

POST SIZING

Post size does not affect the design of an aeration system, but is calculated to assist the program user in determining the allowable grain depth on the side walls of the storage structure. Post size is determined based on post spacing and the highest grain depth on a wall. Post size, spacing and allowable grain depth data from Irish et al. (1984) is used to find the minimum post size (Table 9).

Table 9. Allowable grain depth for post size and post spacing[1].

	Post Spacing on Centers			
Post Size cm (in.)	0.6 m (2 ft)	1.2 m (4 ft)	1.8 m (6 ft)	2.4 (8 ft)
20 x 20 (8 x 8)	-----------	3.2 m (10.6 ft)	2.8 m (9.2 ft)	2.6 m (8.4 ft)
15 x 20 (6 x 8)	3.7 m (12 ft)	2.9 m (9.5 ft)	2.5 m (8.3 ft)	2.3 m (7.5 ft)
15 x 15 (6 x 6)	3.0 m (9.7 ft)	2.3 m (7.7 ft)	2.1 m (6.8 ft)	1.9 m (6.1 ft)
10 x 15 (4 x 6)	2.6 m (8.4 ft)	2.0 m (6.6 ft)	1.8 m (5.8 ft)	1.6 m (5.3 ft)
10 x 10 (4 x 4)	2.2 m (7.1 ft)	1.7 m (5.6 ft)	1.5 m (4.9 ft)	1.4 m (4.5 ft)

[1]Post sizes listed are nominal. Allowable grain depth from posts of actual dimensions (e.g. allowable grain depth for 6 x 6 post from 5.5 x 5.5 post size listed by Irish et al.).

STORAGE CAPACITY

The first step in the aeration system design process is to determine the grain capacity of the storage. This procedure is executed during the interview component and the capacity is displayed to the user. If needed, the user can alter building dimensions and grain depths to arrive at the desired capacity. The storage capacity procedure performs the following calculations:

1) peak grain depth of storage
2) width and length of the peak grain depth
3) grain capacity of the storage

The peak grain depth calculation uses the storage dimensions and grain depth to calculate the maximum possible peak depth obtainable both widthwise and lengthwise in the storage. The potential peak grain depth widthwise in the storage is determined with the following equation:

$$D_{peak} = D_{hs} + \frac{W \tan\theta - |D_{hs} - D_{ls}|}{2} \qquad (6)$$

where: D_{peak} = peak grain depth, m (ft)
D_{hs} = grain depth at higher side wall, m (ft)
D_{ls} = grain depth at lower side wall, m (ft)
W = storage width, m (ft)
θ = angle of repose of grain, deg

The calculation for lengthwise peak grain depth exchanges side wall depths for end wall depths and storage width for storage length. The potential peak grain depths widthwise and lengthwise in the storage are compared to maximum piling height information provided by the client and the smallest of the three values is the peak grain depth of the storage.

The width and length of the peak grain depth is calculated for use in the storage volume and duct spacing calculations of the design process. The width of the peak grain depth is calculated as follows:

$$W_{peak} = W - 2 \frac{D_{peak}}{\tan\theta} + \frac{D_{ls} + D_{hs}}{\tan\theta} \qquad (7)$$

where: W_{peak} = width of peak grain depth, m (ft)
W = storage width, m (ft)
D_{peak} = peak grain depth, m (ft)
θ = angle of repose of grain, deg
D_{ls} = grain depth at lower side wall, m (ft)
D_{hs} = grain depth at higher side wall, m (ft)

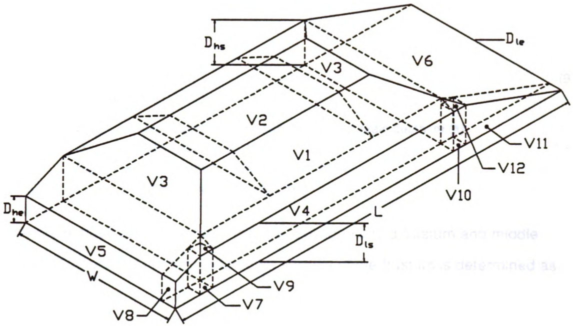
The calculation for length of peak grain depth exchanges side wall depths for end wall depths and storage width for storage length.

The capacity of a grain storage is calculated by dividing the storage into twelve volumes (Figure 8). This method is a refinement of the method suggested by Midwest Plan Service (1987) in which the grain storage is divided into three volumes. A storage profile with different grain depths on the walls requires this enhanced procedure to more accurately estimate storage capacity. The grain depth on the highest wall determines the perimeter for the base volume calculation. The length of the grain mass extension from the base volume to the lower side wall is calculated as follows:

$$L_{ls} = \frac{D_{hw} - D_{ls}}{\tan\theta} \qquad (8)$$

where: L_{ls} = length of lower side wall extension less than grain depth at highest wall, m (ft)
D_{hw} = grain depth at highest wall, m (ft)
D_{ls} = grain depth at lower side wall, m (ft)
θ = angle of repose of grain, deg

Grain depth at the lower side wall is replaced by the grain depth at the other two walls to determine the length from the base volume to the walls. The horizontal



W = storage width, m (ft)
L = storage length, m (ft)
D_{hs} = grain depth at higher side wall, m (ft)
D_{ls} = grain depth at lower side wall, m (ft)
D_{he} = grain depth at higher end wall, m (ft)
D_{le} = grain depth at lower end wall, m (ft)
V1 = base volume, m^3 (ft^3)
V2 = middle peak volume, m^3 (ft^3)
V3 = end peak frustum volume, m^3 (ft^3)
V4 = lower side wall extension volume, m^3 (ft^3)
V5 = higher end wall extension volume, m^3 (ft^3)
V6 = lower end wall extension volume, m^3 (ft^3)
V7 = higher corner extension base volume, m^3 (ft^3)
V8 = higher corner extension volume, m^3 (ft^3)
V9 = higher corner extension peak volume, m^3 (ft^3)
V10 = lower corner extension base volume, m^3 (ft^3)
V11 = lower corner extension volume, m^3 (ft^3)
V12 = lower corner extension peak volume, m^3 (ft^3)

Figure 8. Grain storage divisions for volume calculation of flat storages.

length from the peak grain depth to the highest wall grain depth is calculated as follows:

$$L_{shw} = \frac{D_{peak} - D_{hw}}{\tan \theta} \tag{9}$$

where: L_{shw} = length of slope from wall with highest grain depth, m (ft)
D_{peak} = peak grain depth, m (ft)
D_{hw} = grain depth at highest wall, m (ft)
θ = angle of repose of grain, deg

The grain mass above the base volume is divided into a frustum and middle peak . The area of the top and bottom surface of the frustum is determined as follows:

$$A_{ft} = (W - L_{ls} - L_{hs} - 2\ L_{shw})^2 \tag{10}$$

and

$$A_{fb} = (W - L_{ls} - L_{hs})^2 \tag{11}$$

where: A_{ft} = area at top of frustum, m^2 (ft^2)
A_{fb} = area at base of frustum, m^2 (ft^2)
W = width of storage, m (ft)
L_{ls} = length of lower side wall extension less than grain depth at highest wall, m (ft)
L_{hs} = length of higher side wall extension less than grain depth at highest wall, m (ft)
L_{shw} = length of slope from wall with highest grain depth, m (ft)

Volume equations for the twelve grain volumes depicted in Figure 8 are as follows:

$$V_1 = D_{hw}\ (W - L_{ls} - L_{hs})\ (L - L_{le} - L_{he}) \tag{12}$$

$$V_2 = \frac{L - L_{le} - L_{he} - W + L_{ls} + L_{hs}}{2}\ (D_{peak} - D_{hw})\ (W - L_{hs} - L_{ls} + W_p) \tag{13}$$

$$V_3 = \frac{(A_{fb} + A_{ft} + (A_{fb}\ A_{ft})^{1/2})\ (D_{peak} - D_{hw})}{3} \tag{14}$$

$$V_4 = \frac{(L - L_{le} - L_{he})\ L_{ls}}{2}\ (D_{hw} + D_{ls}) \tag{15}$$

$$V_5 = \frac{(W - L_{ls} - L_{hs})\ L_{he}}{2}\ (D_{hw} + D_{he}) \tag{16}$$

$$V_6 = \frac{(W - L_{ls} - L_{hs})\ L_{le}}{2}\ (D_{hw} + D_{le}) \tag{17}$$

$$V_7 = D_{ls}\ L_{ls}^2 \tag{18}$$

$$V_8 = \frac{L_{ls}^2\ (D_{hw} - D_{ls})}{3} \tag{19}$$

$$V_9 = L_{ls}\ \frac{L_{he} - L_{ls}}{2}\ (D_{ls} + D_{he}) \tag{20}$$

$$V_{10} = D_{ls}\ L_{ls}^2 \tag{21}$$

$$V_{11} = \frac{L_{ls}^2\ (D_{hw} - D_{ls})}{3} \tag{22}$$

$$V_{12} = L_{ls}\ \frac{L_{le} - L_{ls}}{2}\ (D_{ls} + D_{le}) \tag{23}$$

where: V_1 = base volume, m^3 (ft^3)
V_2 = middle peak volume, m^3 (ft^3)
V_3 = end peak frustum volumes, m^3 (ft^3)
V_4 = lower side wall extension volume, m^3 (ft^3)
V_5 = higher end wall extension volume, m^3 (ft^3)
V_6 = lower end wall extension volume, m^3 (ft^3)
V_7 = corner base volume, m^3 (ft^3)
V_8 = corner peak volume, m^3 (ft^3)
V_9 = higher corner extension volume, m^3 (ft^3)
V_{10} = corner base volume, m^3 (ft^3)
V_{11} = corner peak volume, m^3 (ft^3)
V_{12} = lower corner extension volume, m^3 (ft^3)
D_{hw} = grain depth at highest wall, m (ft)
W = width of storage, m (ft)
L = length of storage, m (ft)
L_{ls} = length of lower side wall extension less than grain depth at highest wall, m (ft)
L_{hs} = length of higher side wall extension less than grain depth at highest wall, m (ft)
L_{le} = length of lower end wall extension less than grain depth at highest wall, m (ft)
L_{he} = length of higher end wall extension less than grain depth at highest wall, m (ft)
D_{peak} = peak grain depth, m (ft)
W_{peak} = width of peak grain depth, m (ft)
A_{ft} = area at top of frustum, m^2 (ft^2)
A_{fb} = area at base of frustum, m^2 (ft^2)
D_{ls} = grain depth at lower side wall, m (ft)
D_{hs} = grain depth at higher side wall, m (ft)
D_{le} = grain depth at lower end wall, m (ft)
D_{he} = grain depth at higher end wall, m (ft)

For traditional units, the sum of the equations 12 through 23 is divided by the factor 1.244 to determine storage capacity in bushels.

The filling angle of grain used in volume calculations affects the peak height and storage capacity. The filling angles used are: 25 degrees for shelled corn, 28 degrees for soybeans, 23 degrees for wheat and 23 degrees for grain sorghum.

Some small grain storages with very shallow grain depths will result in more ducts than are commonly considered necessary. In an attempt to minimize this problem two threshold values of 106 m^3 (3000 bu) of grain and 1.8 m (6 ft) peak grain depth were used as minimum requirements for designing an aeration system. If the grain capacity or peak depth are less than these thresholds the user is informed of the program limitation.

DUCT PLACEMENT

This procedure of the calculations component performs the time-consuming task of determining the position of ducts in the storage based on air path ratios as described by Holman (1960) and Burrell (1974). The aeration design program uses an air path ratio of 1.5 to place ducts, with the exception that the air path ratio from the first or last duct to the nearest wall may be greater. The allowable air path ratio to the wall is 1.8 if grain depth at wall is 1.5 m (5 ft) or higher or 2.0 if grain depth is less than 1.5 m (5 ft). This modified air path ratio method is a combination of air path ratios given by Holman (1960) and Burrell (1974).

When comparing the air path ratio of 1.5 with the higher air path ratios or the guidelines given by Midwest Plan Service(1987), the latter methods essentially assume that some grain near a wall will cool or warm naturally by conduction. However, no guidelines have been published that could be incorporated into a program to determine the amount of grain which does not need to be aerated. Data is needed to support the hypothesis that grain within a certain distance of an outside wall, or grain up to a certain depth, will cool or warm naturally by conduction. If this data were available grain near an outside wall or in shallow depths could be ignored when designing an aeration system.

The duct placement procedure performs the following tasks:

1) estimates number of ducts for storage
2) places estimated number of ducts based on air path ratio factors
3) calculates the air path ratio from the first and last ducts to the nearest wall
4) compares calculated air path ratio to guidelines
5) if needed, adjusts estimated number of ducts and repeat steps 2 through 5

An estimate of the number of ducts required by the storage is determined by calculating the average grain depth in the grain section opposite the direction of the duct runs. The following equation is used for estimating average grain depth with lengthwise placement of ducts.

$$D_{ave} = \frac{W_{peak}\, D_{peak} + \dfrac{D_{ls} + D_{peak}}{2}\,(L_{ls} + L_{shw}) + \dfrac{D_{hs} + D_{peak}}{2}\,(L_{hs} + L_{shw})}{W} \qquad (24)$$

where: D_{ave} = average depth of grain, m (ft)
W_{peak} = width of peak grain depth, m (ft)
D_{peak} = peak grain depth, m (ft)
D_{ls} = grain depth at lower side wall, m (ft)
L_{ls} = length of lower side wall extension less than grain depth at highest wall, m (ft)
L_{shw} = length of slope from wall with highest grain depth, m (ft)
D_{hs} = grain depth at higher side wall, m (ft)
L_{hs} = length of higher side wall extension less than grain depth at highest wall, m (ft)
W = width of storage, m (ft)

For widthwise placement of ducts, storage length replaces storage width and end wall lengths and depths replace side wall lengths and depths. The average grain depth is divided by the storage length for widthwise placement.

Once the number of ducts has been estimated, the ducts are positioned in the storage. Ducts are placed starting in the center of the storage. If the number of ducts is odd then the middle duct is placed directly under the center of the grain peak. If the number of ducts is even, then the boundary of grain aerated by the two center ducts is directly under the grain peak. The borders of the area aerated by a duct are determined by calculating the distance from a previously placed duct to the border or from a previously established border to a duct. The air path ratio method is used to determine when a border is reached. To determine positioning of a duct, the previously known duct or border position is incremented by a factor of 7.6 cm (3 in.) until the air path ratio is equal to or slightly less than the design air path ratio. This process continues until the estimated number of ducts is placed or a duct is placed within 0.9 m (3 ft) of an edge of the storage.

After the ducts are placed, based on the 1.5 air path ratio, the air path ratios to the side walls are calculated. These ratios are compared to the allowable side wall air path ratios. If the calculated air path ratio is not equal to the design ratio, the estimated number of ducts is incremented or decremented by one and the ducts spacing algorithm is used to place the revised number of ducts. This procedure continues until the outside air path ratios equal the design ratios or until the number of ducts has been both decremented and incremented. The higher number of ducts is used to perform a final duct spacing.

If the number of ducts is set by the program user, the duct spacing algorithm uses the 1.5 air path ratio to place the desired number of ducts. If the user has selected more ducts than can be placed in the storage with the 1.5 air path ratio, the number of ducts is decremented by one and the duct placement algorithm is used to place the revised number of ducts. The outside air path ratio is calculated and recorded for display to the user. If the outside air path ratio is higher than the appropriate allowable value of 1.8 or 2.0, a warning message is displayed to the user. The outside air path ratio from the outermost duct to the outside wall is calculated as follows:

$$R_{ap} = \frac{W - P_d + D_w}{D_{sh}} \quad (25)$$

where:
- R_{ap} = air path ratio
- W = width of storage, m (ft)
- P_d = duct distance from lower wall, m (ft)
- D_w = grain depth at wall, m (ft)
- D_{sh} = shortest distance from duct to grain surface, m (ft)

DUCT LENGTH

The length of a duct is determined by first calculating the distance from the end walls that the duct should be placed. A reference point for offsetting the perforated duct section from the end wall is determined by calculating the shortest distance from the duct to the grain surface in the grain profile section perpendicular to the direction of duct run. Beginning at the end wall and incrementing the distance from the wall, the shortest distance in the direction of the duct run is compared to the reference point. When the two distances are equal, the end of the duct is placed at that point. The duct length is the difference between the storage length (in the direction of the duct run) and the sum of the perforated duct offset from the two end walls.

In some grain storages the duct length calculation can result in a value of zero. In this case, the depth of the storage varies too greatly in the direction of the duct run to effectively aerate the grain. Possible solutions are to change the direction of duct run or provide a flatter grain profile.

FAN PLACEMENT AND SIZE

Sizing of a fan or fans for a duct consists of determining the number and positioning of fans for a duct and sizing the fan based on a static pressure estimate and airflow requirement. The aeration system design program allows one or two fans per duct. One fan may be placed at one end of a duct or at the middle of a duct. Fan placement at the middle of a duct is permissible if the duct is the first or last one in the storage. With two fans, one fan is placed at each end of the duct.

The determining factors for fan placement are the arrangement desired by the user and the maximum length of a duct served by an air source. The user may choose middle and end placement, end placement only or middle placement. Middle and end placement results in the fans being arranged in the manner which requires the least number of fans. The various recommendations for the maximum length of duct served by an air source were listed in Chapter II. The aeration program uses 18.3 m (60 ft) for plastic duct (Brook, 1983) and 24.4 m (80 ft) for metal duct (Cloud and Morey, 1980; MWPS, 1987). If the perforated duct is longer than the maximum length allowed from one fan either one fan must be used at each end of the duct or one fan must be placed at the middle of the duct.

An estimate of the static pressure of the grain is calculated according to the American Society of Agricultural Engineers standard D272.1 (ASAE, 1987) (equation 1). The shortest distance from the duct to the grain surface is used for bed depth (Holman, 1960). A packing factor for adjusting static pressure to reflect field conditions is used as referenced from Midwest Plan Service (1987) in Chapter II. The estimated static pressure is increased by 0.06 kPa (0.25 in. H_2O) for supply tube losses and 0.06 kPa (0.25 in. H_2O) for each tee or elbow connector in the supply tube. If the estimated static pressure is still less than

0.125 kPa (0.5 in. H_2O), the static pressure is increased to this factor, as it is usually the threshold for fan performance data.

The required airflow is based on the user determined airflow rate and the volume of grain served by the duct. The default value for airflow rate is 0.12 $m^3/min/m^3$ (0.15 $ft^3/min/bu$). The same equations used to calculate capacity of the storage are used to calculate the capacity of the volume served by the duct.

Fan curve data for 11 axial and 5 centrifugal fans from Brook and Harmsen (1982) are stored in the aeration program. Equation 3 (Brook and Harmsen, 1982) is used to estimate airflow output of a fan at the estimated static pressure. The estimated airflow was increased by five percent as a sizing allowance for accepting lower airflow instead of using the next larger size fan. The required airflow is compared to estimated airflow of available fans, beginning with the smallest fan, until the estimated airflow is greater or equal to the required airflow. If the required airflow is greater than the estimated airflow of the largest fan a message is displayed to the user noting this fact. Once a fan is selected, the operating static pressure and airflow are re-estimated to approximate operating conditions.

DUCT SIZE

Duct size is based on the allowable airflow velocities in the duct and exiting the duct. The aeration program uses 457 m/min (1500 ft/min) (Brook, 1979; MWPS, 1987) maximum airflow velocity in the duct and 7.6 m/min (25 ft/min) (Cloud and Morey, 1980) exit velocity. The maximum velocities were increased by five percent to allow a slight increase in airflow velocity rather than use the next larger duct. Minimum cross-sectional area and surface area of the duct are determined from equations 4 and 5, respectively. The required duct diameter for cross-sectional area was calculated as:

duct diameter m (ft) = (cross-sectional area m^2 (ft^2) / 3.1416)$^{1/2}$ * 2 (26)

and the required duct diameter for surface area was calculated as:

duct diameter m (ft) = surface area m^2 (ft^2) / (duct length * 3.1416) (27)

The larger of the two calculated diameters is used to specify duct size.

SUPPLY TUBE PLACEMENT AND SIZE

Supply tubes are sized to channel air from the fan on the outside of the storage to the duct. Supply tubes are placed in accordance with the fan arrangement. Supply tube diameter is determined based on the allowable airflow velocity in the supply tube of 610 m/min (2000 ft/min) (Foster and Tuite, 1986; Holman, 1960) plus the five percent factor used in sizing ducts. Equations 4 and 26 are used to specify the supply tube diameter. Length of the supply tube is the same as the offset of the perforated duct from the end of the storage.

DESIGN DRAWING

The design drawing component of the aeration system design program prints the component specifications and an aeration system plan. A program was written in the 'C' language for the design drawing processor. One function of the program is to print the fan, duct and supply tube specifications based on the values determined from the calculations component (Figure 9).

As discussed in Chapter III, parametric computer aided drafting software (Synthesis and AutoCAD commercial software products) was used to generate the custom aeration system design drawings. The generic master drawings were prepared according to the instructions in the Synthesis user's guide. Three master drawings were initially planned, but due to problems in rotating text and

AERATION SYSTEM COMPONENT SPECIFICATIONS
for Dennis Watson

The accompanying floor plan of the grain storage illustrates the placement of the components. Ducts are labeled with numbers and fans are labeled with letters. The following table lists the specifications of each component.

DUCT		FAN					
#	size	#	size		cfm	sp	connector size
1	12" x 81'	A	12"	0.33hp	1740	0.6	14" x 9'
2	21" x 53'-6"	A	16"	1.50hp	3773	0.5	21" x 23'-3"
3	21" x 53'-6"	A	16"	1.50hp	3773	0.5	21" x 23'-3"
4	12" x 81'	A	12"	0.33hp	1740	0.6	14" x 9'

cfm -- airflow in cubic feet per minute required from fan.
sp -- operating static pressure of the fan in inches of water.

Note: BP (base point) on the following drawing is the corner at which the lower side wall and lower end wall meet.

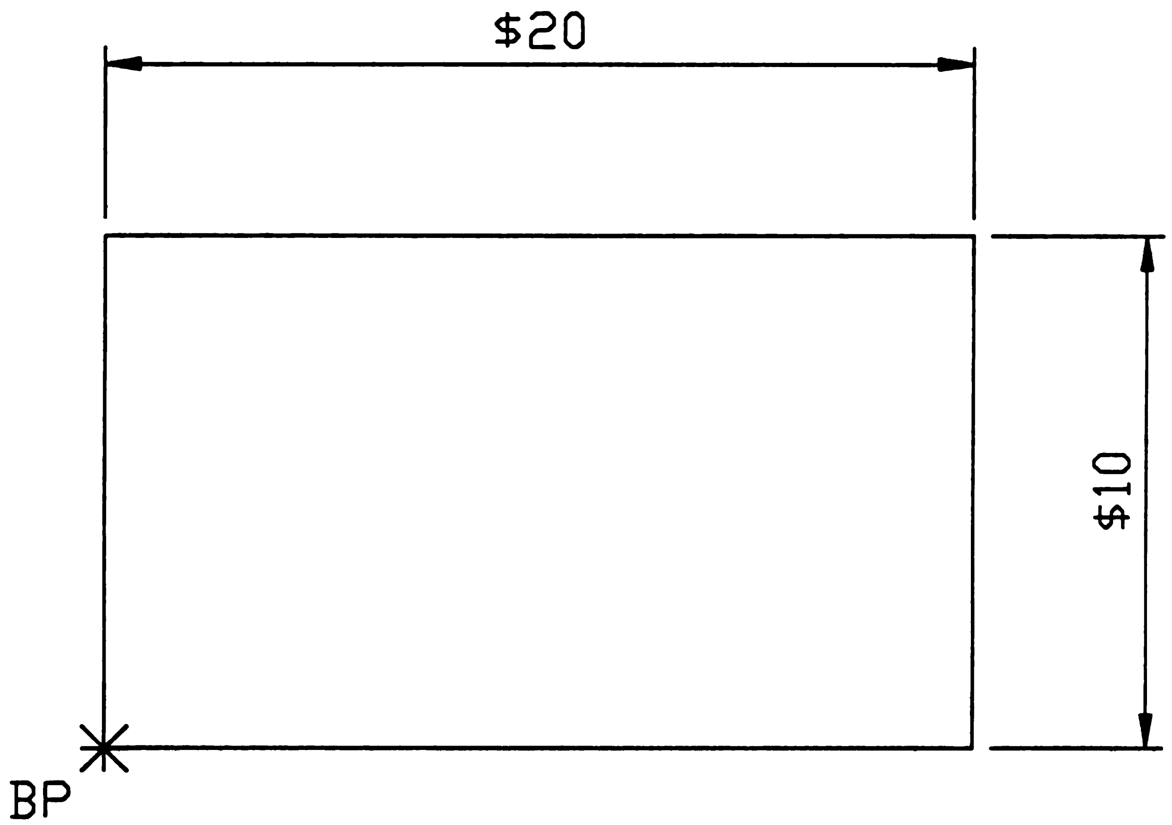
Figure 9. Sample component specification listing generated by the aeration system design program.

adding optional dimensions, eleven master drawings were required to generate the design drawings. The drawings resemble typical computer aided drafting (CAD) drawings with the exception that dimension text is replaced with variable identifiers. The variable identifiers consist of a '$' and digits (e.g. $123). Some of the dimensions on the master drawings are hidden. These hidden dimensions are used to place and size certain entities. Table 10 lists the master drawing names and descriptions.

Table 10. Master drawings for the aeration system design program.

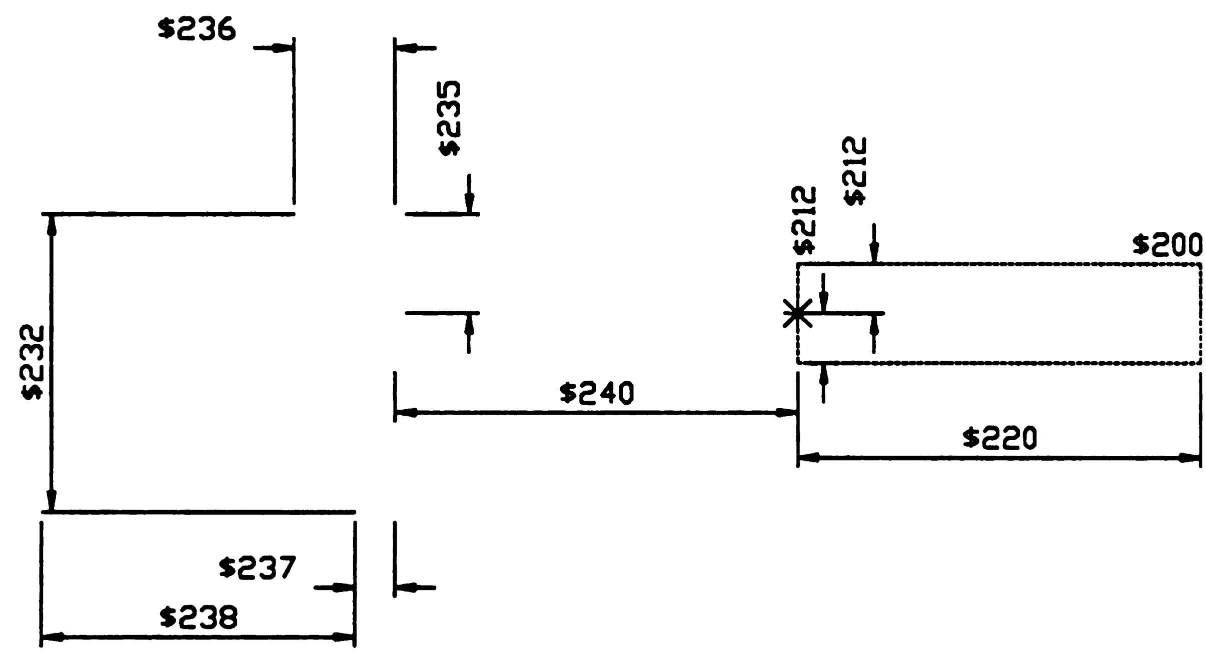
Drawing Name	Drawing description
BASE	rectangular outline of grain storage
DUCT	perforated duct to be placed horizontally on drawing
DUCTV	perforated duct to be placed vertically on drawing
FAN	fan and supply tube to be placed horizontally on drawing
FANV	fan and supply tube to be placed vertically on drawing
DIMH0	dimension for middle fan placement from end wall at bottom of drawing
DIMH1	dimension for middle fan placement from end wall at top of drawing
DIMV0	dimension for middle fan placement from side wall at left of drawing
DIMV1	dimension for middle fan placement from side wall at right of drawing
TEXTH	label text oriented horizontally for middle fan placement
TEXTV	label text oriented vertically for middle fan placement

The primary master drawings are the storage outline (Figure 10), perforated duct (Figure 11) and fan and supply tube (Figure 12).



$10 -- storage width
$20 -- storage length
* -- reference point for inserting component drawings

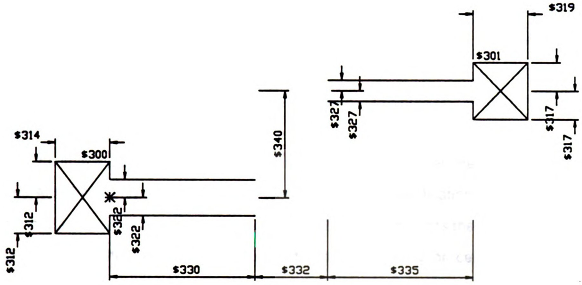
Figure 10. BASE master drawing: rectangular outline of grain storage.



$200	--	label for duct number
$212	--	duct radius (hidden dimension)
$220	--	duct length (hidden dimension)
$232	--	duct offset from edge of storage parallel to duct
$235	--	offset of upper dimension line extension from duct center (hidden dimension)
$236	--	offset of upper dimension line extension from edge of storage (hidden dimension)
$237	--	offset of lower dimension line extension from edge of storage (hidden dimension)
$238	--	length of dimension line extensions (hidden dimension)
$240	--	duct offset from edge of storage perpendicular to duct
*	--	reference point for inserting into base drawing

Note: all dimensions on this drawing are hidden from program user except $232 and $240.

Figure 11. DUCT master drawing: perforated duct to be placed in drawing.



$300 -- label for fan A
$301 -- label for fan B
$312 -- radius of fan A (hidden dimension)
$314 -- length of fan B (hidden dimension)
$317 -- radius of fan A (hidden dimension)
$319 -- length of fan B (hidden dimension)
$322 -- radius of supply tube A (hidden dimension)
$327 -- radius of supply tube B (hidden dimension)
$330 -- length of supply tube A (hidden dimension)
$332 -- length of perforated duct (hidden dimension)
$335 -- length of supply tube B (hidden dimension)
$340 -- offset of fans (hidden dimension)
* -- reference point for inserting into base drawing

Note: all dimensions on this drawing are hidden from program user.

Figure 12. FAN master drawing: fan and supply tube to be placed in drawing.

A second function of the design drawing processor is to generate a drawing specification file (Figure 13) for use by Synthesis in generating a custom drawing from the various master drawings. This function assigns values to variable identifiers, determines which master drawings to use in the custom drawing and places the master drawings in the custom drawing. Appendix F contains the 'C' code listing of this function.

The final function of the design drawing processor executes the Synthesis and AutoCAD programs. Synthesis uses the drawing specification file to generate the custom drawing and AutoCAD displays and prints the drawing (Figure 14). After the drawing is printed, the design drawing processor relinquishes program control to the framework.

MANAGEMENT RECOMMENDATIONS

The management recommendations component of the aeration system design program consists of an ASCII file of recommendations text and a set of rules for printing recommendations. The recommendations were divided into four sections of: 1) user inputs listing, 2) flat storage comments, 3) specific plan comments and 4) grain management comments (Figure 15).

The user responses are summarized on the management recommendations printout to attach the plan to a specific set of design parameters. Flat storage comments define flat storage and its appropriate usage and term of storage. Comments on the specific plan are important to the user in implementing the plan successfully. These comments include recommendations on vapor barrier, roofing, post size and spacing and grain liners. Management comments include the need for clean grain for good air distribution, grain observation, temperature

```
/AERATION DESIGN DRAWING SPECIFICATION FILE
/for .
/NUM       VALUE              DIMENSION TEXT
!$$$       @@@@@@@@@      ******************************
/---       ---------      ------------------------------
$10        60.00          60'
$20        100.00         100'

/OUTFILE      INFILE        ORIGIN        SCALE X Y        ROTATION
#CLIENT       AERBASE      0.0  0.0       1.0    1.0          0.0
$200       1.00           Duct 1
$212       0.5
$220       81.00
$240       9.50           9'-6"
$232       9.50           9'-6"
$235       0.01
$236       1.00
$237       1.00
$238       7.00
#CLIENT    aerduct          9.50       9.50    1.0    1.0      0
$312       0.5
$314       1.50
$322       0.58
$330       9.00
$332       81.00
$300       1.00           A
$301       1.00
$317       0.00
$319       0.00
$327       0.00
$335       0.00
#CLIENT    aerfanv          50.00       0.00    1.0    1.0      0
$410       2.50
$420       3.50
$430       1.00
$440       50.00          50'
#CLIENT    aerdimh0          50.00       0.00    1.0    1.0      0
```

Figure 13. Partial listing of a drawing specification file for an aeration system design.

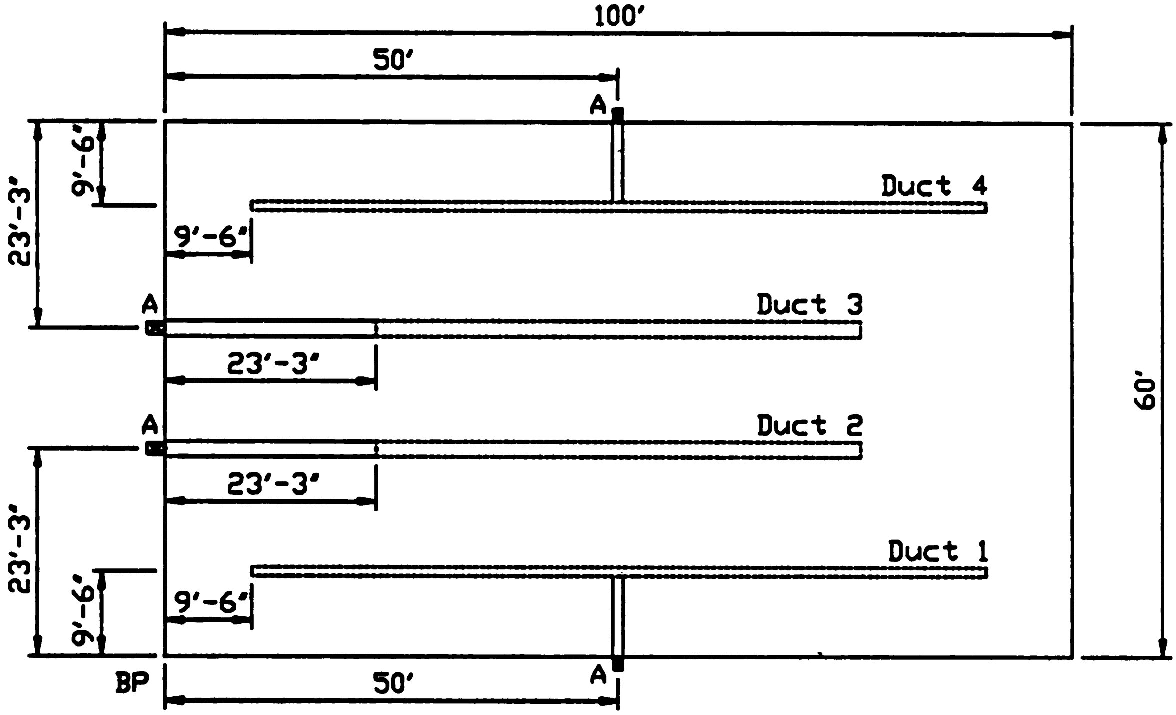


Figure 14. Sample aeration system plan displayed and printed for user of aeration system design program.

This aeration system has been designed for:

Dennis Watson
Michigan State University
106A Farrall Hall
E. Lansing, Michigan 48824
123-456-7890

The following listing summarizes information about the aeration system:

Grain --	shelled corn
Building --	existing
Construction --	post frame
Post spacing --	8'
Grain liner information --	not requested
Storage size --	60.0' by 100.0'
Wall depths:	
higher side wall --	6.0'
lower side wall --	6.0'
higher end wall --	6.0'
lower end wall --	6.0'
Maximum piling height --	16.0'
Bushel capacity --	54517
Actual peak height --	16.0'
Width of peak --	17.1'
Ducts --	computer selected 4
Fan arrangement --	end or middle placement
Fan type --	axial
Duct direction --	lengthwise
Duct type --	round metal
Airflow rate --	0.15 cfm/bu

GENERAL COMMENTS ON FLAT STORAGES:

The use of buildings for grain storage is not recommended for more than 1 to 2 months storage if not equipped with an adequate aeration storage.

The use of buildings for grain storage when adequate aeration is installed is not recommended for storage of grain past late spring.

Figure 15. Partial listing of management recommendations from an aeration system design.

SPECIFIC COMMENTS ON THIS AERATION PLAN:

The grain will be piled, at most, 6.0 feet on the side wall of your building. With the posts spaced 8 feet on center, a post size of at least 6" x 6" is required. The smaller post dimension must face the grain. Higher grain depths or smaller posts will likely to cause structural damage to the building.

GRAIN MANAGEMENT COMMENTS:

The design airflow may be greater than the effective delivered airflow. Grain with excess amounts of fines or foreign material will increase the static pressure caused by the grain. The change in static pressure will lower the delivered airflow for that general area of the grain storage.

The fans should be operated for upward airflow in order to help ensure as uniform an airflow as possible along the length of the duct(s). The upward airflow also helps the management of the cooling phase by allowing observation of the air exiting the surface of the grain mass which will help show the progress of cooling in different areas of the storage.

Proper management practices are essential to successful storage of grain. Grain should be clean, dry and cool to insure the maintenance of quality during storage. A regular inspection of the grain during the storage period will help to avoid storage problems. For more details, see Michigan State University Cooperative Extension Service bulletin E-1431.

Figure 15. (Cont'd)

monitoring systems, fan operation, fan types, grain inspection and aeration management procedures. The text file of management recommendations and the source code of rules for printing the recommendations are in Appendices G and H, respectively.

CHAPTER V

EVALUATION OF AERATION SYSTEM DESIGN PROGRAM

A structured expert review process was used to evaluate the aeration system design program. Persons experienced with aeration system design reviewed the program and compared it with their own approach and provided an evaluation of the aeration system design program. Reviewers were extension specialists at land grant universities, agricultural engineering consultants and industry representatives. The purpose of evaluation was two-fold: first, to evaluate the technical content of the program for validity; and second, to evaluate the usability of the program. This chapter discusses the evaluation objectives, describes the evaluation instruments and procedure, reports evaluation results and discusses implications of the evaluation.

EVALUATION OBJECTIVES

Objectives of the evaluation process guided development of evaluation instruments. The following description of objectives is divided into technical and usability aspects of the evaluation process.

TECHNICAL EVALUATION OBJECTIVES

The technical content of the computer program on aeration system design was reviewed to determine its validity. Objectives of the technical evaluation were to determine concurrent validity, construct validity, content validity and sensitivity.

Concurrent validity is determined by relating a test to a criterion measure administered at about the same time (Borg and Gall, 1971). Two case studies of aeration design problems were described and reviewers were asked to solve them by their usual method and then to use the design program to solve the problems.

Construct validity is the extent to which logical and theoretically consistent constructs are represented (Borg and Gall, 1971). The accuracy of the underlying logical structure of design guidelines and equations was tested. Reviewers' comments and solutions to case studies were examined to determine the accuracy of the program's logical structure.

Content validity is the degree to which items or components, in this case the questions asked of the user, are pertinent to solving the problem for which the program was designed (Borg and Gall, 1971). Appropriateness of information requested of the user to solve the problem was determined by reviewers' comments and responses to a questionnaire.

Sensitivity refers to the degree to which the program can utilize incomplete or poor information and still produce an acceptable design. The aeration design program includes a 'help' facility which program users can activate to learn why a question was asked and what needs to be considered to respond. Reviewers rated the sufficiency of help information for assisting a user in answering questions.

USABILITY EVALUATION OBJECTIVES

An important measure of the success of a design program is usability. As design programs are seldom used on a regular basis, they should be easy to use and time spent relearning a program should be kept to a minimum. Although a user may initially need to reference a manual to run a program, the user interface should be logical and easy to remember.

Objectives of the usability evaluation were to determine ease of use, conveyance of information, pertinence of illustrations and usefulness of design drawings. To evaluate ease of use, reviewers' comments and responses to questions requesting an 'ease of use' rating were used.

An engineering design program must convey information to a user in a concise manner to eliminate ambiguities that result in a poor plan. Reviewers rated the effectiveness of information conveyance through text and graphics.

Illustrations were used in the program to increase the efficiency of information conveyance. Illustration content was reviewed to determine appropriateness of the illustrations.

The aeration system design program produces a design drawing and management recommendations which the client can use to implement the aeration system design. Reviewers rated the usefulness of the design drawing and management recommendations.

EVALUATION INSTRUMENTS AND PROCEDURE

Evaluation instruments and procedures were devised for evaluation of the aeration system design program. The evaluation procedure included developing evaluation instruments, contacting reviewers prior to on-site evaluation and conducting the on-site evaluation.

EVALUATION INSTRUMENTS

The first set of evaluation instruments consisted of aeration system design case studies. Two case studies were prepared for evaluating concurrent and construct validity (see Appendix I for instruments). Reviewers completed the case studies, using their usual procedures, before the on-site phase of the evaluation. The two case studies were similar in duct placement, but differed in storage profile, duct direction, duct type and fan placement. For the reviewers' convenience, five worksheets were prepared for each case study as listed in Table 11.

Table 11. Description of worksheets included with case studies.

Worksheet	Description and Usage
1	case study description including storage specifications and equipment preferences
2	cross-sectional drawing of case study with grid for clarification of grain profile
3	floor plan (with grid) of case study storage for sketching component placement
4	table of component specifications for listing design results
5	recommendations list for listing any design implementation and management recommendations for the case study

The worksheets made it easier for the reviewers to complete the case studies and provided a common format for summarizing results.

A questionnaire about aeration system design guidelines was included with the case studies. This questionnaire was used to determine the source of differences between a reviewer's design and the program's. Responses to this questionnaire summarized the reviewer's method for determining duct placement, duct length, fan size, duct size and supply tube size.

Five questionnaires were devised to meet the technical and usability evaluation objectives (see Appendix J for questionnaires). These questionnaires were used during the on-site evaluation. A description of the questionnaires in the order presented to the reviewers follows:

1 **rating of design results** -- design results of the program were compared to reviewers' results and the differences were rated as "none", "minor", "moderate" or "substantial".

2 **explanation of moderate or substantial rating** -- the reason a design result was rated as moderately or substantially different from the program result was explained on this form, and any suggestions for changing the program were made.

3 **review of design guidelines** -- a reviewer's agreement or disagreement with design guidelines used in the program was recorded, and alternative guidelines were requested.

4 **review of response screens** -- reviewers were asked to respond "yes" or "no" to the following questions about a response screen of the program and were given a chance to make suggestions or comments.

Is this information you typically ask of a client?

Is this information readily available to the client?

Is the question worded adequately?

Is the help information sufficient to assist a client in answering the question?

5 **usability evaluation** -- reviewers were asked to rate the usability of the program in terms of the user interface, information conveyance, design drawing and management recommendations.

Questionnaires one and two address concurrent validity by having the reviewers directly compare their designs to the program results. Results of the concurrent validity test and questionnaire three were used to determine construct validity. If any results of the concurrent validity test had not been explained by differences in design guidelines a potential problem with construct validity would have existed. Content validity and sensitivity were measured with questionnaire four. Questionnaire five addressed the usability of the program.

CONTACT WITH REVIEWERS

Nine reviewers were selected to evaluate the aeration system design program. Five reviewers were associated with extension work in agricultural engineering at universities and four were associated with aeration system component manufacturers as listed in Table 12.

Table 12. Reviewers for aeration system design program.

Reviewer Name	Employer	Position Title
B. A. McKenzie, PH.D.	Purdue University	Professor and Project Leader
G. H. Foster, PH.D.	Purdue University	Professor emeritus
W. H. Peterson, PH.D.	Univ. of Illinois	Professor
G. C. Shove, PH.D.	Univ. of Illinois	Professor and Division Leader
M. Hall	Univ. of Illinois	Extension Agricultural Engineer
W. Altermatt	Hancor, Inc.	Manager of Marketing & Sales Engineering
J. McNall	Hancor, Inc.	Applications Engineer
D. Hansen	Aerovent, Inc.	Engineering Manager
S. Ganser	Aerovent, Inc.	Design Supervisor

On-site evaluations by university reviewers were scheduled at both universities. Date and time of the visits were confirmed approximately eight weeks in advance. The case studies were sent to the reviewers four weeks before the on-site visit and a subsequent contact to verify plans was made two weeks prior to the visit.

On-site evaluations by industry representatives were conducted in the Interactive Computer Graphics Laboratory of the Agricultural Engineering department of Michigan State University. Visits were scheduled two to four weeks in advance and case study material was sent as soon as the visits were scheduled. A subsequent contact was made the day before the scheduled visit to verify plans.

ON-SITE EVALUATION

On-site evaluations were scheduled for three hours plus a luncheon. The agenda for the evaluation meetings is presented in Table 13.

Table 13. Agenda for on-site evaluation of aeration system design program.

Relative Time	Activity
0:00	opening remarks on research project
0:10	introduction to aeration system design program
0:20	program demonstration with case study 1
0:35	reviewers use program with case study 2 plus their case studies
	rating of design results
	interaction with reviewers discussing differences in results
1:30	explanation of moderate or substantial ratings
1:45	review of design guidelines
2:00	review of response screens
2:30	usability evaluation
3:00	luncheon
	impromptu discussion of program and aeration system design

The evaluation procedure progressed according to the agenda under the direction of the researcher. At times, discussion was cut short to keep on schedule. Two microcomputers were taken to the Purdue University and

University of Illinois sites to insure that proper equipment would be available. One computer was used for the evaluation sessions held at Michigan State University. During the sessions, notes were made of pertinent comments made by the reviewers. Two people familiar with the program directed reviewers during the evaluation process, except for the session with the people from Hancor when only one was available. The luncheons, after the evaluation session, provided a relaxed environment for discussing the program and aeration system design.

RESULTS OF EVALUATION

Responses to the questionnaires were quantified and summarized (see Appendix K for details). Results of the technical content and usability evaluation are presented here.

TECHNICAL EVALUATION

Utilizing outside experts in the technical evaluation process was very beneficial, as reviewers were cooperative and shared their technical expertise in aeration system design. The technical evaluation consisted of concurrent validity, construct validity, content validity and sensitivity components.

Concurrent Validity

Questionnaires for rating design results and explanations of moderate or substantial differences between the reviewers' and the program's results were used to determine concurrent validity. The reviewers' ratings of the design results are summarized in Table 14.

Table 14. Summary of reviewers' ratings of design results.

Design Result	Differences* None or Minor	Differences* Moderate or Substantial
number of ducts	7	2
placement of ducts	3	6
duct diameter	6	3
duct length	3	6
number of fans	3	5
fan size	4	4
connector size	6	3
totals	32	29

*Some reviewers did not respond to every question.

Three of these categories received more ratings of "none" or "minor" differences than "moderate" or "substantial" and three categories received more ratings of "moderate" or "substantial" differences. "Moderate" or "substantial" differences were associated with differences in choice of design guidelines between expert reviewers and the design program.

number of ducts

The two "moderate" or "substantial" differences in the "number of ducts" category were caused by the program placing too many ducts in shallow storages and reviewers using a 1.5 air path ratio for the outside ducts compared to the 1.8 or 2.0 ratio in the program. The program does have limitations in placing ducts in shallow storages. In shallow storages, such as one with a side wall grain depth of near zero and a width of 9 m (30 ft) or less, the air path ratio method results in more ducts being placed than are normally considered reasonable.

Reviewers suggested ignoring shallow grain depths to overcome the problem with over-design in shallow storages. A similar guideline was desired when developing the program, but no research data were available to establish a depth of grain that could be ignored. Two reviewers reported ignoring grain depths less than 0.9 m (3 ft) in their designs. Other reviewers suggested that grain depths of 1.2 or 1.8 m (4 or 6 ft) could be ignored in designing an aeration system.

placement of ducts

The six "moderate" or "substantial" difference ratings in the "placement of ducts" category were primarily caused by the use of a higher air path ratio from the outside wall to the nearest duct in the program and the accuracy with which the ducts were placed. Three of the six reviewers with "moderate" or "substantial" difference ratings did not think the program should be changed. Two reviewers wanted the program to include extra capabilities, such as allowing an expert to change the air path ratio or to consider a tarp-covered pile. The other suggestion for change was related to ignoring shallow grain depths, as discussed above.

On the questionnaire for design guidelines included with the case studies, reviewers reported using the following methods for placing ducts:

- spacing approximately equal to grain depth
- spacing no farther apart than minimum grain depth served by duct
- 1.5 air path ratio for center ducts, 2.0 or 3.0 air path ratio for outer ducts
- 1.5 air path ratio based on average depth of grain served by duct

duct diameter

"Moderate" or "substantial" difference ratings in the "duct diameter" category were caused by reviewers 1) varying the size of a duct by using a smaller diameter at the ends; 2) allowing duct velocities greater than 457 m/min (1500 ft/min) when grain depth was 9 m (30 ft) and 3) sizing the duct based on required airflow rather than the airflow delivered by a selected fan. On the design guideline questionnaire, reviewers reported allowing 10, 20, and 25 percent increases in duct velocity in order to recommend use of a smaller duct size. One reviewer said no increase was recommended. The program allowed a 5 percent increase.

Six of nine reviewers had "moderate" or "substantial" differences in the "duct length" category. These differences were caused by a difference in the guidelines used to determine the distance to offset a perforated section of duct from an end of a storage. The program used a rule which required air paths to be as equal as possible. Based on the following responses to the design guideline questionnaire; reviewers typically allowed a larger variation in air paths:

- distance from perforated duct to end wall about equal to spacing from side duct to side wall
- air path ratio from duct to grain surface at end wall equal to longest air path ratio laterally from duct
- judgment call assuming that grain near the edge of a pile will cool adequately by conduction without aeration
- distance from duct to end wall equal to end wall grain depth
- judgment call that places the end point of a duct so that the shortest air path is approximately 75 percent of the maximum depth on a center level fill. If storage is totally conical, try to orient ducts so that separate systems supply shallow vs. deep sections

One reviewer, who uses plastic aeration tubing for most designs, used tubing under shallow grain with one-half the perforated area of that placed in the middle of the storage. This method assumes that the perforated area 'throttles' the airflow.

number of fans

The number of "moderate" or "substantial" ratings for the "number of fans" category was related to the allowable length of plastic tubing from a fan and the number of ducts one fan was allowed to supply. The program's limit of 18.2 m (60 ft) of plastic tubing from a fan was less than the reviewers allowed. With a storage profile such as that used for case study 1, the 18.2 m (60 ft) length resulted in the program placing a fan at each end of the ducts. For this case study, the reviewers used one fan and allowed a longer length of plastic tubing from a fan. Some reviewers used one fan to supply multiple ducts; an alternative the program did not consider.

fan size

"Moderate" or "substantial" differences in fan size were caused by reviewers using one fan for multiple ducts, being unaware of the small fan size used in the program and having data (not included in program) to estimate static pressure of plastic tubing. The length of grain used to estimate static pressure of grain varied among reviewers. Two used the grain depth directly above duct, two used peak grain depth served by a duct and one used the longest air flow path. One reviewer allowed no airflow reduction to recommend a smaller fan, while others allowed 10 and 15 percent reductions compared to 5 percent used by the program.

connector size

"Moderate" or "substantial" differences in connector size were related to a difference in guidelines for determining the distance to offset the perforated section of duct from the end of the storage as discussed above and to a reviewer misinterpreting the term 'connector' when completing the case studies.

Construct Validity

Reviewers registered their agreement or disagreement with some key design guidelines used in the program (summarized in Table 15). The reviewers generally agreed with the values used in the program. One notable exception was the maximum length of plastic aeration tubing from a fan, which the reviewers felt should be increased to 22.9, 24.4 or 30 m (75, 80 or 100 ft). Three reviewers also suggested the maximum length of a metal aeration tube from a fan be increased to 30 m (100 ft). Other suggestions were to use 1) 1.2m (4 ft) as the minimum grain depth on a wall to be considered deep enough for determining the air path ratio to use; 2) static pressure data for plastic tubing to estimate static pressure for a connector; 3) 0.1 kPa (0.5 in. H_2O) or 10 to 15 percent of the total static pressure, for static pressure of a turn in a connector or duct; 4) no minimum capacity as a threshold for designing an aeration system for a storage and 5) 1.5 or 1.8 m (5 or 6 ft) as the minimum distance to place a duct from a wall parallel to the duct.

Table 15. Summary of reviewers' agreement with design guidelines.

Design Factor	Program Value	Number* Agreed	Disagreed
air path ratio for middle ducts	1.5	8	0
minimum grain depth on wall to be considered deep (ft)	5	7	1
air path ratio to outside with shallow grain depth	2.0	8	0
air path ratio to outside with deep grain depth	1.8	8	0
maximum length of plastic aeration tube from fan (ft)	60	1	6
maximum length of metal aeration tube from fan (ft)	80	4	3
minimum static pressure for fan sizing (in. water)	0.5	8	0
static pressure of connector (in. water)	0.25	6	1
static pressure of turn in connector or duct (in. water)	0.25	5	2
minimum bushels to design aeration system (bu)	3000	6	2
minimum peak grain depth to design aeration system (ft)	6	8	0
minimum distance from duct to wall parallel to duct (ft)	3	5	3
totals		74	18

*Some reviewers did not respond to every question.

Content Validity

Content validity of the program was measured by reviewers' responses to questions about the response screens in the program. The reviewers' opinions are summarized in Table 16. In general, the reviewers said that the questions in the program were typical of questions they asked, the information to answer the questions was readily available to the clients and the questions were worded adequately.

Table 16. Summary of reviewers' opinions regarding response screens.

Response Screen	Typical Question of Reviewer? YES	NO	Information Available to Client? YES	NO	Question Worded Adequately? YES	NO
client information	8	0	8	0	8	0
grain type	8	0	8	0	8	0
new structure	8	0	8	0	8	0
construction type	6	2	8	0	8	0
post spacing	6	2	8	0	8	0
structure liner	4	4	5	0*	5	3
storage size	8	0	8	0	8	0
grain depths on walls	8	0	8	0	6	2
maximum piling height	8	0	7	1	5	3
number of ducts	6	2	6	2	8	0
duct type	8	0	6	2	7	1
duct direction	8	0	8	0	7	1
fan type	5	3	7	1	7	1
fan arrangement	6	2	8	0	5	3
airflow rate	8	0	8	0	5	3
totals	105	15	111	6	103	17

*Some reviewers did not respond to every question.

Some reviewers did not ask all of the questions when working with a client. Four of the reviewers typically did not ask a client about the structure liner. Three did not ask the client to select a fan type. The questions about construction type and post spacing, which were used to recommend a minimum post size, were excluded by two reviewers. Two reviewers did not ask a client the number of ducts to use or the client's preferred fan arrangement.

Two reviewers did not think the user would be able to determine the number of ducts to use or the duct type. One reviewer thought a client would not know the maximum piling height in a structure and one thought a client would not be able to select a fan type.

Some reviewers marked eight questions as not being worded adequately. Improvements in the wording or the illustrations were suggested for seven response screens as listed in Table 17.

Table 17. Improvements to response screens suggested by reviewers.

Response Screen	Suggestion
structure liner	state that information on liners will be printed **later** if requested (2)*
grain depths on walls	change the illustration for side depth to a leveled top (2)
maximum piling height	calculate the maximum piling height based on angle of repose and display it as the default value (2)
duct type	use HDPE (High Density Polyethylene), the term preferred by industry, instead of plastic, a generic term (1)
fan type	make axial the default type and provide extra spaces between axial and centrifugal types with note for user to see help if he wants centrifugal (1)
fan arrangement	include option "one end only" or redo illustration to show fans at one end and redo illustrations to fit lengthwise and widthwise duct direction (4)
airflow rate	ask "design airflow rate desired (cfm/bu)?" or "air flow rate cfm/bu desired?" (1) airflow of 0.1 cfm/bu is better default (2)

*Numbers in parenthesis are number of reviewers making a suggestion.

Sensitivity

Sensitivity of the program was measured by the reviewers' opinions of the sufficiency of the 'help' information available to a program user as listed in Table 18. The reviewers generally responded that the 'help' information was sufficient. One exception was the 'help' information available for fan arrangement. Eight other response screens received some 'no' responses to the sufficiency of 'help' information question. Table 19 summarizes comments pertinent to the 'help' information.

Table 18. Summary of reviewers' opinions of 'help' information.

Response Screen	Help Information Sufficient YES	NO
client information	7	1
grain type	8	0
new structure	8	0
construction type	8	0
post spacing	8	0
structure liner	7	1
storage size	8	0
grain depths on walls	8	0
maximum piling height	6	2
number of ducts	5	3
duct type	5	3
duct direction	6	2
fan type	6	2
fan arrangement	3	4*
airflow rate	5	3
totals	98	21

*Some reviewers did not respond to every question.

Table 19. Summary of reviewers' comments on 'help' information.

Response Screen	Comment
client information	need to instruct in use of 'Enter' and 'PgDn' keys (1)*
structure liner	it is not clear if a liner is needed or under what conditions a liner is recommended (1)
maximum piling height	should have instructions on calculating 'natural' piling height (1)
number of ducts	have manager look at the computer design and then modify it a bit to conform to available sizes (1) advise that initially the 'computer selected' option should be chosen (1) change to read "This program will determine and make a recommendation for the number of ducts required to aerate the grain..." (1)
duct type	depth is a limit for plastic duct (1) may need to recognize greater duct loss in plastic, also limits in the percent of open area(1) plastic ducts are not limited to shorter runs nor are they more susceptible to damage in handling (2)
duct direction	reference layout vs. clean-out efficiency and layout vs. number of fans and wiring cost (1) other considerations are fan location and filling method (1)
fan type	choose axial in flat storage because they are more cost effective and centrifugal are not needed due to low static pressure (1) there are centrifugal fans available smaller than 27 in. and 5 hp (1)
fan arrangement	other considerations are fan location and filling method (1)

Table 19. (cont'd.).

Response Screen	Comment
airflow rate	fines need to be managed - work at uniform or central distribution; if excess accumulations cannot be avoided, consider 0.2 cfm/bu (1) include cooling time for different airflows (1) relate grain quality to grain grading parameters (1)

*Numbers in parenthesis are number of reviewers making a suggestion.

USABILITY EVALUATION

One questionnaire was prepared for and completed by the reviewers to rate the usability of the program. Ratings were requested for user interface, information conveyance, design drawing, management recommendations and general categories.

Reviewers rated the user interface very easy to use. All reviewers agreed that beginning microcomputer users, county agents and farmers could use a program with this type of user interface. Some suggestions for improvement were to include a capability for rapidly changing responses entered early in the interview process and to have the currently highlighted response always be chosen when a screen is exited.

Information conveyance with text and graphics was rated very effective by the reviewers. Reviewers responded that the illustrations would be helpful to other experts, county agents and farmers. The illustrations were rated somewhat useful for 1) involving a user in the design process; 2) considering different options and 3) amplifying the meaning of the text. The illustrations were rated very important to the accuracy of communication with the user.

The design drawing was rated very usable for purchasing components and installing an aeration system. Suggestions for the design drawing were to differentiate the lines of the storage outline, supply tubes and perforated ducts to a greater extent and to relate the base point to a direction. Suggestions for the component specification listing were to 1) change the terms connector and duct to solid duct and perforated duct, respectively; 2) add total power and number of fans and estimate warming/cooling time; 3) use standard lengths and sizes and 4) draw a line under each duct size across a page.

Seven of eight reviewers agreed that management recommendations are important in a program of this type. The management recommendations were rated as being very helpful to a client. Reviewers felt that the recommendations were communicated well. Reviewers stated that for the most part the correct emphasis was placed on critical recommendations and the recommendations were somewhat similar to the ones they make.

Suggestions for changes to recommendations were 1) to add comments on moisture and grain temperature for continuous or intermittent operation; 2) to estimate fan operation time; 3) to list required exhaust area; 4) to recommend downward airflow and 5) to include comments on pest control, birds, rodents and insects.

Reviewers agreed that the program (as is or with changes) would be helpful to them in the process of designing aeration systems. They would recommend it to county agents, farmers and aeration equipment suppliers. Half of the reviewers responding reported that the technical evaluation process caused them to think about the problem of aeration system design differently, and six indicated that they would consider changes to their current aeration system design procedure. Most of these reviewers were considering the use of different air path ratios for the outer ducts depending on the grain depth. One reviewer said the evaluation process did not cause him to think about the problem differently, but he would use the program to design more accurately and to quickly try different alternatives.

Reviewers made additional comments on the usability of the program. One reviewer, who designs aeration systems on a regular basis, suggested modifying the program so it would run without a printer or commercial software. Others reiterated their previous comments to add new capabilities. The reviewers also wanted expert users to be able to change design guideline factors easily. Some very positive comments were 1) "good program"; 2) "it serves the audience you identify"; 3) "with use it, like old wine, will get better with age"; 4) "generally very good and easy to use" and 5) "very impressed".

IMPLICATIONS OF EVALUATION

The results of the evaluation process were scrutinized to consider the implications for future use of the aeration system design program. Following are implications for the technical content and usability of the program.

TECHNICAL IMPLICATIONS

The concurrent validity test indicated that a "moderate" or "substantial" difference exists between the design guidelines used in the program and by the reviewers. Differences in design guidelines among the reviewers were also found. The results generated by the program were concurrent with the guidelines used to develop the program, so the difference in problem solutions is a function of variation in experts' preferred guidelines. Reviewers generally approved the content and sensitivity of the program.

Construct Considerations

Changing the program to completely satisfy all reviewers may be an enormous task. However, some key changes would make the program more flexible. One change would be to allow an expert to change design guideline factors in the program. This capability should be available to experts only and not to clients. For example, an expert could customize the program by changing the air path ratio factors.

Five changes are recommended for the construct of the program. The program could generate more practical designs for shallow storages by ignoring grain depths equal to or less than a given parameter. This parameter should be alterable by an aeration design expert and would initially be set at 1.2 m (4 ft). This parameter should be verified with experimental data or observations.

The second recommended change is to increase the percent airflow velocity variation from 5 to 10 percent, to allow selection of a smaller size fan, duct or supply tube.

The third change addresses the variation in rules used to determine the distance to offset a perforated duct from the end of a storage. The current method maintains air paths as equal as possible and should be retained as a calculation of the maximum distance to offset a duct from the end of a storage. Another method is needed which allows a greater variation in air flow paths, similar to the results of the reviewers. A ratio factor should be used to allow an aeration design expert to place the end of a duct between the points determined by the two methods. For example, if the ratio factor was set at 0.5, the end of the duct would be placed halfway between the two points.

Another change is to increase the allowable length of plastic aeration tubing from a fan. The current value of 18.2 m (60 ft) should be changed to 24.4 m (80 ft).

The fifth change is to include additional fan size data in the program, particularly data for centrifugal fans less than 3.7 kW (5 hp).

Development of the aeration system design program and the technical review process pointed out several areas of aeration system design that would benefit from additional research. Some topics that should be considered for investigation are

- the allowable depth of grain that will cool or warm by conduction without aeration
- effects of a tarp-covered storage on airflow distribution along a duct
- effects of a small percentage of open area in ducts on airflow distribution
- rules for determining the offset of a perforated duct from the end of a storage
- effects of corrugated and smooth wall conduits on airflow distribution
- bed depth to use in estimating static pressure of grain in a flat storage

Content Considerations

Reviewers suggested improvements to the response screens and 'help' information as listed in Tables 17 and 19. Some suggestions are purely cosmetic. Incorporation of these changes should depend on the expert who is using the program or preparing it for use by non-experts.

Two changes are recommended for the response screens. First, the question about structure liners should be clarified to state that, if requested, information will be printed at the end of the program. Second, illustrations for the fan arrangement screen should be improved. The illustration for "fans at ends only" should be changed to have fans at only one end of the storage. The figures should be rescaled so that length and width are approximately equal or different figures should be used for widthwise and lengthwise duct direction.

An expert who wants to use the program himself or have clients use it should consider making changes to the questions and 'help' information to customize the program. The text displayed on the screens is defined in an ASCII file that can easily be modified with common text editing software.

USABILITY IMPLICATIONS

Results of the usability evaluation were very favorable. The user interface developed for this program was very easy to use and was recommended for use by beginning microcomputer users, county extension agents and farmers. Two changes are recommended for the interview processor. One, the user interface should be changed so the highlighted option on choice response screens is always selected when the screen is exited. Two, the user interface should be adapted to run on common IBM-compatible computers with graphics capabilities by adding display device independence.

Reviewers offered suggestions for the design drawing, component specification list and management recommendations. The term 'connector' on the component specification list should be changed to 'supply tube'. Changes to the management recommendations should be tailored to the expert using the program. Any changes to the management recommendations can be made with text editing software since an ASCII file similar to the interview text is used.

The aeration system design program should be evaluated by county extension agents and farmers for ease of use. This additional evaluation may result in further improvements to the interview processor.

The development system (described in Chapter III) should be used to develop additional applications to test its flexibilities. Software tools in the development system should be updated as improved versions become available. Software improvements should make it easier to develop a new application.

The cost of commercial software used in the development system is a hindrance to distribution of programs developed with the system. Lower cost commercial products should be considered or advantageous licensing agreements should be pursued with the manufacturers.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

A computer program was developed to design aeration systems for farm-sized flat grain storages. The program utilizes interactive computer graphics technology to interact with users.

Aeration system design guidelines and recommendations from various sources were consolidated into a set of guidelines for use in the computer program.

A development system was presented and set of software tools was synthesized for development of agricultural engineering design programs. The development system was modeled after an expert's problem solving process for design applications and divides a computer program into components of interview, calculations, design drawing and management recommendations. With this development system a computer program may be developed using several different software products, but the program appears as one to a user.

A group of software tools suitable for implementing each component of the development system was presented and the tools used to implement the aeration system design program were described. The interview, management recommendations and framework components were implemented with software developed in the Interactive Computer Graphics Laboratory in the Agricultural Engineering department at Michigan State University. The calculations component consisted of a program written by the author in the 'C' programming language. Commercial software products, AutoCAD and Synthesis, were used to implement the design drawing processor.

The calculations component of the aeration system design program consists of post spacing, storage capacity and component placement and sizing modules. The placement of ducts was accomplished with a modified air path ratio method. A higher air path ratio was used to place a duct from an outer wall of a storage compared to placement in the center of a storage. This method results in duct placement similar to methods which base the number and placement of ducts on the size of the storage. Based on the user responses to questions about a grain storage, the program prepares paper copy of a floor plan of the duct layout, a list of component specifications and a list management recommendations for the user.

A structured review process was used to evaluate the aeration system design program. Nine extension specialists and industry representatives evaluated technical and usability aspects of the program. Technical content was evaluated for concurrent validity, construct validity, content validity and sensitivity. Usability evaluation centered on ease of use, information conveyance, pertinence of illustrations and usefulness of the design drawing and management recommendations.

Differences were found between results generated by the computer program and the reviewers. Differences were also found among reviewers. The difference in problem solutions is a function of variation in the reviewers' preferred guidelines. Reviewers generally approved the content and sensitivity of the program.

Results of the usability evaluation were very favorable. The user interface was rated very easy to use and was recommended for use by beginning microcomputer users, county extension agents and farmers. Reviewers agreed that the program (as is or with changes) would be helpful to them in the process of designing aeration systems. They would recommend the program to county extension agents, farmers and aeration equipment suppliers. Two-thirds of the reviewers were considering changes to their design process as a result of the evaluation process.

RECOMMENDATIONS FOR AGRICULTURAL DESIGN PROGRAMS

The development system described in Chapter III should be used for development of agricultural engineering design programs. By dividing the program development process into components, commercial software products can be used when available and the software used to implement one component of the program can be upgraded or replaced without redoing the entire program. Graphics should be utilized in a program as much as possible, as they stimulate a user's interest and can be used to reduce the amount of text a user must read.

Software tools in the development system should be upgraded as improved versions become available. Software improvements should make it easier to develop an application. Lower cost commercial software products should be considered to make it easier for interested parties to obtain and run the program.

RECOMMENDATIONS FOR AERATION SYSTEM DESIGN

Development of the aeration system design program and the technical review process pointed out several areas of aeration system design that would benefit from additional research. Some topics that should be investigated are

- the allowable depth of grain that will cool or warm by conduction without aeration.
- the effects of a tarp-covered storage on airflow distribution along a duct.

- the effects of a small percentage of open area in ducts on airflow distribution.
- the effects of corrugated and smooth wall conduits on airflow distribution.
- rules for determining the offset of a perforated duct from the end of a storage.
- the bed depth to use in estimating static pressure of grain in a peaked storage.

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APPENDICES

APPENDIX A

Listing of Interview Text File

```
%/ID INF1
%/TL1 AERATION SYSTEM DESIGN
%/TX            Developed by:

       D.G. Watson and R.C. Brook

    Kellogg Computer Graphics Project
        Agricultural Engineering
        Michigan State University
        E. Lansing, MI 48824
           (517)  355-1890

            Copyright 1987
          All Rights Reserved
%/EX
%/HP aerplan
%/HL INF2
%/NX INF50

%/ID INF10
%/TL1 Help with key commands
%/TX    Key                         Function
    ----------------------------------------------
    F1              Help with current screen
    F2              Help with key commands
    F3 or PgUp       Back up to previous screen
    F4 or PgDn       Continue to next screen
    F9              Restart from beginning
    Alt-F10           Quit program

Use the Up and Down arrow keys to change position of the highlight box.

The 'Enter' key is used to:
    1)  select or deselect a choice response
    2)  end an alphanumeric or numeric response.
%/EX
%/NP
%/NX END

%/ID INF50
%/TL General instructions
%/TXPlease note the two lines in the green
area at the bottom of the screen.  These
two lines of help information are visible
at all times.

Press the F1 key, a sample help screen
will be displayed.

Press the F2 key, a list of special key
commands will be displayed.

The F1 and F2 keys can be pressed at
any time.
```

```
%/EX
%/HP keys
%/HL INF51
%/NX ALP110

%/ID ALP110
%/TL1 Client information
%/QN1 Enter the following information about
%/QN2 the client:
%/PR1 name
%/PR2 company
%/PR3 address
%/PR4 city
%/PR5 state
%/PR6 zip code
%/PR7 phone
%/VR1 name  %1.30s
%/VR2 company   %1.30s
%/VR3 address   %1.30s
%/VR4 city  %1.30s
%/VR5 state %1.30s
%/VR6 zip_code  %1.30s
%/VR7 phone %1.30s
%/HP clientin
%/HL INF111
%/NX CHO120

%/ID CHO120
%/TL1 Grain type
%/QN1 Select the type of grain to be stored:
%/PR1 shelled corn
%/PR2 soybeans
%/PR3 wheat
%/PR4 grain sorghum
%/VR1 grain_type    %1d
%/HP grains
%/HL INF121
%/NX CHO140

%/ID CHO140
%/TL1 New structure
%/QN1 Is a new structure planned for the
%/QN2 grain storage?
%/PR1 no
%/PR2 yes
%/VR1 new_building %1d
%/HP structur
%/HL INF141
%/NX CHO145  CHO147

%/ID CHO145
%/TL1 Construction type
%/QN1 Is your storage structure of post-frame
%/QN2 construction?
%/PR1 yes
%/PR2 no
%/VR1 construction_type %1d
%/HL INF146
%/NX CHO150  CHO160

%/ID CHO147
%/TL1 Construction type
%/QN1 Are you planning to use post-frame
%/QN2 construction for your new building?
%/PR1 yes
%/PR2 no
%/VR1 construction_type %1d
%/HL INF148
%/NX CHO150  CHO160

%/ID CHO150
%/TL1 Post spacing
```

```
%/QN1 Select the post spacing of the storage
%/QN2 structure or self supporting grain
%/QN3 wall:
%/PR1 2 feet
%/PR2 4 feet
%/PR3 6 feet
%/PR4 8 feet
%/PR5 self supporting grain wall
%/VR1 post_spacing %1d
%/HP postspac
%/HL INF151
%/NX CHO160

%/ID CHO160
%/TL1 Structure liner
%/QN1 Do you need information on grain liners
%/QN2 or self supporting grain walls?
%/PR1 no
%/PR2 yes
%/VR1 liner_info %1d
%/HP liners
%/HL INF161
%/NX NUM170

%/ID NUM170
%/TL1 Storage size
%/QN1 Enter the length and width of the storage:
%/PR1 storage width, ft
%/PR2 storage length, ft
%/VR1 storage_width %5.1f   40  1   999
%/VR2 storage_length    %5.1f   80  1   999
%/HP storsize
%/HL INF171
%/NX NUM180

%/ID NUM180
%/TL1 Grain depths on walls
%/QN1 Enter the higher and lower grain depths
%/QN2 planned for the side and end walls:
%/PR1 higher side grain depth, ft
%/PR2 lower side grain depth, ft
%/PR3 higher end grain depth, ft
%/PR4 lower end grain depth, ft
%/VR1 higher_sidewall_height %5.2f  4   0   30
%/VR2 lower_sidewall_height %5.2f   4   0   30
%/VR3 higher_endwall_height %5.2f   4   0   30
%/VR4 lower_endwall_height %5.2f    4   0   30
%/HP walldpth
%/HL INF181
%/NX SPL

%/ID NUM180b
%/TL1 Grain depths on walls
%/QN1 Enter the deep and shallow grain depths
%/QN2 planned for the side and end walls:
%/PR1 deep side grain depth, ft
%/PR2 shallow side grain depth, ft
%/PR3 deep end grain depth, ft
%/PR4 shallow end grain depth, ft
%/VR1 higher_sidewall_height %5.2f  4   0   20
%/VR2 lower_sidewall_height %5.2f   4   0   20
%/VR3 higher_endwall_height %5.2f   4   0   20
%/VR4 lower_endwall_height %5.2f    4   0   20
%/HP walldpth
%/HL INF181
%/NX SPL

%/ID INF185
%/TL1 Post size
%/TXBased on the %/post_spac_ft ft post spacing and
the highest grain depth of %/highest_wall ft, a post
size of at least %/post_size is required.
```

```
%/EX
%/HP postsize
%/HL INF186
%/NX NUM190

%/ID INF187
%/TL1 Post size
%/TXWARNING:

Based on the post spacing of %/post_spac_ft ft and
the highest grain depth on a wall of %/highest_wall ft
a post size of greater than 8" x 8" is
required.
%/EX
%%/HL INF188
%/NX NUM190

%/ID NUM190
%/TL1 Maximum piling height
%/QN1 Enter the maximum piling height of the
%/QN2 grain in the storage structure:
%/PR1 maximum piling height, ft
%/VR1 maximum_piling_height %5.2f   12  1   99
%/HP maxpile
%/HL INF191
%/NX SPL

%/ID INF193
%/TL1 Grain depth problem
%/TXGrain depths on walls are impossible based
on storage dimensions.  Either the storage
is very small or a grain depth on a wall
is very high. Check your storage
dimensions. If they are correct, the grain
depths on the walls must be reduced.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate the program.
%/EX
%/NX END

%/ID INF195
%/TL1 Bushel capacity
%/TXThe grain storage you have described will
hold approximately %/bushel_capacity bushels, with
the actual peak at %/peak_height ft being leveled
to a width of %/width_of_peak_height ft.

If this is more or less than required
you may want to go back and change the
storage size or grain depths.

Press F3 or PgUp if you need to go back
and make changes.
%/EX
%/HP bushel
%/NX CHO200

%/ID INF197
%/TL1 Small storage
%/TXNOTE:
Your grain storage of %/bushel_capacity bushels
with a peak depth of %/peak_height ft is too
small to be used with this program.

Typically storages of less than %/minimum_bushels
bushels or peak grain depth of %/minimum_depth ft or
less can be held for 3 months without
aeration. You may want to recheck the
dimensions or grain depths.
```

```
Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX END

%/ID CHO200
%/TL1 Number of ducts
%/QN1 Select the method for determining the
%/QN2 number of ducts:
%/PR1 computer selected
%/PR2 user selected
%/VR1 duct_selection_method %ld
%/HP compman
%/HL INF201
%/NX SPL

%/ID NUM205
%/TL1 Number of ducts
%/QN1 Enter the number of ducts to place in
%/QN2 the storage:
%/PR1 number of ducts
%/VR1 desired_number_of_ducts   %ld
%/HP numducts
%/HL INF206
%/NX CHO240

%/ID CHO240
%/TL1 Duct type
%/QN1 Select the preferred duct type:
%/PR1 plastic
%/PR2 spiral-lok metal
%/PR3 round metal
%/PR4 half-round metal
%/VR1 duct_type %ld
%/HP ducttype
%/HL INF241
%/NX CHO230

%/ID CHO230
%/TL1 Duct direction
%/QN1 Select the preferred direction of
%/QN2 duct runs:
%/PR1 lengthwise
%/PR2 widthwise
%/VR1 duct_direction %ld
%/HP ductdirc
%/HL INF231
%/NX CHO220

%/ID CHO220
%/TL1 Fan type
%/QN1 Select the type of fan you prefer to use:
%/PR1 axial
%/PR2 centrifugal
%/VR1 fan_type %ld
%/HP fantype
%/HL INF221
%/NX CHO210

%/ID CHO210
%/TL1 Fan arrangement
%/QN1 Select a fan arrangement option:
%/PR1 end and middle placement
%/PR2 end placement only
%/PR3 middle placement preferred
%/VR1 desired_fan_arrangement   %ld
%/HP fanarr
%/HL INF211
%/NX NUM250

%/ID NUM250
```

```
%/TL1 Airflow rate
%/QN1 Enter the design airflow rate for the
%/QN2 aeration system in terms of cfm per
%/QN3 bushel:
%/PR1 airflow rate, cfm/bu
%/VR1 cfm_per_bushel    %4.2f   0.15    0.01    9.99
%/HP airflow
%/HL INF251
%/NX SPL

%/ID INF261
%/TL1 Calculations complete
%/TX
This grain storage requires %/number_of_ducts duct(s).

This program will next print the component
specifications and display the aeration
system plan.

Be sure the printer is ready before
continuing.
%/EX
%/NX SPL

%/ID INF263
%/TL1 Too many ducts
%/TXThis grain storage requires more than 20
ducts, which is the limit for this program.
Either the storage is very large or the
grain profile is very shallow.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF265
%/TL1 Widthwise placement not recommended
%/TXWidthwise duct placement is not
recommended for this storage. The
resulting airflow would be too non-uniform.
Try placing ducts lengthwise or changing
grain depths to provide a more level grain
profile.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF267
%/TL1 Lengthwise placement not recommended
%/TXLengthwise duct placement is not
recommended for this storage. The
resulting airflow would be too non-uniform.
Try changing grain depths to provide a more
level grain profile.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF269
%/TL1 More than 2 fans per duct
%/TXMore than 2 fans are required for a
duct, which is the limit for this program.
Try shortening the storage dimension
corresponding to the direction of duct runs
```

```
or change the duct direction.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF271
%/TL1 Fan size not available
%/TXA fan size required for the storage is
larger than the maximum available size.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF273
%/TL1 Duct size not available
%/TXA duct size required for the storage is
larger than the maximum available size.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF275
%/TL1 Connector size not available
%/TXA connector size required for the storage
is larger than the maximum available size.

Use F3 or PgUp keys to go back and
change your responses or continue forward
to terminate this program.
%/EX
%/NX INF300

%/ID INF277
%/TL1 Calculations complete
%/TX
You selected %/desired_number_of_ducts duct(s) and the program
designed for %/number_of_ducts duct(s).

This program will next print the component
specifications and display the aeration
system plan.

Be sure the printer is ready before
continuing.
%/EX
%/NX SPL

%/ID INF278
%/TL1 Calculations complete
%/TXYou selected %/desired_number_of_ducts duct(s) and the program
designed for %/number_of_ducts duct(s).

WARNING:
This arrangement is not recommended. The
air path ratio from the outermost duct to
the wall is %/max_apr which exceeds the normal
maximum of %/design_max_apr for this situation.

You should back up and increase the
number of ducts or let this program select
the number of ducts.
%/EX
%/NX INF279
```

```
%/ID INF279
%/TL1 Calculations complete
%/TX
Should you continue and use this design,
be advised that the risk of grain spoilage
is very high.

This program will next print the component
specifications and display the aeration
system plan.

Be sure the printer is ready before
continuing.
%/EX
%/NX SPL

%/ID CHO280
%/TL1 Recommendations
%/QN1 Are you satisfied with the design?
%/QN2 (If so, the recommendations will be
%/QN3 printed.)
%/PR1 yes
%/PR2 no
%/VR1 recommendations  %1d
%/HL
%/NX SPL INF290

%/ID INF290
%/TL1 Unfinished design
%/TX
You can use the F3 or PgUp keys to go
back and change your responses or continue
forward to terminate this program.
%/EX
%/NX INF300

%/ID INF300
%/TL1 End of program
%/TX
Thank you for using this aeration system
design program.

Remember to take your printouts.

Pressing F4 or PgDn on this screen will
end this program.
%/EX
%/NX END

%/ID INF2
%/TL1 Help for aeration system design
%/TXThe aeration system design program
generates a customized aeration system
plan based on the information provided
by the user.

This program was developed for farm-size
flat grain storages.
%/EX
%/HP aerplan
%/NX END

%/ID INF51
%/TL1 Help for general instructions
%/TXThis is a sample help screen.

If you press the F1 key when a question
is displayed on a screen, a help screen
like this will contain information about
the question.
%/EX
```

```
%/HP keys
%/NX END

%/ID INF111
%/TL1 Help for client information
%/TXThe client is the person for whom the
aeration system is being designed.

Information about the client is requested
for future reference in contacting the
client and printing name and address on
printouts.

Company name may be a farm name or left
blank.
%/EX
%/HP clientin
%/NX END

%/ID INF121
%/TL1 Help for grain type
%/TXThe aeration system design program will
design an aeration system for 4 crops:
shelled corn, soybeans, wheat and grain
sorghum.

The type of grain determines the angle of
repose or filling angle of the grain in
storage and the performance of an
aeration system.

Small grains such as wheat and grain
sorghum offer higher static pressure and
result in lower airflow from a given
aeration fan.
%/EX
%/HP grains
%/NX END

%/ID INF141
%/TL1 Help for new structure
%/TXThis response is used to make an
appropriate management recommendation.

If an existing structure is to be used for
grain storage, a vapor barrier will
probably be needed on the floor. Also, a
metal roof invariably leaks somewhere and
will need to be patched.

If a new structure is to be built, a vapor
barrier should be placed on the ground
before pouring the concrete floor.  Also
consider a shingled roof to eliminate
water leakage.
%/EX
%/HP structure
%/NX END

%/ID INF146
%/TL1 Help for construction type
%/TXIf your storage structure is post-frame
construction, you will be asked about
post spacing and the required post size
will be calculated.

If your structure is not post-frame
construction and you plan to pile grain
against the walls, you should contact the
manufacturer, builder or a consulting
engineer to verify that the structure will
support the desired depth of grain on the
```

```
side walls.
%/EX
%/NX END

%/ID INF148
%/TL1 Help for construction type
%/TXIf your storage structure will be
post-frame construction, you will be asked
about post spacing. You can enter a
planned post spacing and the required post
size will be calculated for you.

If your structure will not be post-frame
construction and you plan to pile grain
against the walls, you should consult with
potential builders about the suitability of
the building to support grain on the
side walls.
%/EX
%/NX END

%/ID INF151
%/TL1 Help for post spacing
%/TXThis response is used to calculate the
required post size for the building.

A self supporting grain wall may be used to
eliminate having to reinforce the building
wall. If this is the case select the 'self
supporting grain wall' option.

Post spacing often limits the depth to
which grain can be piled on the building
walls.  Grain piled too high on a side wall
may result in structural damage.
%/EX
%/HP postspac
%/NX END

%/ID INF161
%/TL1 Help for structure liner
%/TXBy responding yes to this question, a
source of plans for grain liners and self
supporting grain walls will be included in
the recommendations printed later in the
program.

A liner must be installed in the storage
structure to withstand the force of the
grain on the walls. Various types of liners
are available.  Two common ones are
plywood liners and self supporting grain
walls.
%/EX
%/HP liners
%/NX END

%/ID INF171
%/TL1 Help for storage size
%/TXThe storage size is used to calculate
the bushel capacity of the storage and
determine the placement of ducts.

If you are not sure how much space in a
building will be needed for grain storage,
you can start with a trial width and length.
The actual capacity will be calculated and
you can revise the storage dimensions.
%/EX
%/HP storsize
%/NX END
```

```
%/ID INF181
%/TL1 Help for grain depth on walls
%/TXGrain depths are used to calculate the
storage size and determine the placement
of ducts.

This program will work with different
grain depths on the four walls. Consider
the side walls separately from the end
walls. The side walls are the longer
walls in the storage.

If the two side (or end) walls will be at
different grain depths then enter the
higher of the two depths as the higher
side (or end) grain depth.
%/EX
%/HP walldpth
%/NX END

%/ID INF186
%/TL1 Help for post size
%/TXThe post size was calculated based on
the post spacing and the highest grain
depth on a wall.

If a post smaller than %/post_size is used,
then structural damage may occur.

If your posts are smaller than %/post_size
consider reducing grain depths on the
walls or using a self supporting grain
wall.
%/EX
%/HP postsize
%/NX END

%/ID INF188
%/TL1 Help for post size
%/TXThis program attempted to determine the
required post size based on the post
spacing and the highest grain depth on
a wall.

The largest post size for which information
is available is 8" x 8".

Consider reducing the grain depths on the
walls or using a self supporting grain
wall.
%/EX
%/NX END

%/ID INF191
%/TL1 Help for maximum piling height
%/TXMaximum piling height is used to
determine the bushel capacity of the
storage and size aeration equipment.

Maximum piling height is the limit for
how high the grain can be piled in the
storage. A common limitation is the height
of the trusses, since grain should not be
piled up into the trusses.

Loading equipment may further limit the
piling height of the grain.
%/EX
%/HP maxpile
%/NX END

%/ID INF201
```

```
%/TL1 Help for number of ducts
%/TXThis program can determine the number
of ducts to aerate the grain properly or
you can set the number of ducts.

It is advised that the 'computer selected'
option be selected.
%/EX
%/HP compman
%/NX END

%/ID INF206
%/TL1 Help for number of ducts
%/TXYou have elected to enter the number of
ducts to be placed in the storage.  If you
would rather have this program determine
the number of ducts, use F3 or PgUp to
back up to the previous screen and choose
the 'computer selected' option.

If the program has previously indicated
that the required fan or duct size was
larger than available, then you may need to
increment the number of ducts determined
by this program until the fan and duct
sizes match available sizes.
%/EX
%/HP numducts
%/NX END

%/ID INF211
%/TL1 Help for fan arrangement
%/TXThis response is used to determine
whether to place a fan at the end or
middle of a duct. In long storages (100'
or more) the number of fans required can
be reduced by placing 1 fan in the middle
of the outermost ducts instead of 1 fan at
each end. For long duct lengths the option
'end and middle placement' allows the
program to select the placement with the
least fans.

The choice 'middle placement preferred'
will place fans in the middle of the
outermost ducts regardless of duct length.
%/EX
%/HP fanarr
%/NX END

%/ID INF221
%/TL1 Help for fan type
%/TXA fan size will be determined for the
fan type you select. An axial fan is usually
chosen for flat storages. The smallest
centrifugal fan (27"-5hp) is too large in
most cases and a matching duct size is not
available.

Centrifugal fans are required if static
pressures exceed 4" of water (which is
rarely the case in flat storages) or noise
level limits require a centrifugal fan.
In either case, 1 fan may need to supply
multiple ducts and this program does not
allow a fan to supply more than 1 duct.
%/EX
%/HP fantype
%/NX END

%/ID INF231
%/TL1 Help for duct direction
```

%/TXDucts should be placed in the storage in the direction which will result in the most uniform grain depth over the duct. In most cases this means lengthwise placement.

In some storages, widthwise placement is not recommended because the variation in grain depth will severely reduce the performance of the aeration system.
%/EX
%/HP ductdirc
%/NX END

%/ID INF241
%/TL1 Help for duct type
%/TXThe duct type affects the cost of an aeration system. Any of the ducts types will do an acceptable job in distributing air through the grain.

Plastic ducts are often desirable due to lower costs, but are more susceptible to damage during handling. Spiral-lok metal is usually less expensive than round metal.

The design difference between plastic and other round ducts is the allowable length of a duct. Plastic ducts are limited to shorter runs.
%/EX
%/HP ducttype
%/NX END

%/ID INF251
%/TL1 Help for airflow rate
%/TXThe airflow rate is a factor in sizing a fan. A proper airflow rate should be selected for grain aeration.

An airflow of 0.1 to 0.2 cfm (cubic feet/minute) per bushel is needed for farm stored grains. An airflow of 0.1 cfm/bu is adequate for clean, dry grain. For poor quality grain (high broken kernels and fines content) use 0.2 cfm/bu for an adequate airflow.

For grain of average condition an airflow rate of 0.15 cfm/bu is recommended.
%/EX
%/HP airflow
%/NX END

%/ID MES170
%/TXThe length of the storage must be greater than or equal to its width.

Press a key to continue.
%/EX

%/ID MES180A
%/TXGrain depth on the higher side wall must be greater than or equal to the lower side wall depth.

Press a key to continue.
%/EX

%/ID MES180B
%/TXGrain depth on the higher end wall must be greater than or equal to the lower end wall depth.

```
Press a key to continue.
%/EX

%/ID MES190
%/TXGrain depth on the walls of the storage
cannot be higher than the maximum piling
height.

Press a key to continue.
%/EX

%/ID MES250
%/TXOne moment please, while the
necessary calculations are performed.
%/EX

%/ID MES261
%/TXOne moment please, while the component
specifications are being printed and the
drawing is being prepared for display.
%/EX

%/ID MES280
%/TXOne moment please, while the
recommendations are being prepared and
printed.
%/EX

%/ID MESA101
%/TXUnable to open file to write data
structure.
%/EX

%/ID MESA102
%/TXUnable to close file after writing data
structure.
%/EX

%/ID MESA103
%/TXUnable to open file to read data into
structure.
%/EX

%/ID MESA104
%/TXUnable to close file after reading data
into structure.
%/EX

%/ID MESA105
%/TXUnable to open file to write data items.
%/EX

%/ID MESA106
%/TXUnable to close file after writing data
items.
%/EX

%/ID MESA107
%/TXUnable to open file to read data items
into structure.
%/EX

%/ID MESA108
%/TXUnable to close file after reading data
items into structure.
%/EX

%/ID MESA109
%/TXUnable to open drawing specification
file.
%/EX
```

```
%/ID MESA110
%/TXUnable to close drawing specification
file.
%/EX

%/ID MESA111
%/TXUnable to open component specification
file.
%/EX

%/ID MESA112
%/TXUnable to close component specification
file.
%/EX
```

APPENDIX B

'C' Source Code for Function to Perform Consistency Checks

```
int consistency_check(key)
char *key;
{                          /* consistency_check */
    double x, y, z;
    char value_string[MAX_STRING_LENGTH];
    if (!strnicmp(key, "NUM170", 6))
    {
        get_intview_data_item("storage_width", value_string);
        x = atof(value_string);
        get_intview_data_item("storage_length", value_string);
        y = atof(value_string);
        if (y < x)
        {
            display_message("MES170", TIL_KBHIT);
            return (-1);
        }
    }
    else if (!strnicmp(key, "NUM180", 6))
    {
        get_intview_data_item("higher_sidewall_height", value_string);
        x = atof(value_string);
        get_intview_data_item("lower_sidewall_height", value_string);
        y = atof(value_string);
        if (x < y)
        {
            display_message("MES180a", TIL_KBHIT);
            return (-1);
        }
        get_intview_data_item("higher_endwall_height", value_string);
        x = atof(value_string);
        get_intview_data_item("lower_endwall_height", value_string);
        y = atof(value_string);
        if (x < y)
        {
            display_message("MES180b", TIL_KBHIT);
            return (-1);
        }
    }
    else if (!strnicmp(key, "NUM190", 6))
    {
        get_intview_data_item("higher_sidewall_height", value_string);
        x = atof(value_string);
        get_intview_data_item("higher_endwall_height", value_string);
        y = atof(value_string);
        get_intview_data_item("maximum_piling_height", value_string);
        z = atof(value_string);
        if (z < max(x, y))
        {
            display_message("MES190", TIL_KBHIT);
            return (-1);
        }
    }
    return (0);
}                          /* consistency_check */
```

APPENDIX C

'C' Source Code for Function to Perform Special Flow Control

```
void special_next_screen(key)

char *key;

{                       /* special_next_screen */

    char temp_string[MAX_STRING_LENGTH];

    if (!strnicmp(key, "NUM180", 6))
    {
        copy_data_to_struct();
        if (design_data.post_spacing && larger(design_data.higher_sidewall_height,
            design_data.higher_endwall_height) > 0)
        {
            if (post_sizing())
                strcpy(screen_key, "INF187");
            else
            {
            sprintf(temp_string, "%d", design_data.post_spacing);
            put_intview_data_item("post_spac_ft", temp_string);
            put_intview_data_item("post_size", design_data.post_size);
            sprintf(temp_string, "%3.1f", larger(design_data.higher_sidewall_height,
                design_data.higher_endwall_height));
            put_intview_data_item("highest_wall", temp_string);
            strcpy(screen_key, "INF185");
            }
        }
        else
        {
            put_intview_data_item("post_size", design_data.post_size);
            strcpy(screen_key, "NUM190");
        }
    }
    else if (!strnicmp(key, "NUM190", 6))
    {
        copy_data_to_struct();
        switch (storage_capacity())
        {
        case 0:
            sprintf(temp_string, "%ld", (long) design_data.bushel_capacity);
            put_intview_data_item("bushel_capacity", temp_string);
            sprintf(temp_string, "%3.1f", design_data.peak_height);
            put_intview_data_item("peak_height", temp_string);
            sprintf(temp_string, "%3.1f", design_data.width_of_peak_height);
            put_intview_data_item("width_of_peak_height", temp_string);
            strcpy(screen_key, "INF195");
            break;
        case 1:
            strcpy(screen_key, "INF193");
            break;
        case 2:
            sprintf(temp_string, "%3.1f", design_data.peak_height);
            put_intview_data_item("peak_height", temp_string);
            sprintf(temp_string, "%ld", (long) design_data.bushel_capacity);
```

```
            put_intview_data_item("bushel_capacity", temp_string);
            sprintf(temp_string, "%d", (int) factor.minimum_bushels);
            put_intview_data_item("minimum_bushels", temp_string);
            sprintf(temp_string, "%d", (int) factor.minimum_depth);
            put_intview_data_item("minimum_depth", temp_string);
            strcpy(screen_key, "INF197");
            break;
        }
    }
    else if (!strnicmp(key, "CHO200", 6))
    {
        get_intview_data_item("duct_selection_method", temp_string);
        if (atoi(temp_string) == 0)
        {
            sprintf(temp_string, "0");
            put_intview_data_item("desired_number_of_ducts", temp_string);
            strcpy(screen_key, "CHO240");
        }
        else
            strcpy(screen_key, "NUM205");
    }
    else if (!strnicmp(key, "NUM250", 6))
    {
        display_message("MES250", LEAVE_UP);
        copy_data_to_struct();
        switch (component_placement_sizing())
        {
        case 0:
            sprintf(temp_string, "%d", design_data.number_of_ducts);
            put_intview_data_item("number_of_ducts", temp_string);
            if (design_data.desired_number_of_ducts)
            {
                float higher_wall, design_apr;

                if (design_data.duct_direction == LENGTHWISE)
                    higher_wall = design_data.higher_sidewall_height;
                else
                    higher_wall = design_data.higher_endwall_height;
                if (higher_wall >= factor.depth_deep)
                    design_apr = factor.ratio_deep;
                else
                    design_apr = factor.ratio_shallow;
                if (max(design_data.lower_side_air_path_ratio,
                    design_data.higher_side_air_path_ratio) > design_apr)
                {
                    sprintf(temp_string, "%3.2f", max(design_data.
                        lower_side_air_path_ratio, design_data.
                        higher_side_air_path_ratio));
                    put_intview_data_item("max_apr", temp_string);
                    sprintf(temp_string, "%3.1f", design_apr);
                    put_intview_data_item("design_max_apr", temp_string);
                    strcpy(screen_key, "INF278");
                }
                else
                    strcpy(screen_key, "INF277");
            }
            else
                strcpy(screen_key, "INF261");
            break;
        case 1:
            strcpy(screen_key, "INF263");
            break;
        case 2:
            strcpy(screen_key, "INF265");
            break;
        case 3:
            strcpy(screen_key, "INF267");
            break;
        case 4:
            strcpy(screen_key, "INF269");
            break;
        case 5:
```

```
            strcpy(screen_key, "INF271");
            break;
        case 6:
            strcpy(screen_key, "INF273");
            break;
        case 7:
            strcpy(screen_key, "INF275");
            break;
        }
        flush_keyboard();
    }
    else if (!strnicmp(key, "INF261", 6) || !strnicmp(key, "INF277", 6) || !strnicmp(key,
        "INF279", 6))
    {
        display_message("MES261", LEAVE_UP);
        drawing_processor();
        strcpy(screen_key, "CHO280");
        flush_keyboard();
    }
    else if (!strnicmp(key, "CHO280", 6))
    {
        get_intview_data_item("recommendations", temp_string);
        if (atoi(temp_string) == 0)
        {
            display_message("MES280", LEAVE_UP);
            recommendations_processor();
        }
        strcpy(screen_key, "INF300");
        flush_keyboard();
    }

}                        /* special_next_screen */
```

APPENDIX D

Sample Data File Produced by Interview Component

name	Dennis Watson
company	Michigan State University
address	106A Farrall Hall
city	E. Lansing
state	Michigan
zip_code	48824
phone	123-456-7890
grain_type	0
new_building	0
construction_type	0
post_spacing	3
liner_info	0
storage_width	60
storage_length	100
higher_sidewall_height	6
lower_sidewall_height	6
higher_endwall_height	6
lower_endwall_height	6
post_spac_ft	8
post_size	6" x 6"
highest_wall	6.0
maximum_piling_height	16
bushel_capacity	54517
peak_height	16.0
width_of_peak_height	17.1
duct_selection_method	0
desired_number_of_ducts	0
duct_type	2
duct_direction	0
fan_type	0
desired_fan_arrangement	0
cfm_per_bushel	0.15

APPENDIX E

Sample Data File Produced by Calculations Component

name	Dennis Watson
company	Michigan State University
address	106A Farrall Hall
city	E. Lansing
state	Michigan
zip_code	48824
phone	123-456-7890
grain_type	0
new_building	0
construction_type	0
post_spacing	8
liner_info	0
storage_width	60.000000
storage_length	100.000000
higher_sidewall_height	6.000000
lower_sidewall_height	6.000000
higher_endwall_height	6.000000
lower_endwall_height	6.000000
maximum_piling_height	16.000000
desired_number_of_ducts	0
desired_fan_arrangement	0
fan_type	0
duct_direction	0
duct_type	2
cfm_per_bushel	0.150000
post_size	6" x 6"
tan_angle_of_repose	0.466308
peak_height	16.000000
width_of_peak_height	17.109862
length_of_peak_height	57.109862
bushel_capacity	54517.499342
lower_side_air_path_ratio	1.639740
higher_side_air_path_ratio	1.639740
number_of_ducts	4
duct_diameter	12
duct_length	81.000000
duct_distance_from_lower_sidewall	9.500000
duct_distance_from_lower_endwall	9.500000
duct_distance_to_lower_boundary	0.000000
duct_distance_to_higher_boundary	12.000000
duct_bushels	8270.757177
duct_fan_arrangement	0
number_of_fans	1
fan_diameter	12
fan_horsepower	0.330000
fan_cfm	1740.190226
fan_operating_static_pressure	0.596495
connector_diameter	14
connector_length	9.000000
connector_distance_from_lower_sidewall	0.000000
connector_distance_from_lower_endwall	50.000000
duct_diameter	21
duct_length	53.500000
duct_distance_from_lower_sidewall	23.250000

duct_distance_from_lower_endwall	23.250000
duct_distance_to_lower_boundary	12.000000
duct_distance_to_higher_boundary	30.000000
duct_bushels	18987.992494
duct_fan_arrangement	1
number_of_fans	1
fan_diameter	16
fan_horsepower	1.500000
fan_cfm	3773.250000
fan_operating_static_pressure	0.5
connector_diameter	21
connector_length	23.250000
connector_distance_from_lower_sidewall	23.250000
connector_distance_from_lower_endwall	0.000000
duct_diameter	21
duct_length	53.500000
duct_distance_from_lower_sidewall	36.750000
duct_distance_from_lower_endwall	23.250000
duct_distance_to_lower_boundary	30.000000
duct_distance_to_higher_boundary	48.000000
duct_bushels	18987.992494
duct_fan_arrangement	1
number_of_fans	1
fan_diameter	16
fan_horsepower	1.500000
fan_cfm	3773.250000
fan_operating_static_pressure	0.5
connector_diameter	21
connector_length	23.250000
connector_distance_from_lower_sidewall	36.750000
connector_distance_from_lower_endwall	0.000000
duct_diameter	12
duct_length	81.000000
duct_distance_from_lower_sidewall	50.500000
duct_distance_from_lower_endwall	9.500000
duct_distance_to_lower_boundary	48.000000
duct_distance_to_higher_boundary	60.000000
duct_bushels	8270.757177
duct_fan_arrangement	0
number_of_fans	1
fan_diameter	12
fan_horsepower	0.330000
fan_cfm	1740.190226
fan_operating_static_pressure	0.596495
connector_diameter	14
connector_length	9.000000
connector_distance_from_lower_sidewall	60.000000
connector_distance_from_lower_endwall	50.000000

APPENDIX F

'C' Source Code for Function to Write Specification File for Synthesis

```
int write_drawing_spec_file(filename)

char filename[];

{                       /* write_drawing_spec_file */

    FILE *spec_fp;
    double *distance_end, *distance_side, length, lower_dim_offset;
    double dim_x, dim_y, fan_length;
    int middle_duct, duct_number, rotation_angle;
    char duct_filename[9], fan_filename[9], dim_filename[9], text_filename[9];
    char *dectoarch(), ftin[30];

    middle_duct = design_data.number_of_ducts / 2 - 1;
    if (design_data.number_of_ducts % 2)
        ++middle_duct;
    if ((spec_fp = fopen(filename, "w")) == NULL)
    {
        printf("\nERROR 109: Unable to open drawing specification file
            %s.", filename);
        display_message("MESA109", TIL_KBHIT);
        return (1);
    }
    fprintf(spec_fp, "/AERATION DESIGN DRAWING SPECIFICATION FILE\n");
    fprintf(spec_fp, "/for %s.\n", design_data.name);
    fprintf(spec_fp, "/NUM     VALUE               DIMENSION TEXT\n");
    fprintf(spec_fp, "!$$$     @@@@@@@@@     ******************************\n");
    fprintf(spec_fp, "/---     ---------     ------------------------------\n");
    strcpy(ftin, dectoarch(design_data.storage_width));
    fprintf(spec_fp, "$10      %-9.2f     %s\n", design_data.storage_width, ftin);
    strcpy(ftin, dectoarch(design_data.storage_length));
    fprintf(spec_fp, "$20      %-9.2f     %s\n", design_data.storage_length, ftin);
    fprintf(spec_fp, "\n/OUTFILE    INFILE         ORIGIN      SCALE X Y      ROTATION\n");
    fprintf(spec_fp, "#CLIENT     AERBASE      0.0  0.0     1.0   1.0        0.0\n");
    if (design_data.duct_direction == LENGTHWISE)
    {
        distance_end = &design_data.duct_distance_from_lower_endwall[0];
        distance_side = &design_data.duct_distance_from_lower_sidewall[0];
        length = design_data.storage_width;
        strcpy(duct_filename, LENGTHWISE_DUCT_FILENAME);
    }
    else
    {
        distance_end = &design_data.duct_distance_from_lower_sidewall[0];
        distance_side = &design_data.duct_distance_from_lower_endwall[0];
        length = design_data.storage_length;
        strcpy(duct_filename, WIDTHWISE_DUCT_FILENAME);
    }
    for (duct_number = 0;  duct_number < design_data.number_of_ducts;  ++duct_number)
    {
        rotation_angle = 0;
        fprintf(spec_fp, "$200     %-9.2f     Duct %d\n", 1.0, duct_number + 1);
        fprintf(spec_fp, "$212     %-9.2f\n", (float) design_data.duct_diameter
            [duct_number] / FEET_INCH / 2);
```

```
fprintf(spec_fp, "$220     %-9.2f\n", design_data.duct_length[duct_number]);
strcpy(ftin, dectoarch(*(distance_end + duct_number)));
fprintf(spec_fp, "$240     %-9.2f     %s\n", *(distance_end + duct_number), ftin);
if (duct_number <= middle_duct)
{
    strcpy(ftin, dectoarch(*(distance_side + duct_number)));
    fprintf(spec_fp, "$232     %-9.2f     %s\n", *(distance_side + duct_number),
        ftin);
    fprintf(spec_fp, "$235     %-9.2f\n", 0.005);
    if (design_data.duct_fan_arrangement[duct_number] > 0)
        fprintf(spec_fp, "$236     %-9.2f\n", (float) design_data.fan_diameter
            [duct_number][0] / FEET_INCH * FAN_LENGTH_FACTOR + DIM_OFFSET);
    else
        fprintf(spec_fp, "$236     %-9.2f\n", DIM_OFFSET);
    fprintf(spec_fp, "$237     %-9.2f\n", DIM_OFFSET);
    fprintf(spec_fp, "$238     %-9.2f\n", (float) ((duct_number + 1) *
        DIM_LINE_LENGTH));
}
else
{
    strcpy(ftin, dectoarch(length - *(distance_side + duct_number)));
    fprintf(spec_fp, "$232     %-9.2f     %s\n", length - *(distance_side +
        duct_number), ftin);
    fprintf(spec_fp, "$235     %-9.2f\n", length - *(distance_side +
        duct_number));
    fprintf(spec_fp, "$236     %-9.2f\n", DIM_OFFSET);
    if (design_data.duct_fan_arrangement[duct_number] > 0)
        lower_dim_offset = (float) design_data.fan_diameter[duct_number][0] /
            FEET_INCH * FAN_LENGTH_FACTOR + DIM_OFFSET;
    else
        lower_dim_offset = DIM_OFFSET;
    fprintf(spec_fp, "$237     %-9.2f\n", lower_dim_offset);
    fprintf(spec_fp, "$238     %-9.2f\n", (float) ((design_data.number_of_ducts -
        duct_number) * DIM_LINE_LENGTH + DIM_OFFSET - lower_dim_offset));
}
if (design_data.duct_direction == LENGTHWISE)
    fprintf(spec_fp, "#CLIENT   %s   %9.2f %9.2f   1.0   1.0   %3d\n",
        duct_filename, *(distance_end + duct_number), *(distance_side +
        duct_number), rotation_angle);
else
    fprintf(spec_fp, "#CLIENT   %s   %9.2f %9.2f   1.0   1.0   %3d\n",
        duct_filename, *(distance_side + duct_number), *(distance_end +
        duct_number), rotation_angle);
fprintf(spec_fp, "$312     %-9.2f\n", (float) design_data.fan_diameter
    [duct_number][0] / FEET_INCH / 2);
fprintf(spec_fp, "$314     %-9.2f\n", (float) design_data.fan_diameter
    [duct_number][0] / FEET_INCH * FAN_LENGTH_FACTOR);
fprintf(spec_fp, "$322     %-9.2f\n", (float) design_data.connector_diameter
    [duct_number][0] / FEET_INCH / 2);
fprintf(spec_fp, "$330     %-9.2f\n", design_data.connector_length
    [duct_number][0]);
fprintf(spec_fp, "$332     %-9.2f\n", design_data.duct_length[duct_number]);
if (design_data.duct_fan_arrangement[duct_number] == 2)
{
    fprintf(spec_fp, "$300     %-9.2f     %s\n", 1.0, "A");
    fprintf(spec_fp, "$301     %-9.2f     %s\n", 1.0, "B");
    fprintf(spec_fp, "$317     %-9.2f\n", (float) design_data.fan_diameter
        [duct_number][1] / FEET_INCH / 2);
    fprintf(spec_fp, "$319     %-9.2f\n", (float) design_data.fan_diameter
        [duct_number][1] / FEET_INCH * FAN_LENGTH_FACTOR);
    fprintf(spec_fp, "$327     %-9.2f\n", (float) design_data.connector_diameter
        [duct_number][1] / FEET_INCH / 2);
    fprintf(spec_fp, "$335     %-9.2f\n", design_data.connector_length
        [duct_number][1]);
    fprintf(spec_fp, "$340     %-9.2f\n", 0.0);
}
else
{
    if (design_data.duct_fan_arrangement[duct_number] == 1 || duct_number == 0)
        fprintf(spec_fp, "$300     %-9.2f     %s\n", 1.0, "A");
    else
        fprintf(spec_fp, "$300     %-9.2f     %s\n", 1.0, "  ");
```

```
        fprintf(spec_fp, "$301      %-9.2f      %s\n", 1.0, "  ");
        fprintf(spec_fp, "$317      %-9.2f\n", 0.0);
        fprintf(spec_fp, "$319      %-9.2f\n", 0.0);
        fprintf(spec_fp, "$327      %-9.2f\n", 0.0);
        fprintf(spec_fp, "$335      %-9.2f\n", 0.0);
    }
    if (design_data.duct_direction == LENGTHWISE)
        if (design_data.duct_fan_arrangement[duct_number])
            strcpy(fan_filename, LENGTHWISE_FAN_FILENAME);
        else
        {
            strcpy(fan_filename, WIDTHWISE_FAN_FILENAME);
            if (duct_number)
                rotation_angle = 180;
        }
    else
        if (design_data.duct_fan_arrangement[duct_number])
            strcpy(fan_filename, WIDTHWISE_FAN_FILENAME);
        else
        {
            strcpy(fan_filename, LENGTHWISE_FAN_FILENAME);
            if (duct_number)
                rotation_angle = 180;
        }
    fprintf(spec_fp, "#CLIENT   %s    %9.2f %9.2f   1.0   1.0   %3d\n", fan_filename,
        design_data.connector_distance_from_lower_endwall[duct_number][0],
        design_data.connector_distance_from_lower_sidewall[duct_number][0],
        rotation_angle);
    if (design_data.duct_fan_arrangement[duct_number] == 0)
    {
        if (duct_number)
        {
            fprintf(spec_fp, "$500      %-9.2f      %s\n", 1.0, "A");
            fprintf(spec_fp, "$510      %-9.2f\n", (float) design_data.fan_diameter
                [duct_number][0] / FEET_INCH / 2);
            if (design_data.duct_direction == LENGTHWISE)
                strcpy(text_filename, VERTICAL_TEXT_FILENAME);
            else
                strcpy(text_filename, HORIZONTAL_TEXT_FILENAME);
            rotation_angle = 0;
            fprintf(spec_fp, "#CLIENT   %s    %9.2f %9.2f   1.0   1.0   %3d\n",
                text_filename, design_data.connector_distance_from_lower_endwall
                [duct_number][0], design_data.connector_distance_from_lower_sidewall
                [duct_number][0], rotation_angle);
        }
        dim_x = design_data.connector_distance_from_lower_endwall[duct_number][0];
        dim_y = design_data.connector_distance_from_lower_sidewall[duct_number][0];
        fan_length = design_data.fan_diameter[duct_number][0] / FEET_INCH *
            FAN_LENGTH_FACTOR;
        fprintf(spec_fp, "$410      %-9.2f\n", fan_length + DIM_OFFSET);
        fprintf(spec_fp, "$420      %-9.2f\n", 6.0 - (fan_length + DIM_OFFSET));
        fprintf(spec_fp, "$430      %-9.2f\n", DIM_OFFSET);
        if (design_data.duct_direction == LENGTHWISE)
        {
            strcpy(ftin, dectoarch(dim_x));
            fprintf(spec_fp, "$440      %-9.21f     %s\n", dim_x, ftin);
            if (duct_number)
                strcpy(dim_filename, HORIZONTAL_DIM1_FILENAME);
            else
                strcpy(dim_filename, HORIZONTAL_DIM0_FILENAME);
        }
        else
        {
            strcpy(ftin, dectoarch(dim_y));
            fprintf(spec_fp, "$440      %-9.2f      %s\n", dim_y, ftin);
            if (duct_number)
                strcpy(dim_filename, VERTICAL_DIM1_FILENAME);
            else
                strcpy(dim_filename, VERTICAL_DIM0_FILENAME);
        }
        rotation_angle = 0;
        fprintf(spec_fp, "#CLIENT   %s    %9.2f %9.2f   1.0   1.0   %3d\n",
```

```
                dim_filename, dim_x, dim_y, rotation_angle);
        }
    }
    if (fclose(spec_fp) == -1)
    {
        printf("\nERROR 110: Unable to close drawing specification file %s.", filename);
        display_message("MESA110", TIL_KBHIT);
        return (2);
    }
    return (0);

}                           /* write_drawing_spec_file */
```

APPENDIX G

Listing of Management Recommendations Text File

```
%/VR    110     name                              %1.30s
%/VR    111     company                           %1.30s
%/VR    112     address                           %1.30s
%/VR    113     city                              %1.30s
%/VR    114     state                             %1.15s
%/VR    115     zip_code                          %1.15s
%/VR    116     phone                             %1.15s
%/VR    150     post_spacing                      %2d
%/VR    155     post_size                         %7.7s
%/VR    171     storage_width                     %4.1f
%/VR    172     storage_length                    %4.1f
%/VR    175     bushel_capacity                   %7.0f
%/VR    176     peak_height                       %3.1f
%/VR    177     width_of_peak_height              %3.1f
%/VR    180     higher_sidewall_height            %3.1f
%/VR    181     lower_sidewall_height             %3.1f
%/VR    182     higher_endwall_height             %3.1f
%/VR    183     lower_endwall_height              %3.1f
%/VR    190     maximum_piling_height             %3.1f
%/VR    205     desired_number_of_ducts           %2d
%/VR    207     number_of_ducts                   %2d
%/VR    208     lower_side_air_path_ratio         %3.2f
%/VR    209     higher_side_air_path_ratio        %3.2f
%/VR    250     cfm_per_bushel                    %3.2f

%/ID DAT10
%/DS Client name and address
%/AT DG Watson
%/DT 04-07-87
%/TX
This aeration system has been designed for:

    %/VR110
    %/VR111
    %/VR112
    %/VR113, %/VR114  %/VR115
    %/VR116

The following listing summarizes information about the
aeration system:

%/EX

%/ID DAT20a
%/DS Interview data -- grain
%/AT DG Watson
%/DT 04-07-87
%/TX Grain --                   shelled corn
%/EX
%/ID DAT20b
%/TX Grain --                   soybeans
%/EX
%/ID DAT20c
%/TX Grain --                   wheat
```

```
%/EX
%/ID DAT20d
%/TX Grain --                       grain sorghum
%/EX

%/ID DAT25a
%/DS Interview data -- structure
%/AT DG Watson
%/DT 04-07-87
%/TX Building --                    existing
%/EX
%/ID DAT25b
%/TX Building --                    new
%/EX

%/ID DAT30a
%/DS Interview data -- frame construction
%/AT DG Watson
%/DT 04-12-87
%/TX Construction --                post frame
Post spacing --                %/VR150'
%/EX
%/ID DAT30b
%/TX Construction --                non-post frame
%/EX

%/ID DAT35a
%/DS Interview data -- liner
%/AT DG Watson
%/DT 04-07-87
%/TX Grain liner information --     not requested
%/EX
%/ID DAT35b
%/TX Grain liner information --     requested
%/EX

%/ID DAT40
%/DS Interview data -- storage dimensions
%/AT DG Watson
%/DT 04-07-87
%/TX Storage size --               %/VR171' by %/VR172'
Sidewall depths:
    higher side wall --        %/VR180'
    lower side wall  --        %/VR181'
    higher end wall  --        %/VR182'
    lower end wall   --        %/VR183'
Maximum piling height --       %/VR190'
Bushel capacity --             %/VR175
Actual peak height --          %/VR176'
Width of peak --               %/VR177'
%/EX

%/ID DAT45a
%/DS Interview data -- number of ducts
%/AT DG Watson
%/DT 04-07-87
%/TX Ducts --                       computer selected %/VR207
%/EX
%/ID DAT45b
%/TX Ducts --                       user requested %/VR205
                               computer used  %/VR207
%/EX

%/ID DAT50a
%/DS Calculated air path ratios
%/AT DG Watson
%/DT 04-12-87
%/TX Air path ratios:
    from lower side wall --     %/VR208
    from higher side wall --    %/VR209
%/EX
%/ID DAT50b
```

```
%/TX Air path ratios:
    from lower end wall --     %/VR208
    from higher end wall --    %/VR209
%/EX

%/ID DAT55a
%/DS Interview data -- fan arrangement
%/AT DG Watson
%/DT 04-07-87
%/TX Fan arrangement --              end or middle placement
%/EX
%/ID DAT55b
%/TX Fan arrangement --              end placement only
%/EX
%/ID DAT55c
%/TX Fan arrangement --              middle placement preferred
%/EX

%/ID DAT60a
%/DS Interview data -- fan type
%/AT DG Watson
%/DT 04-07-87
%/TX Fan type --                     axial
%/EX
%/ID DAT60b
%/TX Fan type --                     centrifugal
%/EX

%/ID DAT65a
%/DS Interview data -- duct direction
%/AT DG Watson
%/DT 04-07-87
%/TX Duct direction --               lengthwise
%/EX
%/ID DAT65b
%/DS Interview data -- duct direction
%/AT DG Watson
%/DT 04-07-87
%/TX Duct direction --               widthwise
%/EX

%/ID DAT70a
%/DS Interview data -- duct type
%/AT DG Watson
%/DT 04-07-87
%/TX Duct type --                    plastic
%/EX
%/ID DAT70b
%/TX Duct type --                    spiral-lok metal
%/EX
%/ID DAT70c
%/TX Duct type --                    round metal
%/EX
%/ID DAT70d
%/TX Duct type --                    half-round metal
%/EX

%/ID DAT75
%/DS Interview data -- airflow rate
%/AT DG Watson
%/DT 04-07-87
%/TX Airflow rate --                 %/VR250 cfm/bu
%/EX

%/ID GEN1
%/DS Definition:
%/AT RC Brook
%/DT 10Dec86
%/TX
GENERAL COMMENTS ON FLAT STORAGES:

Flat grain storages are buildings in which neither the length nor
```

width is less than two times the height of the grain on the sidewall. Otherwise, the grain tends to bridge, as does ground feed, thus increasing the sidewall pressure.
%/EX

%/ID GEN2
%/DS Limitation - without aeration:
%/AT RC Brook
%/DT 10Dec86
%/TX
The use of buildings for grain storage is not recommended for more than 1 to 2 months storage if not equipped with an adequate aeration storage.
%/EX

%/ID GEN3
%/DS Limitation - with aeration:
%/AT RC Brook
%/DT 10Dec86
%/TX
The use of buildings for grain storage when adequate aeration is installed is not recommended for storage of grain past late spring.
%/EX

%/ID FLR1
%/DS Floors in existing buildings:
%/AT RC Brook
%/DT 10Dec86
%/TX
SPECIFIC COMMENTS ON THIS AERATION PLAN:

Open areas in existing buildings frequently have irregular and cracked concrete floors or earth floors. Such floors normally have no vapor barrier. A vapor barrier of 4-6 mil plastic sheet should be placed on the floor before the aeration ducting and grain. Care should be exercised when filling the storage so that the vapor barrier is not broken or torn.
%/EX

%/ID FLR2
%/DS Floors in new buildings:
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
SPECIFIC COMMENTS ON THIS AERATION PLAN:

Before pouring the concrete floor in a new building designated for grain storage, place a vapor barrier of 4-6 mil plastic sheet on the ground. When pouring the concrete, care should be exercised that the vapor barrier is not broken or torn.
%/EX

%/ID SWS1
%/DS Sidewall Strength - acceptable
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
The grain will be piled, at most, %/VR180 feet on the sidewall of your building. With the posts spaced %/VR150 feet on center, a post size of at least %/VR155 is required. The smaller post dimension must face the grain. Higher grain depths or smaller posts will likely to cause structural damage to the building.
%/EX

%/ID SWS2
%/DS Sidewall Strength - unacceptable
%/AT RC Brook
%/DT 10Dec86
%/KW

```
%/TX

WARNING:
The grain will be piled, at most, %/VR180 feet on the sidewall of
your building. With a posts spacing of %/VR150 feet on center, you
are likely to cause structural damage to your building. Either
add posts to the building or use a grain retaining wall.
%/EX

%/ID SWS3
%/DS Sidewall Covering
%/AT DG Watson
%/DT 5-5-87
%/KW
%/TX
Grain liners can be constructed by adding a stud wall between
posts or by building portable restraining walls. Request a copy
of a grain liner plan for adding a stud wall or the Midwest Plan
Service plan for portable grain bulkheads.
%/EX

%/ID SWS4
%/DS Non post frame construction
%/AT DG WATSON
%/DT 28Apr87
%/KW
%/TX
WARNING:
Contact the manufacturer or builder of your building to determine
if the walls of the building will support the grain depth of
%/VR180 feet. If the manufacturer or builder cannot answer this
question, contact an agricultural engineering consultant.
DO NOT pile grain on the walls until you have verified the
ability of the walls to support the grain.
%/EX

%/ID RFC1
%/DS Roofing Considerations -- exist building
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
Consider carefully the roof of an existing building. Corrugated
metal roofing nailed directly to a wood rafter or truss
invariably leaks water somewhere. A sealant should be used
around nail heads to minimize leakage.
%/EX

%/ID RFC2
%/DS Roofing Considerations -- new building
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
Consider carefully the type of roofing used. Corrugated metal
roofing nailed directly to a wood rafter or truss invariably
leaks water somewhere. A shingled roof is preferable to help
eliminate water leakage and the potential grain spoilage
problems.
%/EX

%/ID DCTP10
%/DS Duct Placement -- not recommended
%/AT DG Watson
%/DT June 6, 1987
%/KW
%/TX

WARNING:
This design is based on a 'user selected' number of ducts.
This arrangement is not recommended. The air path ratios as
listed above are too high to insure adequate aeration of the
```

```
grain. If this design is used the risk of grain spoilage is
greatly increased.
%/EX

%/ID MAN1
%/DS Caution on airflow delivery
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
GRAIN MANAGEMENT COMMENTS:

The design airflow may be greater than the effective delivered
airflow.  Grain with excess amounts of fines or foreign material
will increase the static pressure caused by the grain. The
change in static pressure will lower the delivered airflow for
that general area of the grain storage.  The grain directly
between the ducts will also receive a lower airflow than the
grain directly over the ducts. Careful observation of the grain
surface during cooling is important to help insure adequate
cooling of all the grain in storage.
%/EX

%/ID MAN2
%/DS Temperature Cables if Volume > 30,000 bushels
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
A temperature monitoring system should be installed in the grain
storage.  A monitoring system consists of temperature sensing
cables and a conveniently located monitor for temperature
display.
%/EX

%/ID MAN3
%/DS Airflow direction
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
The fans should be operated for upward airflow in order to help
ensure as uniform an airflow as possible along the length of the
duct(s).  The upward airflow also helps the management of the
cooling phase by allowing observation of the air exiting the
surface of the grain mass which will help show the progress of
cooling in different areas of the storage.
%/EX

%/ID MAN4
%/DS Fan type
%/AT RC Brook   DG Watson
%/DT 10Dec86    June 6, 1987
%/KW
%/TX
Generally, axial flow fans are used for grain storage aeration
because they are less expensive for the low static pressures
involved than centrifugal fans.  Ducts are always sized for a
specific fan output.  Do not use a fan size different from the
one specified with having the duct size recalculated.
%/EX

%/ID MAN5
%/DS Gain Management Practices
%/AT RC Brook
%/DT 10Dec86
%/KW
%/TX
Proper management practices are essential to successful storage
of grain.  Grain should be clean, dry and cool to insure the
maintenance of quality during storage.  A regular inspection of
the grain during the storage period will help to avoid storage
```

problems. For more details, see Michigan State University Cooperative Extension Service bulletin E-1431.
%/EX

APPENDIX H

'C' Source Code of Rules for Printing Management Recommendations

```
int man_rec_selection_rules()
{                        /* man_rec_selection_rules */

    float higher_wall, design_apr;
    int man_rec_counter = 0;

    select_man_rec("DAT10", &man_rec_counter);
    switch (design_data.grain_type)
    {
    case 0:
        select_man_rec("DAT20a", &man_rec_counter);
        break;
    case 1:
        select_man_rec("DAT20b", &man_rec_counter);
        break;
    case 2:
        select_man_rec("DAT20c", &man_rec_counter);
        break;
    case 3:
        select_man_rec("DAT20d", &man_rec_counter);
        break;
    }
    if (design_data.new_building)
        select_man_rec("DAT25b", &man_rec_counter);
    else
        select_man_rec("DAT25a", &man_rec_counter);
    if (design_data.construction_type)
        select_man_rec("DAT30b", &man_rec_counter);
    else
        select_man_rec("DAT30a", &man_rec_counter);
    if (design_data.liner_info)
        select_man_rec("DAT35b", &man_rec_counter);
    else
        select_man_rec("DAT35a", &man_rec_counter);
    select_man_rec("DAT40", &man_rec_counter);
    if (design_data.desired_number_of_ducts)
        select_man_rec("DAT45b", &man_rec_counter);
    else
        select_man_rec("DAT45a", &man_rec_counter);
    if (design_data.duct_direction)
        select_man_rec("DAT50b", &man_rec_counter);
    else
        select_man_rec("DAT50a", &man_rec_counter);
    switch (design_data.desired_fan_arrangement)
    {
    case 0:
        select_man_rec("DAT55a", &man_rec_counter);
        break;
    case 1:
        select_man_rec("DAT55b", &man_rec_counter);
        break;
    case 2:
        select_man_rec("DAT55c", &man_rec_counter);
```

```
        break;
    }
    if (design_data.fan_type)
        select_man_rec("DAT60b", &man_rec_counter);
    else
        select_man_rec("DAT60a", &man_rec_counter);
    if (design_data.duct_direction)
        select_man_rec("DAT65b", &man_rec_counter);
    else
        select_man_rec("DAT65a", &man_rec_counter);
    switch (design_data.duct_type)
    {
    case 0:
        select_man_rec("DAT70a", &man_rec_counter);
        break;
    case 1:
        select_man_rec("DAT70b", &man_rec_counter);
        break;
    case 2:
        select_man_rec("DAT70c", &man_rec_counter);
        break;
    case 3:
        select_man_rec("DAT70d", &man_rec_counter);
        break;
    }
    select_man_rec("DAT75", &man_rec_counter);
    select_man_rec("GEN1", &man_rec_counter);
    select_man_rec("GEN2", &man_rec_counter);
    select_man_rec("GEN3", &man_rec_counter);
    if (design_data.new_building)
    {
        select_man_rec("FLR2", &man_rec_counter);
        select_man_rec("RFC2", &man_rec_counter);
    }
    else
    {
        select_man_rec("FLR1", &man_rec_counter);
        select_man_rec("RFC1", &man_rec_counter);
    }
    if (design_data.construction_type)
        select_man_rec("SWS4", &man_rec_counter);
    else
        if (design_data.post_spacing != 0)
        {
            if (design_data.post_size[0] == '\0')
                select_man_rec("SWS2", &man_rec_counter);
            else
                select_man_rec("SWS1", &man_rec_counter);
        }
    if (design_data.liner_info)
        select_man_rec("SWS3", &man_rec_counter);
    if (design_data.duct_direction == LENGTHWISE)
        higher_wall = design_data.higher_sidewall_height;
    else
        higher_wall = design_data.higher_endwall_height;
    if (higher_wall >= factor.depth_deep)
        design_apr = factor.ratio_deep;
    else
        design_apr = factor.ratio_shallow;
    if (larger(design_data.lower_side_air_path_ratio,
        design_data.higher_side_air_path_ratio) > design_apr)
        select_man_rec("DCTP10", &man_rec_counter);
    select_man_rec("MAN1", &man_rec_counter);
    if (design_data.bushel_capacity > 30000)
        select_man_rec("MAN2", &man_rec_counter);
    select_man_rec("MAN3", &man_rec_counter);
    select_man_rec("MAN4", &man_rec_counter);
    select_man_rec("MAN5", &man_rec_counter);
    return (man_rec_counter);

}                       /* man_rec_selection_rules */
```

APPENDIX I

Information Sheets and Evaluation Instruments Sent to Reviewers Before On-Site Visit

Information sheets and evaluation instruments sent to the reviewers before the on-site visit consisted of the following:

- -- case study overview and instructions information sheet
- -- case study 1 description
- -- case study 1 cross-sectional view of grain storage
- -- case study 1 floor plan for sketching and dimensioning component placement
- -- case study 1 table of component specifications
- -- case study 1 recommendations list
- -- case study 2 description
- -- case study 2 cross-sectional view of grain storage
- -- case study 2 floor plan for sketching and dimensioning component placement
- -- case study 2 table of component specifications
- -- case study 2 recommendations list
- -- questionnaire for aeration system design guidelines

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Studies

Overview of evaluation plan

An aeration system design program has been developed which generates custom aeration system designs. The program derives a design from information about the grain storage described by the program user and the design guidelines built into the program. As an expert in aeration system design, you have been asked to evaluate the computer program for technical content and usability. This evaluation is divided into two phases and the activities for each phase are as follows:

Phase 1 -- before our on-site visit:
- designing an aeration system (by your usually methods) for our two case studies
- summarizing aeration system design guidelines
- selecting of one or two case studies from your files for use during the hands-on evaluation

Phase 2 -- during our on-site visit:
- hands-on introduction to the computer program
- solving case studies with the computer program
- comparing computer solutions to your solutions
- discussing differences in design methodology
- summarizing results of technical content and usability evaluation

Instructions for case studies

Two case studies are attached. Your solution of these case studies will assist us in evaluating the design guidelines used in the computer program. For your convenience, five worksheets are provided for each case study. The contents and use of the worksheets is as follows:

Worksheet	Contents and usage
#1	case study description including storage specifications and equipment preferences
#2	cross sectional drawing of case study with grid for clarification of grain profile
#3	floor plan (with grid) of case study storage for sketching component placement
#4	table of component specifications for listing design results
#5	recommendations list for listing any design implementation and management recommendations for the case study

Please solve the case studies and use the worksheets to describe your design.

We have prepared a questionaire for you to use in summarizing your design guidelines and procedures. Please complete this questionaire as it will be a basis for discussion during our on-site visit.

As the final step in preparing for our on-site visit, please select one or two case studies from your files. Your case studies will be used during the hands-on evaluation of the computer program.

During the on site visit, we will pick up your completed case studies and questionaire.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 1

A grain producer needs an aeration system for an existing pole barn in which shelled corn will be stored from November to August. Grain will be dry, clean and cool.

Storage specifications are as follows:

width	60.0 ft
length	120.0 ft
grain depths:	
side walls	6.0 ft
end walls	0.0 ft
maximum peak	12.0 ft

The piling height is limited to 12 ft by the trusses, but equipment is available to level the pile in the center to maximize storage capacity (refer to cross sectional view of case study 1).

Bushel capacity of this storage is 49,800 bushels.

Assume that the structure can support the grain depths listed above.

The grain producer's preferences regarding equipment and placement are:

duct type	:	plastic aeration tubing
duct direction	:	lengthwise in storage
fan type	:	axial
fan placement	:	either ends or middle of ducts
air flow rate	:	1/10 cfm/bu

The grain producer requests your assistance in determining the number and placement of ducts and sizing of ducts, fans and fan-to-duct connectors. The above preferences may be changed if you feel it is important to achieve a good design.

The attached cross sectional view of case study 1 is provided for your convenience. Please complete the table of component specifications to summarize the results of your design and sketch the placement of components on the floor plan provided.

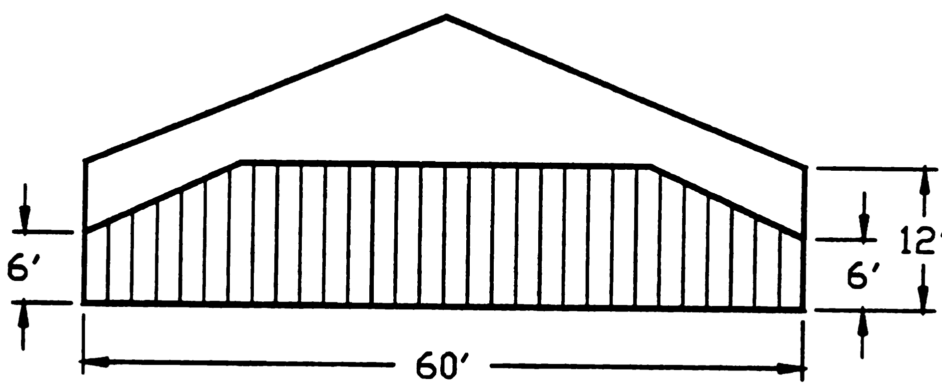
On the recommendation sheet, list any design implementation or management recommendations which you would make to the grain producer in addition to the component list and floor plan.

If you need additional information contact Dennis Watson or Roger Brook at (517) 353-7888 or 353-4456.

Case Study 1 -- Worksheet #1

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 1

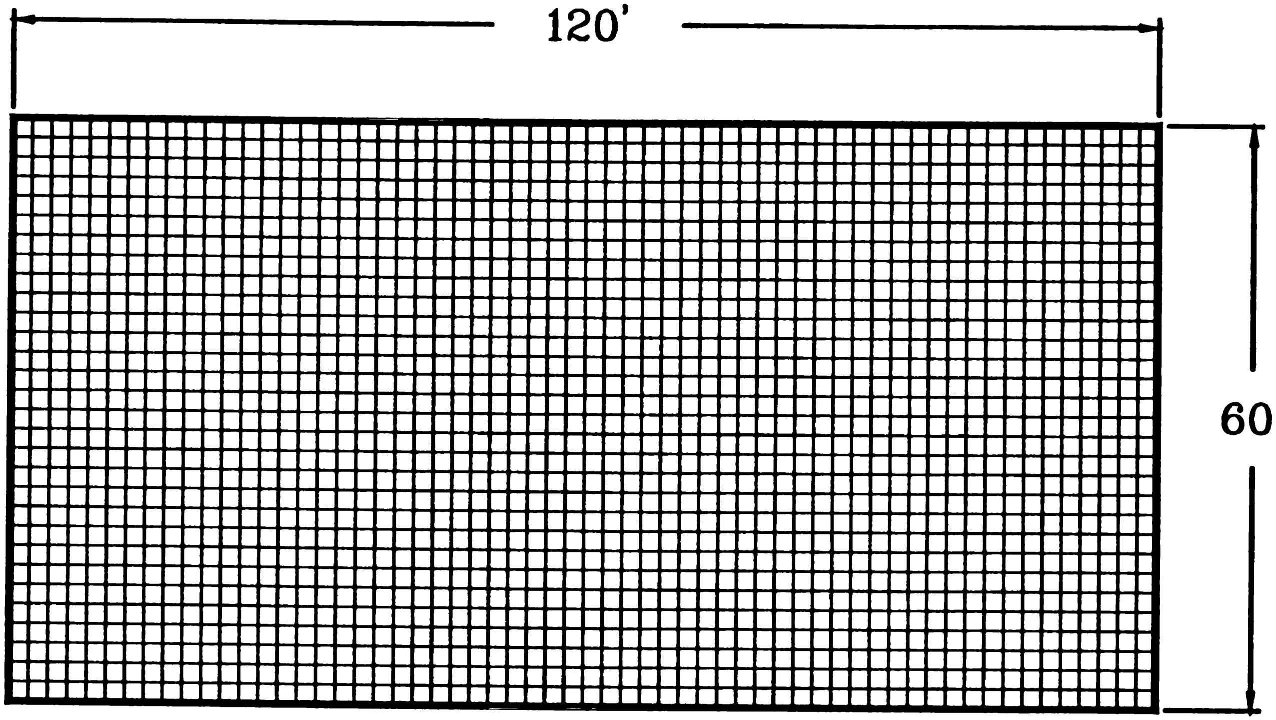
Cross-Sectional View of Grain Storage



Vertical grid lines in grain area are 2' on center.

Case Study 1 -- Worksheet #2

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 1
Floor Plan for Sketching and Dimensioning Component Placement



Horizontal and vertical grid lines are 2' on center.

Case Study 1 -- Worksheet #3

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 1
Table of Component Specifications

When completing the following table of component sizes, place the floor plan drawing with the printed text in the normal reading position. Reference the ducts by number with duct # 1 being closest to the lower left corner of the drawing.

Component Size	Duct Number 1	2	3	4	5	6	7
diameter, in							
length, ft							
number of fans							
fan diameter, in							
fan horsepower, hp							
fan cfm output, cfm							
static pressure, in H_2O							
fanconnector diameter, in							

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 1
Recommendations List

When an expert works with a client on a design problem, he often provides additional recommendations to the client for implementation and management of the design.

For the case study, list the design implementation and management recommendations and any supplemental information you would provide to the client.

List of Recommendations

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 2

A grain producer needs an aeration system for an existing pole barn in which shelled corn will be stored from November to June. Grain will be dry and cool, but the producer does not use a grain cleaner.

Storage specifications are as follows:

width	50.0 ft
length	60.0 ft
grain depths:	
side walls	6.0 ft
end walls	6.0 ft
maximum peak	12.0 ft

The piling height is limited to 12 ft by the trusses, but equipment is available to level the pile in the center to maximize storage capacity (refer to cross sectional view of case study 2).

Bushel capacity of this storage is 23,200 bushels.

Assume that the structure can support the grain depths listed above.

The grain producer's preferences regarding equipment and placement are:

duct type	:	round metal aeration tubing
duct direction	:	widthwise in the storage
fan type	:	axial
fan placement	:	ends of duct only
air flow rate	:	1/5 cfm/bu

The grain producer requests your assistance in determining the number and placement of ducts and sizing of ducts, fans and fan-to-duct connectors. The above preferences may be changed if you feel it is important to achieve a good design.

The attached cross sectional view of case study 2 is provided for your convenience. Please complete the table of component specifications to summarize the results of your design and sketch the placement of components on the floor plan provided.

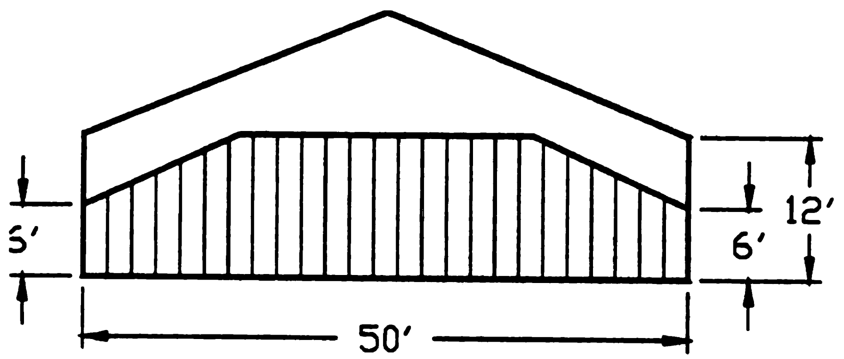
On the recommendation sheet, list any design implementation or management recommendations which you would make to the grain producer in addition to the component list and floor plan.

If you need additional information contact Dennis Watson or Roger Brook at (517) 353-7888 or 353-4456.

Case Study 2 -- Worksheet #1

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 2

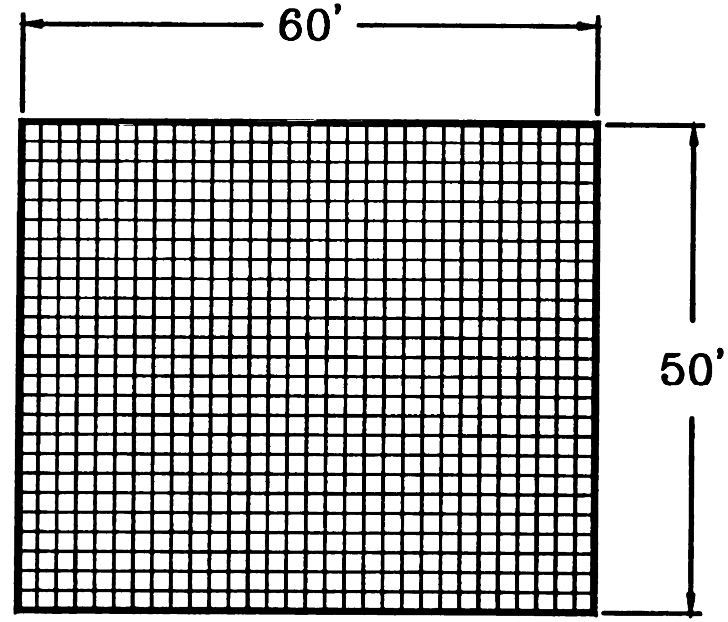
Cross-Sectional View of Grain Storage



Vertical grid lines in grain area are 2' on center.

Case Study 2 -- Worksheet #2

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 2
Floor Plan for Sketching and Dimensioning Component Placement



Horizontal and vertical grid lines are 2' on center.

Case Study 2 -- Worksheet #3

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 2
Table of Component Specifications

When completing the following table of component sizes, place the floor plan drawing with the printed text in the normal reading position. Reference the ducts by number with duct # 1 being closest to the lower left corner of the drawing.

Component Size	Duct Number 1	2	3	4	5	6	7
diameter, in							
length, ft							
number of fans							
fan diameter, in							
fan horsepower, hp							
fan cfm output, cfm							
static pressure, in H_2O							
fanconnector diameter, in							

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Case Study 2
Recommendations List

When an expert works with a client on a design problem, he often provides additional recommendations to the client for implementation and management of the design.

For the case study, list the design implementation and management recommendations and any supplemental information you would provide to the client.

List of Recommendations

Case Study 2 -- Worksheet #5

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Questionaire for Aeration System Design Guidelines

Please answer the following questions which will provide information regarding design guidelines you use in aeration system design for flat grain storages.

1. Do you use an air path ratio method to determine the number and placement of ducts in a storage?
   YES NO

1a. If yes?
   What air path ratio(s) do you use and under what conditions?
   Ratio Condition

   ____
   ____
   ____

1b. If no?
   What method or guideline do you use in determining the number and placement of ducts?

   ____
   ____
   ____
   ____

2. Which method do you use to determine the offset of a perforated duct section from the end wall?
   A. distance from duct to end wall = end wall grain depth
   B. distance from duct to end wall = peak grain depth above duct
   C. distance from duct to end wall + grain depth on end wall = shortest distance from duct to grain surface.
   D. distance from duct to end wall + grain depth on end wall = peak grain depth above duct
   E. air path ratio from duct to grain surface at end wall = longest air path ratio laterally from duct.
   F. other method as described below

   ____
   ____
   ____
   ____

3. When sizing a fan which grain depth do you use to estimate static pressure?

   A. depth directly above duct
   B. peak depth served by duct
   C. shortest distance from duct to storage surface
   D. one of above multiplied by a weighting factor (circle number above also) where weighting factor is ___________
   E. other method described below

   ____

   ____

   ____

   ____

4. Suppose a required fan airflow (in cfm) has been calculated which is slightly higher than the output of an available fan size. What is the largest percent reduction in cfm you would allow to use a slightly smaller fan as opposed to requiring a larger fan size? _______________ % cfm reduction

5. List the air flow velocities you use in sizing a duct for the following duct types in feet per minute:

	in duct	through duct perforations
plastic duct		
metal duct		

6. Suppose a duct size has been calculated which is slightly larger than an available size. What is the largest percent increase in air velocity (fpm) you would allow to use the smaller size as opposed to requiring the next larger size?
   _______________ % cfm increase

7. When sizing a connector which connects a fan to the middle of a duct, what is the maximum air velocity allowable in the connector? _______________ fpm

APPENDIX J

Evaluation Instruments Used During On-Site Evaluation

Evaluation Instruments used during the on-site evaluation consisted of the follows:

- -- rating of design results
- -- explanation of moderate or substantial rating
- -- review of design guidelines
- -- review of response screens
- -- usability evaluation

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Rating of Design Results

Reviewer: ____________________________

Please rate the design results produced by the aeration design program based on the magnitude of difference between your results and the program results. Consider the case studies you used with the program and check the appropriate box. The rating categories of the differences are none, minor, moderate and substantial.

	DIFFERENCES			
Design result	**None**	**Minor**	**Moderate**	**Substantial**
1. number of ducts				
2. placement of ducts				
3. duct diameter				
4. duct length				
5. number of fans				
6. fan size				
7. connector size				

If you checked the categories of *moderate* or *substantial* for any of the above items, please complete one of the attached rating explanation sheets for each item receiving a *moderate* or *substantial* rating.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: ______________________________

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	placement of ducts
duct diameter	duct length
number of fans	fan size
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

____

____

____

____

____

____

____

Do you think the program should be changed? YES NO

If yes, how would you recommend the program be changed?

____

____

____

____

____

____

____

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Design Guidelines

Reviewer: ______________________

This section of the evaluation requests your opinions regarding design factors used in the aeration system design program. Please, indicate whether or not you agree with the following factors. If you disagree, indicate your preferred value in the space provided.

Design Factor	Value	Agree?	If no, your value
1. air path ratio for middle ducts	1.5	YES NO	
2. minimum grain depth on wall to be considered deep (ft) (related to 3 and 4 below)	5	YES NO	
3. air path ratio to outside with shallow grain depth	2.0	YES NO	
4. air path ratio to outside with deep grain depth	1.8	YES NO	
5. maximum length of plastic aeration tube from fan (ft)	60	YES NO	
6. maximum length of metal aeration tube from fan (ft)	80	YES NO	
7. minimum static pressure for fan sizing (in. water)	0.5	YES NO	
8. static pressure of connector (in. water)	0.25	YES NO	
9. static pressure of turn in connector or duct (in. water)	0.25	YES NO	
10. minimum bushels to design aeration system (bu)	3000	YES NO	
11. minimum peak grain depth to design aeration system (ft)	6	YES NO	
12. minimum distance from duct to wall parallel to duct (ft)	3	YES NO	

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Response Screens

Reviewer: ____________________________

Please evaluate the information the program requests of the user. All items asked on one screen are grouped together. Circle your response to the four questions for each response screen. The four questions are:

Is this information you typically ask of a client?
Is this information readily available to the client?
Is the question worded adequately?
Is the help information sufficient to assist a client in answering the question?

Response screen	**Typical question**	**Information readily available**	**Worded adequately**	**Help information sufficient**
1. client information	YES NO	YES NO	YES NO	YES NO
2. grain type	YES NO	YES NO	YES NO	YES NO
3. new structure	YES NO	YES NO	YES NO	YES NO
4. construction type	YES NO	YES NO	YES NO	YES NO
5. post spacing	YES NO	YES NO	YES NO	YES NO
6. structure liner	YES NO	YES NO	YES NO	YES NO
7. storage size	YES NO	YES NO	YES NO	YES NO
8. grain depths on walls	YES NO	YES NO	YES NO	YES NO
9. maximum piling height	YES NO	YES NO	YES NO	YES NO
10. number of ducts	YES NO	YES NO	YES NO	YES NO
11. duct type	YES NO	YES NO	YES NO	YES NO
12. duct direction	YES NO	YES NO	YES NO	YES NO
13. fan type	YES NO	YES NO	YES NO	YES NO
14. fan arrangement	YES NO	YES NO	YES NO	YES NO
15. airflow rate	YES NO	YES NO	YES NO	YES NO

Space if provided on the following page for your comments.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Response Screens

Please use this sheet to provide us with your suggestions and comments on the questions and order of presentation? Such as, needed wording changes, questions to be left out and questions to be added.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Usability Evaluation

Reviewer: ______________________

Please respond to the following questions to help us evaluate the usability of the program.

USER INTERFACE

1. **How convenient are the keys used for the special key commands in the program?**
   VERY SOMEWHAT A LITTLE NOT VERY

2. **After using the program once, how comfortable were you with the key operations?**
   VERY SOMEWHAT A LITTLE NOT VERY

3. **What changes would you make to the key operations?**

   ____

   ____

   ____

   ____

4. **How acceptable is the speed of program execution?**
   VERY SOMEWHAT A LITTLE NOT VERY

5. **Generally speaking, how easy was the program to use?**
   VERY SOMEWHAT A LITTLE NOT VERY

6. **Based on the operation of the key commands and the appearance of information on the screen, do you think the following groups of people could use a program such as this one (not including technical aspects) after a few minutes of training?**

a) beginning microcomputer user	YES	NO
b) average county agent	YES	NO
c) average farmer	YES	NO

INFORMATION CONVEYANCE

7. **How effective are the text and illustrations in conveying the appropriate points?**
   VERY SOMEWHAT A LITTLE NOT VERY

8. **In general, how well does the text convey the appropriate information?**
   VERY SOMEWHAT A LITTLE NOT VERY

9. Would the illustrations associated with the response screens be helpful to:
   a) you or other expert YES NO
   b) average county agent YES NO
   c) average farmer YES NO

10. How useful are the illustrations for:
    a) involving a user in the design process?
    VERY SOMEWHAT A LITTLE NOT VERY

    b) helping the user to consider different options or new ideas?
    VERY SOMEWHAT A LITTLE NOT VERY

    c) amplifying the meaning of the text?
    VERY SOMEWHAT A LITTLE NOT VERY

11. Considering the response screens in general, how important are the illustrations to the accuracy of communication with the user?
    VERY SOMEWHAT A LITTLE NOT VERY

DESIGN DRAWING

12. How usable are the design drawing and component specification list for a client to:
    a) purchase components of an aeration system?
    VERY SOMEWHAT A LITTLE NOT VERY

    b) install an aeration system?
    VERY SOMEWHAT A LITTLE NOT VERY

13. How would you change the design drawing?

    ____

    ____

    ____

    ____

14. How would you change the component specification listing?

    ____

    ____

    ____

    ____

MANAGEMENT RECOMMENDATIONS

15. How important are management recommendations in a program of this type?
    VERY SOMEWHAT A LITTLE NOT VERY

16. How helpful, to a client, are the management recommendations generated by the program?
    VERY HELPFUL SOMEWHAT HELPFUL NOT HELPFUL

17. How effectively are the management recommendations communicated?
    VERY GOOD GOOD AVERAGE BELOW AVERAGE

18. Generally, is the correct emphasis placed on critical recommendations?
    YES, DEFINITELY YES, MOSTLY NO

    If No, how would you change the emphasis?

    ____

    ____

    ____

    ____

19. How similar are the recommendations provided to ones you commonly make?
    VERY SOMEWHAT A LITTLE NOT VERY

20. What changes, additions or deletions would you make to the management recommendations?

    ____

    ____

    ____

    ____

GENERAL

21. Would this program be useful to you in the practice of designing aeration systems?
    YES, AS IS YES, W/ CHANGES NO

22. Would you recommend this program for use in the pratice of designing aeration systems by:

a) county agents	YES, AS IS	YES, W/ CHANGES	NO
b) farmers	YES, AS IS	YES, W/ CHANGES	NO
c) aeration equipment suppliers	YES, AS IS	YES, W/ CHANGES	NO

23. Did participation in this technical evaluation cause you to think about the problem of aeration system design differently?
YES NO

24. As a result of participating in this technical evaluation would you consider changes to your current aeration system design procedure?
YES NO

If Yes, what changes would you consider?

25. Please use the space provided below to make any additional comments on the usability of this program.

APPENDIX K

Summary of Reviewers' Responses to Questionnaires

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Rating of Design Results

Reviewer: SUMMARY

Please rate the design results produced by the aeration design program based on the magnitude of difference between your results and the program results. Consider the case studies you used with the program and check the appropriate box. The rating categories of the differences are none, minor, moderate and substantial.

	DIFFERENCES			
Design result	**None**	**Minor**	**Moderate**	**Substantial**
1. number of ducts	4	3	2	0
2. placement of ducts	1	2	5	1
3. duct diameter	3	3	2	1
4. duct length	1	2	6	0
5. number of fans	2	1	2	3
6. fan size	2	2	2	2
7. connector size	2	4	2	1

If you checked the categories of *moderate* or *substantial* for any of the above items, please complete one of the attached rating explanation sheets for each item receiving a *moderate* or *substantial* rating.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	placement of ducts
duct diameter	duct length
number of fans	fan size
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

too many ducts placed in shallow storage

used 1.5 air path ratio throughout

Do you think the program should be changed? YES 2 NO 0

If yes, how would you recommend the program be changed?

disregard grain depths <= 4' (<= 3')

allow expert to change air path ratio

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	**placement of ducts**
duct diameter	duct length
number of fans	fan size
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

ducts placed close to wall in shallow storage

used 1.5 air path ratio for all ducts

tarp covered pile effect of widthwise placement not considered by program

using a spacing > depth of grain over duct

used 1.5 air path ratio for all ducts

disregarded outside 3-5 ft: depth - use evenly spaced ducts for convenience

Do you think the program should be changed?	YES	NO
	3	3

If yes, how would you recommend the program be changed?

disregard grain depths <= 4' (<= 3')

allow expert to change air path ratio

option for tarp covered pile

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts
duct diameter
number of fans
connector size
placement of ducts
duct length
fan size

For the category you circled above, what do you think caused the difference between your results and program's results?

duct size based on airflow required not delivered at fan

used higher velocities when grain depth at 30'

varied duct diameter along run

Do you think the program should be changed? YES 3 NO 0

If yes, how would you recommend the program be changed?

use required airflow for ducts

allow expert to make changes

add staggering duct diameter

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	placement of ducts
duct diameter	**duct length**
number of fans	fan size
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

I tend to extend duct closer to wall

offset from wall. we use pipe with less open area under shallow grain

duct offset rules

difference in offset from wall rules

offset from wall. we use 1.5 * maximum depth to side and disregard last 3-5'

Do you think the program should be changed? YES 4 NO 1

If yes, how would you recommend the program be changed?

allow for different % openings in tube

allow placing ducts closer to wall

allow ratio of side wall depth to peak depth

could use higher ratio up to 2.0 and disregard less than 5 ft grain depth

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts
duct diameter
number of fans
connector size
placement of ducts
duct length
fan size

For the category you circled above, what do you think caused the difference between your results and program's results?

I select a larger fan and use less -- manifolding

limit on plastic tube length increased number of fans

limit on plastic tube length increased number of fans

limit on plastic tube length increased number of fans

minimum size available (calculated hp and manifolded ducts)

Do you think the program should be changed? YES 3 NO 1

If yes, how would you recommend the program be changed?

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: ___SUMMARY___

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	placement of ducts
duct diameter	duct length
number of fans	**fan size**
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

I tend to oversize fan -- manifolding

difference in static pressure, we use chart of static pressure/ft of duct

static pressure estimate may be low, I did not consider 12" 1/3 hp size

minimum fan size (calculated hp and manifolded ducts)

Do you think the program should be changed?	YES	NO
	1	1

If yes, how would you recommend the program be changed?

estimate static pressure per length of duct

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Explanation of Moderate or Substantial Rating

Reviewer: SUMMARY

Circle the category rated *moderate* or *substantial* which is being explained on this sheet:

number of ducts	placement of ducts
duct diameter	duct length
number of fans	fan size
connector size	

For the category you circled above, what do you think caused the difference between your results and program's results?

tarp covered pile

related to duct size

connector interpretted as manifold or reducer

Do you think the program should be changed? YES 1 NO 1

If yes, how would you recommend the program be changed?

option for tarp covered pile

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Design Guidelines

Reviewer: SUMMARY

This section of the evaluation requests your opinions regarding design factors used in the aeration system design program. Please, indicate whether or not you agree with the following factors. If you disagree, indicate your preferred value in the space provided.

Design Factor	Value	Agree?	If no, your value
1. air path ratio for middle ducts	1.5	8 YES NO 0	
2. minimum grain depth on wall to be considered deep (ft) (related to 3 and 4 below)	5	7 YES NO 1	4
3. air path ratio to outside with shallow grain depth	2.0	8 YES NO 0	
4. air path ratio to outside with deep grain depth	1.8	8 YES NO 0	
5. maximum length of plastic aeration tube from fan (ft)	60	1 YES NO 6	75 80 80 100 100 press chart
6. maximum length of metal aeration tube from fan (ft)	80	4 YES NO 3	100 100 100
7. minimum static pressure for fan sizing (in. water)	0.5	8 YES NO 0	
8. static pressure of connector (in. water)	0.25	6 YES NO 1	Hancor curve data
9. static pressure of turn in connector or duct (in. water)	0.25	5 YES NO 2	0.5 10-15% total sp
10. minimum bushels to design aeration system (bu)	3000	6 YES NO 2	no minimum no minimum
11. minimum peak grain depth to design aeration system (ft)	6	8 YES NO 0	
12. minimum distance from duct to wall parallel to duct (ft)	3	5 YES NO 3	5-6' 5' 6'

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Response Screens

Reviewer: SUMMARY

Please evaluate the information the program requests of the user. All items asked on one screen are grouped together. Circle your response to the four questions for each response screen. The four questions are:

Is this information you typically ask of a client?
Is this information readily available to the client?
Is the question worded adequately?
Is the help information sufficient to assist a client in answering the question?

Response screen	Typical question	Information readily available	Worded adequately	Help information sufficient
1. client information	8 YES NO 0	8 YES NO 0	8 YES NO 0	7 YES NO 1
2. grain type	8 YES NO 0	8 YES NO 0	8 YES NO 0	8 YES NO 0
3. new structure	8 YES NO 0	8 YES NO 0	8 YES NO 0	8 YES NO 0
4. construction type	6 YES NO 2	8 YES NO 0	8 YES NO 0	8 YES NO 0
5. post spacing	6 YES NO 2	8 YES NO 0	8 YES NO 0	8 YES NO 0
6. structure liner	4 YES NO 4	5 YES NO 0	5 YES NO 3	7 YES NO 1
7. storage size	8 YES NO 0	8 YES NO 0	8 YES NO 0	8 YES NO 0
8. grain depths on walls	8 YES NO 0	8 YES NO 0	6 YES NO 2	8 YES NO 0
9. maximum piling height	8 YES NO 0	7 YES NO 1	5 YES NO 3	6 YES NO 2
10. number of ducts	6 YES NO 2	6 YES NO 2	8 YES NO 0	5 YES NO 3
11. duct type	8 YES NO 0	6 YES NO 2	7 YES NO 1	5 YES NO 3
12. duct direction	8 YES NO 0	8 YES NO 0	7 YES NO 1	6 YES NO 2
13. fan type	5 YES NO 3	7 YES NO 1	7 YES NO 1	6 YES NO 2
14. fan arrangement	6 YES NO 2	8 YES NO 0	5 YES NO 3	3 YES NO 4
15. airflow rate	8 YES NO 0	8 YES NO 0	5 YES NO 3	5 YES NO 3

Space if provided on the following page for your comments.

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Review of Response Screens

Please use this sheet to provide us with your suggestions and comments on the questions and order of presentation? Such as, needed wording changes, questions to be left out and questions to be added.

#6 state info will be printed later if selected; unclear if liner needed or conditions

#8 change illustration for side depth to show levelled top

#9 calculate max. pile height w/ angle of repose and display as default; instructions on figuring "natural" piling height

#10 advise 'computer' selection first; change help to "this program will determine and make a recommendation for the number of ducts required to aerate the grain..."

#11 disagree w/ paragraphs 2&3 (Altermatt); instead of plastic some say HDPE (High Density Polyethylene); plastic not limit to shorter runs and not more susceptible to damage than metal (McNall); may need to recognize greater duct loss-also % opening; depth is a limit for plastic

#12 other considerations - fan location, filling method; consider expanding to consider layout vs. efficiency and cost

#13 re-orient sequence since axial only real choice; separate axial & centrifugal by space w/ note to see help if centrifugal needed; smaller centrifugal fans are available

#14 other considerations- fan location, filling method; different illustration for widthwise placement; only one illustration shown for all designs - include downward air source from fan tower

#15 poor or average undefined; fines can be managed in help - consider 0.2 cfm/bu; include cooling time; default at 0.1 cfm/bu; default should be 0.1 cfm/bu

AERATION SYSTEM DESIGN FOR FLAT GRAIN STORAGES
Usability Evaluation

Reviewer: SUMMARY

Please respond to the following questions to help us evaluate the usability of the program.

USER INTERFACE

1. **How convenient are the keys used for the special key commands in the program?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
8	0	0	0

2. **After using the program once, how comfortable were you with the key operations?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
7	1	0	0

3. **What changes would you make to the key operations?**

   update capability for quick change of responses

   have program go to next screen after 'enter' key hit

   change highlight & selection on choice screen

4. **How acceptable is the speed of program execution?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
5	3	0	0

5. **Generally speaking, how easy was the program to use?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
8	0	0	0

6. **Based on the operation of the key commands and the appearance of information on the screen, do you think the following groups of people could use a program such as this one (not including technical aspects) after a few minutes of training?**

a) beginning microcomputer user	8	YES	NO	0
b) average county agent	8	YES	NO	0
c) average farmer	8	YES	NO	0

INFORMATION CONVEYANCE

7. **How effective are the text and illustrations in conveying the appropriate points?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
7	1	0	0

8. **In general, how well does the text convey the appropriate information?**

VERY	SOMEWHAT	A LITTLE	NOT VERY
6	2	0	0

9. Would the illustrations associated with the response screens be helpful to:

a) you or other expert	6	YES	NO	1
b) average county agent	7	YES	NO	0
c) average farmer	7	YES	NO	0

10. How useful are the illustrations for:

a) involving a user in the design process?

VERY	SOMEWHAT	A LITTLE	NOT VERY
3	4	0	0

b) helping the user to consider different options or new ideas?

VERY	SOMEWHAT	A LITTLE	NOT VERY
3	2	1	1

c) amplifying the meaning of the text?

VERY	SOMEWHAT	A LITTLE	NOT VERY
4	3	0	0

11. Considering the response screens in general, how important are the illustrations to the accuracy of communication with the user?

VERY	SOMEWHAT	A LITTLE	NOT VERY
5	2	0	0

DESIGN DRAWING

12. How usable are the design drawing and component specification list for a client to:

a) purchase components of an aeration system?

VERY	SOMEWHAT	A LITTLE	NOT VERY
5	2	0	0

b) install an aeration system?

VERY	SOMEWHAT	A LITTLE	NOT VERY
5	2	0	0

13. How would you change the design drawing?

symbol for solid vs. perforated w/ legend

put duct diameter on drawing; show footage of pipe not just location

BP should be related to direction; print plan w/ client information

heavier line for building; use modular lengths; drawing displayed longer

14. How would you change the component specification listing?

change connec tor size to solid duct size; change duct to perforated duct

add total hp & number of fans; add warming/cooling time

standard lengths and sizes

draw line under each duct size across page

MANAGEMENT RECOMMENDATIONS

15. How important are management recommendations in a program of this type?
    VERY SOMEWHAT A LITTLE NOT VERY
    7 0 0 1
16. How helpful, to a client, are the management recommendations generated by the program?
    VERY HELPFUL SOMEWHAT HELPFUL NOT HELPFUL
    5 2 0
17. How effectively are the management recommendations communicated?
    VERY GOOD GOOD AVERAGE BELOW AVERAGE
    3 4 0 0
18. Generally, is the correct emphasis placed on critical recommendations?
    YES, DEFINITELY YES, MOSTLY NO
    1 6 1
    If No, how would you change the emphasis?

    moisture/temp of grain - continuous or intermittent operation

    fan run time; exhaust area; bird-rodents; ventilation area

    number them add -more- & -end- at end of pages; insect control

19. How similar are the recommendations provided to ones you commonly make?
    VERY SOMEWHAT A LITTLE NOT VERY
    0 6 1 1
20. What changes, additions or deletions would you make to the management recommendations?

    time/temp/moisture; fan run time; exhaust area; insect control

    downward airflow recommended

GENERAL

21. Would this program be useful to you in the practice of designing aeration systems?
    YES, AS IS YES, W/ CHANGES NO
    2 6 0
22. Would you recommend this program for use in the pratice of designing aeration systems by:
    a) county agents 4 YES, AS IS 4 YES, W/ CHANGES 0 NO
    b) farmers 4 YES, AS IS 3 YES, W/ CHANGES 1 NO
    c) aeration equipment suppliers 2 YES, AS IS 6 YES, W/ CHANGES 0 NO

23. **Did participation in this technical evaluation cause you to think about the problem of aeration system design differently?**

YES	NO
4	4

24. **As a result of participating in this technical evaluation would you consider changes to your current aeration system design procedure?**

YES	NO
6	2

If Yes, what changes would you consider?

change air path ratio for ducts near side wall

consider using varying air path ratios

use air path ratios per your design method

determining length of connector: fan in middle of duct

25. **Please use the space provided below to make any additional comments on the usability of this program.**

print recommendations on screen; run w/o AutoCAD & Synthesis

add other products such as potatoes

allow other than rectangular storages - polygons

maximum side wall grain depth > 20'

change plastic to HDPE and max. lengths to 80'

calculate static pressure thru conduit vs .25 or have option to override default

for expert users allow more flexibility in design parameters

allow vertical fan placement

very impressed; very good and easy to use; will improve with use

it serves audience you identify; good program

APPENDIX L

Hardware and Software Requirements for Program

Hardware requirements:
- IBM-compatible personal computer with a hard disk drive
- 640K of random access memory (RAM)
- math co-processor
- graphics display adaptor and monitor compatible with AutoCAD
- AT&T Video Display Adapter/Digital Enhancement (VDA/D) and monitor
- Epson FX-80 compatible graphics printer

Software requirements:
- IBM DOS 3.0 or higher (or compatible)
- AutoCAD 2.5 with ADE-III extensions, by AutoDesk
- Synthesis 2.5, available by TransformerCAD
- Aeration System Design program containing INTPRO and RECPRO developed in the Interactive Computer Graphics Laboratory, Agricultural Engineering, Michigan State University