OPTIMIZING DIVERTER SHAPE FOR THE DIVERTER GRAIN SAMPLING METHOD

by

GARY DEAN STROMBERG

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Approved by:

Charles K. Spillman

Major Professor

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INTRODUCTION

As a result of the increased awareness of commodity prices by consumers, each phase of processing a commodity has come under close scrutiny. In the grain industry the farmers, country elevator operators, terminal operators, millers, and exporters are all very concerned about the quality of the grain they buy or sell.

Grain standards are based on a variety of parameters depending upon the grain in question. Generally they are test weight, moisture content, heat damaged kernels, shrunken and broken kernels, foreign material, contrasting classes, other classes, odors, and toxic substances. Since a variation of even one-tenth of one percent for some of these parameters will involve a change of grade for the grain, it is very important to obtain an unbiased representative sample from the grain lot.

There are various times during the transfer of grain to its destination at which samples may be taken. As grain is being loaded into boxcars, ships, etc., a sample may be taken from the grain stream at any place from the discharge gate to just before the grain enters the container. The grain may be sampled after it has been loaded on the ship, barge, truck, or boxcar. Thirdly, grain may be sampled after it has been sacked. Methods for the sampling of grain are set by the Grain Inspection Manual for each instance. Although there are set procedures to cover almost every case, the accuracy of the sample taken is admittedly only an approximate value. The error involved is usually unknown.

There are two important considerations when referring to the sampling of grain. The first is to obtain a representative sample of the grain lot, and the second is to obtain the sample in a minimal amount of time. The sampling of grain with the use of a probe or an in-stream sampler (pelican) requires much in the way of manpower and time consumption. Therefore, to increase efficiency and to collect a more representative sample it is necessary to increase the use of automation and to reduce human error to a minimum. Probably the best method is to mechanize the sampling of grain before it reaches the transport device. One technique is to use a transporter mechanism which will move a collection device through the stream of grain to obtain a sample.

The overall objective of a sampling device is to collect a true representative sample of the entire grain lot. Due to the non-uniformity of grain lots, the best a sampler can do is to accurately sample the grain which is passing by the sampler at that particular instant in time. The first step of the development is to design a collection device (diverter) which will take an unbiased uniform sample cut through the grain stream. The next step is to determine the interval between cuts, such that the total sample will be representative of the entire grain lot within certain limits of accuracy.

The intent of this research is to determine the parameters which affect the size and bias of a grain sample and to propose an optimum shape from the diverters studied which will collect a representative sample from the grain stream. This will satisfy the first step in the overall objective of accurately sampling a non-uniform grain lot.

REVIEW OF LITERATURE

History of Grain Sampling

The trading of grain has been a fundamental institution throughout history. Recorded history as early as 400 BC has shown the need for publicly employed food inspectors due to the suspicious nature of the consumer towards the producer and middlemen. In 1511 terms such as sweet, dry, and merchantable were used in an effort to describe grain (McDonald, 1932).

A systematic approach did not develop until circumstances necessitated the trading of grain over long distances during the early 1800's in the United States. Grain produced more economically in the midwest was sold to buyers from the east. Therefore, in order that the producers and buyers would understand each others merchandizing operations, various parameters, such as test weight, odor, etc. were established.

The Chicago Board of Trade (formed in 1848) was the first organization to initiate a systematic approach. In 1854 Chicago adopted buying and selling of grain by weight instead of by bushel. The first standards for grades of wheat were established in 1856, and in 1857 a system for inspection was instituted. The first grain probe was made in 1858. In 1860 inspectors were required to take samples and issue certificates for the grade of grain with this first sampling device (Elstner, 1958). During these formative years many other cities, which were centers of trade, developed their own criteria for the grading of various commodities. Milwaukee introduced the factor, test weight per bushel for the first time. Corn was added to the grading system. Definitions of grain grades became more precise. By 1863 inspectors were required to state their reasons for the grade of grain.

During the period from 1871 to 1921 grain grading and sampling reached its greatest development (McDonald, 1932). At one time there were seventy-three separate and distinct sets of grades and rules. From these varied systems a uniform set of grades and rules were comprised. In 1916 the United States Grain Standards Act was enacted. It is of importance to note that the process of grain grading was developed by grain dealers, not a government agency. This Act provided for federal supervision over grain inspection, not federal inspection of grain (USDA, 1972c).

From the United States Grain Standards Act, federal standards were adopted for sampling equipment and methods. An important aspect of having national standards was that the confidence of foreign buyers and domestic trade increased (Elstner, 1958). McDonald (1932) noted that an "important phase of grain inspection is the sampling" and "in order to obtain uniform application of grading grain, grading equipment has been devised, thereby reducing the grading to a mechanical application so far as possible and eliminating the personal equation." The first devices approved were the trier or probe and the pelican. Unfortunately, any research which brought about their acceptance was not referenced (Albert, 1973).

Mechanical sampling research was begun in the 1940's. From this research the Woodside type sampler for sampling of grain on belt conveyors was approved. Also a pattern used for probe sampling of boxcars was developed and approved. During the 1950's research was begun on the diverter method of sampling. It was not until 1968 that a program of study was initiated to determine the reliability of the diverter method of sampling. This research was conducted through the cooperation of Cargill, Inc., and the United States Department of Agriculture.

United States Grain Standards Act

Our grain standards are defined by law enacted by Congress. Therefore, all forms of inspection, sampling, and standards for quality of grain can only be changed when the law is revised by Congress (USDA, 1972c). From this type of control, an official policy can be established which will promote uniform application by official inspection personnel and provide an official inspection system for grain. The objective of this system is to market grain in an orderly manner and facilitate the trading of grain.

Inspection of grain for official grade is mandatory if exported from the United States or offered for sale or consigned for sale by grade which involves shipment of grain in interstate or foreign commerce (USDA, 1972c). The inspection of the grain is comprised of two parts: (1) to obtain an official representative sample, and (2) to analyze the various factors which determine the grade of grain. A sample is official if the sample is obtained by official inspection personnel who are licensed or authorized to sample grain or by a licensed sampler, sample size is of the prescribed amount, and the sample is obtained, handled, and submitted in accordance with prescribed methods and procedures (USDA, 1972a). Grain may be sampled while it is at rest in the container, during unloading, after unloading, or immediately after the initial elevation. If a grain sample is mandatory, then it must be sampled while the grain is being loaded or after the grain is in its final carrier. Before samples can be composited, each additional sample must be compared to the preceding samples to test for uniformity of the grain lot. The Grain Division Field Office is charged with authorization of all mechanical samplers and the licensing of inspection personnel (USDA, 1972b).

Importance of Mechanical Grain Sampling

Increased utilization of larger boxcars for the transport of grain has prompted interest towards the use of mechanical grain samplers to replace manual means. Since mechanical samplers allow the drawing of samples from a grain stream at the time of loading or unloading, economic benefits are realized by the grain industry in terms of faster turnaround of railroad boxcars, more efficient use of larger hopper cars, elimination of trimming in boxcars, and the elimination of grade disputes at destination (Kramer, 1968b). Carter-Day Company (1971) estimates that by sampling 250,000 bushels of grain, the sampler will have paid for itself. At port terminals the importance of mechanical samplers is most evident. An extreme example would be the sampling of a 100,000 bushel per hour flow rate. This flow rate would produce a sample size of approximately fifty bushels from one cut through the grain stream (McGinty, 1973).

The importance of mechanical grain sampling is playing a larger role in the area of quality control. Quality control implies an accurate description of the properties of the materials received, a means of maintaining or improving the qualities of the material, and a description of the qualities of the materials to be shipped (Kaufmann, 1964). Good sampling will provide good information concerning the physical properties of the material.

Economically, elevators are operating on a very tight margin compared to that of fifteen years ago. One of their largest incomes, storage of government grain, has decreased from 43 percent to less than 15 percent of their gross income (McGrane, 1967). Storage, delivery, and drying of grain coming directly from the field has increased the problems of storage space and materials handling. Because of these additional problems, elevators have had to update facilities in the way of aeration equipment and space for larger merchandise inventories, and have widened financial responsibilities in the areas of carrying hedged and cash grain inventories until transportation is available and extending credit to customers at peak times. Quality control of grain implies a significant, direct relationship to an elevator's margin of profit since the country elevator is now becoming more involved in the export market (McGrane, 1967). Considering the increased importance of a good sample to determine the physical condition of grains, a mechanical method of inspection is preferrable due to the short time available for inspecting and evaluating the grain sample during peak receiving periods (Kaufmann, 1964).

Sampling Methods

The four methods of primary sampling in common use within the grain industry are: (1) probe, (2) pelican, (3) belt, (4) diverter. These methods are termed primary sampling techniques, as opposed to secondary methods. The primary sample is collected from the original grain lot. To break this sample down to a workable amount for analysis, secondary methods are used. Secondary samples are in effect samples of the primary sample.

Probe

The probe was the first type of sampler to be approved, and is probably the most commonly used. In 1968 a performance check was made on three types of probe samplers (12 foot barge, pneumatic, and Prob-A-Vac) (Kramer, 1968c). The Prob-A-Vac drew the largest sample while the pneumatic sampler drew about one-half as much and the 12 foot barge probe drew about one-tenth of that drawn by the Prob-A-Vac. Concern over relocation of lot components, such as fines during transport was found to be insignificant after a statistical analysis was run on samples collected with the three probes. Taking samples by probing vertically versus vertical plus slant was also tested. In this particular testing program using a vertical probing pattern was more in agreement with the actual percentage of components in the lot of grain. Data on these tests are quite limited. From the probe testing, Kramer (1968c) observed "the possibility of specifying an adequate, yet practical probing pattern for nonhomogeneous grain loaded into hopper cars seems remote."

The pneumatic-type probe sampler was designed to use air as the means for collecting a grain sample (Kramer, 1965). In the pneumatic probe there are two concentric tubes with the outer tube slightly longer. Air is forced down the outer tube, and the air plus grain is returned through the inner tube. Since grain is not pulled from the surrounding area, the probe does not take any grain unless the probe is pushed down which theoretically lessens the bias of the sample. The purpose of this probe is to possibly replace the conventional probe in sampling large 100 ton hopper cars which are fourteen to sixteen feet deep. The advantages of this device are that it does not involve heavy manual labor, it will work through tightly compacted grain or mold, it is able to fit into small areas or openings, and it gives a more representative sample of insects. Its disadvantages include a high initial cost per sampler, and it requires an electrical power source.

The Probe-A-Vac sampler was designed to collect samples with suction. Principally it worked like a vacuum cleaner. Extensions, 2 feet in length, were added as the probe was pushed down through the grain. Depths of up to 100 feet have been sampled with this device. The grain collected was separated from the air with the use of a small cyclone (Probe-A-Vac Sampler, 1971). In Kramer's (1968c) report on probe analysis, the Probe-A-Vac was correlated with the other two types of probes. This correlation was 0.97.

Pelican

The pelican sampler was officially approved at approximately the same time as the probe. A pelican can be described as a leather pouch on the end of a pole. By swinging the pouch through a flowing stream of grain a sample is collected. There are two sampling techniques. The "Standard" sample is collected by swinging the pelican horizontally from right to left. The "Check" sample is drawn by swinging it from the far side toward the near side and from below to the top. The time interval between increment samples depends upon the flow rate of the grain. The pelican performed as well as mechanical samplers, but samples drawn were more variable (Kramer, 1968b).

Belt

Belt-type samplers (Woodside type) are primarily used for the sampling of material which is being handled by conveyor belts. This sampler collects grain by running a series of cups through the transported grain. Samplers of this type sample discręte parts of the grain bed cross-section a part of the time, and consequently may be biased by stratification of components within the grain bed (Kramer, 1968b).

Diverter

Samples collected by the diverter are less biased since the sample is taken from the entire cross section of the grain stream. Although a falling grain stream will stratify as it draws together in free fall, it is possible for all components of the grain stream to be collected. Accuracy and variability of the sample collected are considered to be as good or better than the other methods of sampling (Kramer, 1968b).

Principles of Diverter Sampling

"A diverter-type mechanical sampler is defined as a mechanical device installed in a spout or at a belt end to periodically obtain a sample of grain by cutting completely across the entire stream of moving grain (USDA, 1972b)." The principles for sampling of grain by the diverter method are as follows (ASTM, 1965):

1. Draw from the full cross section of the stream.
2. Minimize cutter width without obstructing normal flow.
3. Minimize disturbance of the product to prevent separation of densities and sizes.
4. Pass through the grain stream without loss or spillage.
5. Minimize the circulation of air through the sampler to prevent loss of fines.
6. Be self cleaning and non-clogging.
7. Prevent contamination of samples.
8. Take representative samples of the constituent to be analyzed.

By employing the above principles the goal of obtaining an unbiased representative sample can be achieved.

Reliability of the sample must be given special consideration since the analysis for the entire lot can be no more reliable than the samples on which it is based. The size of the sample must be large enough to represent the lot of grain, yet small enough to remain workable for analysis purposes. To produce reliable and optimum size samples by the diverter method, the following aspects should be considered: the cutter speed through the grain stream must be uniform; to prevent bridging, binding, or stoppages, the cutter opening must be of adequate size; design of the sampler must prevent contamination due to splash or dust conditions; to prevent the cutter from overflowing while in the grain stream, the cutter must discharge rapidly; frequency of sampling must be enough, such that, its analysis will reflect the true condition of the entire grain stream during a designated period of time; and the technique used for taking the sample must be proper for the stream being sampled (Joy Manufacturing Company, Denver Equipment Division, 1971).

Parameters Affecting Sample Weight and Quality

From a diverter which will collect an unbiased representative sample, two end results are known, the weight and quality of the sample. The end results are apparent, but the parameters which cause them are not. The following parameters may affect the weight and quality of the sample.

Friction Coefficient

The coefficient of friction between the grain and the surface material within the diverter may affect the size of sample collected by a diverter. According to material summarized by Stewart, Hossain, and Kunze (1969), the significance of normal load and relative velocity between materials (both within certain limits) on static and dynamic friction coefficients is less than formerly believed. With respect to grain such variables as grain moisture content, time of exposure, surface materials, hardness, and environmental conditions are more important. Only kinetic friction will be discussed since static friction is not of concern in this problem.

Bickert and Buelow (1966) noted the surface of a material should be conditioned before tests were run. Materials deposited by the grain tend to increase the coefficient of friction. This increase is partially due to the liquefication of fatty acids that are a component of the cuticular of kernels. Another contribution is the variation in deposits from the kernel along the sliding path. This increase extends to a finite condition beyond which there seems to be no additional effect. Passing grain over the surface until the deposits are produced completes the conditioning process.

On a steel surface (hot rolled 1010 steel 16 gauge) the kinetic coefficient of friction increased with an increase in moisture content. The effect of moisture increases was greater for higher moisture contents. In these tests the term moisture content was more meaningful when defined as surface moisture rather than gross moisture content (Stewart, Hossain, and Kunze, 1969).

A Teflon surface was studied under the same test conditions as in steel. Values for the Teflon friction coefficient were relatively low. The effect of moisture content was small and produced opposite results to that of steel. Friction decreased with an increase in moisture content until 17 percent was reached. The increased grain moisture tended to lubricate the Teflon surface. Two definite disadvantages of Teflon were its low resistance to indentation and its static electricity characteristics.

From the above studies it is generally agreed that surface moisture of grain was the controlling factor in determining friction coefficient for structural surfaces with small roughness factors (Stewart, Hossain, and Kunze, 1969).

Effective Cutter Width

Cutter width is a major parameter in determining amount of sample collected. The distance between the entrance lips is defined as cutter width. The effective cutter width is dependent on the relative value of the horizontal velocity of the cutter to the vertical velocity of the falling grain. If the horizontal velocity is a significant percent of the vertical velocity value, the width of the cutter available for collection of grain is reduced. Figure 1 shows the geometric relationship between cutter width and effective cutter width. The variables are:

V_s = Velocity of the falling grain stream

V_c = Velocity of the cutter

V_r = Velocity of the grain stream entering the diverter

B = Angle between V_r and V_c

W_a = Cutter width

W_e = Effective cutter width

The equation for this relationship is:

$$W_e = W_a \text{ Sin } B \qquad (1)$$

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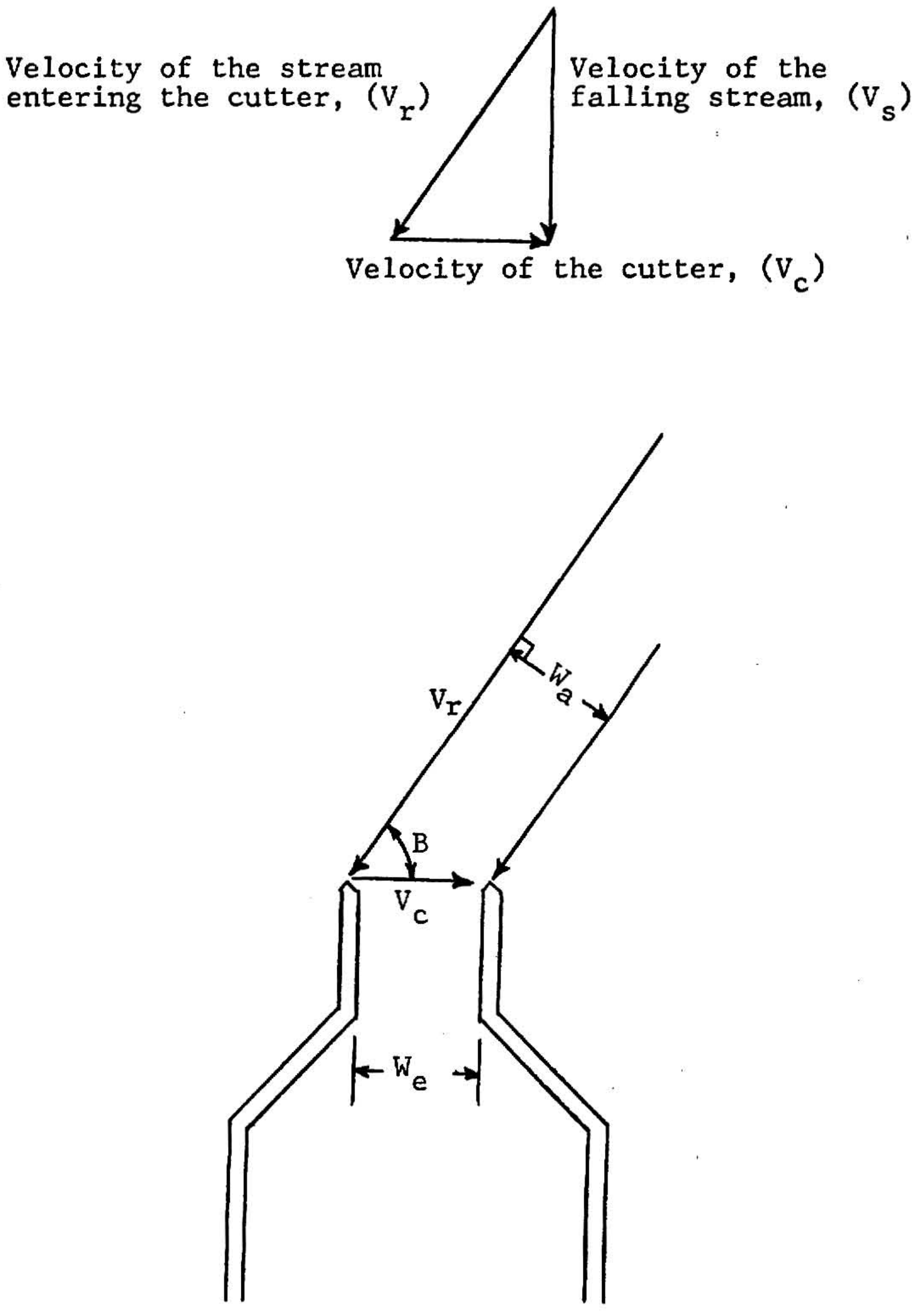

Figure 1. Geometric Relationship Between Actual and Effective Cutter Width.

The angle on the cutter blades need not be changed unless B varies appreciably from 90 degrees (ASTM, 1965). The cutter speed should be fast enough to keep the amount of sample small, but slow enough so the cutter does not deflect particles that should enter the cutter opening.

Joy Manufacturing Company, Denver Equipment Division (1971) suggests a safe rule of thumb for the effective width of cutter to be three times the size of the maximum diameter of the particle to be sampled. This width should allow unimpeded entrance of large and small particles, and minimize collision of particles as they enter the cutter. Particle size distribution of the commodity to be sampled may indicate that a relative factor other than three is practical. The larger the percent of larger size particles, the higher the relative factor for width (95-100% = 3½ to 5-10% = 1½).

Grain Velocity

Velocity of the grain at the cutter entrance affects not only the size of the sample, but is a cause for mechanical damage to the grain. This may affect the accuracy or variability of the sample. As stated in the discussion on cutter width, if the velocity of the cutter is a large percentage of the grain velocity, the amount of sample will be less due to the deflection of particles by the cutter. Therefore, it is necessary to determine the effects of grain sampled at various free-fall heights. Kramer (1968b) reported on a study where grain was dropped from heights of one, fifty, and eighty feet. The size of sample collected for a one foot fall was much less than that collected for the fifty and eighty foot falls, but the sample weights for the fifty and eighty foot falls were approximately the same. This in part sustains the hypothesis of the effect of cutter speed relative to grain velocity.

The prediction of free-fall grain velocity is desirable. Fiscus, Foster, and Kaufmann (1971) developed prediction equations for velocity of a grain stream and determined the terminal velocity of a single grain particle. Neglecting air resistance the theoretical free-fall velocity for an individual particle is:

$$V = 96.24\ D^{0.5} \tag{2}$$

where V = velocity, in/second,

D = vertical distance, ft.

The shape of an individual kernel of grain had a degree of influence on grain stream velocity. There was no significant difference in terminal velocities for wheat and corn, but it was six percent greater for soybeans. Hawk, Brooker, and Cassidy (1966) found soybeans have a lower aerodynamic drag coefficient. It is assumed lower drag accounts for the increased velocity value.

Grain stream velocities exceeded values for a single particle since a stream of grain acts as a mass in which each particle is affected differently by aerodynamic drag. In this test, drop heights ranged from 0 to 85 feet. At drop heights of less than forty-one feet orifice size had little effect on stream velocities. Over 41 feet, the larger orifice size produced higher stream velocities. A linear regression analysis produced the following equations from experimental data (Fiscus, Foster, and Kaufmann, 1971):

12 in. orifice

$$V = 51.3 + 73.3\ D^{0.5} \quad (3)$$

8 in. orifice

$$V = 59.9 + 67.0\ D^{0.5} \quad (4)$$

The intercept constant in the grain velocity equations accounts for the "coring" effect of grain moving towards the discharge orifice.

A method of experimentally determining grain stream velocities is the use of high speed photography. Film speeds of 1000 to 1500 frames per second produce pictures which show clearly defined particles. By adding a timing light or light generator to the camera, a spot can be incorporated on the film edge at specified time intervals. A specified time interval in conjunction with a grid background behind the grain stream yields the factors necessary for determining velocity. The true travel distance is depicted in Figure 2 which has the variables (Cargill, 1968b):

BC = Grain stream travel line

DE = Grid line

L_1 = Distance from the camera to the grain

L_2 = Distance from the camera to the grid

X = Travel distance on the grid

X' = True travel distance of the grain

The relationship between true travel distance and measured distance

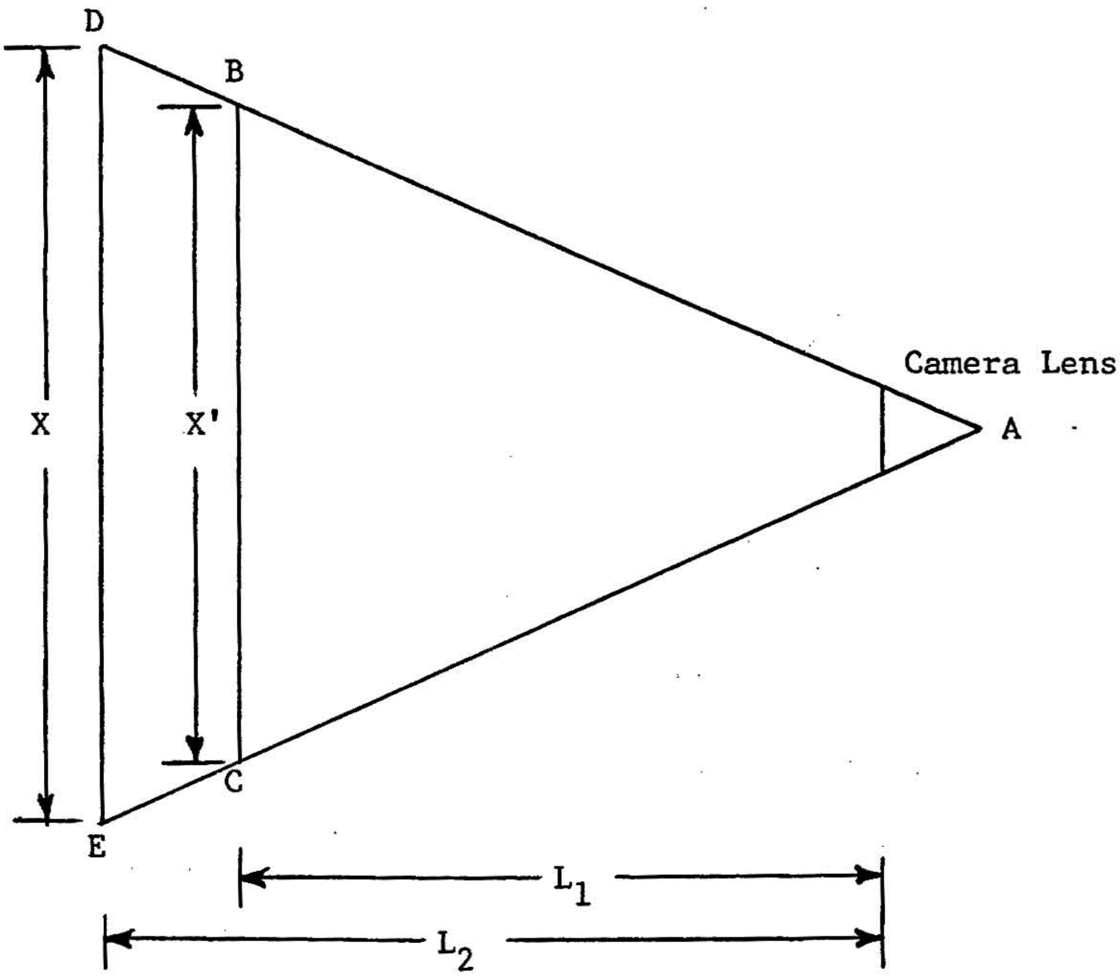

Figure 2. True Travel Distance for Velocity Measurements.

is:

$$X' = X L_1 / L_2 \tag{5}$$

By following a kernel of grain on film, its average velocity can be determined by the equation:

$$V = X' / T \tag{6}$$

where V = velocity

X' = true travel distance

T = time interval

From this method an average grain velocity can be determined at the cutter entrance.

Fiscus, Foster, and Kaufmann (1971) found grain breakage to be a function of velocity.

$$B = c V^n \tag{7}$$

where B = percent breakage,

V = velocity, in/second,

c,n = constants varying with grain type, moisture, and temperature.

From the study conducted by Kramer (1968b) fragile corn breakage increased 2 percent when sampled after a 50 foot fall and 4½ percent after an 80 foot fall. An optimum height for sampling would be high enough to obtain minimum breakage but low enough to neglect the effect of diverter velocity on effective cutter width.

Additional Parameters

The United States Department of Agriculture and Cargill conducted various tests to determine the effect of spout angle, travel direction of the diverter, flow rate, shape of the diverter entrance, diverter velocity, and entrance width of the diverter on the amount of sample collected. These tests were conducted with wheat and corn under conditions considered as representative to that in country elevators.

Spout angles of 30 and 90 degrees from the horizontal produced little difference as to the amount of sample collected at the same flow rate. All flow rates were less than 4000 lbs/min. The cutter entrance was perpendicular to the grain stream at both angles. Ratios of sample weight to flow rate were not significantly different for the two angles (Kramer, 1968b).

Assuming the diverter travels at an equal and constant velocity in both directions (left to right and right to left), travel direction should not influence the weight of increment samples. Differences found from travel direction in experimental sampling were expressed in terms of the lighter average as a percentage of the heavier average weight. An electric motor driven sampler produced significantly less differences than those samplers driven by pneumatic systems (Kramer, 1968b).

Cargill (1970a) conducted tests to compare sample weight to flow rate. Flow rates ranged from 400 to 6400 lbs per minute.

The ratio of sample weight to flow rate was significantly larger at the lower flow rates.

A study comparing the effect of two shapes for the cutter entrance was conducted by Cargill (1970a). Both diverters had a 3/4 inch wide slot for the inlet. The sides on one diverter were 2 inches apart and vertical except near the opening. A 27½ degree slope inward to the desired inlet opening width formed the entrance shape. The second diverter was similar, except after the 27½ degree inward slope the lips extended vertically about one inch. These two shapes are similar to shapes A2 and A in Figure 16. The diverter without the one inch vertical extension consistently collected larger samples in this comparative study.

By reducing entrance width from 3/4 inch to 1/2 inch at velocities of 100 and 200 ft per minute, sample weight was reduced 34 to 49 percent. Increasing the diverter velocity from 100 to 200 ft per minute with an entrance width of 1/2 and 3/4 inch decreased sample weight 47 to 51 percent. In this particular study, tests were run with wheat, corn, and soybeans. Estimates of lot composition did not vary considerably by changing these two parameters. Flow rates for this study were relatively low, an average of 1600 to 2000 lbs per minute (Kramer, 1968c).

INVESTIGATION

Objectives

The objectives of this investigation were: (1) to evaluate various sampling parameters with the use of three commercial grain diverters by comparing their characteristics to those of earlier studies, (2) to determine grain flow patterns which develop within the diverters as they pass through the grain stream, and (3) to propose guidelines for an optimum shape diverter from diverters studied which will collect an unbiased representative sample of grain.

Materials and Equipment

Materials

Wheat and corn were the two grains used in this investigation. Soybeans were not available. The moisture content for wheat was 12.2 percent wet basis and corn was 11.8 percent. The same grain lots were used for all sample collections. No cleaning of the grain was made during the investigation period.

Sampling Apparatus

The sampling apparatus used for experimental tests was located on the third floor of the elevator at the USDA Grain Marketing Research Center. Grain was dropped from a bin located above the apparatus to a bin below. The primary control for the flow of grain was a sliding gate located at ceiling level. A flow control valve, Syntron Division DFV 12 Style Number 117510, located 22 inches below the sliding gate was used to vary the flow rate of the grain. The drop distance for the grain from the flow control valve to the diverter entrance was approximately 56 inches but depended on the diverter used. A 10 inch diameter tube extended from the flow control valve down 47 inches.

A Gamet Automatic Sampler, Dean Gamet Manufacturing Company, was the drive mechanism used for these tests. It was powered by an electric motor driven gear reducer, which reversed direction for each traverse. Its diverter velocity was controlled by gear ratio and motor r.p.m. The diverters were carried on a belt powered by the motor. This sampling apparatus could also be rotated up 45 degrees for sampling at various spout angles. A chute below the sampler channeled the grain to the lower bin. Figure 3 is a photograph of the vertical position (spout angle, 90 degrees), and Figure 4 is a schematic of the apparatus in both the vertical and 45 degree positions.

Photographic Equipment

Photography was employed to determine grain velocities at the cutter entrance, flow patterns within the diverters, and flow patterns for various diverter entrance shapes. A Hycam Model K20S4E 16 mm high speed motion picture camera was used for filming. A Milli-Mite timing light generator Model TLG-3 was added to the camera to place light marks on the film edge. Kodak Ektachrome film (EF 7241-107-09) was used. The developed film was viewed with an Optical Data Analyzer Projector Model 224-A.

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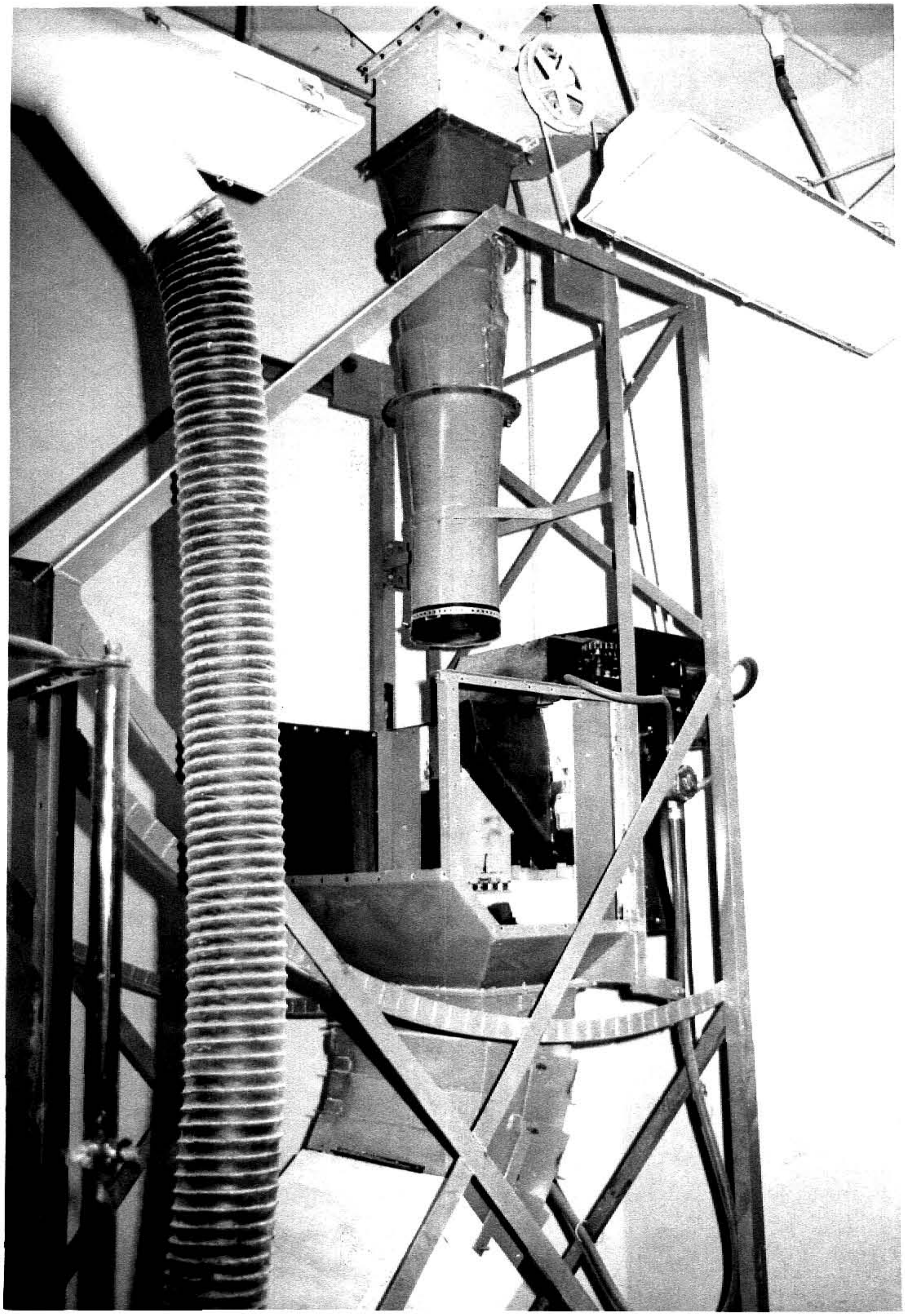


Figure 3. Sampling Apparatus in Vertical Position, Spout Angle of 90 Degrees.

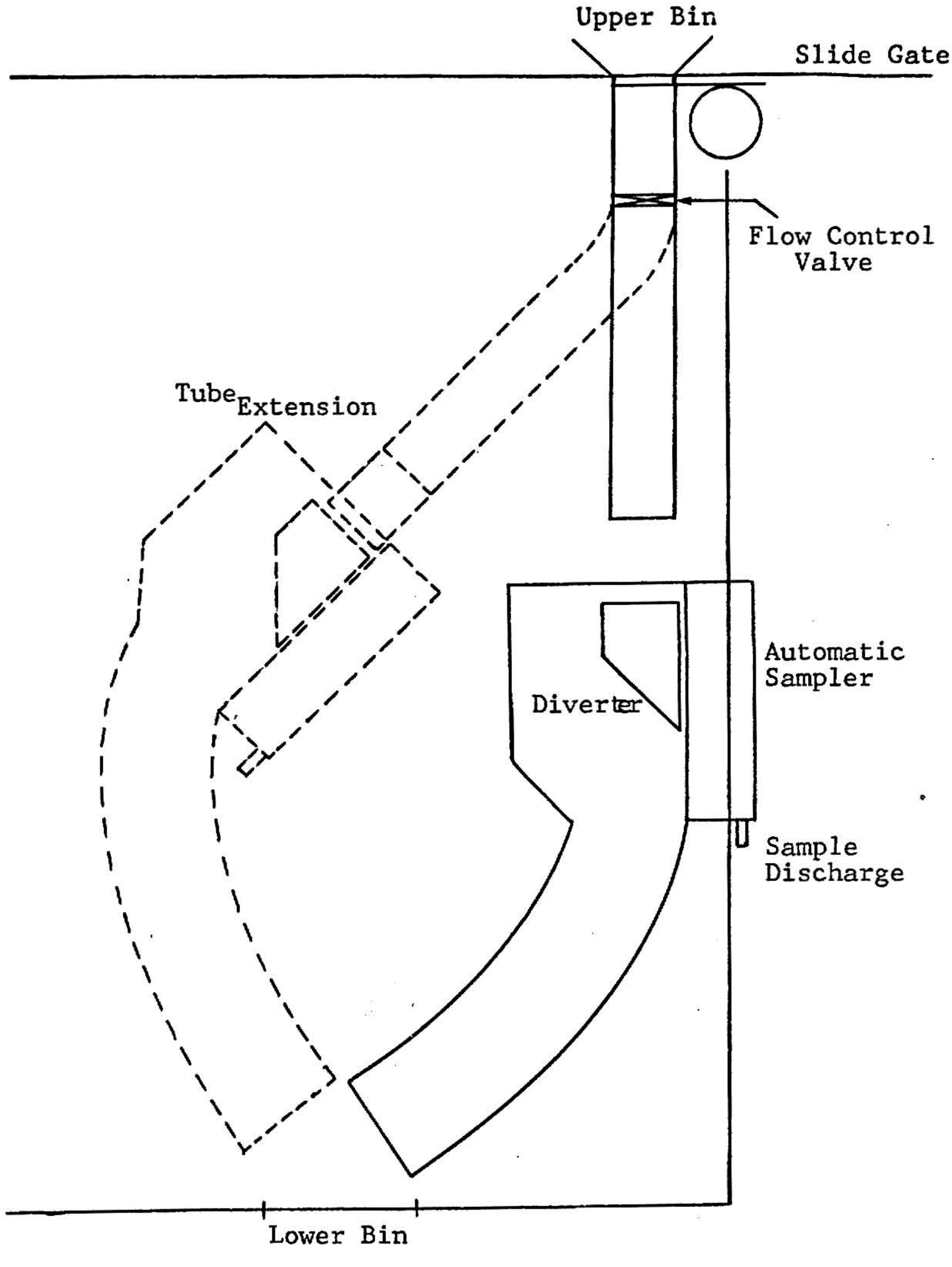


Figure 4. Schematic of Sampling Apparatus in the 45 and 90 Degree Spout Angle Position.

Sample Cutting Device

The sample cutting device was designed to produce the effect, not a model, of a diverter passing through a grain stream. A 10 inch diameter hole was cut in a slide panel. This panel was then located, such that, it would pass the cross section of the 10 inch tube. Operation of the slide panel was powered by the automatic sampler or moved manually. A diverter was then positioned on the center line of the 10 inch tube and 11 inches below the slide panel. To facilitate filming of various flow patterns and velocity determinations, a diversion panel was placed to divert grain from the near half of the tube. Figure 5 is a photograph and Figure 6 is a schematic of the device with a diverter in place.

Diverters

Three commercial diverters plus one diverter constructed in the shop were used in the experimental tests. Two of the commercial diverters were supplied by Dean Gamet Manufacturing Company, and the other diverter was from the Strand Company. Photographs of all four diverters are in Figure 7, and a schematic end view of each in Figure 8. Diverters A and B had flat channel shapes whereas diverters C and D had circular channel shapes. Internal volume ranked from the largest to the smallest was A, D, B, and C. Diverter C originally had a circular discharge area. In later tests C was modified by enlarging the discharge area as depicted in Figure 8. Diverter D was made to provide an entrance shape representative of another commercial diverter which was not adaptable to the automatic sampler used in these tests.

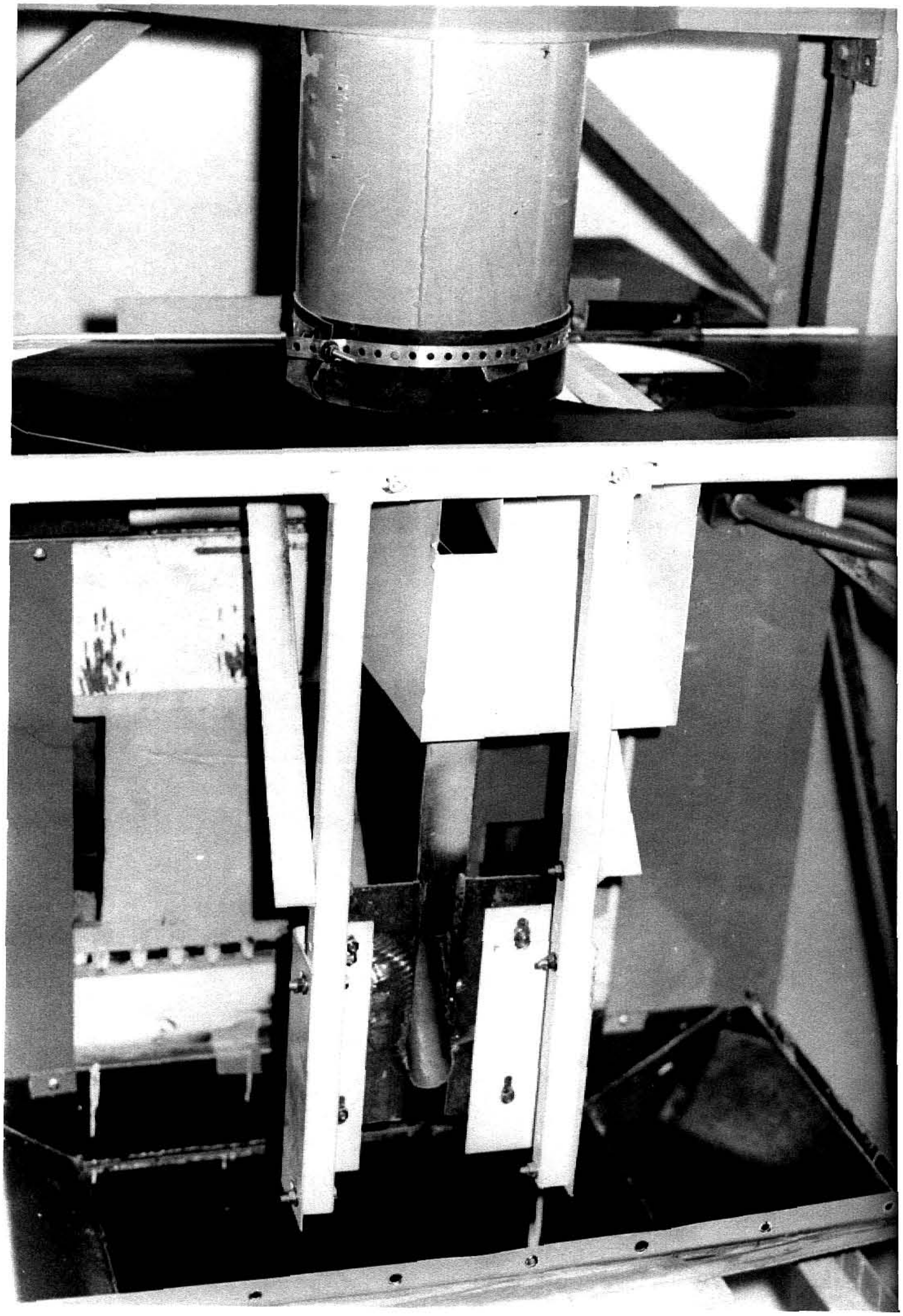


Figure 5. Photograph of Sample Cutting Device.

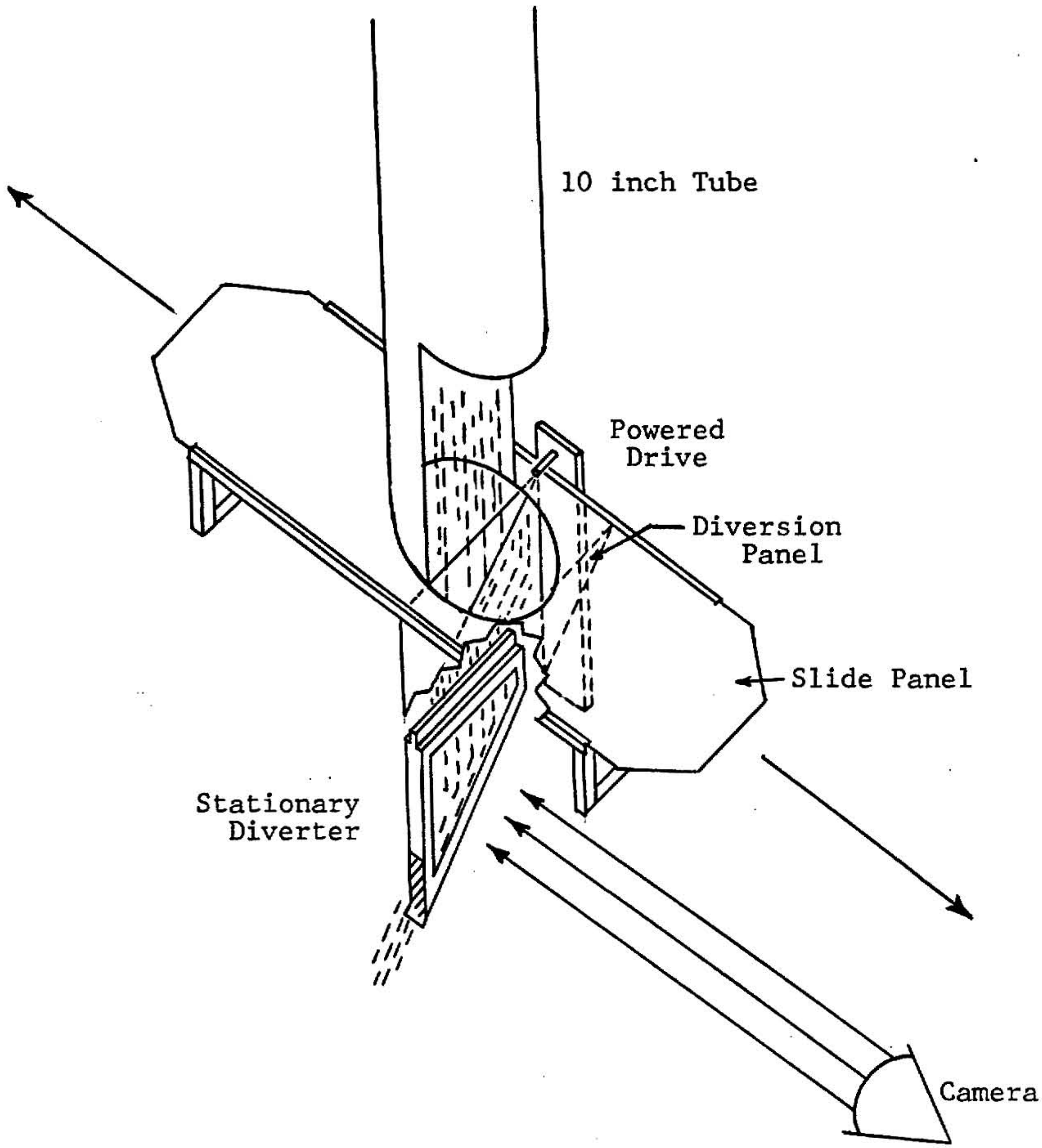
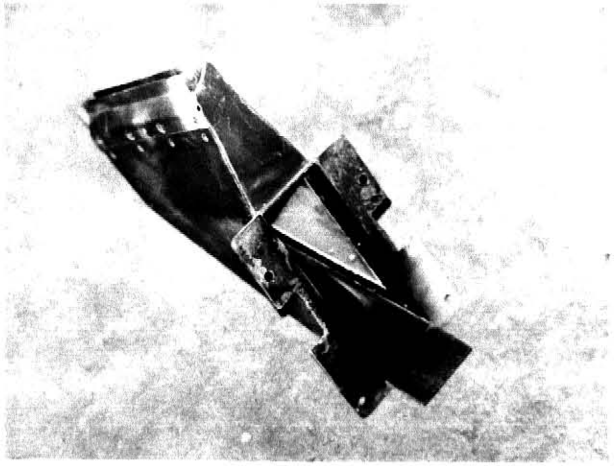
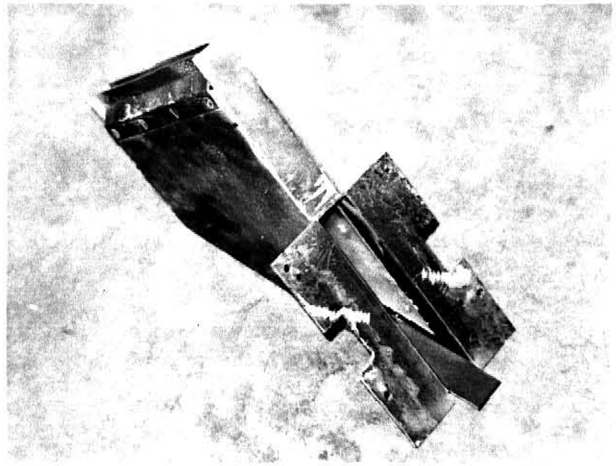


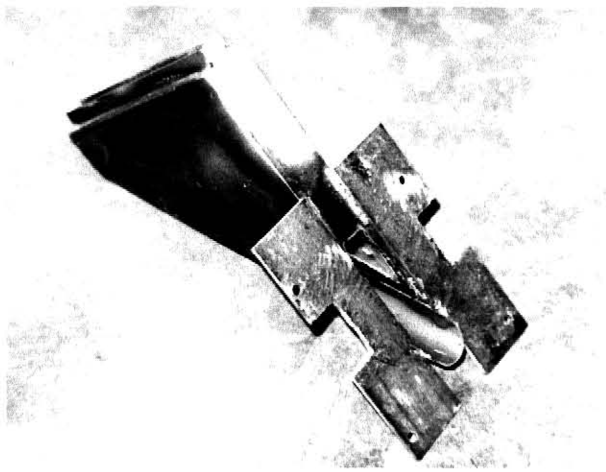
Figure 6. Schematic of Sample Cutting Device with a Stationary Diverter in Place.



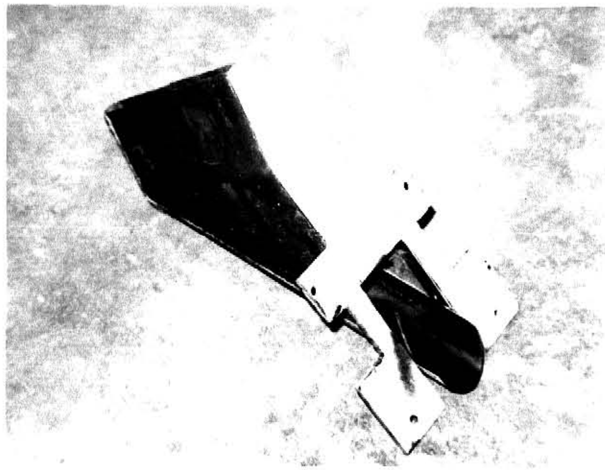
Diverter A



Diverter B



Diverter C



Diverter D

Figure 7. Photographs of the Four Diverters.

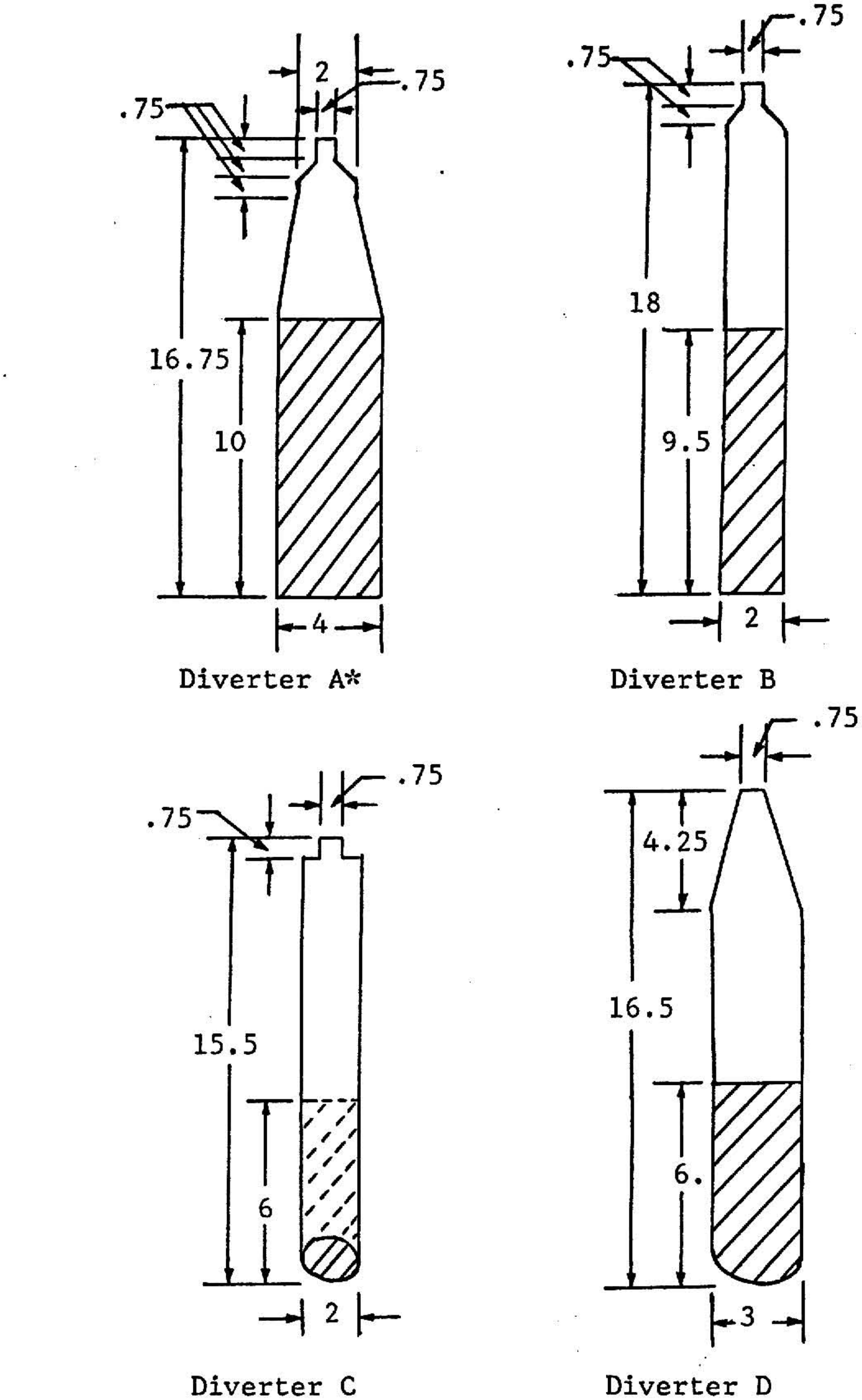


Figure 8. Schematic End View of Each Diverter.

Diverter Entrance Attachment

An attachment for holding various entrance shapes was added to the sample cutting device. End views of flow patterns around various diverter entrance shapes were photographed. The attachment was a holder located 9 inches below the diversion panel as shown in Figure 9. A piece of 1/4 inch plexiglass was placed flush with the end of the cutter lips on the attachment. This facilitated an improved photographic means of filming the flow patterns of grain around the diverter entrances. To determine the average velocity of the grain at the diverter entrance, a horizontal grid was incorporated on the right side of this attachment. Figure 10 shows a photograph of the diverter entrance attachment in position.

Methods of Procedure

Sample Collection

Obtaining a desired flow rate was the first consideration in sample collection. Due to the variability of the flow control valve, a sequence of events was necessary when starting the grain stream. First, the slide gate was opened to a maximum. Second, the flow control valve was opened to the desired setting. Third, the grain stream was allowed to run a specified amount of time depending upon flow rate before sample collection began. At low flow rates (4000 lb/min) 45 seconds was ample time, while at high flow rates (8000 lb/min) at least 90 seconds was required. By allowing the grain stream to run, the "coring" velocity was

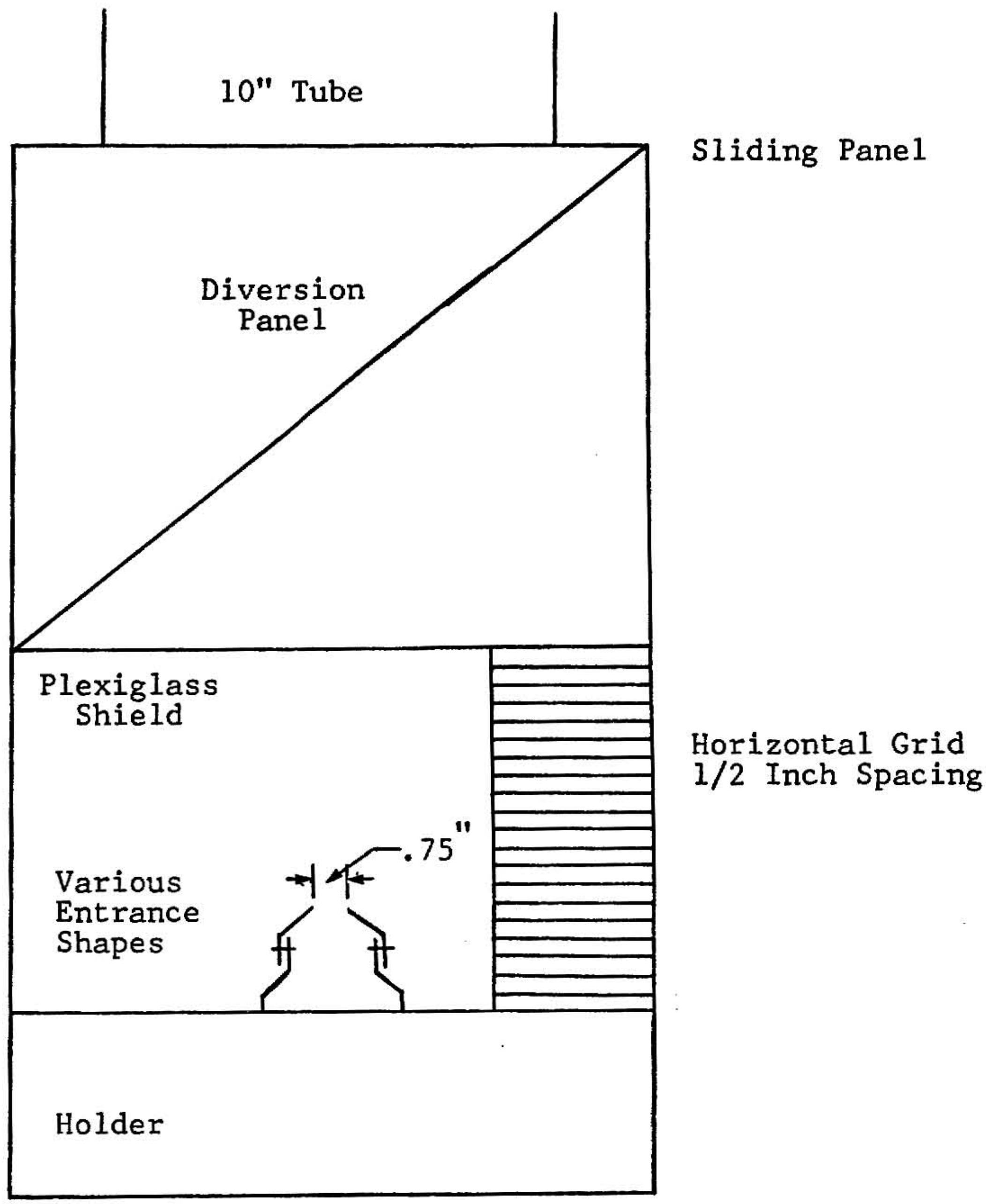


Figure 9. Schematic of Diverter Entrance Attachment.

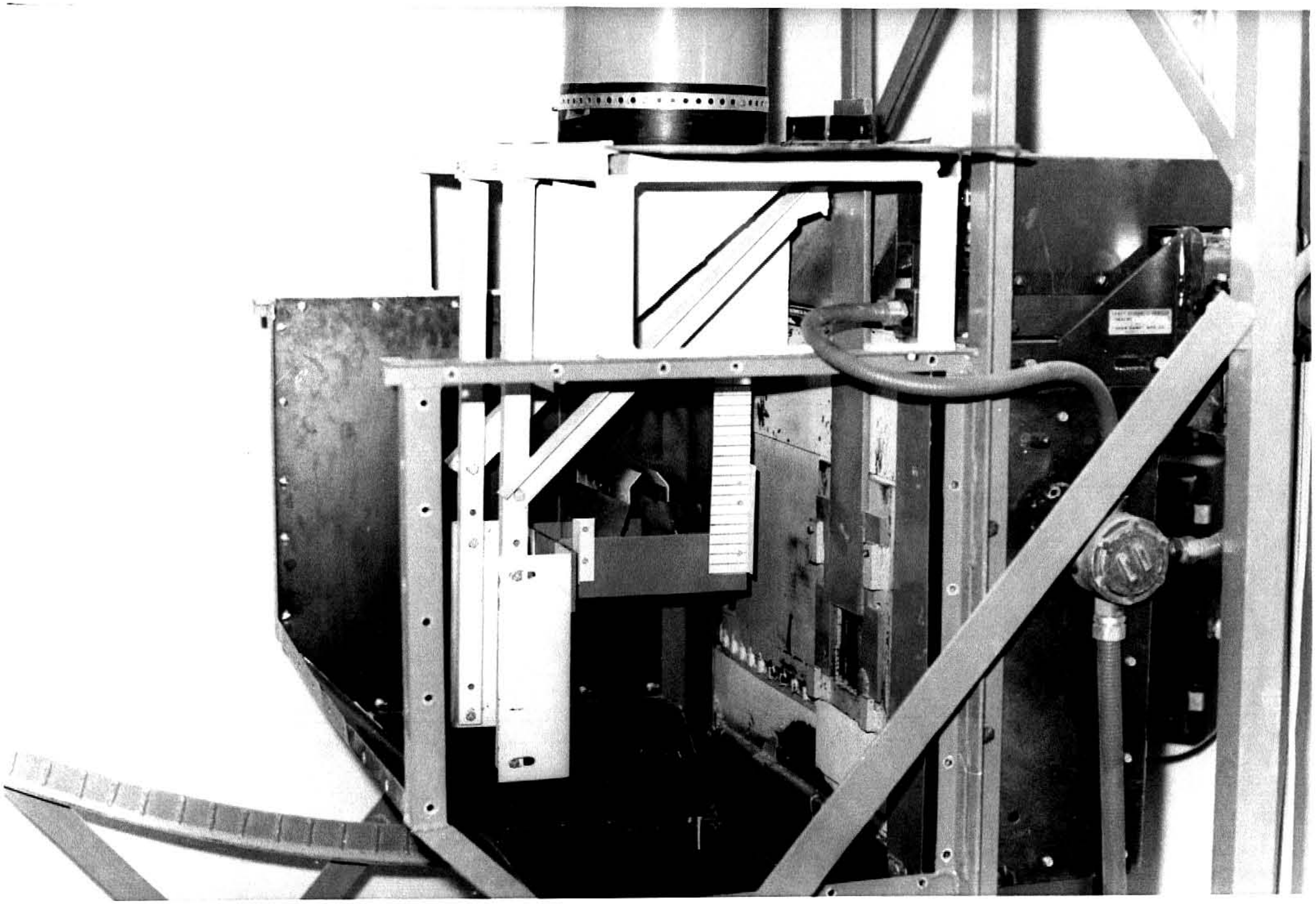


Figure 10. Photograph of Diverter Entrance Attachment in Place.

stabilized. Even though the flow control valve was set at the same setting for various drops of the grain lot, the flow rate still varied appreciably. Therefore, when the grain lot was dropped, the time had to be recorded to insure a known flow rate. Ten cuts through the grain stream by one diverter produced ten increment samples. These samples were then weighed, recorded in order, and averaged to determine the representative sample weight for that flow rate and that diverter. The diverters were made, such that they could be placed on and taken off the transporter quickly. Because of this, more than one diverter could be tested during one drop of the grain lot.

Flow Patterns Within the Diverter

Since there had been little success by Cargill to photograph a diverter passing through a grain stream, the slide arrangement with the diverter held stationary was used. This was not meant to be a model of sample collection by a diverter passing through a grain stream, but rather a means of determining the effect of a sample cut of grain passing through a diverter. Plexiglass was placed in one side of the diverter. One piece of plexiglass fit flush with the inside edges of the diverter, and an outer piece held the inner piece in place. The entrance shape was not affected by the plexiglass. Three effects were photographed for each diverter: (1) with the slide connected to the transporter, one cut of grain was passed through the diverter, (2) the same as number 1, except the diverter exit was closed off, and the sample was weighed, (3) the slide was adjusted manually to give maximum constant flow through the diverter. To start the grain stream both the slide gate and flow control valve were opened completely. The tube was allowed to fill before the slide panel was operated. A more uniform and controlled flow of grain was established by this method.

Flow Patterns Around Entrance Shapes

The apparatus for attaching entrance shapes described under Materials and Equipment was used to determine the flow patterns around the entrance shapes. Essentially, this represented an end view of the grain entering the diverter. The flow patterns established by the various shapes were photographed on the Hycam camera. Two results were desired: (1) the flow pattern around the entrance shape, (2) the grain velocity at which these patterns developed. The grain stream was begun in the same manner as stated in Flow Patterns Within a Diverter. The slide was adjusted to give maximum constant flow past the diverter entrance. A 3/4 inch width for the cutter entrance was maintained for all shapes studied. Plexiglass was placed at the edge of the cutter entrance to eliminate grain splatter, and to provide a more consistent surface of grain for photographing. Distance from the slide to the cutter entrance varied with the entrance shapes.

Velocity Measurements

High speed photography was used to determine the kernel velocity as it entered the diverter entrance. In the description of the Diverter Entrance Attachment a horizontal grid with 1/2 inch spacings was attached to the holder. Since the grid and grain surface were in the same plane, no true travel distance correction had to be made. A Hycam camera equipped with a light generator which placed marks on the edge of the film at intervals of 10 milliseconds was used for time references. The camera was run at 1000 frames per second. Figure 11 shows the camera, lights, and Diverter Entrance Attachment in position.

An Optical Data Analyzer Projector was used to view the developed film. The timing marks on the film edge were used to determine when the camera was up to speed. The kernel velocities were an average velocity over a distance of up to 6 inches.

Experimental Procedure

Since the nature of this investigation was intended to be a qualitative rather than a quantative assessment, procedure for the experiment was often determined by the observations made. There were four phases to the investigation.

The first phase was to verify the various sampling parameters by collecting samples with the three commercial diverters at three flow rates and two spout angles. The purpose of this was to compare these results with those conducted by Cargill and USDA. Since they had done their work with flow rates ranging from 400 to 6400 lbs/min, this investigation covered a range from 4000 to 9000 lbs/min. By overlapping the range of flow rates, it was possible to draw from assumptions and conclusions reached by Cargill and to extend this information as far as applicable to this investigation. The various parameters studied were spout angle (45 and 90 degrees),

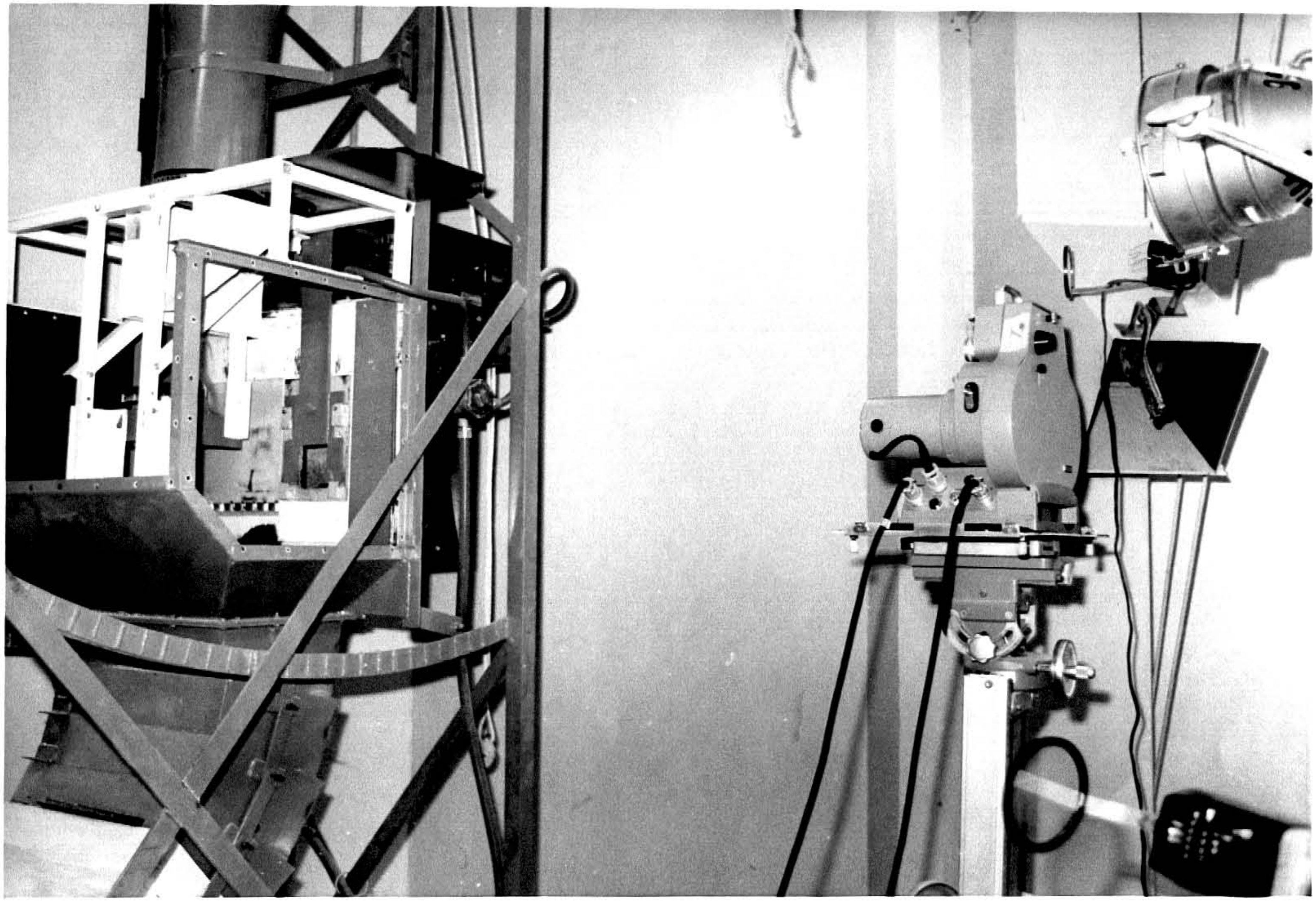


Figure 11. Diverter Entrance Attachment with Camera and Lights in Place.

direction of cutter travel (left to right and right to left), and flow rate (4000, 6000, 8000 lbs/min) on amount of sample collected.

The second phase was to determine the flow patterns which developed within a diverter as the diverter passed through a grain stream. Since Cargill had tried various techniques to photograph this event, all of which produced inadequate results, the sample cutting device was designed and used. Using the indicated procedure with this device, the importance of body configuration was assessed. The three commercial diverters plus one constructed in the laboratory represented different body configurations and entrance shapes.

Entrance shape was found to be of additional interest from the results achieved by observing the flow patterns within the diverters. In the third phase an attachment was made to hold various diverter entrance shapes using the sample cutting device. The various shapes are shown in Figure 16. Following the procedure on Flow Patterns for Entrance Shapes, a hypothesis that the entrance shape affected the amount of sample collected and the degree of bias was formed. The films taken of the flow patterns demonstrated the bias of various entrance shapes. The amount of sample collected was determined in the next phase.

The fourth phase was to determine the effect of diverter entrance and body shape on amount of sample collected. Four diverter entrances (A, A1, A2, and A3 shown in Figure 16) were used on diverter body A (shown in Figure 8). With the automatic sampler in the vertical position, spout angle 90 degrees, grain samples were collected at flow rates of approximately 4000, 6000, and 8000 lbs/min by diverter A and its various entrance shapes. To determine the effect of body shape on sample weight, diverter C and D were also used. Diverter C's entrance shape was the same as diverter A1, and diverter D's was the same as diverter A3. Therefore, by comparing diverts A, A1, A2, and A3 entrance shape effect could be seen from sample weights, and by comparing diverter A1 to diverter C and diverter A3 to diverter D body shape effect could be seen on the amount of sample collected.

RESULTS AND DISCUSSION

Parameters for Sample Collection

As many parameters as possible for the grain sampling process were held constant. Diverter traverse speed, which was measured by photographic means, was 96 ft/min in both directions. Cutter width was adjusted to 3/4 inch for diverter and entrance shape tests, but no referenced material was found for why the USDA and industry selected this width to be a standard for diverter samplers. Spout angle at which samples were collected was either 45 or 90 degrees from the horizontal. Grain kernel configuration effect on amount of sample collected was represented by corn for large kernels and wheat for small kernels. Soybeans were desired for study because of their round shape, but they were unavailable.

Flow rates of approximately 4000, 6000, and 8000 lbs/min were examined. The flow control valve produced an apparent uniform flow of grain. When the valve was set at the same setting to reproduce that flow, the flow rate would vary up to 1000 lbs/min. Therefore, the entire lot of grain had to be dropped during one time interval to determine the flow rate for each test. After discussing this project with a statistician, ten sample cuts with one diverter at one flow rate were determined to be sufficient for obtaining a representative average sample weight. The distance from the flow control valve to the diverter entrance was kept nearly the same to maintain an equivalent grain velocity at the diverter entrance for all diverters at approximately the same flow rate.

Nonhomogeneity of the grain lot was the most unpredictable parameter. Over a designated time interval the composition of the grain stream changed as various concentrations of fines, broken kernels, foreign matter, etc., within the grain lot passed into the grain stream. From information determined in later tests, the velocity of the grain stream would vary 10 to 20 in/second from an average velocity of 236 in/second over a limited time interval. As a result, sample weight variation can at least be partially attributed to varying velocity and density of the grain stream.

Verification of Sampling Parameters

The results of the sample collection data were used as a means for determining the relative performance between diverters and sample collection parameters, but not as a calibration guide for the diverters. The range of flow rates for this testing was from approximately 4000 to 9000 lbs/min. Extrapolation beyond these limits with the equations derived from sample data would not be desireable. Equations were developed through the use of the WANG General Program Library 520/600 Series. Programs for Linear Regression Analysis and Least Square Fit - Power Curve were used.

A linear relationship between grain flow rate and amount of sample collected existed for all three diverters with the sampling apparatus in the vertical position, spout angle of 90 degrees. Figure 12 shows the data and lines for the regression equations for wheat. The equations with their correlation coefficient r were:

Spout Angle 90 degrees

Diverter A $Y = 8.92 + 0.223\ X$ $r = 0.998$ (8)

Diverter B $Y = 83.85 + 0.197\ X$ $r = 0.994$ (9)

Diverter C $Y = -24.22 + 0.270\ X$ $r = 0.999$ (10)

where X = Flow rate, lbs/min,

Y = Sample weight, grams.

General trends from the graph for wheat indicate that the higher the flow rate, the larger the differences between diverters in the amount of sample collected with the sampler in the vertical position. Kramer (1968b) reported that there was less difference between diverters at lower flow rates.

Figure 13 shows the data and lines for the regression equations for corn, spout angle of 90 degrees. The equations with their correlation coefficient r are:

Spout Angle 90 degrees

Diverter A $Y = 190.32 + 0.120\ X$ $r = 0.997$ (11)

Diverter B $Y = 179.08 + 0.109\ X$ $r = 0.999$ (12)

Diverter C $Y = 216.29 + 0.110\ X$ $r = 0.996$ (13)

The linear relationships from the corn data show each diverter produces approximately the same slope and are equi-distant at the higher flow rates.

The important difference between wheat and corn results was that diverter C consistently collected more grain than diverter A

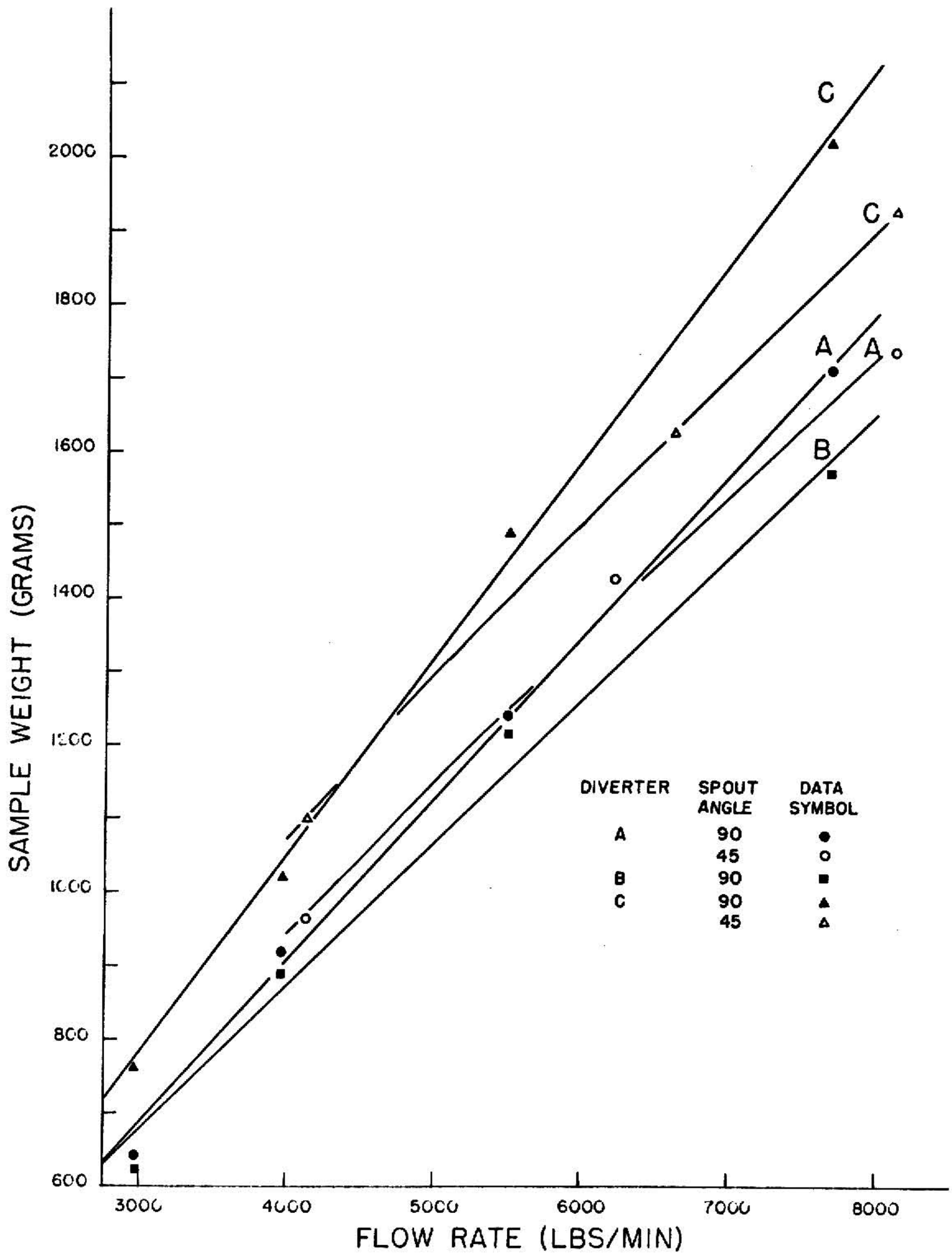


Figure 12. Grain Flow Rate Versus Sample Weight for Each Diverter, Wheat.

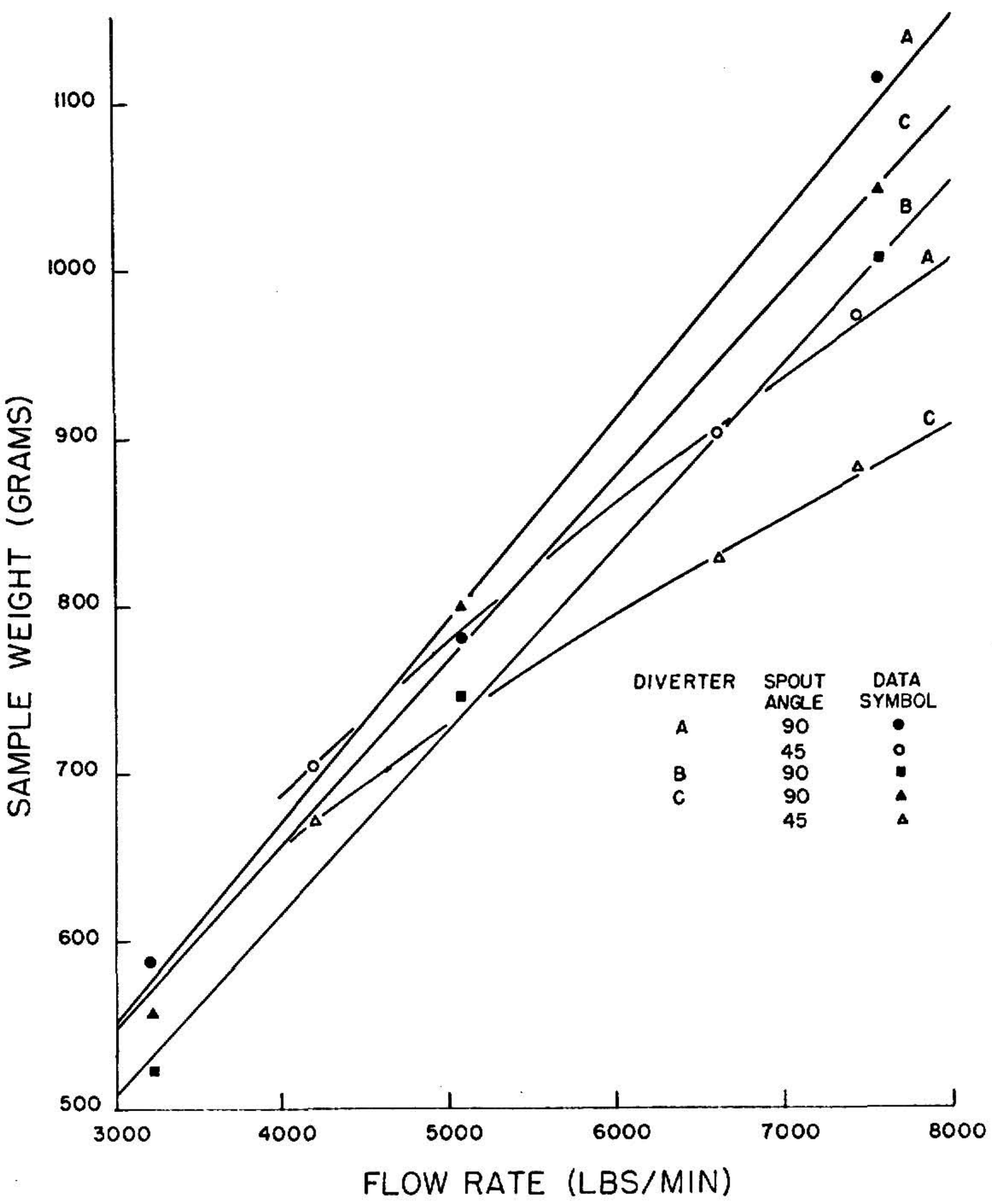


Figure 13. Grain Flow Rate Versus Sample Weight for Each Diverter, Corn.

during the wheat tests, but diverter A collected more than diverter C except for one case during the corn tests at a spout angle of 90 degrees. Diverter B collected the least amount in all cases.

When the spout angle was changed to 45 degrees, an extension was added to the spout to keep the grain stream together until it reached the diverter entrance. Diverter B was deleted from this test because its entrance was higher than that of diverters A and C. Since diverter B was very similar to that of diverter A in amount of sample collected for wheat under the vertical condition and had the same entrance shape as diverter A, the amount of modification in the apparatus and extra tests required were determined to be unwarranted.

With the sampling apparatus in the 45 degree position and the grain stream running, a trickle of grain continuously ran through the sample discharge while the diverter was located to one side. There was no flow when the diverter was located on the other side. Therefore, all samples were taken with the diverter moving from the trickling side to the other side. By doing this, the amount of bias was the same for all samples collected and there was no travel direction error involved.

The results of wheat sample collection with the spout at a 45 degree angle showed that both diverter C and diverter A performed with a linear relationship to flow rate. The following equations describe the results for wheat shown in Figure 12.

Spout Angle 45 degrees

Diverter A $\quad Y = 175.35 + 0.194\ X \quad r = 0.998 \quad (14)$

Diverter C $\quad Y = 251.22 + 0.207\ X \quad r = 0.999 \quad (15)$

Diverter A collected approximately the same amount of grain in the two spout positions for each flow rate, and diverter C collected proportionately less grain at the same flow rate from the 45 degree position as compared to the 90 degree position for the higher flow rates. The grain stream from a 45 degree spout angle was observed to be more dense than that of a grain stream in free fall. In this position the diverter's available entrance area for the same amount of grain was less. As a result, only a part of the internal volume was available for grain entering the diverter. Diverter C may have begun to overflow at higher flow rates, while diverter A had sufficient internal volume to accommodate the grain entering the diverter. Another reason may have been the effect of entrance shape on a more dense grain flow.

In the sampling of corn diverters A and C collected lesser amounts of grain at a spout angle of 45 degrees compared to that collected in the vertical position at the same flow rate. The results for sampling with a spout angle of 45 degrees in Figure 13 are described by the equations:

Spout Angle 45 degrees

Diverter A $\quad Y = 13.61\ X^{0.467} \quad r = 0.999 \quad (16)$

Diverter C $\quad Y = 7.62\ X^{0.549} \quad r = 0.999 \quad (17)$

Since both diverters collected less grain in the 45 degree position compared to the 90 degree position, size of the grain kernel under a dense grain flow condition was assumed to be the affecting parameter.

Samples were collected from the grain stream with the sampler alternating from left to right and right to left. The average weights of the odd numbered increment samples and the even numbered increment samples were ascertained. The overall average effect of diverter travel direction based on the lighter of the two averages expressed as a percentage of the heavier average weight was 96 percent for all cases. Table 1 shows the results for each case. Kramer (1968b) also reported a difference in sample weights as a result of travel direction. His explanation was that diverter velocity was controlled by gear ratio and motor r.p.m. which was not always ideally the same for both directions.

From the preliminary study of sampling parameters, diverter characteristics affecting sample bias and amount collected were observed to be: (1) the volume needed within the diverter to prevent clogging or overflow of the diverter, (2) the area required for the discharge point to prevent excessive buildup within the diverter, and (3) the effect of diverter entrance shape on the size and quality of the sample. These characteristics were studied in the following sections.

Table 1. Effect of Diverter Travel Direction Based on the Average Weight of the Lighterweight Sample of Alternating Samples of Grain, Expressed as a Percentage of the Heavier Average Sample for Wheat and Corn*

Diverter	Lighterweight Average / Heavierweight Average (%)						
	Wheat				Corn		
	Flow Rate (lbs/min)						
	2953	3908	5515	7668	3215	5091	7636
	%	%	%	%	%	%	%
A	97.3	98.1	98.8	98.6	94.0	98.0	98.6
B	94.6	96.2	96.3	99.4	99.3	95.1	97.0
C	88.9	89.3	91.2	97.5	91.7	95.8	98.3

*The automatic sampler was in the vertical position, spout angle 90 degrees.

Flow Patterns Within the Diverter

By holding the diverter stationary and simulating the movement of the grain tube passing over the diverter, the effect of one cut of grain passing through the diverter was observed and photographed. A relative comparison between sample weights incurred from actual sampling and those from the sample cutting device were made to determine whether or not what was photographed represented actual conditions. To determine the presence of excessive restrictions of grain within the diverters, a continuous grain stream was run through. Diverter D was constructed after the three commercial diverters had been observed. This diverter had a different entrance shape and was a composite of the other three diverters for its body configuration.

Figure 14 shows the schematic patterns for wheat within the diverters for three conditions: (1) maximum level for one cut of grain, (2) grain level with the exit closed off, (3) grain level under continuous run conditions. The sample weights measured from condition 2 ranged in value from 2000 to 2300 grams of wheat. This was slightly heavier than those weights measured under actual sampling conditions. Diverters B and C had vertical side walls 2 inches apart. Grain build up in these two diverters was excessive. Diverter C did not have the discharge area or depth of diverter B, and consequently overflowed under all three conditions. When diverter C's discharge area was increased, it did not overflow for one cut of grain, but the other two conditions were the same. Diverters A and D had side walls 4 and 3 inches apart. These

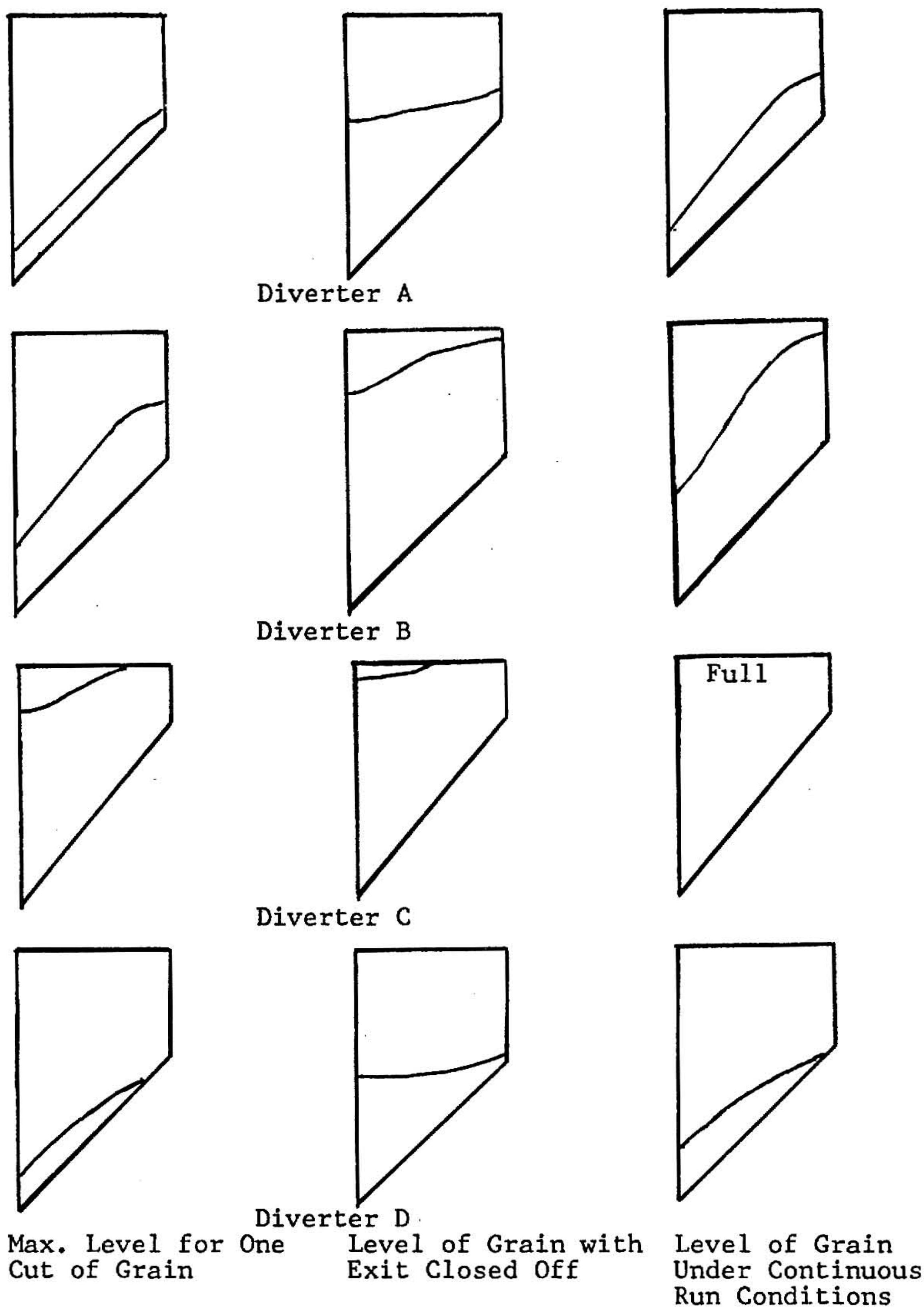


Figure 14. Schematic of Flow Patterns Within a Diverter for Wheat.

diverters had sufficient internal volume and discharge area. Conditions 1 and 3 for each of these two diverters were very similar.

Figure 15 shows the schematic patterns for corn within the diverters for the same three conditions as for wheat. The range of weighed samples measured from condition 2 was from 1400 to 1500 grams which was more than the weight of samples taken under actual sampling conditions. For corn all four diverters had ample internal volume and discharge area for one cut of grain to pass through. A build up was still noticeable for diverters B and C. Diverter C with its larger discharge area still overflowed under condition 3. Diverters A and D each showed similar grain flow patterns between conditions 1 and 3.

For the range of flow rates covered in this investigation, none of the diverters overflowed under actual sampling conditions as a result of internal volume or discharge area restrictions. Yet, each diverter collected a different amount of sample in the first part of this investigation. The effect of diverter entrance shape on the amount and bias of samples was the next area studied.

Flow Patterns Around the Diverter Entrance

Six entrance shapes were used on the diverter entrance attachment. Wheat was dropped over all these shapes and corn was dropped over four of the shapes. The velocity of the grain at the entrance edge was about half of that measured under actual sampling conditions. Velocity measurements are discussed in the next section. Figure 16 shows these shapes along with a schematic

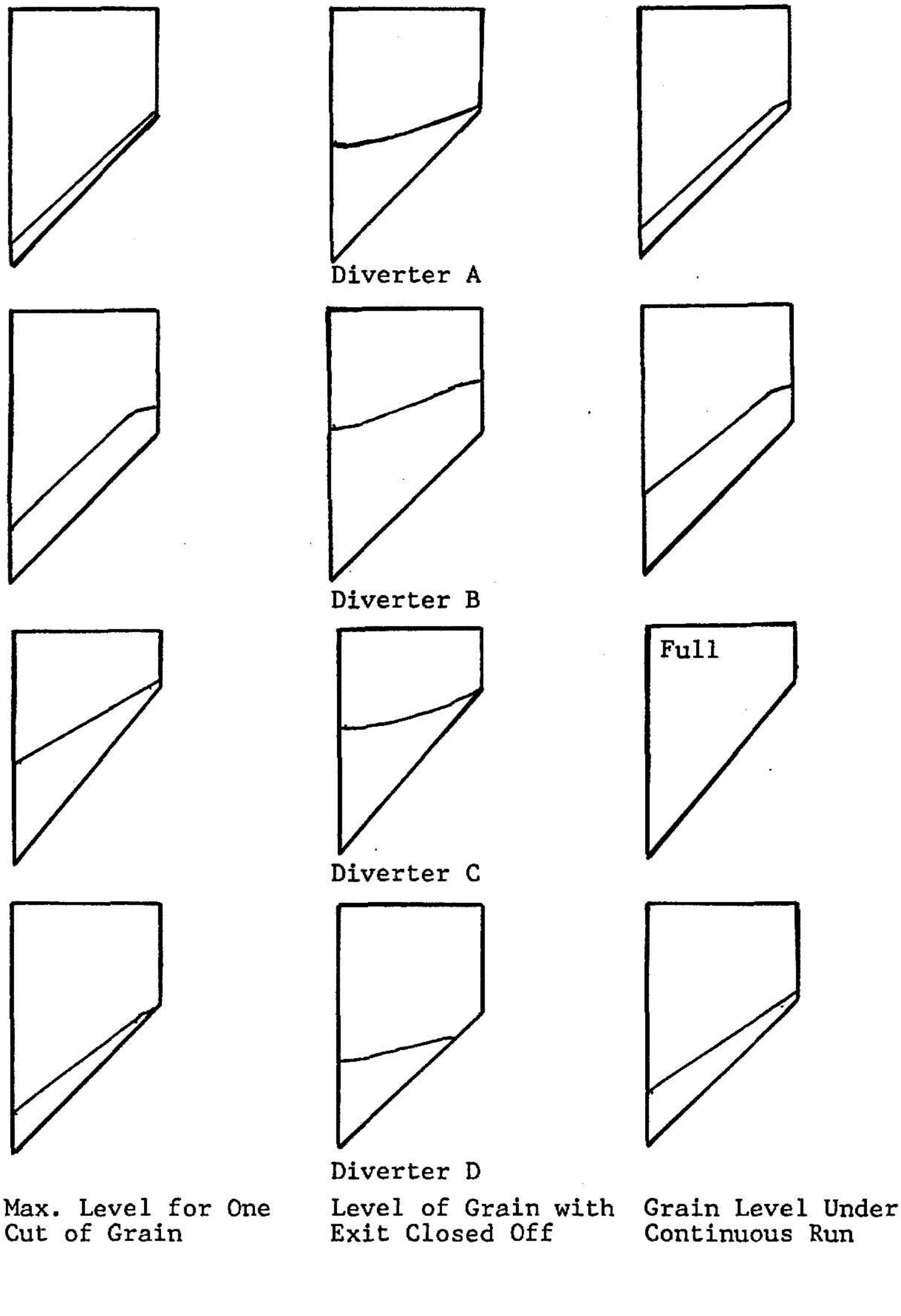


Figure 15. Schematic of Flow Patterns Within a Diverter for Corn.

of their flow patterns for wheat and Figure 17 shows the flow patterns for corn.

There were two shape A configurations. One was made with 1/8 inch metal (A) and the other with 1/16 inch metal (A_t). Observations made on metal strips of varying thickness held in a wheat grain stream showed that the thicker the metal, the more deflection produced. The effect of metal thickness on grain flow patterns was observed in the films of wheat in which a distinct difference was clearly seen between shapes A and A_t. Grain build up on the leading edge of entrance shape A was greater than that on A_t. A horizontal velocity component was introduced by grain striking the leading edge on each side of the diverter entrance area. Since the grain stream was kept from gaining immediate relief as it entered the diverter, these collisions formed a binding effect between the vertical metal strips of the entrance shape. The difference between the amount of congestion for shapes A and A_t is shown in Figure 16. Corn kernels deflected into the entrance area to a greater degree than wheat. This was especially noticeable when corn kernels in the wheat lot struck the leading edge of the entrance. These kernels moved farther horizontally than the wheat kernels.

Entrance shape A1 and the entrance for diverter C were the same in metal thickness and dimension. When wheat was passed by this shape, a build up occurred on the ledges. This build up extended to the leading edge of the entrance shape in a convex fashion. The overall flow pattern was similar to that produced by shape A2. As corn was passed by shape A1, the build up on the

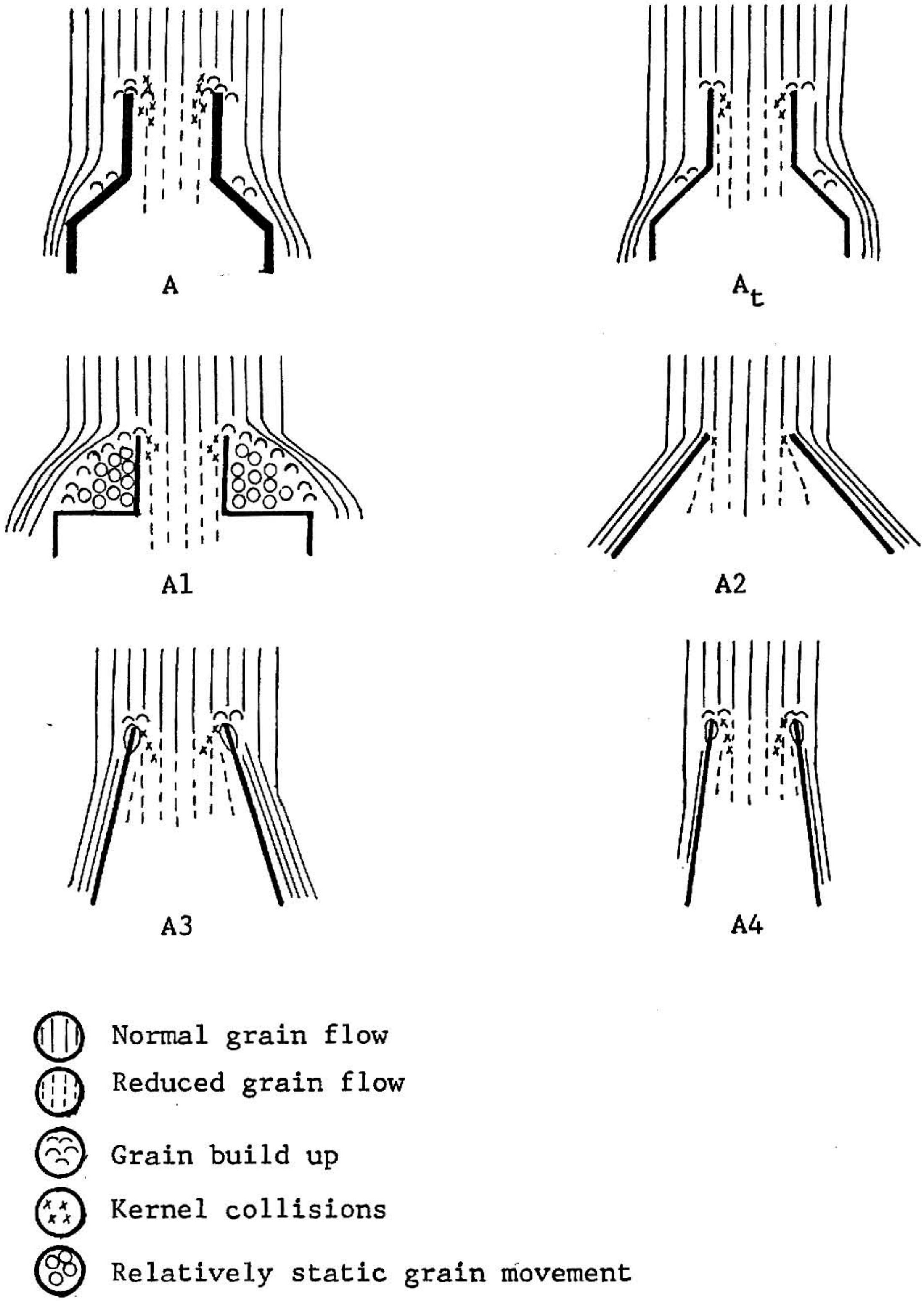


Figure 16. Schematic of Flow Patterns Around Diverter Entrance Shapes for Wheat.

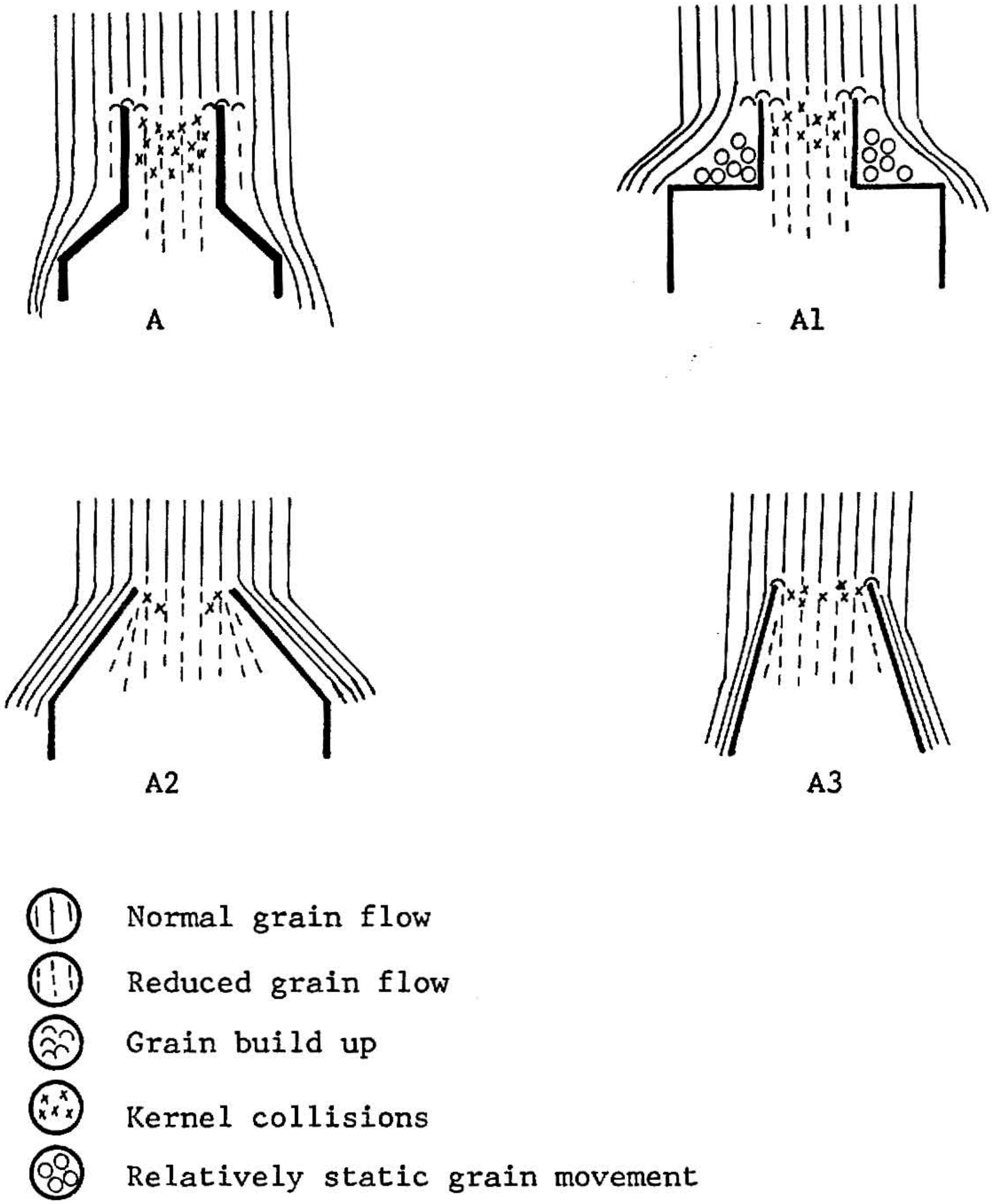


Figure 17. Schematic of Flow Patterns Around Diverter Entrance Shapes for Corn.

ledges was not as well defined as it was for wheat. The overall flow pattern for corn was more similar to shape A rather than shape A2. For both grains the leading edge of the entrance shape caused a noticeable amount of deflection. The degree of deflection was greater for corn. No expansion under the vertical sides was observed.

Entrance shapes A2, A3, and A4 were basically the same. The variation was in the amount of angle at which the entrance sides were bent inwards from the vertical. This progression in varying angle was made to determine the approximate angle at which build up on the leading edge would disappear. Shape A4 was turned inward 8 degrees, A3 was 16 degrees, and A2 was 40 degrees.

Shapes A3 and A4 reacted similarly to shape A along the leading edge. Below the leading edge a degree of relief for the grain stream was provided as it entered the entrance area. Figure 16 shows schematically how the flow pattern drew together at the leading edge similar to that seen in fluid flow passing through an orifice. The available width for grain to enter a diverter was decreased by this flow pattern, thereby decreasing the sample weight and possibly increasing the amount of bias. Diverter D had the same entrance shape as A3.

Shape A2 produced the least amount of grain deflection on the leading edge. Immediate relief for the grain entering the entrance area was shown by a slight expansion on the underside of the leading edge for both grains. The flow pattern did not seem to draw together as it did for shapes A3 and A4. Corn deflected in the entrance area of shape A2 to the point where flow was restricted slightly, but wheat flowed in this region with very little interference. The change in grain direction as it struck the outer surfaces of the entrance shape was substantial, but the grain in the entrance area was not affected by this.

Corn was dropped over entrance shapes A, A1, A2, and A3. In these four cases the overall flow patterns were similar to that of wheat, but collisions between grain kernels in the entrance area was such that grain flow into a diverter would be restricted as shown in Figure 17. Kernels of corn bounced in a zig zag pattern as they passed through shapes A and A1. In shapes A2 and A3, the corn kernels deflected to a greater degree than wheat kernels.

The exact shape of the leading edge for shape A2 was similar to strip "b" in Figure 18. To improve upon this shape the effect of various metal strips on grain stream deflection was observed. Figure 18 shows schematically the deflection produced by varying the thickness and lip edge shape. Thicknesses of 1/16 and 1/8 inch were the limits for metals in commercial use on diverters. Strips "c" and "d" produced the same flow pattern, while metal thickness did alter the flow patterns between strips "a" and "b". Considering commercial use, strip "c" would be more durable and produce no more deflection than that of strip "d".

Damage to the grain as a result of the knife edge can not be determined intuitively. Actual sample analysis comparing results from a sharp knife edge to a slightly rounded edge is needed. This is beyond the scope of this investigation. The grain damage resulting from grain striking the outer portion of the diverter entrance decreases as the angle of impaction decreases. Keller's

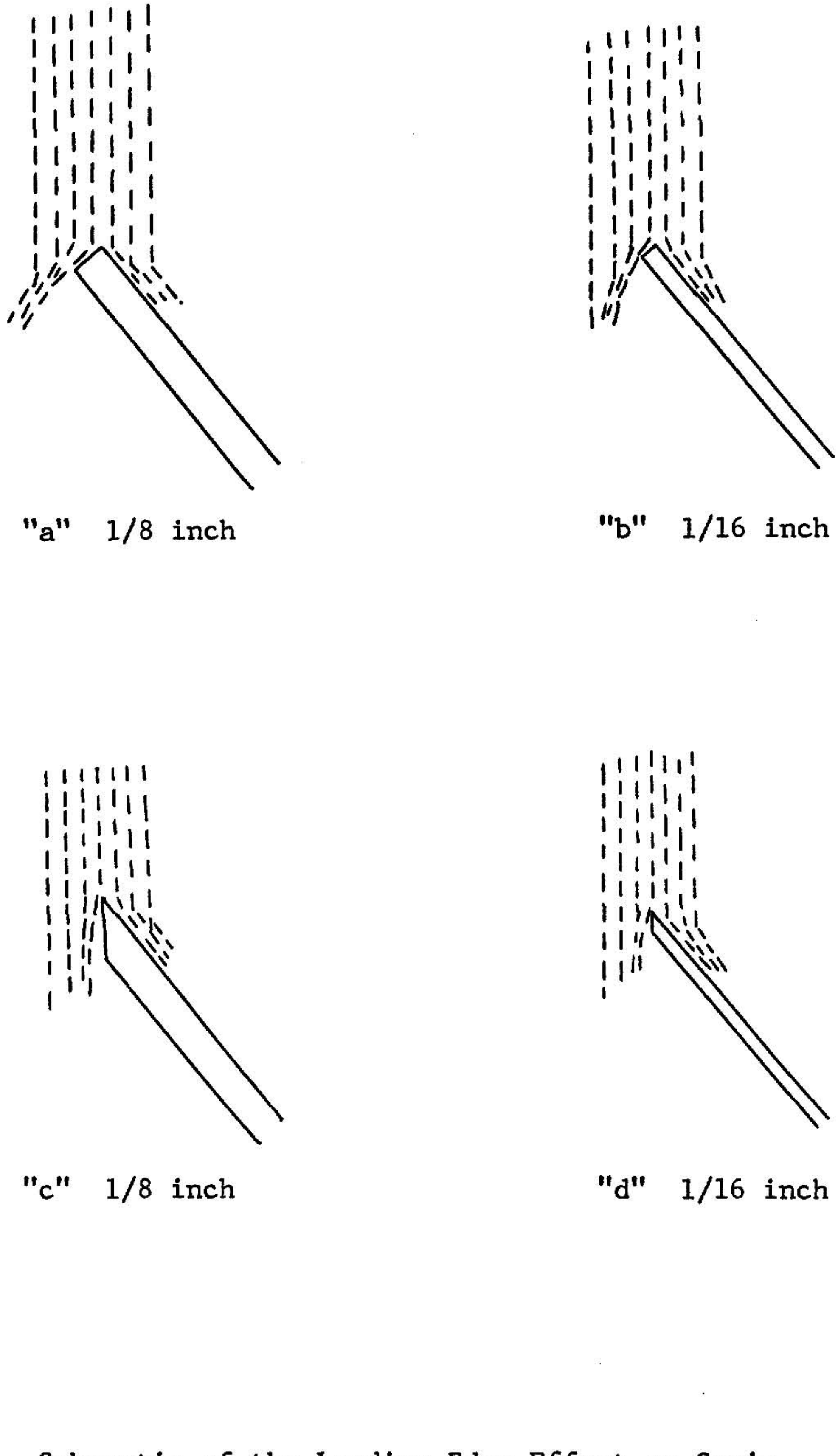


Figure 18. Schematic of the Leading Edge Effect on Grain Deflection for Entrance Shape A2.

(1970) study on damage to grain as a result of impaction angle showed total damage was reduced by 33 percent with impaction against a 45 degree angle steel surface compared to a 90 degree angle surface.

By minimizing the turbulence at the diverter entrance, bias of the sample was reduced. Shape A2 did this for wheat. For corn, entrance width needed to be increased to reduce the amount of bias on the grain sample caused by corn kernel deflection. Minimal damage to the grain was achieved by having no horizontal surfaces or vertical edges for the grain to strike.

Velocity Measurements

The velocity of grain under various conditions was measured by photographic means. These velocities were then compared to values calculated from the prediction equations 3 and 4.

Wheat kernel velocities were measured in a high flow rate grain stream. An average velocity over a 6 inch distance was 236.4 in/second with a standard deviation of 7.1 in/second. From prediction equations 3 and 4 calculated velocities were 238 and 231 in/second respectively. This shows comparable results were achieved by this velocity measurement method.

Velocity measurements taken at the diverter entrance end view condition were about half of that measured under high flow conditions. Compared to predicted values for a 1.25 foot drop distance, velocities were less than expected. The predicted values were 133 in/second from equation 3 and 135 in/second from equation 4. The average measured velocity for wheat over a distance of 3 inches was 110 in/second with a standard deviation of 8.3 in/second. For corn the average velocity was 92.5 in/second with a standard deviation of 10.1 in/second. The deflection shield in the sample cutting device restricted normal flow which reduced grain velocities. Since wheat and corn velocities were found to be the same in previous studies by Fiscus, Foster, and Kaufman (1971), the size of kernel passing through the restricted area was possibly the reason for the average corn velocity being less than the average wheat velocity.

Diverter travel speed was also measured. No measurable difference was detected in the travel time required for the diverter to travel one direction as opposed to the other direction. The time required was 0.4 ± 0.01 seconds. At a film speed of 1000 frames per second, a resolution error was noticeable in that the exact time of starting and stopping was hard to define. Possibly a small difference in travel speed was the cause for the difference in amount of sample collected with respect to travel direction.

Effect of Diverter Entrance and Body Shape

The sampling collection procedure was used to determine the effect of diverter entrance shape and body shape on amount of sample collected from a grain stream. Diverter A had additional entrance shapes A1, A2, and A3 to compare entrance shape effects. Diverters C and D had the same entrance shapes as A1 and A3 respectively to determine the effect of body shape. All samples were collected with the sampling apparatus in the vertical position, spout angle 90 degrees.

The results for grain flow rate versus sample collection weight for wheat are presented in Figure 19 and the results for corn in Figure 20. The relationship between the two variables was linear with approximately the same slope for all diverters in each type of grain. From a linear regression analysis of the wheat data the equation and correlation coefficient (r) for each diverter were:

Diverter A $Y = 225.74 + 0.160\ X$ $r = 0.998$ (18)

Diverter A1 $Y = 388.70 + 0.161\ X$ $r = 0.993$ (19)

Diverter A2 $Y = 376.14 + 0.181\ X$ $r = 0.999$ (20)

Diverter A3 $Y = 53.14 + 0.201\ X$ $r = 0.999$ (21)

Diverter C $Y = 299.70 + 0.175\ X$ $r = 0.982$ (22)

Diverter D $Y = 245.10 + 0.182\ X$ $r = 0.995$ (23)

The equation and correlation coefficient (r) for each diverter on corn data were:

Diverter A $Y = 149.02 + 0.116\ X$ $r = 0.998$ (24)

Diverter A1 $Y = 177.24 + 0.119\ X$ $r = 0.999$ (25)

$$\text{Diverter A2} \quad Y = 287.62 + 0.113\,X \qquad r = 0.998 \tag{26}$$

$$\text{Diverter A3} \quad Y = 211.55 + 0.116\,X \qquad r = 0.996 \tag{27}$$

$$\text{Diverter C} \quad Y = 197.54 + 0.116\,X \qquad r = 0.997 \tag{28}$$

$$\text{Diverter D} \quad Y = 152.89 + 0.125\,X \qquad r = 0.995 \tag{29}$$

where X = Flow rate, lbs/min,

Y = Sample weight, grams.

In all cases diverter A2 collected the largest amount of sample and diverter A the least. The results filmed and observed from flow patterns around entrance shapes were supported by this difference in sample weight. Shape A2 had the least amount of turbulence or build up in the entrance area, while shape A had the most. The other four diverters collected grain in a region between the limits set by diverters A2 and A. Their entrance shapes correspondingly produced flow patterns between those of A2 and A with respect to interference in the entrance area.

Although diverter A1 and diverter C had different internal body shapes, the results of sample collection were very similar during the collection of both wheat and corn. Diverters A3 and D also collected similar amounts of grain within the range of flow rates studied. Corn data produced better results for similarity between diverters A3 and D than did the wheat data. From Figure 19 wheat data for diverter A3 compared to that of diverter D at lower flow rates is noticeable less, yet the regression lines

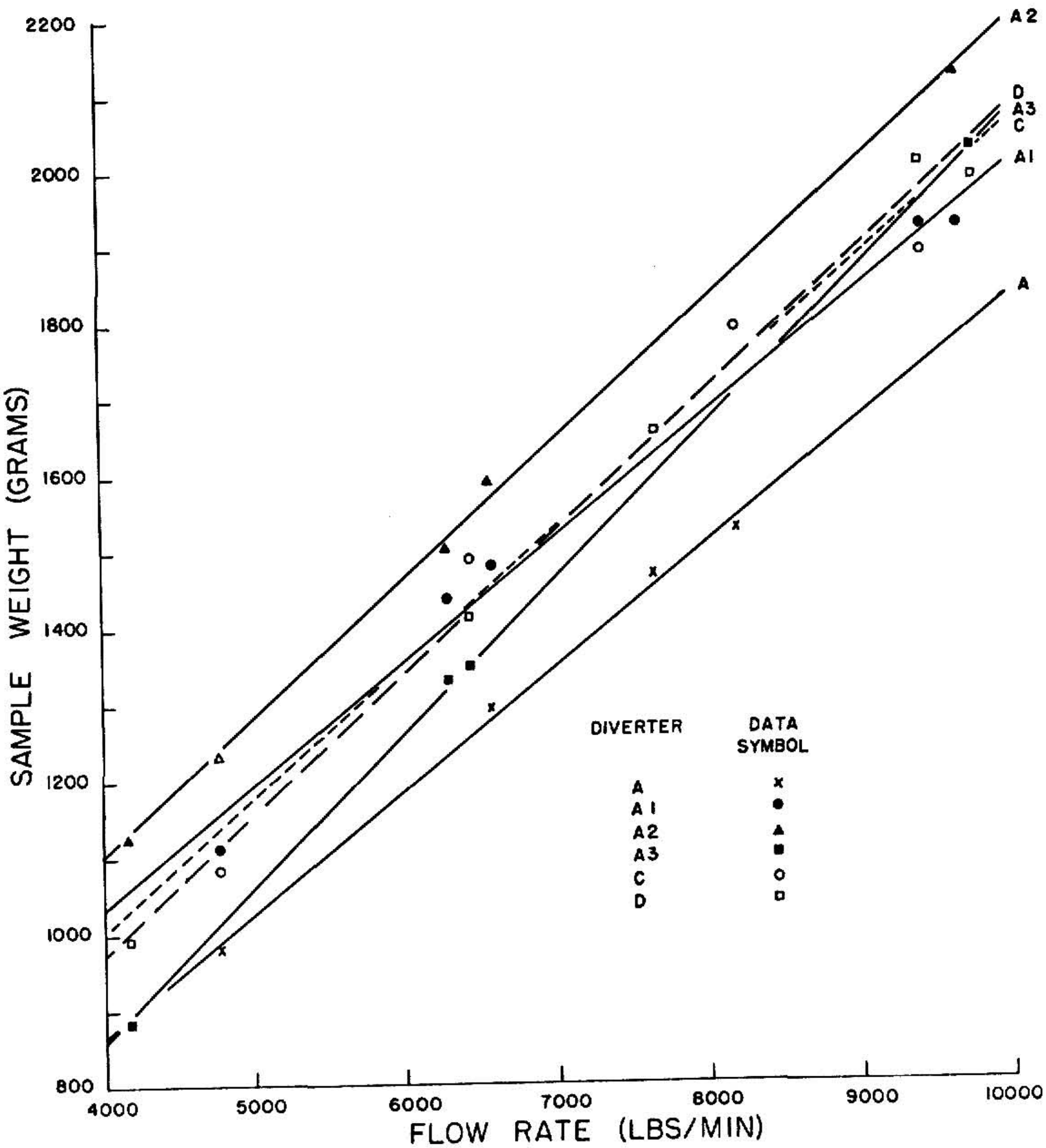


Figure 19. Grain Flow Rate Versus Sample Weight for Each Diverter, Wheat.

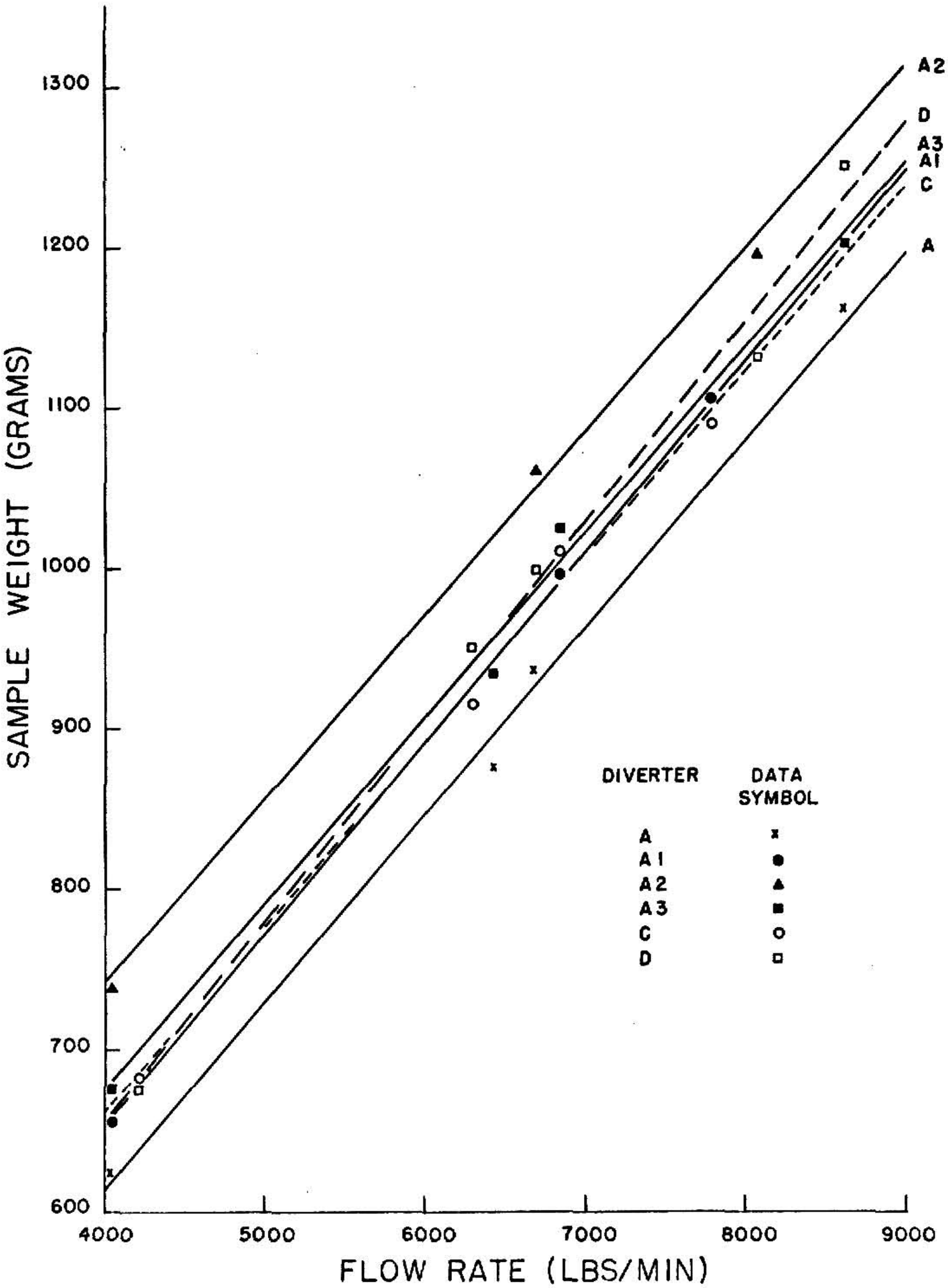


Figure 20. Grain Flow Rate Versus Sample Weight for Each Diverter, Corn.

converge at the higher flow rates. Since entrance shape was the same for each of the two diverter pairs and sample collection was similar for the diverter pairs, internal diverter shape did not affect sample weight for the diverters studied.

The average sample weight and standard deviation at each flow rate and grain type were calculated to determine the consistency for each diverter. Tables 2 and 3 show the results for wheat and corn respectively. For wheat, the amount of deviation tended to be greater at the higher flow rates with a few exceptions. The range for standard deviations on wheat data was from 9.5 to 51.1 grams. Diverter A2 was the most consistent in that the standard deviation varied little with respect to flow rate. There was less variation in the range of standard deviations for corn data, 17.1 to 38.9 grams. Average sample weights were also lower for corn compared to wheat at the same flow rates. All of the diverters had about the same degree of consistency for corn with diverter A1 having the best in the limited data shown.

Results concerning the effect of travel direction on sample weight produced the same variation as found in earlier tests with the equipment. Tables 4 and 5 show for wheat and corn respectively the lighterweight average expressed as a percentage of the heavier average sample weight. The data from each table averaged 96 percent for all diverters. This was the same as reported by Kramer (1968b) during his work using the same Gamet Automatic Sampler. The technique for mounting the samplers on the automatic sampler included using a level to insure that the diverter entrance was perpendicular to

Table 2. Average Sample Weight and Standard Deviation for Each Diverter by Flow Rate, Wheat*

Diverter	Average Sample Weight ($\overline{x}$), Standard Deviation (s) (Grams)																			
	Flow Rate (lbs/min)																			
	4170		4776		6300		6437		6580		7691		8225		9400		9708		9870	
	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s	$\overline{x}$	s
	Grams		Grams		Grams		Grams		Grams		Grams		Grams		Grams		Grams		Grams	
A			982	13.2					1290	30.8	1466	48.1	1526	57.2						
A1			1110	19.6	1439	40.0			1484	38.9					1919	38.5	1896	51.1		
A2	1129	25.7	1231	16.6	1499	22.9			1598	31.2							2123	32.1		
A3	879	32.0			1331	34.3	1349	25.6											2027	40.2
C			1083	9.5			1493	50.8					1793	34.8	1886	23.8				
D	997	10.4					1415	28.5			1656	35.0			2013	42.6			1971	49.8

*Not all diverters could be tested during the same flow rate due to grain stream time limitations. The automatic sampler was in the vertical position, spout angle 90 degrees.

Table 3. Average Sample Weight and Standard Deviation for Each Diverter by Flow Rate, Corn*

Diverter	Average Sample Weight ($\bar{x}$), Standard Deviation (s) (Grams)																	
	Flow Rate (lbs/min)																	
	4012		4200		6300		6428		6702		6848		7778		8077		8630	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
	Grams		Grams		Grams		Grams		Grams		Grams		Grams		Grams		Grams	
A	617	22.1	647	23.4			875	25.4	937	33.5							1165	38.9
A1	656	25.9									998	24.1	1106	24.5				
A2	739	17.5							1063	35.5					1197	28.0		
A3	675	19.3					935	37.5			1028	25.6					1204	25.1
C			683	17.1	916	31.5					1008	34.4	1090	33.9				
D			673	19.2	955	33.0			1000	26.5					1131	28.4	1253	36.4

*Not all diverters could be tested during the same flow rate due to grain stream time limitations. The automatic sampler was in the vertical position, spout angle 90 degrees.

Table 4. Effect of Diverter Travel Direction Based on the Average Weight of the Lighterweight Sample of Alternating Samples of Grain, Expressed as a Percentage of the Heavier Average Sample for Wheat*

Diverter	Lighterweight Average / Heavierweight Average (%)									
	Flow Rate (lbs/min)									
	4170	4776	6300	6937	6580	7691	8225	9400	9708	9870
	%	%	%	%	%	%	%	%	%	%
A		98.0			96.0	94.0	93.3			
A1		96.9	96.1		95.7			96.4	95.4	
A2	96.0	97.4	93.7		96.1				99.4	
A3	94.8		99.5	97.8						96.8
C		96.6		93.8			96.6	97.3		
D	98.5			96.5		96.4		95.7		96.7

*Not all diverters could be tested during the same flow rate due to grain stream time limitations. Automatic sampler was in the vertical position, spout angle 90 degrees.

Table 5. Effect of Diverter Travel Direction Based on the Average Weight of the Lighterweight Sample of Alternating Samples of Grain, Expressed as a Percentage of the Heavier Average Sample for Corn*

Diverter	Lighterweight Average / Heavierweight Average (%)								
	Flow Rate (lbs/min)								
	4012	4200	6300	6428	6702	6848	7778	8077	8630
	%	%	%	%	%	%	%	%	%
A	99.0	96.5		95.9	95.8				97.8
A1	97.8					97.3	96.2		
A2	97.5				94.5			97.5	
A3	97.8			98.2		97.0			97.4
C		99.4	95.8			98.6	95.3		
D		97.0	94.4		96.3			96.4	95.9

*Not all diverters could be tested during the same flow rate due to grain stream time limitations. Automatic sampler was in the vertical position, spout angle 90 degrees.

the grain stream. If a diverter varied from the perpendicular, an increased affect was observed in the sample weight variation as a result of travel direction.

Proposed Guidelines

From the diverter body shapes and entrance shapes studied, diverter entrance shape was found to be the dominant factor in sample weight collection and sample bias. To minimize grain kernel collisions in the entrance area, build up on the leading edge was minimized by turning the entrance cutting edge inward which also allowed for immediate relief of the grain to prevent binding. Build up of grain to possible overflow conditions within the diverter was prevented by making the discharge area equal to or larger than the entrance area. Width of the diverter body opposite the discharge area should be wide enough and/or deep enough to prevent the backup of grain to the entrance area.

With an entrance width of 3/4 inch an expansion to 2 inches below the leading edge was adequate to prevent binding of grain in the entrance area. For fast clearing of the diverter a 3 inch width for the diverter body prevented any build up of grain within the diverter. The slope on the bottom of the diverter was 1:1 for all diverters tested. This slope was sufficient for immediate discharge of grain from the diverter.

Diverter A2 met all of the above guidelines. Consistency in the performance of sample collection was equal to or better than the other diverters tested. The largest samples were collected by this diverter at all flow rates of both wheat and corn, and the least amount of bias to the grain sample was observed in the flow pattern studies. The leading edge shape should be the same as "c" rather than "b" in Figure 18 for this diverter to be the optimum shape for diverter parameters tested in the sampling of grain.

CONCLUSIONS

1. The differences in sample weights resulting from travel direction were due to the inherent operation of the automatic sampler.
2. A linear relationship existed between flow rate and sample weight in all diverters for wheat and corn over a range of 4000 to 9000 lbs/min with the automatic sampler in the vertical position.
3. Internal shapes of the diverters used in this investigation were not a factor affecting the sample size or quality for the range of flow rates studied. For rapid clearing of the diverter the discharge area should be equal to or larger than the entrance area. Body shape should be wide enough and/or deep enough to allow unrestricted expansion of the grain stream below the entrance shape, and to prevent grain in the space opposite the discharge point from backing up to the entrance area. For a 3/4 inch entrance width a minimum expansion of 2 inches was needed below the entrance area. Body width depends upon the vertical depth of the diverter.
4. Entrance shape for the diverter was the most important factor studied in grain sample collection. Flow patterns around the diverter entrance shape produced an available entrance width which governed the size and possibly the bias of the sample. Deflection of grain on the leading edge and congestion in the entrance area decreased as the sides of the entrance were turned inward. Of the angles studied, an entrance shape angle

of 40 degrees (shape A2) produced the best flow pattern. The relationship between diverter entrance width (3/4 inch) and kernel size was adequate for wheat kernels but not for corn kernels. Corn kernels deflected to a greater extent than wheat kernels.

5. Diverter A2 with an angled entrance of 40 degrees produced the largest sample weights. No build up of grain occurred on the leading edge of the entrance, and there was immediate relief for the grain stream to prevent the binding of grain kernels in the entrance area. Consistency in the performance of sample collection, from standard deviation calculations, was as good or better than the other diverters tested.

SUMMARY

Although some data has been collected to compare the grain sample analysis with the components actually measured in a grain lot, limits of accuracy have not been established for the reliability of the grain sample. Grain sampling by the diverter method has the most potential of the current sampling methods for sample reliability and minimum time requirements. The first step in determining the reliability of the sample is to develop a shape for the diverter which will collect a representative sample from the grain stream. Secondly, the time interval between sample cuts through the grain stream and sample analysis must be examined to set the limits of accuracy. The first step was studied in this investigation.

Diverter travel direction, internal diverter shape, diverter entrance shape, and diverter performance were studied in this investigation. Samples collected with this automatic sampler were lighter when sampled from one direction compared to the other direction by an average of 96 percent. The internal shape of the diverters studied had no effect on sample weight or bias. Entrance shape to the diverter was the dominant factor in sample size and bias. The flow patterns around the shapes studied showed an angled entrance of 40 degrees produced the least amount of grain build up on the leading edge and the least congestion in the entrance area, minimum bias. Diverter performance as measured by standard deviation from the average sample weight at each flow rate showed the diverter with the above entrance shape was as good or better than the other diverters tested. The largest samples at each flow rate for wheat and corn were also collected by this diverter. An entrance width of 3/4 inch did not affect wheat samples, in that leading edge build up and collision of kernels in the entrance area were minimum. This was not true for corn because there was a great amount of kernel deflection in the entrance area.

SUGGESTIONS FOR FUTURE RESEARCH

The investigation on representative sampling from a non-uniform grain lot should be continued by conducting further studies on the effect of diverter travel speed on sample bias and size (effective cutter width). The sample cutting device and diverter entrance attachment can be rearranged such that films of diverter entrance shape traveling through a grain stream are observed.

An analysis of variance could be made with more data collection to determine the effect of various diverter parameters and/or the difference between diverters. A diverter constructed along the proposed guidelines should be compared to the existing diverters.

Confidence intervals for data reliability could be established by analyzing grain samples from a grain lot in which the component percentages are known. Two controlled variables should be flow rate and the time interval between sample cuts.

An analysis of corn samples collected from the same diverter with various entrance widths should be made. Comparing these samples to the known grain lot, the effect of entrance width on sample reliability can be determined.

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APPENDIX A

SAMPLE COLLECTION DATA

Table 6. Increment Sample Weights for Wheat by Flow Rate, Spout Angle, and Diverter*

Flow Rate (lbs/min)	Diverter	Spout Angle (degrees)	Sample Weight (Grams) Sample Number 1	2	3	4	5	6	7	8	9	10
2953	A	90	614	635	626	645	614	645	646	662	651	653
	B	90	622	636	596	645	602	637	619	647	608	655
	C	90	806	716	800	704	794	731	808	721	818	707
3908	A	90	905	920	917	931	916	937	918	928	906	933
	B	90	880	895	864	916	879	895	869	918	869	910
	C	90	924	1040	962	1078	971	1096	980	1079	987	1109
5515	A	90	1210	1235	1240	1233	1226	1252	1230	1261	1254	1278
	B	90	1194	1251	1200	1235	1203	1247	1207	1256	1214	1257
	C	90	1426	1542	1426	1569	1424	1567	1422	1581	1441	1575
7668	A	90	1709	1745	1678	1702	1746	1739	1703	1729	1685	1727
	B	90	1584	1526	1563	1505	1559	1605	1563	1622	1591	1642
	C	90	2004	2048	1995	2037	1992	2020	1995	2073	2010	2071
4120	A	45	1061	998	1061	995	1070	920	977	916	961	985
	C	45	1097	1109	1120	1091	1110	1112	1113	1159	1159	987
6323	A	45	1420	1440	1454	1425	1446	1416	1430	1464	1430	1445
6610	C	45	1622	1650	1585	1596	1628	1648	1643	1620	1661	1624
8137	A	45	1730	1752	1738	1760	1753	1746	1758	1733	1732	1750
	C	45	1859	1923	2041	1976	1922	1900	1943	1968	1916	1930

*Data used for objective 1.

Table 7. Increment Sample Weights for Corn by Flow Rate, Spout Angle, and Diverter.*

Flow Rate (lbs/min)	Diverter	Spout Angle (degrees)	Sample Weight (Grams) Sample Number 1	2	3	4	5	6	7	8	9	10
4174	A	45	653	739	701	725	686	725	705	706	692	715
	C	45	643	663	652	696	639	700	694	683	642	684
6653	A	45	858	855	915	904	908	907	903	910	914	938
	C	45	793	855	852	776	818	851	828	834	800	851
7416	A	45	931	974	984	1053	1012	968	965	919	943	961
	C	45	887	877	858	853	907	890	863	868	887	906
3215	A	90	578	604	569	602	574	605	564	610	564	609
	B	90	520	531	526	536	525	499	502	533	529	519
	C	90	532	563	525	591	578	595	506	595	517	555
5091	A	90	764	773	775	787	781	791	778	786	754	790
	B	90	757	759	718	745	719	770	738	763	701	781
	C	90	804	817	775	786	774	830	786	811	772	838
7636	A	90	1081	1127	1109	1081	1111	1111	1120	1139	1111	1149
	B	90	997	1041	991	1012	998	1003	983	1047	979	998
	C	90	965	1007	1037	1083	996	1089	1050	1086	1069	1067

*Data used for objective 1.

Table 8. Increment Sample Weights for Wheat by Flow Rate and Diverter, Spout Angle 90 Degrees*

Flow Rate (lbs/min)	Diverter	Sample Weight (Grams)									
		Sample Number									
		1	2	3	4	5	6	7	8	9	10
4170	A2	1102	1158	1090	1141	1108	1148	1110	1152	1119	1159
	A3	813	899	847	884	857	911	877	912	885	907
	D	990	1004	993	1002	987	1005	982	991	995	1017
4776	A	980	993	974	981	979	997	958	1004	973	986
	A1	1081	1129	1095	1129	1088	1128	1094	1125	1107	1130
	A2	1198	1241	1232	1246	1211	1250	1230	1245	1220	1234
	C	1084	1089	1082	1091	1077	1092	1074	1075	1068	1098
6300	A1	1366	1436	1395	1447	1434	1480	1419	1481	1438	1496
	A2	1479	1511	1483	1523	1477	1538	1478	1507	1477	1518
	A3	1317	1324	1335	1342	1333	1335	1325	1335	1321	1339
6437	A3	1293	1353	1321	1352	1353	1357	1345	1380	1359	1378
	C	1445	1540	1451	1537	1438	1532	1446	1559	1447	1536
	D	1399	1443	1400	1441	1385	1439	1370	1450	1393	1429
6580	A	1252	1303	1254	1300	1267	1332	1283	1313	1261	1333
	A1	1442	1530	1463	1529	1431	1506	1443	1512	1464	1518
	A2	1564	1629	1576	1623	1575	1630	1562	1628	1568	1628
7691	A	1424	1507	1405	1510	1436	1512	1425	1516	1416	1511
	D	1617	1662	1641	1715	1636	1682	1617	1688	1617	1682

*Data used for objective 3.

Table 8. Continued

Flow Rate (lbs/min)	Diverter	Sample Weight (Grams)									
		Sample Number									
		1	2	3	4	5	6	7	8	9	10
8225	A	1466	1580	1481	1573	1468	1564	1458	1595	1497	1584
	C	1750	1811	1763	1830	1758	1808	1764	1835	1776	1839
9400	A1	1867	1951	1886	1952	1884	1958	1888	1947	1894	1966
	C	1859	1882	1884	1912	1869	1851	1907	1879	1927	1889
	D	1955	2058	1964	2060	1975	2056	1982	2057	2003	2023
9708	A1	1887	1929	1843	1885	1828	1928	1843	1966	1882	1973
	A2	2098	2133	2114	2133	2156	2122	2138	2045	2151	2137
9870	A3	1991	2065	1995	2067	1993	2074	1983	2061	1985	2059
	D	1935	1957	1937	1956	1921	1998	1922	2038	1982	2067

Table 9. Increment Sample Weights for Corn by Flow Rate and Diverter, Spout Angle 90 Degrees*

Flow Rate (lbs/min)	Diverter	Sample Weight (Grams)									
		Sample Number									
		1	2	3	4	5	6	7	8	9	10
4012	A	632	643	591	586	638	637	616	602	593	632
	A1	624	667	631	639	643	674	651	642	696	697
	A2	732	761	706	737	747	754	736	763	727	728
	A3	669	711	639	677	676	688	663	661	690	675
4200	A	604	649	658	669	630	656	641	630	645	689
	C	698	717	682	687	682	652	671	688	673	683
	D	667	679	666	670	633	692	688	674	662	703
6300	C	856	895	886	946	904	937	913	958	925	942
	D	940	1007	935	975	908	959	913	989	939	981
6428	A	844	902	870	884	863	919	856	861	850	902
	A3	853	921	947	929	912	952	930	950	994	967
6702	A	927	927	886	958	963	962	879	978	930	959
	A2	1020	1089	1061	1100	1017	1119	1034	1073	1033	1083
	D	992	1002	985	1009	954	1051	977	1011	1002	1025
6848	A1	966	1009	967	1004	964	1026	1020	1023	1004	993
	A3	1033	1080	1019	1051	1011	1027	988	1015	1014	1046
	C	1004	1048	1024	1049	980	1021	924	1025	970	1039
7778	A1	1104	1140	1088	1133	1074	1117	1081	1125	1076	1119
	C	1091	1118	1087	1136	1030	1100	1055	1127	1057	1100

*Data used for objective 3.

Table 9. Continued.

Flow Rate (lbs/min)	Diverter	Sample Weight (Grams)									
		Sample Number									
		1	2	3	4	5	6	7	8	9	10
8077	A2	1167	1189	1221	1233	1188	1216	1161	1183	1172	1238
	D	1126	1157	1102	1169	1080	1151	1143	1145	1101	1138
8630	A	1147	1128	1164	1214	1173	1213	1184	1172	1082	1153
	A3	1153	1205	1188	1209	1191	1210	1201	1249	1207	1228
	D	1213	1257	1252	1278	1207	1300	1208	1298	1235	1285

OPTIMIZING DIVERTER SHAPE
FOR THE DIVERTER GRAIN SAMPLING METHOD

by

GARY DEAN STROMBERG
B. S., Kansas State University, 1970

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The sampling of grain by the diverter method shows the most potential of the current sampling methods for obtaining a reliable sample from a non-uniform grain lot. Since little research has been done concerning the accuracy of samples collected by diverters, the first step was to determine the diverter shape factors which affect the sample size and bias.

This investigation was carried out in three parts: (1) sampling parameters were evaluated by comparing the characteristics of three commercial diverters to those in earlier studies, (2) grain flow patterns around the entrance shape and within the diverter were observed to determine their effect on sample size and bias, and (3) diverters with various entrance shapes and body configuration were tested in order that guidelines could be proposed for an optimum diverter shape from the parameters studied. Wheat and corn were the grains tested to represent small and large kernels respectively. Entrance width was 3/4 inch throughout the investigation.

From the first part of the investigation diverter travel direction, spout angle (45 and 90 degrees from the horizontal), and flow rate (4000, 6000, and 8000 lbs/min) were studied to determine their effect on weight of sample collected by each diverter. Diverter travel direction had minimal effect on sample weight. Corn was affected by spout angle to a higher degree than wheat. Flow rate had a linear relationship with sample weight for both grains with the automatic sampler in the vertical position, spout angle 90 degrees, and for wheat with the sampler in the 45 degree position. For the same flow rate wheat sample weights were always heavier than corn sample weights.

Internal entrance shape was studied by replacing one side of the diverter with plexiglass and passing a grain stream over the stationary diverter. Within the flow rates studied, internal shape had no effect on sample size and bias. For rapid clearing of the diverter, the discharge area should at least be equal to the entrance area. Body width depends upon the vertical length of the diverter.

Flow patterns around the entrance shapes were observed for wheat and corn. Grain flow patterns were similar to fluid flow patterns. Shapes with vertical sides deflected grain to the extent that there was a restriction of grain flow in the entrance area. By angling the entrance shape sides no build up occurred on the leading edges and congestion in the entrance area was minimized. Of the angles studied 40 degrees inward from the vertical produced the best results.

One diverter body was modified to use four different entrance shapes. Two other diverters which had the same entrance shape as two of those on the first diverter were used to compare the effect of body configuration. All diverters for both grains had a linear relationship between sample weight and flow rate. Diverter performance as measured by standard deviation from the average sample weight was nearly the same for all conditions.

A diverter with an entrance shape angle 40 degrees from the vertical produced the best results overall. Diverter performance was as good or better than other diverters tested. This diverter collected the largest samples under all conditions with the least amount of congestion in the entrance area as observed in flow pattern studies.