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CONSTRUCTION AND EVALUATION OF A PLOT COMBINE

FOR USE IN PLANT BREEDING RESEARCH

By

Egil Øyjord

AN ABSTRACT

Submitted to the College of Agriculture of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1962

Approved Wesley F. Buchele

ABSTRACT

Plant breeders around the world have stated that it is desirable to combine small grain plots in the early stages of a breeding program in order to judge the standing ability of new strains.

Research funds saved by use of labor-saving machinery permits additional experimentation.

The major problem in using combines for harvesting variety plots is avoiding the mixing of the seeds between plots. So far all the reported rebuilt and especially designed plot combines require clean out time to completely clean between each variety.

Only a completely self-cleaning plot combine will have the necessary capacity for harvesting the high number of plots in an early stage of a modern breeding program.

This thesis presents the design and development of a plot combine that was built to test various cutting, threshing, separating, and cleaning principles and develop parameters for the design of an acceptable self-cleaning plot combine for small grain.

The essential parts of the combine were as follows:

1. A 2-row cutterhead with flail and fan action for cutting, threshing, and elevating the grain and straw to the separating and cleaning device.

2. A swirl-chamber for separating the grain from the straw and chaff.

3. A 5.75 hp 2-wheel garden tractor as a power unit.

Four different types of flails were mounted in the cutterhead and used on single rows of wheat, 12 feet long.

The experimental procedure was as follows:

1. Cutterhead losses of threshed and unthreshed grain were caught on a canvas placed on each side of the test row.

2. Swirl-chamber losses of threshed and unthreshed grain, as well as the total straw and chaff entering the machine, were caught in a burlap sack connected to the outlet of the grain separator.

3. The clean grain was collected in the grain box on the machine.

The efficiency of the various parts of the combine were calculated from measurement data gained from weighing the material from each receptacle at the end of the tests.

Visible kernel damage was calculated as percent damaged kernels in the grain box.

The total cutterhead losses of threshed and unthreshed grain were larger than could be accepted for practical use of the experimental machine. The highest percent of grain recovered by the cutterhead was 84.4. This was obtained with the propeller flails and a height of the cutterhead of 27 inches.

In general, the total cutterhead losses of grain decreased with increased plot yield. The cutterhead losses of unthreshed grain were small compared with the cutterhead losses of threshed grain except for the modified direct throwing flails.

The swirl-chamber was tested with two shapes. Shape 1 gave the best solution. The average losses of threshed grain were 2.34 percent at a straw separation of 92.1 percent. The corresponding averages for shape 2 were 1.9 percent at a straw separation of 77.9 percent. A strong relation between swirl-chamber loading and separating efficiency was observed.

Because the percent cylinder losses as determined by the regression equation Y = 0.487 - 0.00108 (flail speed in rpm - 1240) were fairly constant in the speed range between 1,100 and 1,300 rpm, the pooled standard deviation of 0.47 percent provided a fairly good estimate of the dispersion of the calculated average cylinder losses of 0.487 percent.

The visible kernel damage increased from 0 percent at 1,075 rpm to 3.16 percent at 1,300 rpm. It was concluded that a peripheral flail speed above 1,300 rpm or 5,500 fpm should not be used for harvesting wheat plots under average harvesting condition.

The plot-combine was found to be self-cleaning with respect to the grain if the fan speed was reduced between the plots.

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INTRODUCTION

The plant breeders have an important job in developing new and better varieties for human and animal food.

The success of finding better varieties is positively correlated with the number of hybrid strains the plant breeder has time and money to test. While the planting process has been successfully mechanized with a capacity of up to 250 plots an hour, the harvesting capacity is still today not more than 30 to 60 plots an hour and represents a "bottle neck" in the plant breeding work.

In working with thousands of different strains, the plant breeder must be careful that the seeds do not become mixed during harvesting. Commercial combines cannot be readily used to harvest small plots of grain because of the size of the combine and the difficulty in rapidly and completely cleaning them. Rebuilt combines have been used to harvest large plots where the savings in labor are large enough to justify the necessary cleaning time.

At the present time large farm machinery companies are not interested in the development and production of machines for experimental work and small companies which are interested in the production of experimental equipment, cannot afford to spend the money to develop the machines.

The responsibility for the mechanization of experimental work, therefore, rests with the plant breeders themselves and the agricultural engineers of state or federal research groups.

The design and development of custom equipment for field research is a new field which will become increasingly important in the future since increased use of labor-saving equipment will release research funds for additional experimentation.

Mechanization of field experiments is one of the better means of speeding progress in modern agriculture.

The purpose of this thesis is to report the construction and testing of a plot combine built according to the following specifications:

1. Complete self-cleaning in less than 30 seconds.
2. Grain damage less than or equal to the ordinary combines.
3. Grain recovery efficiency better than or equal to the ordinary combines.
4. Complete threshing without adjustment for different varieties within the species in small grain.

This thesis will present the design and development of a plot combine that was built to test various cutting, threshing, separating, and cleaning principles and to develop parameters for the design of an acceptable machine.

REVIEW OF LITERATURE

Harvesting Methods for Small Grain Plots

Hunter and Johnson (1955) reported that harvesting of experimental plots of small grain have generally employed three methods:

1. Cutting the plants from definite lengths of rows or number of quadrats by hand, bagging or wrapping them to prevent shattering or loss of seed during transportation, and threshing with a small stationary plot thresher.

2. Similar to the above method except that cutting was done with a small plot mower, having some type of catcher for collecting the plants as they were cut.

3. Use a self-propelled combine to cut and thresh the crop simultaneously.

Two other methods were described by Øyjord (1957). He reported that a light weight, 4½ feet binder propelled by an 8 hp garden tractor had a capacity of 30 to 40 plots (20 feet long and 4 feet wide) per hour with a 3-man crew. This provided a saving of 30 to 50 percent in labor, compared with a 4-wheel tractor with a steel catching plate located behind the cutter bar for collecting the plants.

The sheaves from the small plots are threshed in the field in areas of the world with a dry harvesting season. In areas with frequent rain and cloudy weather, the collected material is usually threshed in the barn.

In recent years a method called "combining in two steps" has become popular among plant breeders in Germany. The plots are harvested with a small garden tractor equipped with a cutter bar and a catcher when the crop is ripe for combining. The plot thresher is placed in the field and the plot yield is threshed immediately after cutting.

Øyjord (1961) observed the same principle in use at Michigan State University except that the sheaves were tied and threshed immediately after cutting.

Principles of Plot Threshers

The plot threshers are usually built with a spike-tooth or a raspbar cylinder, overshot concave, ordinary straw rack, and a conventional cleaning system with sieves and fan action. These threshers are not self-cleaning, but they are relatively easy to clean with a blower or an air compressor.

Vogel and Johnson (1934) described a self-cleaning nursery thresher. This thresher contained no straw rack or screens. The threshed grain, including straw and chaff, falls on an inclined reciprocating steel plate which directed the material into an air chute or venturi. When the straw is long, the bundles are held by the butts while the cylinder strips the heads. The butts are then cast aside. Otherwise, the whole bundle would pass through the machine.

Vogel, Herman and Naffziger (1938) reported a self-cleaning roller belt thresher for small samples. This thresher consisted of a rough rubber belt traveling about 50 feet per minute. A rough cylinder with a peripheral speed of about 100 feet per minute was pressed against the belt. The samples were fed between the belt and the cylinder where the threshing took place. This thresher had no cleaning device.

Arawinko and Nielsen (1956) reported a thresher consisting of a moving sandpaper belt pressed against a corrugated rubber surface. A half-inch of sponge rubber was placed behind the rubber surface to provide flexibility and a uniform pressure between the belt and the rubber surface. The machine was built mainly for small samples of grass seeds and no cleaning was provided.

Cunningham and Hannah (1956) reported a plot thresher consisting of two rubber-covered rolls operating at different speeds. The samples passed between the rolls in bags.

Øyjord (1956) reported a nursery thresher in which the tops of the bundles were fed into a centrifugal fan. The threshing took place between the blades of the fan and a corrugated concave. The fan was self-cleaning and the grain was blown up to a reciprocating chaffer sieve with air blast. The sieve had to be cleaned between each sample.

Thielebein (1959) reported test results of a two cylinder plot thresher with cyclone cleaning and no sieves. The thresher cleaned itself completely in 14.7 seconds with a variance of 0.174 seconds. The average threshing losses for barley, wheat, rye, and oats were 2.9 percent with a variance of 0.517 percent. The lost grain was of low quality and the author stated that these losses were not important to the plant breeder. The capacity of this thresher was found to be 42 plots (49 square feet in area) per hour or 120 plots (11 square feet) per hour.

Principles of Plot Combines

Liljedahl, Hancock, and Buttler (1951) reported the rebuilding of an Allis-Chalmers Model 40 combine for harvesting 3-foot wide plots.

The combine was made self-propelled by integrating it with an Allis-Chalmers G tractor. The power for the threshing mechanism was supplied by a 6 hp engine. The combine was equipped with an air compressor and the clean grain auger was replaced with a drawer to speed the cleaning of the machine. The tailings auger was also eliminated. The air blast was reduced to prevent loss of grain and the inside of the combine was streamlined so the lodging of grain was reduced to a minimum.

The authors reported a labor saving of 80 percent, compared with hand harvesting methods.

Hancock (1961) reported in a personal letter that three combines similar to the one above were being used on substations in Tennessee and that three men can harvest 100 plots, 68 feet long, and clean the combine between as many as 25 varieties with four replications each in a day. Hancock stated that, without the combine, he doubted they could carry on tests of any value because the combine enables the breeder to judge the standing ability of the small grain varieties just as the farmer would do in the field.

Hunter and Johnson (1955) reported that three self-propelled plot combines have been constructed at the Oregon Agricultural Experiment Station during the 1953 and 1954 seasons. The basic unit of these machines was an Allis-Chalmers Model 40 All Crop Harvester, stripped of frame, wheels, clean grain elevator and tailings elevator, and streamlined inside as recommended by Liljedahl, Hancock, and Butler.

The combine body was placed upon a frame supported at the front by an automobile rear axle and wheels and at the rear by an automobile front axle. Each axle was shortened by 12 inches. A 9 hp air cooled engine propelled the combine and another motor of the same size operated the combine. The combines weighed approximately 3,000 pounds. They were used to harvest fertilizer experiments. A 3-man crew harvested 30 to 40 plots (50 feet long and 40 feet wide) per hour with these combines.

From a study tour to England, Belgium, Germany, Denmark, and Sweden, Øyjord (1958) reported that Allis-Chalmers, Munktell, and Massey-Ferguson 630 commercial combines were rebuilt and used to harvest plots with areas varying from 220 to 1,300 square feet. The necessary idle time between the plots varied between ½ and 2 minutes. None of the visited institutions used the combine in plant breeding because of the long time required to clean the rebuilt combines between each variety.

Chalmers, Nation, and Raybould (1952) reported a plot combine designed in 1947 and tested in 1949, 1950, and 1951. The idea of this combine was that if an endless belt rubbed the grain against a sufficiently long concave or screen complete threshing and separation would result.

The field losses of the first unit tested in 1949 were between 12 and 17 percent and varied with belt speed and concave clearance. The principle was modified in 1950 and 1951. The final combine, tried in 1951, had a 5-foot wide rubber covered endless belt with rubber moulded rasp-type beater bars bounded and riveted to the belt. At a speed of 3,400 feet per minute there were 4,300 beater bar impacts per minute. An Allis-Chalmers Model 60 harvester header was used for cutting and feeding the grain to the threshing belt and the whole unit was front-mounted on a Fordson Major tractor. The total losses (1951) were reported to vary from 1.8 to 6 percent according to the harvesting conditions. The report stated that the combine was easy to clean.

Farm Mechanization (1961) reported a small 2-foot combine using the principle of the Gallic stripper. The combine had a comb instead of a cutter bar. The cylinder consisted of six fan-type beaters attached to a horizontal shaft. The beaters stripped the heads from the comb, threshed them, and blew them into a separating container at the rear. The machine, while being practically self-cleaning, did require some cleaning with a brush to prevent contamination of the varieties. The capacity of the combine was reduced considerably by the checking of the cylinder for lodged seed between varieties.

Hamblin (1961) reported a small plot combine consisting of an ordinary cutter-bar, conveyor and rasp bar cylinder carried on a 3-wheel chassis. Two of the wheels were under the header and the third wheel at the rear was both steered and driven. The combine contained no cleaning device. All the straw was removed from the combine at the end of the plot and shaken to recover the loose grains.

New Threshing and Separating Principles

The Wild Model 50 Harvester Thresher (1959) was sold in England for some time. The success of this harvester is not known. The threshing was done by a series of rotating corrugated plates on a horizontal shaft. The heads were beat back and forth between these plates in the threshing process.

Segler and Peschke (1952, 1953) reported experiments with chop-threshing. The sheaves were fed directly into a chopping mechanism which cut the straw. The threshing occurred in the fan which blew the material to the separator. The length of cut of the straw ranged from 0.9 to 1.6 inches.

Buchele (1953) developed an experimental thresher (patent No. 2.906.270) for small hard-to-thresh seeds. This machine achieved threshing action by continuously rubbing the crop against a perforated screen formed into a cone. To get better threshing action he stated that the cone and the rubber blade impeller could be rotating in the same direction but at different peripheral speeds.

Segler (1957) reported the cone principle and four other axial fed threshing cylinders. In two of the cylinders a combination of propellers and beaters threshed and moved the material, and a screen in the bottom separated the threshed grain from the straw. A third principle used helical bars to thresh and move the material and a screen around the cylinder to separate the grain from the straw. The fourth principle utilized a fan to pull the material through a short cylinder which had no provision for separating the grain from the straw. A screen mounted directly on the blades of the fan prevented the kernels from being hit by the blades. This reduced the kernel damage.

In Norway, Øyjord (1958, 1959) observed experiments with a forage harvester used for harvesting barley. The grain and straw were blown into a wagon. Examinations showed larger field losses than could be tolerated in practice. This forage harvester was of a type equipped with a fan. A large percentage of the grain was skinned and cracked (presumably by the fan rather than by the flails).

Nordaune (1958, 1959) built and tested a precleaner for this forage harvester using the swirl-chamber principle suggested by Øyjord (1958). From the results of his tests, Nordaune concluded that the capacity of the swirl-chamber was too small. This prevented its use as a precleaner for a forage harvester.

Harris (1959) stated that preliminary chopping of straw crops increased the capacity of the threshers from 30 to 50 percent. The author envisaged that the ideal equipment would be a combination of a forage harvester with a detachable finishing thresher and precleaner.

Farm Mechanization (1959) reported that an English farmer used the Lundell forage harvester to cut and thresh a severely storm-damaged field of barley in the fall of 1958. The farmer replaced the cutter bar on a combine with the forage harvester and used the widest possible clearance between drum and concave to insure no threshing action in the combine. The flail action threshed barley completely with small losses. The shear bar within the chopper was removed and recommended flail speed for silage harvesting was used.

Lamp (1959) and Lamp and Buchele (1960) described centrifugal threshing and concluded that wheat and other grains can be threshed by application of centrifugal force.

The threshing and separating process can be integrated, eliminating the need for special grain separating equipment. Air alone would be sufficient for cleaning centrifugally threshed grain.

Lalor, working concurrently with the author at the Agricultural Engineering Department, Michigan State University, has constructed a field-size cone thresher designed to thresh and separate the grain from the straw in a perforated cone. He has obtained promising results.

SELECTION OF COMPONENTS FOR THE COMBINE

Calculation of Required Capacity

The combine was designed to harvest the 2 center rows in 4-row wheat plots, 12 feet long, and with a row spacing of 12 inches. The harvested plot was calculated to be 2 x 12 feet = 24 square feet.

A maximum yield of 2,500 pounds straw and 2,500 pounds grain per acre was assumed. This gives an assumed yield of 1.4 pounds straw and 1.4 pounds grain per plot. Considering an average speed of 2 miles per hour or 3 feet per second, it will take 4 seconds to cut the plot. The combine should, therefore, be able to handle

$\frac{1.4 \text{ pounds}}{4 \text{ seconds}}$ = 0.35 pound of straw and 0.35 pound of grain per second.

Cutting

The following cutting principles were considered:

1. Conventional mower cutter bar.
2. Rotating blades on vertical shafts.
3. Rotating flails on a horizontal shaft.

The flail-type cutting mechanism was selected because of its simplicity and rewarding possibilities. It was hypothesized that this principle would give the 100 percent self-cleaning action required of a variety plot combine.

Conveying

The following conveying principles were considered for use behind the cutting mechanism:

1. Conventional inclined canvas or rubber belt.
2. Platform auger with chain and slats.
3. Air suction.
4. Combined throwing and blowing.

Combined throwing and blowing was the simplest self-cleaning principle and could be integrated into the flail-type cutting mechanism.

Threshing

The following threshing devices were considered:

1. Conventional rasp bar, angle bar, and spike-tooth cylinders.
2. Cone-type cylinder with axial feeding.
3. Conveying cylinder with axial feeding.
4. Rubber belt moving over a corrugated surface with no openings.
5. Rubber belt moving over a screen.
6. Corrugated rubber rolls moving at different speeds.
7. Flail-type forage harvester.
8. Centrifugal fan.
9. Centrifuge or other devices using centrifugal force for pulling the kernels from the heads.

A combination of 7 and 8 was selected as the threshing means as they could be accomplished by the above selected cutting means.

Separating and Cleaning

The literature review showed that in all cases where the conventional separating and cleaning principles have been used, the machines were not self-cleaning. In plot threshers where the separation of grain from straw and chaff was done by air, it was possible to provide a self-cleaning device.

Three possible solutions were considered as follows:

1. The conventional air cleaning device.
2. The cyclone.
3. The swirl-chamber.

The swirl-chamber was selected as a separating and cleaning mechanism in this research because the author felt that with further development it would provide a better solution than the conventional air and cyclone cleaners used on plot threshers.

Propelling

Several power units were studied. The following were considered more or less suited for the task:

1. Allis-Chalmers Model G tractor.
2. David Bradley Super, Model 575 garden tractor.
3. Simplicity, Model W garden tractor.
4. Simplicity Model 700, 4-wheel garden tractor.

5. International Cub Cadet, 4-wheel garden tractor.

A consideration which affected the selection of a tractor was that the combine should be short and have as small turning radius as possible. The David Bradley Super 575 garden tractor with 5.75 hp engine was selected because it provided a compact and simple solution of the power transmission from the tractor to the cutting and threshing mechanism as well as the fan.

CONSTRUCTION OF THE COMBINE

The Cutting and Threshing Mechanism

Figures 1 and 2 show the combine from the right and the left side. Figure 3 shows the transmission.

The straw dividers were placed on 12-inch centers. The throat was 12 inches wide at the gathering points and narrowed to 2 inches at the point where the crop encounters the action of the cutting and threshing flails. Figure 4 shows the straw dividers. To save time testing the machine, the right cutterhead was equipped with a propeller-type flails and the left cutterhead was equipped with a direct throwing-type flails. Later, the modified propeller flails and the modified direct throwing flails were constructed and tested. Figures 5 and 6 show the different types of flails.

The propeller flails

The theory of design of the propeller-type flails was to impact the heads of the crop from the 2 inches wide cutterhead entrance into the center section of the flail housing where a series of direct throwing flails would finish the threshing and produce air for transport of the straw to the separator. Four free swinging propeller flails were mounted at 90 degree intervals on the flail

Fig. 1. Right side of the plot combine.

Fig. 2. Left side of the plot combine.

Fig. 3. Right side of the combine with transmission shield removed: transmission pulleys to the flail shaft are 1, 2, 3, 4, 5; 6 is the crank for the speed changer pulley 2; 7 is idle pulley clutch, and 8 is the tachometer.

Fig. 4. The underside of the flail housing and the straw dividers: (1) right cutterhead entrance, (2) fan intake, (3) steering wheel. (From experiment No. 8.)

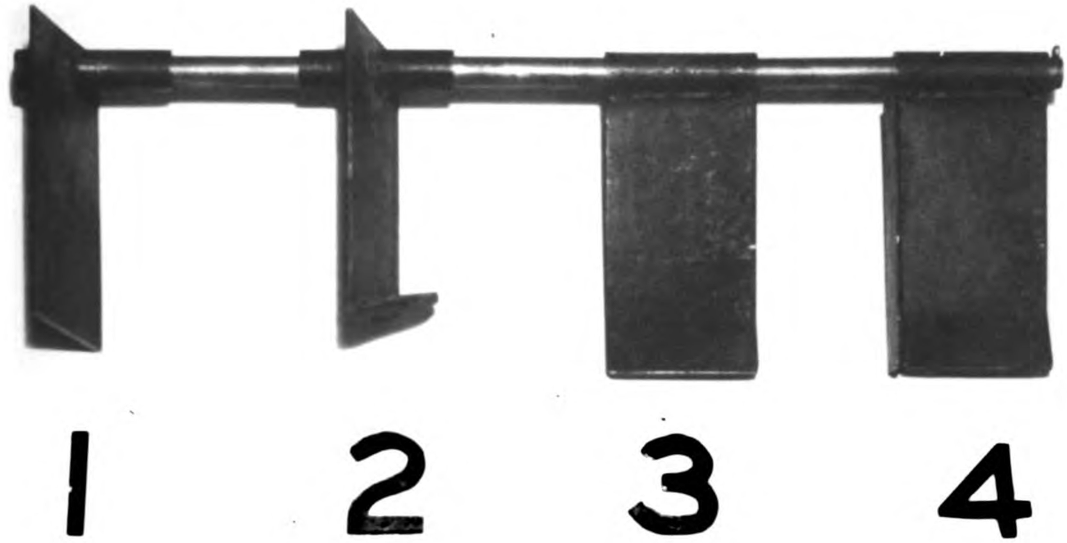

Fig. 5. Front view of the flails: (1) propeller flail, (2) modified propeller flail, (3) direct throwing flail, and (4) modified direct throwing flail.

Fig. 6. Side view of the flails: (1) propeller flail, (2) modified propeller flail, (3) direct throwing flail, and (4) modified direct throwing flail.

shaft in such a way that the leading edge of each flail was 1 inch to the right of the rear edge (Figures 5,1 and 6,1). The leading edge of the next flail, 90 degrees later, was 3/4 inch to the right of the leading edge of the first flail and so forth. The 4 flails covered thus a space of 3 inches behind the opening of the cutterhead throat on the right side of the flail house.

Specification of the Propeller Flails

Length of flails	5½	inches
Width of flails	3	inches
Thickness of flails	1/8	inch
Flail head diameter	16	inches
Flail head periphery	50.3	inches

The direct throwing flails

The principle of these flails were similar to that of the direct throwing flails of forage harvesters. Four free swinging flails were mounted at 90-degree intervals on the flail shaft in such a way that as the crop entered the 2 inches wide left hand throat of the flail housing, it would be cut, threshed, and thrown up to the cleaning device in one operation.

Specification of the Direct Throwing Flails

Length of flails	6 inches
Width of flails	3 inches
Thickness of flails	1/8 inch
Length between cutting edge and bend	1¼ inches
Angle between line of gravity and cutting edge	26 degrees
Shape of cutting edge	Rounded
Flail head diameter	17 inches
Flail head periphery	53.4 inches

The modified propeller flails

The modified propeller flails were constructed from the ordinary propeller flails. Four pieces of steel 1 x 2½ x ¼ inches were welded to the outer end of each of 4 propeller flails so the angle between the line of gravity and the cutting edge was 72 degrees. The front corner of the cutting steel was ground to an angle of 40 degrees and rounded. The rear part of the flails were cut away. Except for these changes, the modified propeller flails meet the specifications of the propeller flails.

The modified direct throwing flails

The modified direct throwing flails were constructed from the direct throwing flails. Two pieces of steel, 1 x 5½ x 1/8 inches were ground and welded to the edge of two opposite flails nearest to the intake of the fan. These flails act as cutting knives for the straws which are guided into the fan. The other two opposite flails nearest to the intake of the fan were removed. The specifications for the chopping flails are the same as for the direct throwing flails except for the modification just described.

The flail housing

The flail housing consisted of the right side straw divider and cutterhead with 4 propeller flails, the center section with 16 direct throwing flails, and the left side straw divider and cutterhead with 4 direct throwing flails. The 16 flails in the center section of the flail house were mounted 4 on line and at 4 positions located at 90 degree intervals on the flail shaft. Preliminary experiments proved that it was necessary to design a fan housing for these flails in order to secure sufficient air pressure in the elevating duct to overcome the back pressure developed in the swirl-chamber by the cleaning fan.

The flail housing (Figures 1, 2, and 4) covers the flails completely except for the crop entrance and the opening between the cutterheads and the ground.

The Elevating Duct

The outlet from the flail housing was 5 x 20 inches and tapered to 5 x 13½ inches during the first 9 inches of duct length. The next section was 40 inches long and slightly tapered to 5 x 12-3/4 inches at the bend. This bend had an internal angle of 87 degrees, but was rounded in the upper side where the material was deflected down to the 11 inches long and 5 x 12-3/4 inches wide duct to the swirl chamber.

The Swirl-Chamber and the Fan

Figures 7 and 8 show the swirl-chamber where the grain is separated and cleaned from the straw and chaff. It was made of 2 pieces of plexiglass 19 x 27-3/4 x 1/4 inches mounted 12.5 inches apart. The swirl-chamber was created between these walls by a strip of formed 28-gauge sheet metal kept in desired position by 8 bolts. The shape of the swirl-chamber was easily adjusted by loosening one or more of these bolts. The swirl-chamber could also be tilted forwards or backwards for finding the right position.

A Brundage furnace blower, AP 10, was used to provide air for operating the swirl-chamber. The capacity of the blower was 1,500 cfm when delivered against a static pressure of ¼ inch of H_2O at 625 rpm. Figures 7 and 8 show the relationship between the fan and the swirl-chamber. The swirl-chamber was constructed in such a way that the grain and short straw with nodes were deflected across the outlet opening. They then slid down the inclined front side of the swirl-chamber perpendicular to the air stream. The heavier grain passed through the air stream and dropped into the grain box, but the straw was carried out by the air stream.

Fig. 7. (1) The swirl-chamber, (2) fan with fan shutters, (3) grain box, (4) duct from the cutterheads, (5) burlap sack.

Fig. 8. Pattern of straw in the swirl-chamber.

The longer straw and chaff, which were not heavy enough to be carried across the outlet of the swirl-chamber were deflected upward by the air stream and escaped through the clear plastic tube to the burlap sack shown in Figure 7.

The Controls

The ground speed was adjusted in two different ways during the experiments.

The two upper curves of Figure 9 show the original adjustment with a floating V-belt pulley (Figure 3). At each engine rpm the forward speed of the combine can be set anywhere between these two curves. The lower curve of Figure 9 shows the relation between engine speed and ground speed with a slow speed pulley. The only way to adjust ground speed with this pulley was to change the engine speed. The curves were not extended above 3,000 rpm because this means high ground speed which makes precision steering difficult while operating the combine in the field.

Figure 10 shows the limits for the flail speed adjustments. The curve between the upper and lower speed limits represents the relationship which was most often used.

Figure 11 shows peripheral flail speed versus revolution per minute of the cutterheads. Figure 12 shows the two relations between engine and fan speed which were used. Before changing from an 8-inch to a 7-inch pulley, a 5-inch pulley was tried in the laboratory. The static pressure

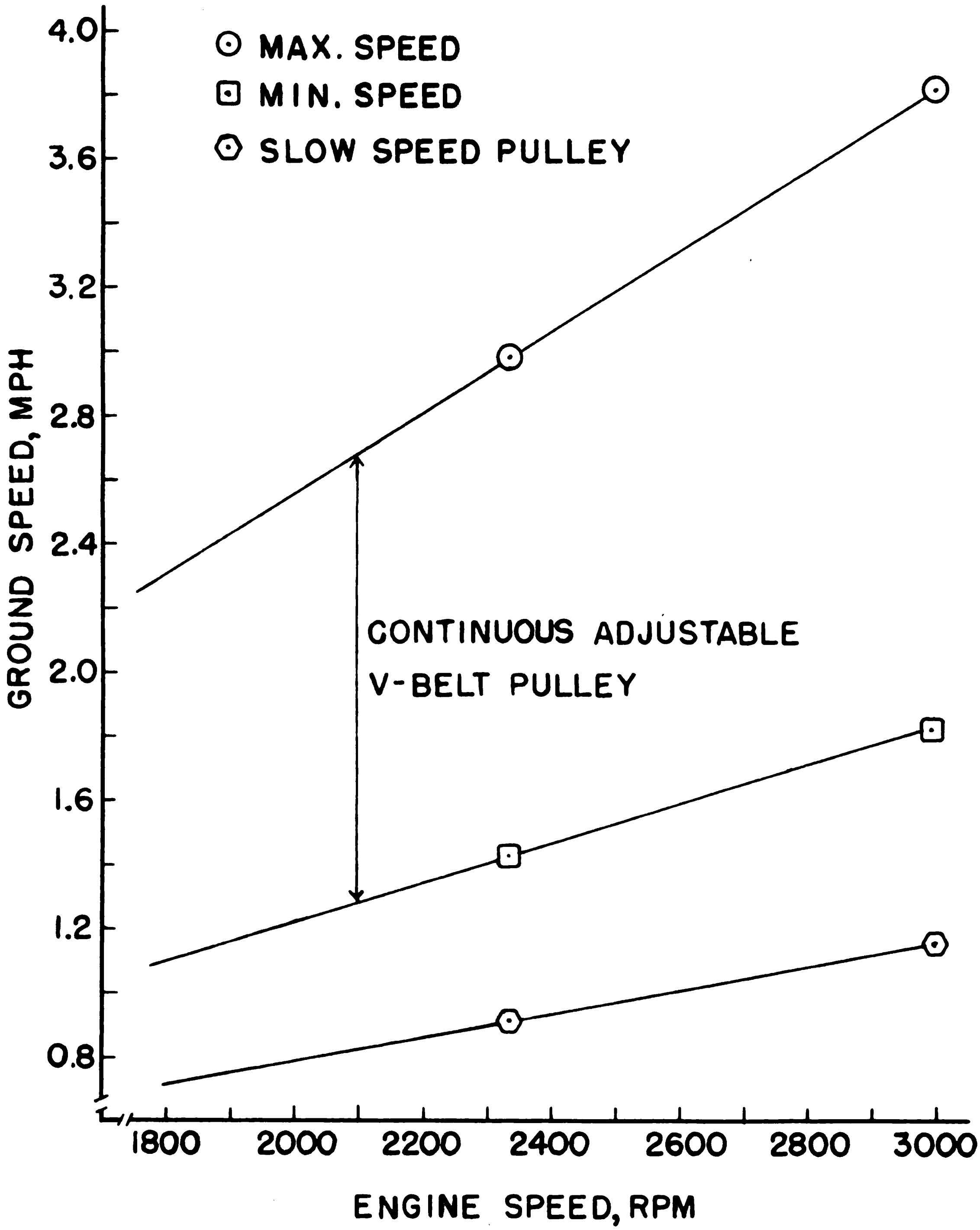

Fig. 9. Ground speed adjustment.

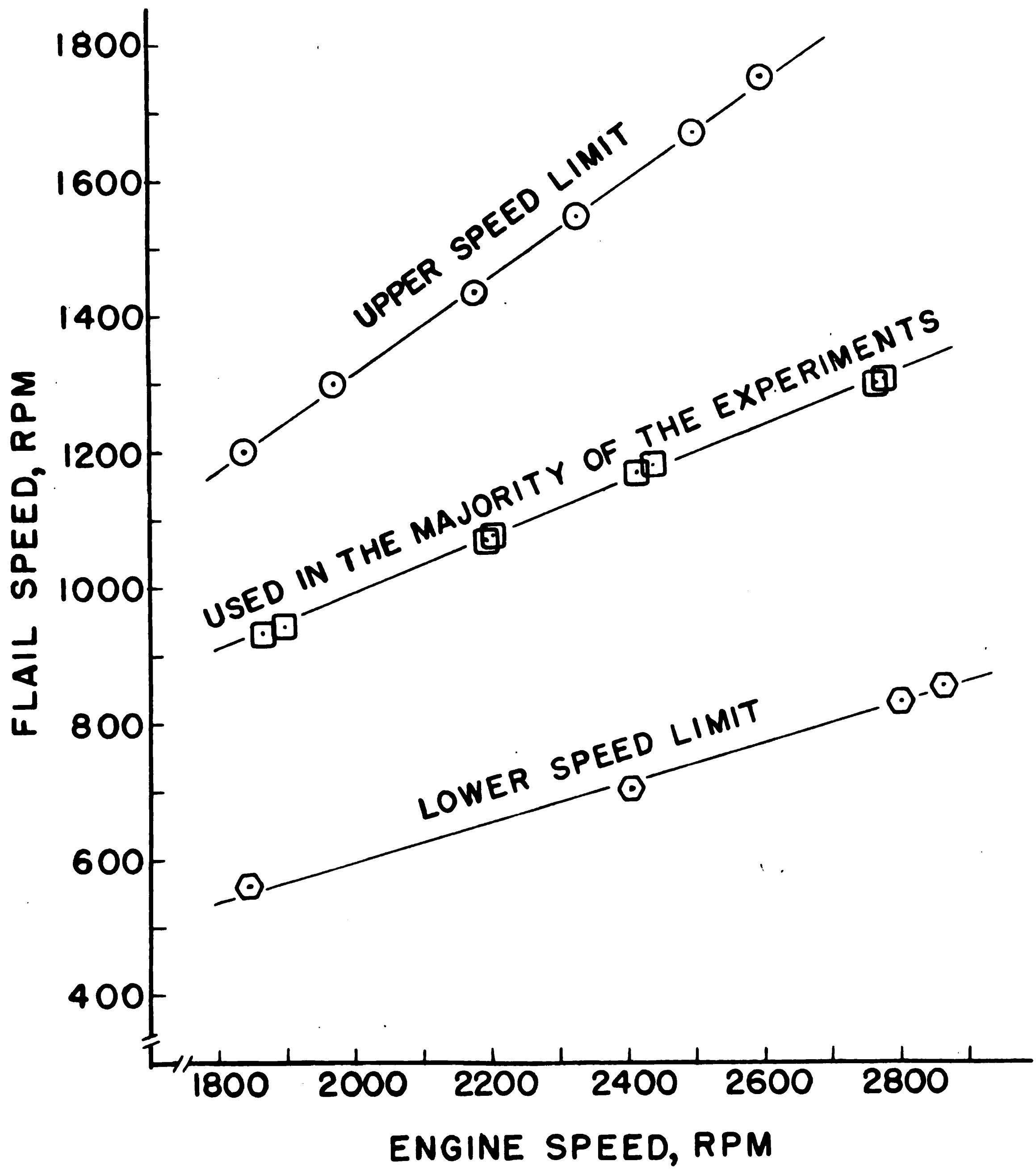

Fig. 10. Flail speed adjustment.

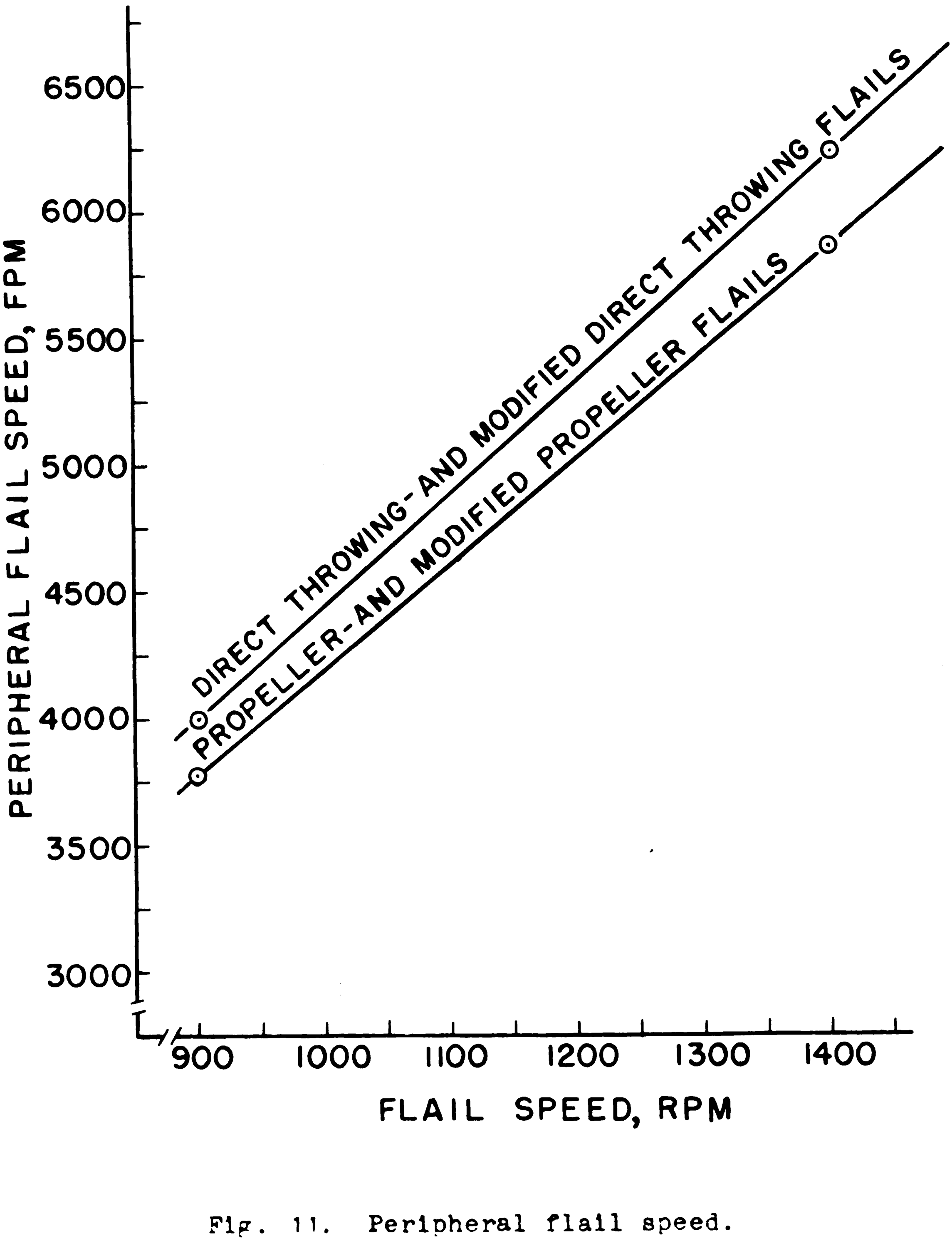

Fig. 11. Peripheral flail speed.

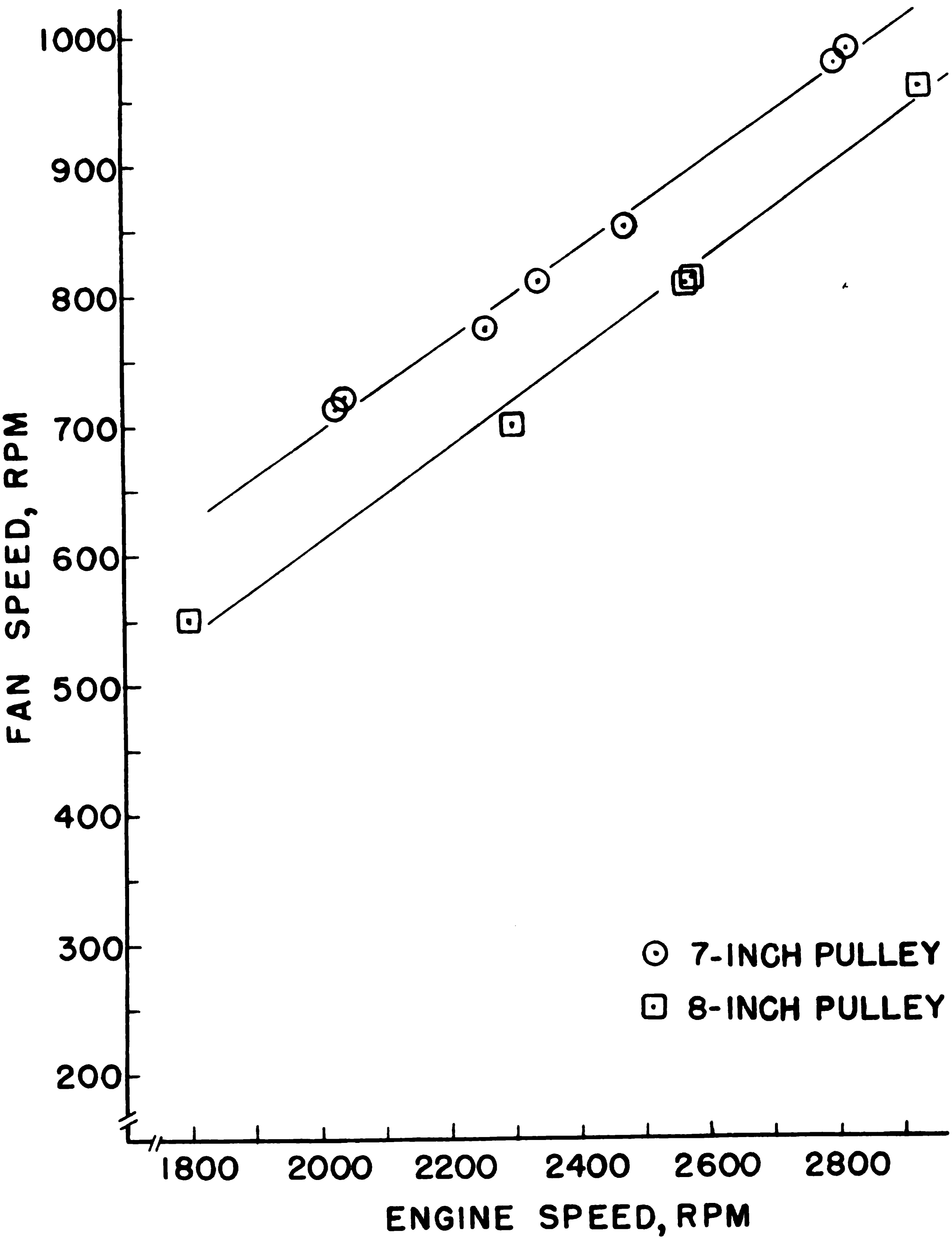

Fig. 12. Speed of cleaning fan.

developed in the swirl-chamber was greater than the static pressure developed in the flail housing. This created a back pressure in the elevating duct so the flails were not able to blow the straw up the duct into the swirl-chamber. The 5-inch pulley was therefore rejected.

The air volume was controlled by continuous adjustable shutters (Figure 7) marked 0 to 12 on each side of the fan. 0 means closed (no air intake) and 12 means open.

An adjustable air deflector was placed in the fan outlet (Figure 8). The deflector controlled the air distribution in the swirl-chamber and could be set according to a scale ranging from 1 to 9.

The machine was steered by a level acting on a pneumatic wheel in front of the tractor wheels (Figure 4).

The upper edge of the crop intake could be adjusted to 23, 25, and 27 inches above the ground. The corresponding height of the cutterhead entrance was 11, 13, and 15 inches.

Specifications of the Combine

Width of cut	24 inches (2 rows 12 inches apart)
Type of cut	Flail action (impact)
Threshing principle	Flail action (mainly impact)
Cleaning principle	Air separation in swirl-chamber
Tractor-type	David Bradley, Super 575 garden tractor
Engine	4 cycle Briggs and Stratton
Horsepower	5.75 maximum at 3,600 rpm 4.51 maximum at 2,700 rpm 2.65 maximum at 1,800 rpm
Torque	8.88 ft.-lbs. maximum at 3,000 rpm
Tractor wheel	6.70 x 15 pneumatic tire
Steering wheel	3.50 x 6
Wheel base distance	52 inches
Maximum length	123 inches
Maximum height	78 inches
Maximum width	32 inches
Turning radius	72 inches
Turning space diameter	218 inches

TEST OF THE COMBINE

The combine was tested in an experimental field of wheat planted in 12-foot rows on 12-inch centers.

Experimental Purpose and Procedure

The purpose of the experimental procedure was to determine the following:

1. Percent threshed plot yield recovered in grain box.
2. Percent unthreshed plot yield recovered in grain box.
3. Percent cutterhead losses of threshed grain.
4. Percent cutterhead losses of unthreshed grain.
5. Percent swirl-chamber losses of threshed grain.
6. Percent swirl-chamber losses of unthreshed grain.
7. Percent straw in the recovered grain (of total straw).
8. Percent visible damage of the threshed grain.

The total plot yield was calculated by the summation of numbers 1 through 6. This total was used for calculation of the different percentages.

The sum of numbers 3 and 4 measured the total cutterhead losses.

The sum of numbers 5 and 6 measured the total swirl-chamber losses and together with numbers 2 and 7, provided an indication of the separating efficiency of the swirl-chamber.

The sum of numbers 2 and 6 established percent "cylinder losses" or the total percent unthreshed grain entering and passing through the threshing device.

The procedure for obtaining these data was the following:

1. A piece of canvas 20 inches by 15 feet was placed on each side of the test row. Because of the nature of the rows, the width of the area actually covered by the canvas varied between 11 and 20 inches (see Figures 13 and 14).

2. The row was harvested with the plot combine.

3. The combine was checked for complete cleaning between the plots.

4. The two pieces of canvas were rolled as shown in Figure 15. The rolls were inserted in a sack and the grain and straw were shaken out before bagging and marking.

5. The seed collected in the grain box (Figure 7) was dumped into a bag and marked.

6. The straw, chaff, and grain blown from the swirl-chamber were collected in a burlap sack (Figure 7). The content of this sack was placed in another sack and marked.

The collected samples were brought to the laboratory and analyzed according to the following procedure.

<u>Grain collected in the grain box</u>

a. The sample was weighed in the bag.

b. The sample was poured on the screen of an experimental grain cleaner.

c. The empty bag was weighed and net weight obtained by subtraction.

d. The unthreshed heads were collected from the screen.

Fig. 13. Right cutterhead harvesting a single row of standing wheat.

Fig. 14. Right cutterhead harvesting a single row of wheat lodged so that the heads entered the cutterhead first.

Fig. 15. Dr. W. F. Buchele and author rolling the two sheets of canvas which were placed on each side of the row to catch the cutterhead losses of grain.

Fig. 16. Left to right: Cutterhead losses, grain box content, and burlap sack content.

e. The cleaned grain was weighed and recorded.

f. The unthreshed heads were counted, handthreshed, cleaned, weighed, and recorded.

g. Weight of straw and chaff in the grain was found by subtraction of threshed and unthreshed grain from the total sample weight.

Grain collected from the canvas (cutterhead losses)

a. The sample was poured on the screen of the experimental grain cleaner.

b. The unthreshed heads were picked from the screen.

c. The threshed grain was weighed and recorded.

d. The unthreshed heads were counted, handthreshed, cleaned, weighed, and recorded.

Grain, straw, and chaff collected in the burlap sack

a. The sample was weighed in the sack.

b. The sample was poured into a big box.

c. The empty sack was weighed and sample weight obtained by subtraction.

d. The unthreshed heads were handpicked, counted, handthreshed, cleaned, weighed, and recorded.

e. The straw was handpicked into a sack.

f. The remaining grain was air-cleaned, weighed, and recorded.

g. Weight of straw and chaff was found by subtraction of threshed and unthreshed grain from the total sample weight.

The opening of the fan shutter was positioned to prevent seed losses in the experimental grain cleaner. Samples under 10 grams were weighed on a scale with ± 0.1 g accuracy. Percent visible damage was determined by dividing the threshed grain from the box several times on a Seedburo sampler until two lots of approximately 150 kernels remained. Visibly damaged kernels were picked out of the sample by hand and the percent kernel damage was determined.

Results of the Field Tests

This section will give the data and deal with the analysis of the obtained results. The number of observations was too small for using statistical inferences, but inferences can also be made with a small number of observations without statistics if the observed differences are large and easily explained.

Symbols used in the tables

G = grain, threshed and unthreshed

T = threshed grain

U = unthreshed grain

S = straw

K = kernels of grain

H = heads of grain

The experimental procedure described in the previous section was not developed in detail when the first field tests were conducted. Tests 1, 2, and 3 of this section describe tests in which the procedure was somewhat different from the procedure used in the rest of the tests. The first field tests with the combine were carried out on August 8, 1961.

Test 1. Two-row operation

Plots consisting of two rows of wheat (straw length between 42 and 45 inches) were harvested and the following observations were recorded.

1. Straw clogged the upper part of the duct between the flail housing and the swirl-chamber at top speed of the engine and a ground speed of approximately 1.8 mph.

2. The tendency of clogging decreased as the ground speed was decreased.

3. The easiest steering was obtained at the lowest ground speed.

A study of the above observations indicated that one or more of the following changes must be made in order to secure efficient two-row operation.

1. Increase cross-sectional area of the duct.

2. Increase air capacity of the cutterhead fan.

3. Decrease angle of the bend of the duct.

4. Sharpen flails to provide a shorter cut of the straw.

Test 2. Direct throwing flails

Test 2 was designed to detect any difference between the right cutterhead with propeller flails and the left cutterhead with direct throwing flails. Since the results were obvious, only a few plots were needed to reach a conclusion.

The losses in the end of the plots were about twice as large for the direct throwing flails as for the propeller flails. Figure 18 shows the heavy losses that occurred at the end of the plots harvested with direct throwing flails.

Test 3. Propeller flails, introduction

To determine the performance of the propeller flails, one row was harvested over two plot lengths without stopping. The straw was bent forward by the machine as in the previous tests. The cutterhead rpm was 1,075. The speed variation, however, was great.

The whole sample collected in the grain box was divided by hand into the following parts:

Threshed seed in grain box	153 grams	
Unthreshed seed in grain box	5 grams	
Total grain weight		158 grams
Straw in grain box		9 grams

The following observations were recorded after an inspection of the sample in the grain box.

1. No visible kernel damage.
2. Chaff was attached to a few kernels.
3. Eight unthreshed heads.
4. Ten completely threshed heads.

The threshed and unthreshed heads were below normal size. Examination of the unthreshed heads showed that they contained kernels of normal size. A larger percentage of threshed heads than of unthreshed heads were attached to the straw.

Three empty heads on ten inches straw

One empty head on six inches straw

One empty head on three inches straw

The largest piece of straw without heads was 7 inches; a node was located on one end of the straw. Two pieces of straw were 6 inches. Most of the straw was split by the flail action. The threshed and unthreshed grain on the ground was gleaned by hand and analyzed. Table 1 gives information concerning the distribution of losses.

Table 1. Laboratory Analysis of Test 3

Source	Weight in grams	%
Threshed seed in the grain box	153	73.3
Unthreshed in the grain box	5	2.4
Threshed grain on the soil*	32	15.3
Unthreshed grain on the soil*	19	9.0
Total row yield	209	100.0

*It was not possible to recover every lost kernel.

Because the loss of 24.3 percent grain was not considered excessive at this stage of development, it was decided to continue the development of the propeller flails.

<u>Improvements based on test 3</u>.

1. The cutterheads were equipped with better designed side covers.
2. A tachometer was mounted for continuous observation of the flail shaft speed.

Fig. 17. Losses in the row with the modified propeller flails.

Fig. 18. Great losses often occurred in the end of the rows with the direct throwing and the modified propeller flails.

Test 4. Propeller flails, cutterhead adjustment

The purpose of this test was to study the effect of the cutterhead adjustment.

Two rows of the same wheat variety, here called plots 1 and 2, were harvested. In plot 1 the height of cut was 27 inches and in plot 2, 23 inches. This distance was measured from the ground to the lowest part of the cutterhead entrance. The shroud over the throat bent the straw forward so the butt end of the stalk entered the cutterhead before the heads (Figure 13). Table 2 shows the adjustment of the combine, Table 3 the observations, and Table 4, the results of the test.

Table 2. Adjustment of the Combine in Test 4

Plot No.	Flail Speed	Ground Speed	Fan Shutters Opening	Air Deflector Position	Shape of Swirl Chamber	Height of Cut
	rpm	mph				inches
1	1300	1.4	10	4	1	27
2	1300	1.4	12	4	1	23

Table 3. Weight of Grain and Straw in Gram in Test 4

Plot No.	Grain box			Cutter-head		Straw sack			Total	
	T	U	S	T	U	T	U	S	G	S
1	152	2K 1H	44	43	1.7 8H	0.9	1K 1H	182	198	226
2	107	0	24	77	4.8 11H	6.0	0.4 1H	239	195	263

Table 4. Percent of Total Yield Recovered in Test 4

Source		Butts first Height of cut, inches 27	 23
		%	%
Recovered seed in grain box	Threshed	77.0	54.8
	Unthreshed	Nil	0.0
	Total	77.0	54.8
Cutterhead losses	Threshed	21.7	39.4
	Unthreshed	0.9	2.5
	Total	22.6	41.9
Swirl-chamber losses	Threshed	0.4	3.1
	Unthreshed	Nil	0.2
	Total	0.4	3.3
Total grain recovered		100.0	100.0
Total losses of grain		23.0	45.2
Total cylinder losses		Nil	0.2
Straw in grain box		19.5	9.1
Straw in straw sack		80.5	90.9
Total straw recovered		100.0	100.0

A hypothesis stating that there was no difference in the cutterhead performance from plot 1 to plot 2 can not be tested with help of statistics and a probability table because no replications were taken. However, logical inferences can also be acceptable. The increase of the total cutterhead losses from 22.6 to 41.9 percent for a lowering of the cutterhead from 27 to 23 inches above the ground, was assumed to be beyond chance, and it was concluded that the lowest cutterhead setting increased the cutterhead losses. This conclusion could also be formed by looking at the losses on harvested plots where no samples were collected.

The increased swirl-chamber losses from 0.4 to 3.3 percent were caused by the stronger air blast as a result of opening the fan shutters from 10 to 12. The corresponding increase in straw separation in the swirl-chamber from 80.5 to 90.9 percent backed up this inference.

Changes based on observations made during test 4. Insufficient air was delivered by the fan operated by an 8-inch pulley. A 5-inch pulley was installed in the laboratory, but it delivered too much air. A 7-inch pulley was mounted and used for the remainder of the tests.

The cutterhead losses in plot 1 and plot 2 were found by handgleaning. Experiments in the field showed that a strip of canvas on each side of the row could be used for recovering the cutterhead losses from the propeller flails. This method could not be used with the direct throwing flails because the canvas was picked up and wrapped around the flail shaft.

Test 5. Propeller flails, crop entrance methods

The purpose of this test was to determine if the efficiency of the combine was affected by whether the heads or butts entered the cutterhead first. Only two replications of each method were taken. Table 5 shows the combine adjustment and Table 6 shows the observations.

Table 5. Adjustment of the Combine in Test 5

Plot No	Flail speed	Ground speed	Fan shutters opening	Air deflector setting	Shape of swirl chamber	Height of cut	Way of entering
	rpm	mph				inches	
3	1300	1.4	12	4	2	25	Heads
4	1300	1.4	12	4	2	25	first
5	1300	1.4	12	2	2	25	Butts
6	1300	1.4	12	3	2	25	first

Table 6. Weight of Grain and Straw in Grams in Test 5

Plot No	Grain box			Cutter-head		Straw sack			Total	
	T	U	S	T	U	T	U	S	G	S
3	172	1K 1H	49	46	3.7 8H	4.9	0.5 3H	201	227	250
4	126	0	65	49	6.3 14H	3.5	1K 1H	188	185	253
5	184	0	46	49	0.2 1H	8.0	0.7 7H	289	242	335
6	67	0.3 4H	51	30	4.5 10H	0.2	0.7 3H	123	103	174

Table 7. Percent of Total Yield Recovered in Test 5

Source		Heads first Plot No. 3	Heads first Plot No. 4	Butts first Plot No. 5	Butts first Plot No. 6
		%	%	%	%
Recovered seed in grain box	Threshed	75.7	68.2	76.1	65.2
	Unthreshed	nil	0.0	0.0	0.3
	Total	75.7	68.2	76.1	65.5
Cutterhead losses	Threshed	20.3	26.5	20.2	29.2
	Unthreshed	1.6	3.4	0.1	4.4
	Total	21.9	29.9	20.3	33.6
Swirl-chamber losses	Threshed	2.2	1.9	3.3	0.2
	Unthreshed	0.2	nil	0.3	0.7
	Total	2.4	1.9	3.6	0.9
Total grain recovered		100.0	100.0	100.0	100.0
Total cylinder losses		0.2	nil	0.3	1.0
Total losses of grain		24.3	31.8	23.9	34.8
Straw in grain box		19.6	25.7	13.7	29.3
Straw in burlap sack		80.4	74.3	86.3	70.7
Total straw recovered		100.0	100.0	100.0	100.0

Table 7 shows the percent distribution for the test. The losses were considerably greater than can be accepted by either method of crop entrance. The cutterhead losses of threshed grain were the main source of the losses, but the sum of the cutterhead losses of unthreshed grain and the total swirl-chamber losses cannot be neglected.

Table 8 is a summary of the main results from Table 7. It was impossible to draw any conclusion about which entering method of the crop was the best. The dispersion was so large that a large number of observations would have been necessary to detect any significant difference.

Table 8. Statistics for Test 5

Source	Heads first		Butts first	
	$\bar{X}$	s	$\bar{X}$	s
	%	%	%	%
Threshed grain in grain box	72.0	5.3	70.7	7.7
Total cutterhead losses	25.9	5.7	27.0	9.4
Total swirl-chamber losses	2.1	0.4	2.3	1.9
Total cylinder losses	0.1	0.14	0.7	0.5
Total losses	28.0	5.3	29.3	7.7

A study of the observations indicated that there was a pronounced relationship between the efficiency of the combine and the plot yield regardless of entering method of the crop. Figure 19 shows that the percent cutterhead losses of threshed and unthreshed grain decreased as the plot yield of grain increased. Figure 20 shows that the swirl-chamber losses of threshed and unthreshed grain increased as the total yield of grain entering the swirl-chamber increased. Figure 21 shows that the percent straw separation in the swirl-chamber increased as the total yield of straw

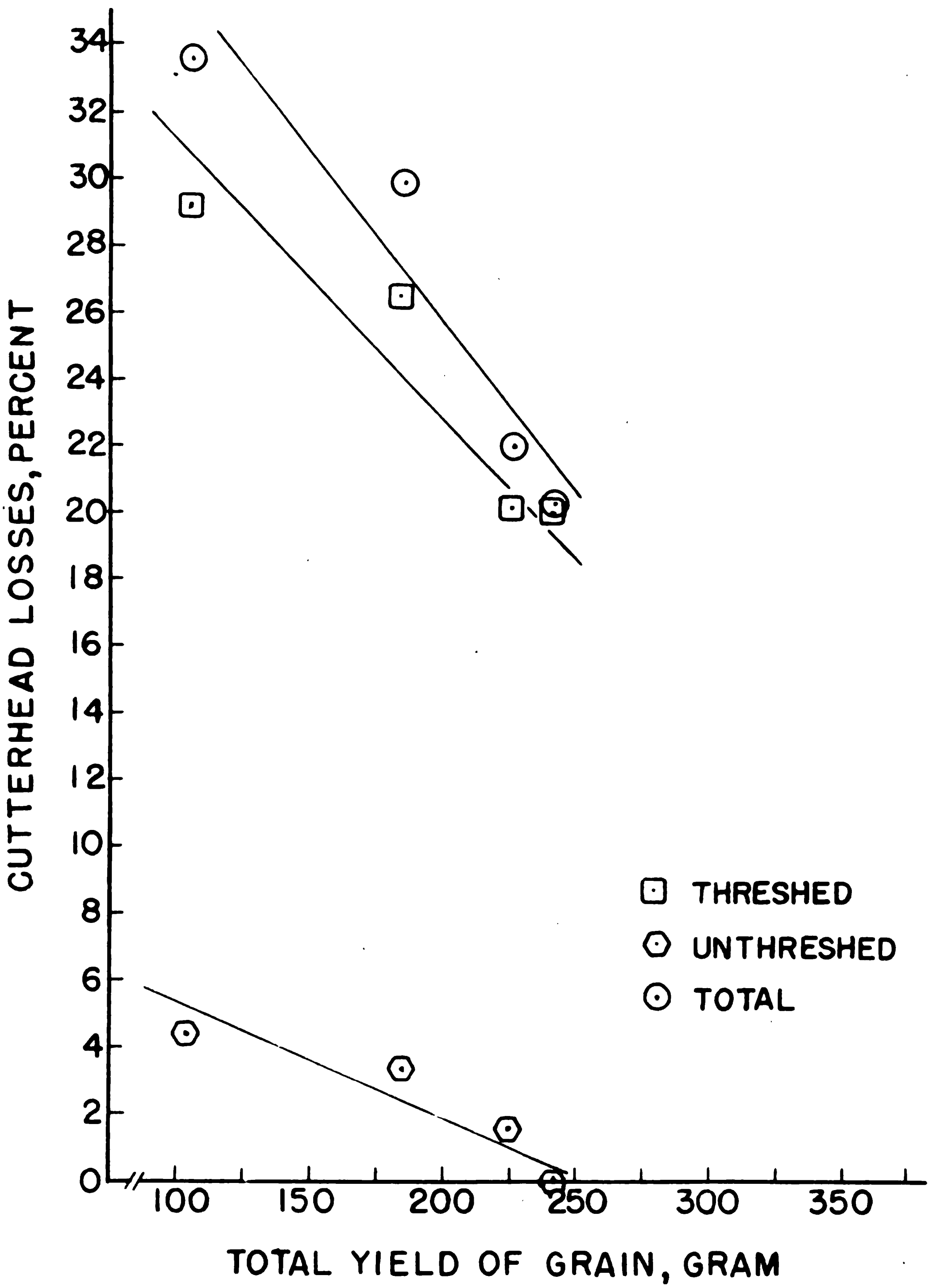

Fig. 19. Correlation between percent cutterhead losses and total yield in Test 5.

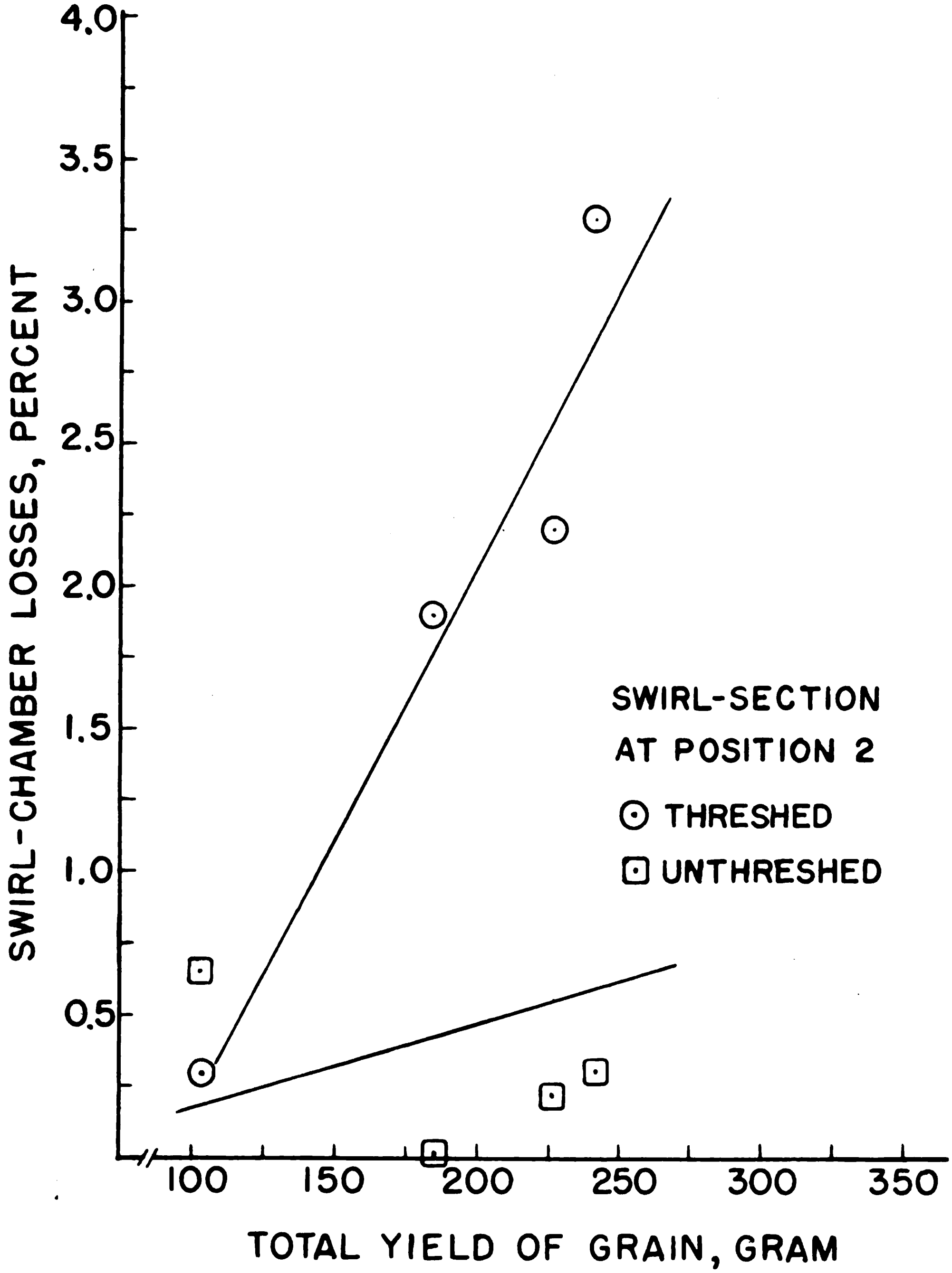

Fig. 20. Correlation between percent swirl-chamber losses and total yield of grain in Test 5.

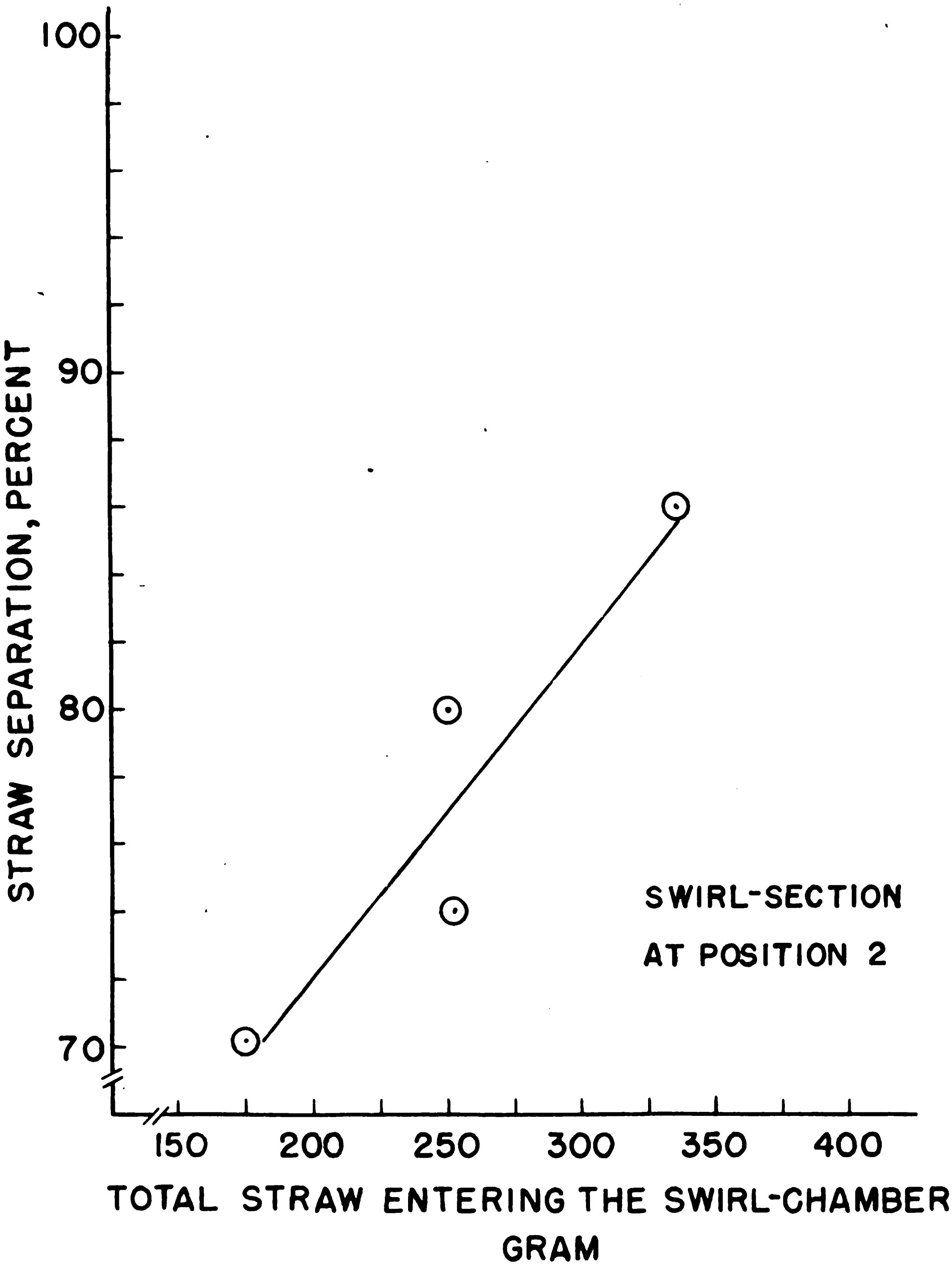

Fig. 21. Correlation between percent straw separation and total yield of straw entering the swirl-chamber in Test 5.

entering the swirl-chamber increased.

Changes based on observations made during test 5. A slow speed pulley was mounted to give lower ground speed. That reduced the rate of material entering the cutterhead and swirl-chamber in the remaining tests.

The shape of the swirl-chamber was adjusted from position 2 to position 1.

Test 6. Propeller flails, slow ground speed

The purpose of this test was to determine if the slow ground speed and the shape of the swirl-chamber influenced the cutterhead losses and the performance of the swirl-chamber.

Table 9 shows the adjustment of the combine, Table 10 shows the observations, and Table 11 shows the percent distribution.

Table 9. Adjustment of the Combine in Test 6

Plot No	Flail speed	Ground speed	Fan shutters opening	Air deflector setting	Shape of the swirl-chamber	Height of cut	Entering way of crop
	rpm	mph				inches	
7	1300	0.90	12	3	1	27	
8	1200	0.84	12	3	1	27	Butts first
9	1100	0.76	12	3	1	27	
10	1300	0.90	12	3	1	27	

Table 10. Weight of Grain and Straw in Grams in Test 6

Plot	Grain box			Cutter-head		Straw sack			Total	
No	T	U	S	T	U	T	U	S	G	S
7	113	0.5	7.5	34	12	11.5	1.3 3H	260	172.3	267.5
8	290	1.0	29	54	1.0	5.0	1.0 9H	338	352.0	367
9	194	8K 7H	10	55	11	16	9K 6H	294	275.0	304
10	77	0	3	42	2.9 7H	33.5	0	224	155.4	227

Table 11. Percent of Total Yield Recovered in Test 6

Source		Butts first		Plot No.	
		7	8	9	10
		%	%	%	%
Recovered seed in grain box	Threshed	65.6	82.4	70.2	49.5
	Unthreshed	0.3	0.3	nil	0.0
	Total	65.9	82.7	70.2	49.5
Cutterhead losses	Threshed	19.7	15.3	20.0	27.0
	Unthreshed	7.0	0.3	4.0	1.9
	Total	26.7	15.6	24.0	28.9
Swirl-chamber losses	Threshed	6.7	1.4	5.8	21.6
	Unthreshed	0.7	0.3	nil	0.0
	Total	7.4	1.7	5.8	21.6
Total grain recovered		100.0	100.0	100.0	100.0
Total cylinder losses		1.0	0.6	nil	0.0
Total losses of grain		34.4	17.6	29.8	50.5
Straw in grain box		2.8	7.9	3.3	1.3
Straw in burlap sack		97.2	92.1	96.7	98.7
Total straw recovered		100.0	100.0	100.0	100.0

Table 12. Statistics for Test 6

Source	Butts first	
	$\bar{X}$	s
	%	%
Threshed seed in grain box	66.9	13.6
Total cutterhead losses	23.8	5.8
Total swirl-chamber losses	9.1	8.7
Total cylinder losses	0.4	0.5
Total losses	33.1	13.6

The variability in the observations was large as shown in Tables 11 and 12. The four observations showed that as an average only 66.9 percent of the grain was recovered in the grain box. The standard deviation was 13.6 percent which means that the recovered plot yields had a large dispersion. An examination of the main source for this dispersion led to the swirl-chamber loss of threshed grain for plot 10. This plot had a low yield of grain and straw and Figures 22, 23, and 24 show that there was a relation between the efficiency of the combine and the plot yield.

Figure 22 shows that the percent cutterhead losses of threshed and unthreshed grain decreased as the total yield of grain increased. The reduction in ground speed had no significant influence on the size of the cutterhead losses as a comparison between Figure 19 (1.4 mph) and Figure 22 (0.8 to 0.9 mph) shows.

Figure 23 shows that the percent swirl-chamber losses of threshed grain decreased as the total plot yield of grain increased. The losses of threshed grain were definitely larger for shape 1 of the swirl-chamber than for shape 2 as a comparison between Figures 20 and 23 shows. The losses of unthreshed grain were negligible compared with the losses of threshed grain. The data gave no reason to state any connection between losses of unthreshed grain and the plot yield or difference from Test 5. One difference, however, between shape 1 and shape 2 of the swirl-chamber was evident.

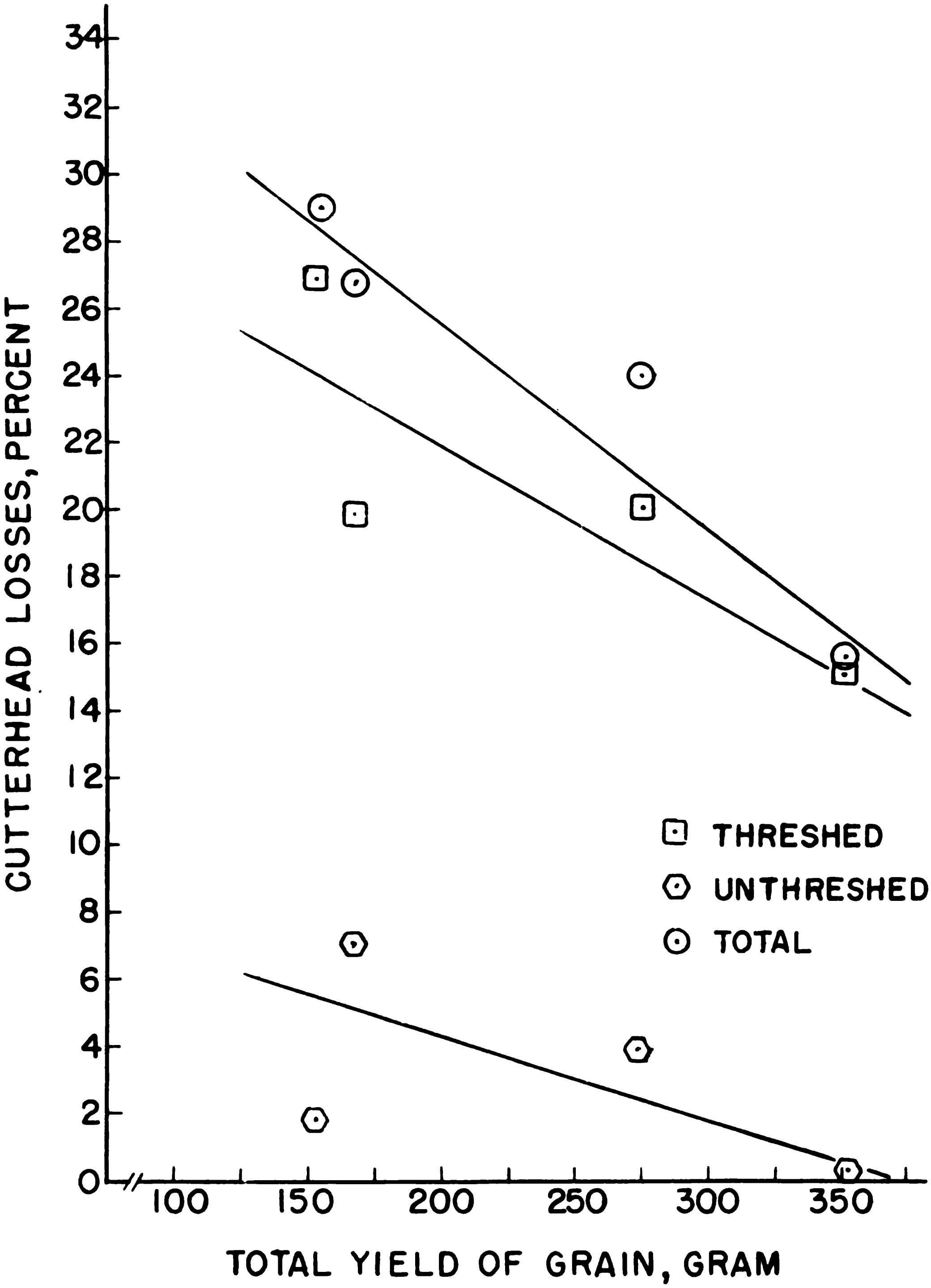

Fig. 22. Correlation between percent cutterhead losses and total yield of grain in Test 6.

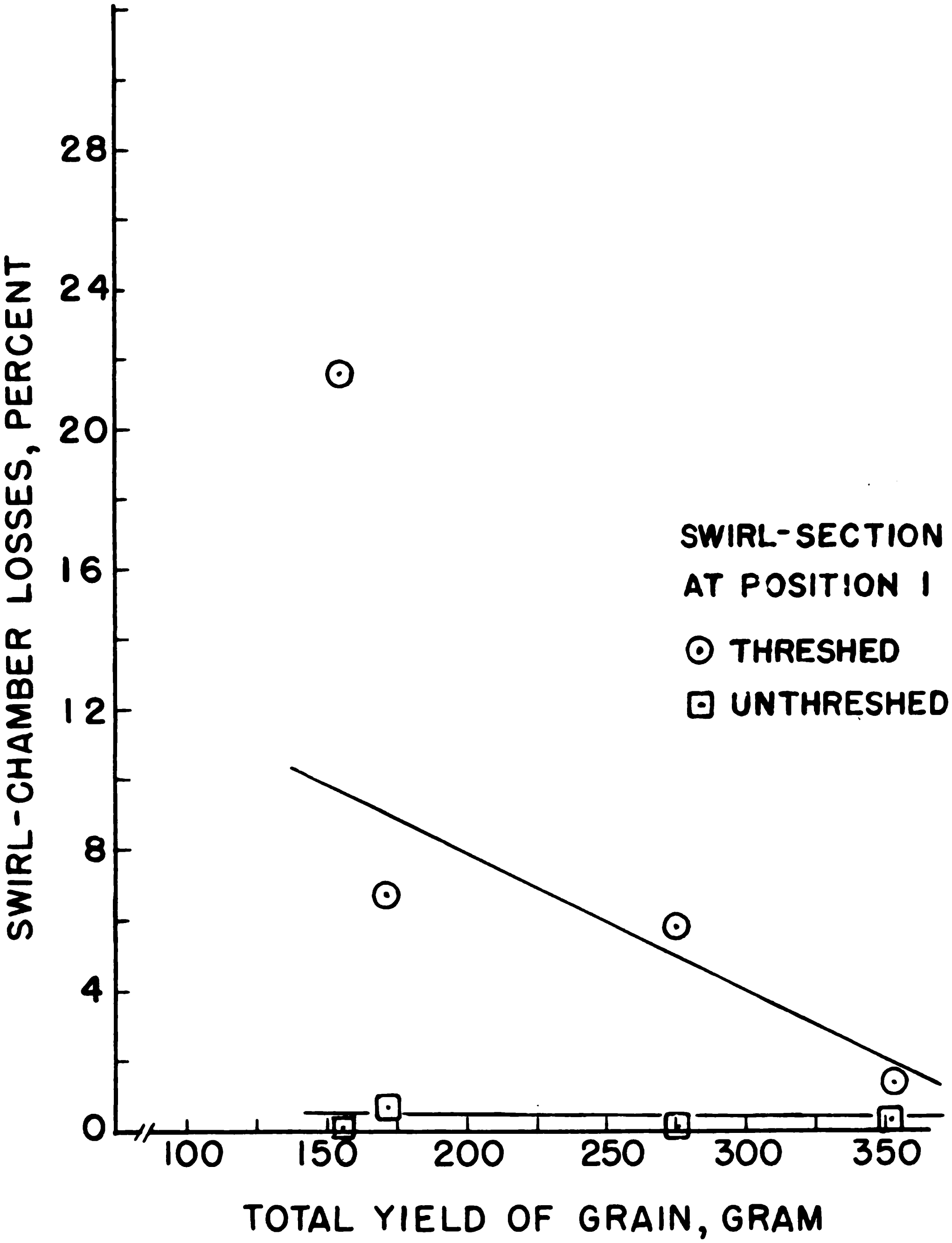

Fig. 23. Correlation between percent swirl-chamber losses and total yield of grain in Test 6.

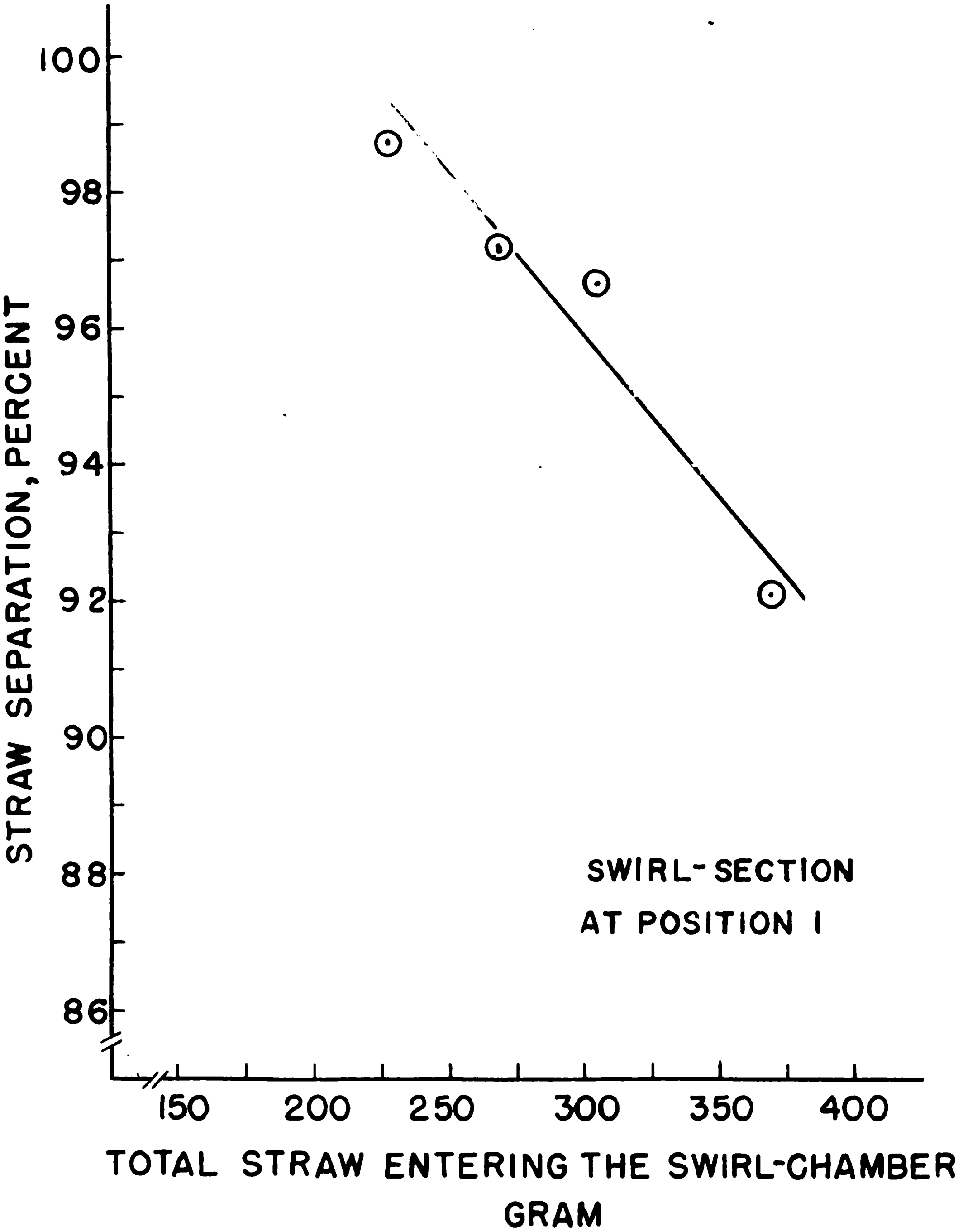

Fig. 24. Correlation between percent straw separation and total yield of straw entering the swirl-chamber in Test 6.

The losses of threshed grain decreased with increased plot yield for shape 1, but increased with increased plot yield for shape 2. (This suggests that there must be a shape of the swirl-chamber between 1 and 2 where the percent losses of threshed grain are constant regardless of plot yield.)

Figure 24 shows that as the plot yield increased, the percent straw separation in the swirl-chamber decreased. This was the opposite reaction as was found for shape 2 of the swirl-chamber shown in Figure 21. The percent separation of the straw from the grain was definitely better in Test 6 than in Test 5, but as the losses of threshed grain was much higher, the adjustment of the swirl-chamber in Test 6 cannot be considered to be an improvement. The separating efficiency cannot be considered as satisfactory.

The reason for the decrease in cutterhead losses with increased plot yield was the same as in Test 5. A high yield of straw made a better sealing in the throat of the cutterhead so the flails did not throw the grain out so easily. The decreased percentage of swirl-chamber losses with increased yield of grain entering the swirl-chamber and a corresponding higher percent of straw in the grain box, must be connected with the lower air velocity at higher loads on the swirl-chamber.

The best estimate of the combine efficiency would have been the regression equation: $Y = \bar{Y} + b(X - \bar{X})$ where

Y = expected combine efficiency.

$\bar{Y}$ = average recovered yield computed from the observations.

X and $\bar{X}$ = plot yield and average plot yield.

This linear regression equation would have determined the combine efficiency with a smaller standard error of estimate than what the standard deviation can provide. With the few observations, the variation in flail speed and the great losses, it was not considered worthwhile to compute the regression equation. Even if the graph, based on a regression equation, was available, it would be to laborious to make the corrections in practice. Because the only known observation would be the recovered seed in the grain box, such a regression equation, if applicable, must use the recovered seed instead of total plot yield for calculating the expected plot yield.

Test 7. Modified propeller flails

This test was carried out in order to find a way to reduce the large cutterhead losses of threshed grain.

A bottom plate under the cutterhead, a front shield and the modified propeller flails, pictured on page 20 and described on page 22, were tested.

Three plots were harvested with the bottom plate under the right cutterhead. The plate covered the opening from the rear to the point where the flails were nearest to the ground. No observations were taken because the results were obvious. The bottom plate bent the straw so a large part of the heads did not come in contact with the flails, and

Table 13. Adjustment of the Combine in Test 7

Plot No	Flail speed	Ground speed	Fan shutter opening	Air deflector setting	Shape of the swirl-chamber	Height of cut	Way of entering
	rpm	mph				inches	
11	1100	0.76	5	3	1	27	Butts first
12	1200	0.84	5	3	1	27	
13	1200	0.84	5	3	1	27	
14	1200	0.84	5	3	1	27	Butts first, front shield
15	1200	0.84	5	3	1	27	

remained unthreshed. The bottom plate was, therefore, removed and a series of observations with the modified propeller flails and the front shield were taken. Table 13 shows the adjustment of the combine.

The speed of 1,100 rpm was too low to prevent clogging in the air duct. An increase to 1,200 rpm gave satisfactory results with clean duct.

Table 14. Weight of Grain and Straw in Grams in Test 7

Plot	Grain box			Cutter-head		Straw sack			Total	
No	T	U	S	T	U	T	U	S	G	S
11	142	0.3 1H	11	73	7.0 16H	2.5	1.0 8H	353	226	364
12*	20	0.0	3.0	89	1.5 3H	6.0	2K 2H	314	117	314
13	71	0.0	9.0	37	7.8 17H	1.0	1.0 8H	242	118	251
14	107	1.0	21	45	42 74H	1.0	2.0 15H	145	198	166
15	160	1.2 9H	19	73	27 50H	3.5	1.5 6H	180	266	199

*Clogging in the cutterhead intake, so the cutterhead losses of threshed grain were extremely large.

The modified propeller flails bent the straw more than the propeller flails. The losses in the end of the plots were therefore almost as high as for the direct throwing flails. The number of unthreshed heads in the end of the five plots ranged from 10 to 21.

Table 15. Percent of Total Yield Recovered in Test 7

Source		Butts first			Butts first Front shield	
		Plot No.			Plot No.	
		11	12*	13	14	15
		%	%	%	%	%
Recovered seed in grain box	Threshed	62.9	17.1	60.4	54.1	60.1
	Unthreshed	0.1	0.0	0.0	0.5	0.5
	Total	63.0	17.1	60.4	54.6	60.6
Cutter-head losses	Threshed	32.3	76.5	31.4	22.7	27.3
	Unthreshed	3.1	1.3	6.6	21.2	10.2
	Total	35.4	77.8	38.0	43.9	37.5
Swirl-chamber losses	Threshed	1.1	5.1	0.8	0.5	1.3
	Unthreshed	0.5	nil	0.8	1.0	0.6
	Total	1.6	5.1	1.6	1.5	1.9
Total grain recovered		100.0	100.0	100.0	100.0	100.0
Total cylinder losses		0.6	nil	0.8	1.5	1.1
Total losses of grain		37.1	82.9	39.6	45.9	39.9
Straw in grain box		3.0	0.9	3.6	12.7	9.5
Straw in burlap sack		97.0	99.1	96.4	87.3	90.5
Total straw recovered		100.0	100.0	100.0	100.0	100.0

*Plot No. 12 must be disregarded as representative for the modified propeller flails because of clogging in the cutterhead inlet.

Table 15 shows the percent distribution of the recovered grain and straw. The cutterhead losses of threshed grain were large even if plot 12 is disregarded as representative for the modified propeller flails because of clogging.

The main effect of the front shield was a pronounced increase in the cutterhead losses of unthreshed grain, and a corresponding decrease in the cutterhead losses of threshed grain. The reason was that the front shield prevented a large proportion of the heads from coming in contact with the flails.

Table 16 shows the main results of Test 7. Plot 12 was disregarded in this summary.

Table 16. Statistics for Test 7

Source	Butts first			
	No front shield		Front shield	
	$\bar{X}$	s	$\bar{X}$	s
	%	%	%	%
Threshed seed in grain box	61.7	1.8	57.1	4.2
Total cutterhead losses	36.7	1.8	40.7	4.5
Total swirl-chamber losses	1.6	0.0	1.7	0.3
Total cylinder losses	0.7	0.14	1.3	0.3
Total losses	38.3	1.8	42.9	4.2

It was obvious that the modified propeller flails and the front shield did not improve the combine. The total losses of 38.3 percent grain without a front shield and 42.9 percent with a front shield do not need further comments.

A discussion of the graphical appearance of the

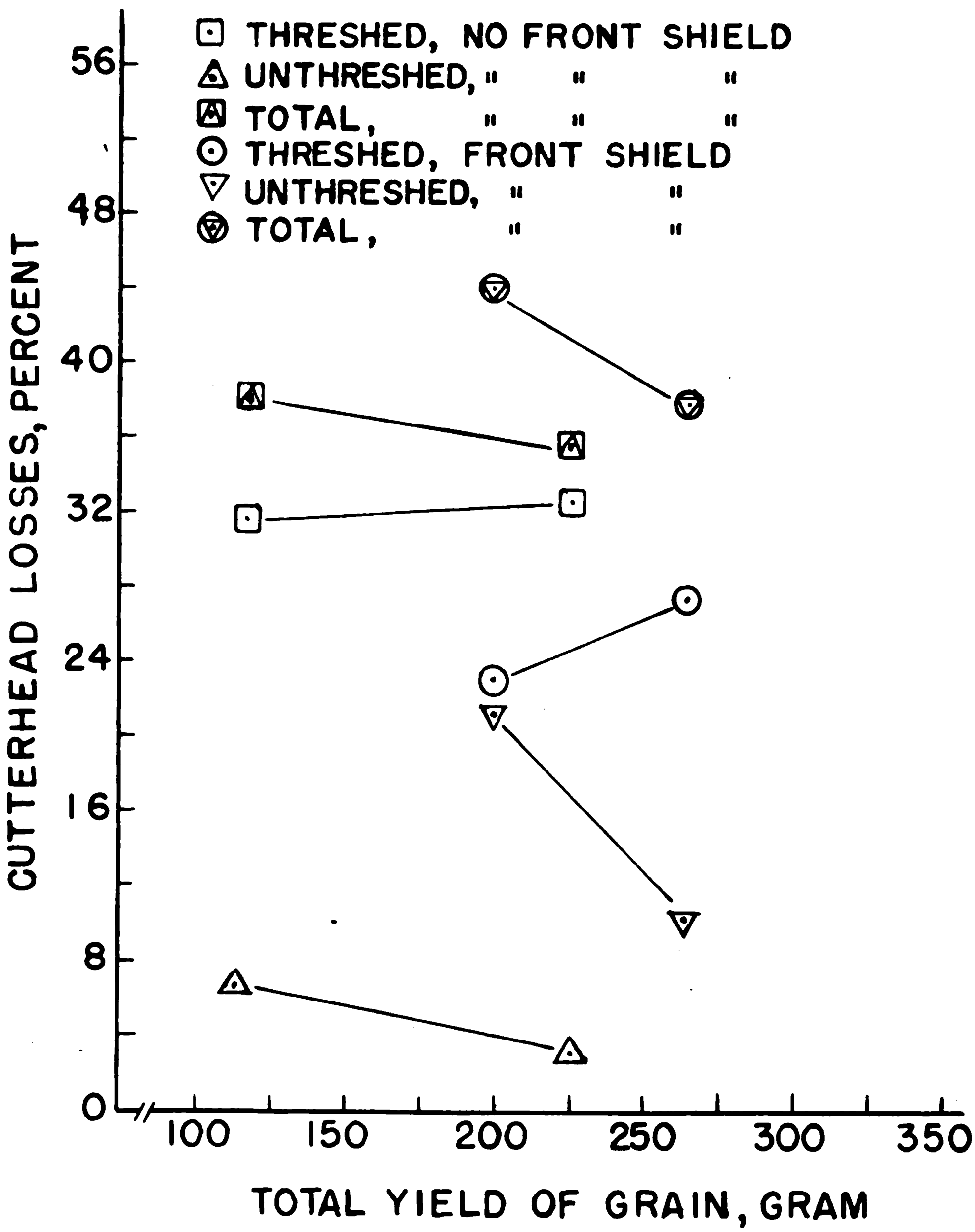

Fig. 25. Correlation between percent cutterhead losses and total yield of grain in Test 7.

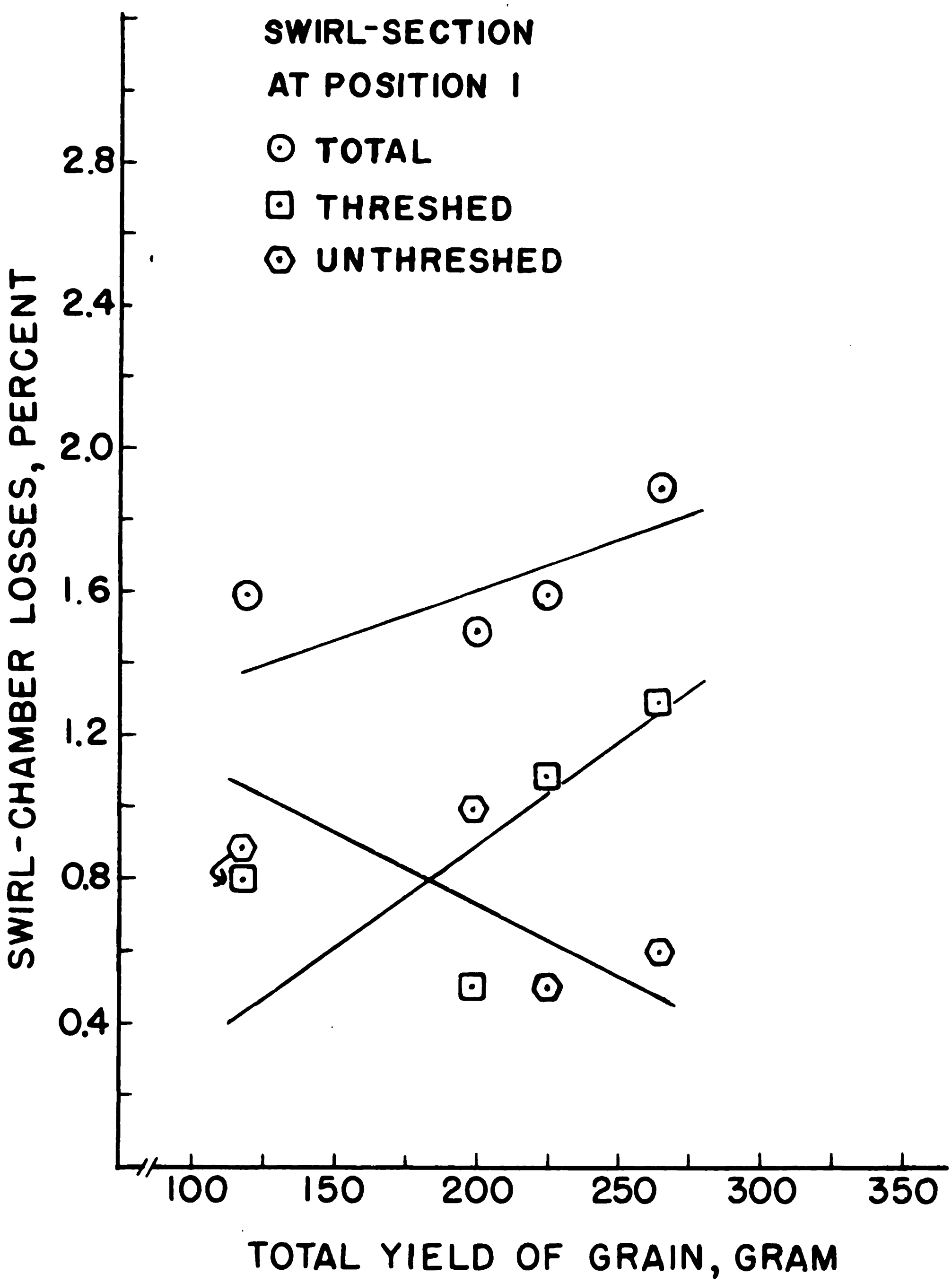

Fig. 26. Correlation between percent swirl-chamber losses and total yield of grain in Test 7.

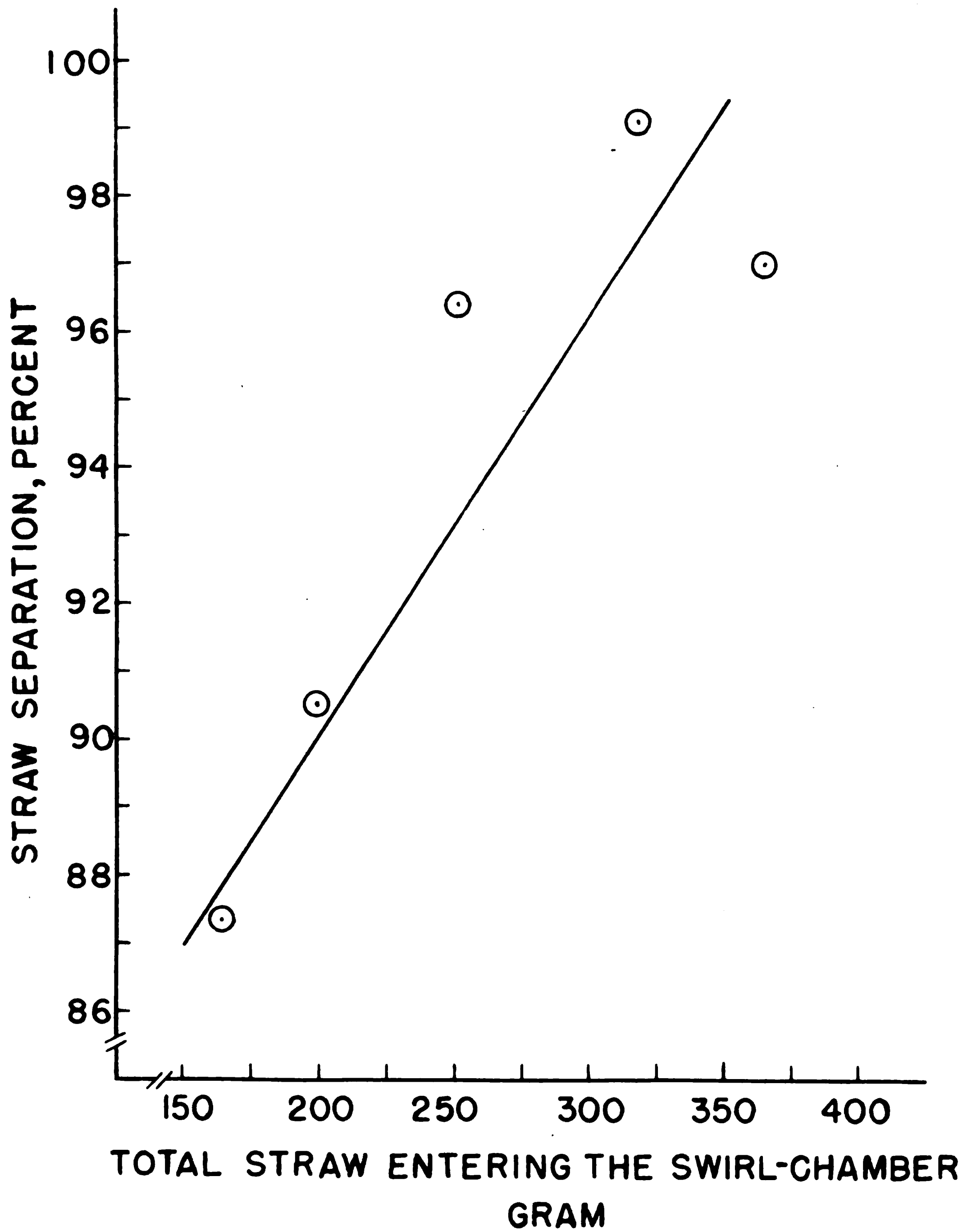

Fig. 27. Correlation between percent straw separation and total yield of straw entering the swirl-chamber in Test 7.

observations might be worthwhile.

Figure 25 shows that the percent cutterhead losses of unthreshed grain and the total cutterhead losses decreased with increased yield. This was also the case for Test 5 and Test 6. The cutterhead losses of threshed grain, however, seemed to increase slightly with increased yield, which was not in agreement with the previous observations.

Figure 26 shows that the percent swirl-chamber losses of threshed grain and the total swirl-chamber losses increased with increased yield. The losses of unthreshed grain decreased with increased yield. As the only difference between Tests 6 and 7, regarding the swirl-chamber, was that the fan shutters were set back from full opening to opening 5, this adjustment must be responsible for the opposite reaction of the swirl-chamber with respect to the percent losses of threshed grain.

Figure 27 shows that the percent straw separation increased with increased yield of straw entering the swirl-chamber. This was also an opposite reaction to that observed in Test 6.

Test 8. Modified direct throwing flails.

All previous tests with the flails mounted directly behind the cutterhead entrance failed to reduce the cutterhead losses. This test was made to determine if it was possible to suck the heads and straw into the fan from the side. The modified propeller flails were removed and a metal sheet was mounted behind the cutterhead throat to lead the grain into the fan housing. Experiments in the laboratory showed that the direct throwing flails in the fan housing threw out a large percentage of the threshed kernels. The four flails nearest the fan intake were, therefore, removed and replaced with two propeller flails mounted opposite on the shaft. The direct throwing flails in the left cutterhead were removed and the left fan opening covered in order to increase the suction of the fan on the right side. The direct throwing flails left in the fan were not able to produce any air suction of significance, and the modified direct throwing flails, pictured on page 20 and described on pages 22 and 23, were mounted nearest to the right hand fan intake. The air suction was highly increased and laboratory tests with oats showed that it seemed to be possible to suck the heads into a fan moving between the rows in the field.

A period of bad weather prevented the testing of the fan suction cutterhead until September 3. Sprouting in the heads was then so far advanced that taking samples was useless. The losses of threshed grain seemed to be less than in the previous tests. The number of unthreshed heads, however, increased. This was because the fan suction was not large enough to pull the heads into the fan.

SUMMARY OF THE RESULTS FROM THE FIELD TESTS

The number of observations in each test was not large enough to permit the statement of conclusion. But when considered in the light of each other, certain inferences could be made with little risk of being wrong. The high number of combinations in adjustment of the combine made it convenient to use a grouping system for discussing the results.

The Cutterhead Efficiency

The following four different types of flails were constructed and tested in an experimental field of wheat.

1. The direct throwing flails.
2. The propeller flails.
3. The modified propeller flails.
4. The modified direct throwing flails.

The first three types were tested under natural conditions and a limited number of samples were collected to get an idea about the losses. The samples were too small to determine the means and distributions of the losses exactly, but they give an idea about the combine efficiency. Larger samples were not considered important because the losses were considerably higher than could be accepted, with an average ranging from 28.0 to 42.9 percent for different flails and adjustments.

The highest percentage of recovered seed in the grain box was only 82.4 percent of the total plot yield. This was obtained in plot 8, Test 6, with propeller flails, ground speed 0.84 mph, and butts entering the cutterhead first. The largest source of losses from the flails was the percent cutterhead losses of threshed grain. Plot 8, Test 6, was the best single result obtained. The cutterhead loss of threshed grain was only 15.3 percent, but losses up to 39.4 percent were recorded with the propeller flails and lowest setting of the cutterhead.

The cutterhead losses of unthreshed grain were small compared with the losses of threshed grain. If Test 7, plots 14 and 15, which was harvested with a shield in front of the flails, were excepted, these losses were in range of 0.1 to 7.0 percent of the total plot yield. Observations from Test 5, propeller flails, high ground speed, and Test 6, propeller flails, slow ground speed, are shown plotted in Figure 28. This indicated that the total losses from the propeller flails decreased with increased plot yield. The total losses from the modified propeller flails were also in agreement with this general picture.

The explanation for this relationship, which seems to be independent of flail speed within the limits tested, was simple. A high plot yield of grain was positively correlated with a high yield of straw. The straw provided a seal

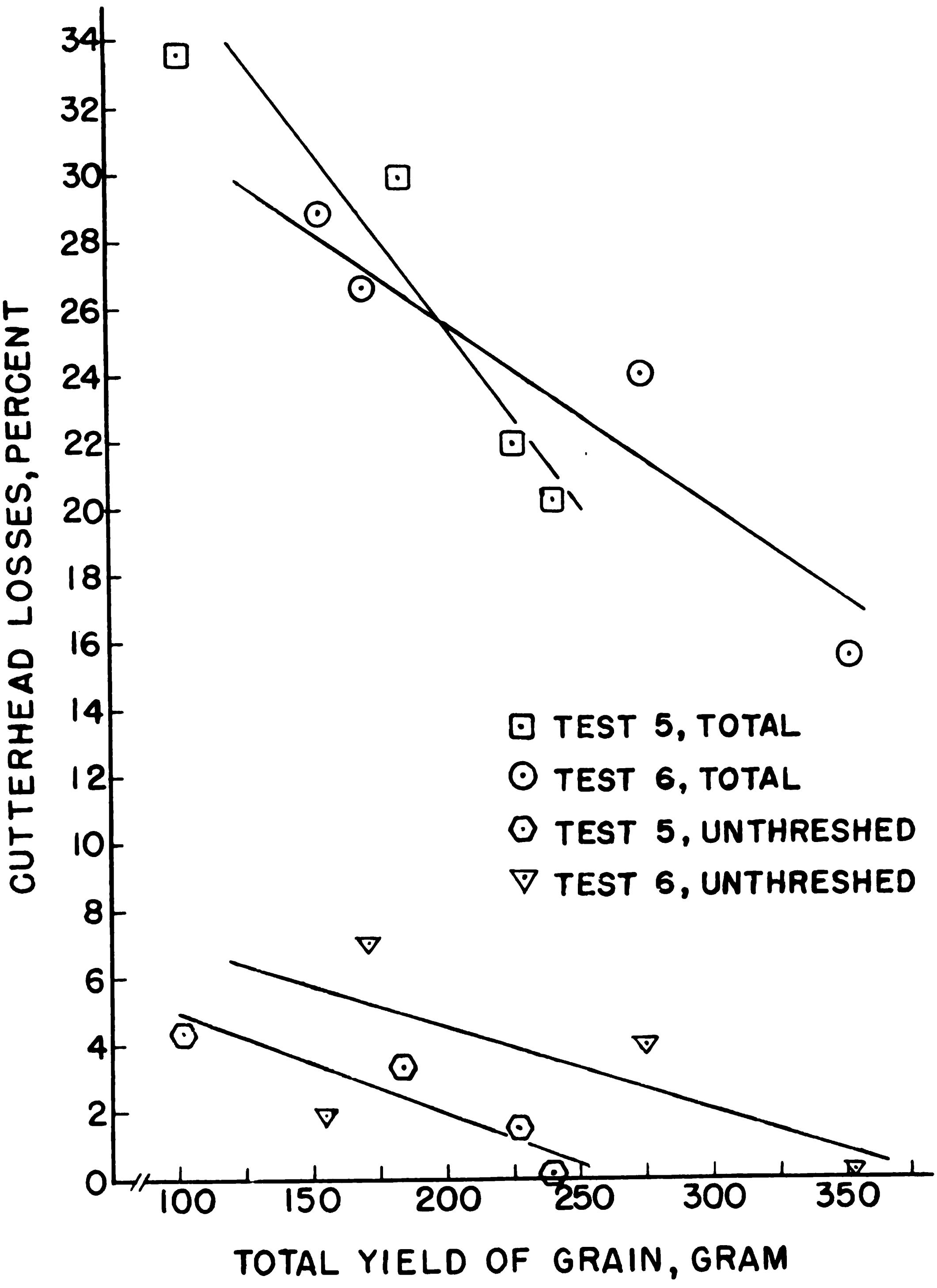

Fig. 28. Correlation between percent cutterhead losses and total yield of grain in Tests 5 and 6.

at the front of the throat which prevented the grain from flying out of the throat when it was hit by the impeller flails. An excellent demonstration of this was the test of the direct throwing flails and the modified direct throwing flails. The large losses of threshed and unthreshed grain in the end of the plots occurred because this wall of straw ceased to seal the opening of the throat and support the straw and heads being threshed by the flails.

The modified direct throwing flails were tried after the kernels in the heads had started to sprout. The top of the heads and straw were led by vanes and suction into a fan housing where cutting and threshing with the modified direct throwing flails took place. The fan housing prevented the threshed grain to be scattered on the ground. The vanes and the fan suction, however, were not able to lead all the heads into the fan and a large part of the heads remained unthreshed. The test indicated that a stronger fan, passing along the rows, would have been able to suck the heads into the fan housing and thresh them with small losses of threshed grain.

The Threshing Efficiency

The threshing efficiency was determined as percent cylinder losses (percent unthreshed grain) versus flail speed and percent visible damage of the kernels versus flail speed regardless of entering way of the crop and types of flails. This was done because the number of observations was too small to determine whether or not there were differences between the entrance methods or types of flails, and because it is well known that speed is the factor which has the greatest influence on the cylinder losses and visible kernel damage by impact threshing.

Cylinder losses

Eight observations with propeller flails at a speed of 1,300 rpm gave an average of 0.34 percent cylinder losses with a standard deviation of 0.42 percent. The range was between 0 and 1 percent.

Five observations for propeller flails and modified propeller flails at a speed of 1,200 rpm gave an average of 0.8 percent cylinder losses with a standard deviation of 0.56 percent. The range was between 0 and 1.5 percent.

Corresponding statistics for 1,100 rpm would have little meaning because only two observations were taken at this speed. The reason was that this speed was not sufficient to blow the straw up to the swirl-chamber.

The best estimate of the relation between cylinder losses and speed of the flails under the given field conditions was provided by the following regression equation based on 15 observations. Linearity, a common variance, and independent observations were assumed.

$$Y = 0.487 - 0.00108\ (X - 1240)$$

where: Y is the expected percent cylinder losses.

X is the flail speed in rpm.

This means that 100 rpm increase in flail speed would only give an expected decrease of .108 percent cylinder loss. In other words, the cylinder loss was only slightly affected by the flail speed in the observed speed range. The observed dispersion in the cylinder losses must be more affected by other factors than by speed. The closest explanation was that different varieties had different threshing characteristics. The flail types themselves must also be assumed to be a source of dispersion in the observations.

Because the cylinder losses, as determined by the regression equation, were fairly constant in the speed range between 1,100 and 1,300 rpm, the pooled standard deviation of 0.47 percent provided a good estimate of the dispersion in the cylinder losses.

No correlation was found between cylinder losses and plot yield in the available material.

Based on this study it was concluded that the flail-type mechanism was able to give a fairly good completeness of wheat threshing at a flail speed of 1,100 to 1,200 rpm or a peripheral speed of 4,500 to 5,000 fpm under the given conditions.

Visible kernel damage

The material from the field tests were investigated with respect to visible kernel damage.

Table 17 gives the observations at different flail speeds regardless of type of flails and entrance method of the crop.

Table 17. Percent Visible Kernel Damage

Flail speed, rpm			
1075	1100	1200	1300
%	%	%	%
0.0	0.5	0.8	4.2
0.0	0.0	0.6	4.1
		0.0	2.1
		0.0	2.2
		0.5	5.0
		0.2	2.6
		0.3	1.9
			3.2
0.0	0.5	2.4	25.3
$\bar{X}$ = 0.0	$\bar{X}$ = 0.25	$\bar{X}$ = 0.34	$\bar{X}$ = 3.16

An examination of the material showed that the three observations with the direct throwing flails and the five observations with the modified propeller flails indicated a similar reaction to speed as the 11 observations taken with the propeller flails. The dispersion of the observations was so great that a large number of observations would have been necessary to detect a possible difference in percent visible damage due to entrance method of the crop.

The best estimate of the visible kernel damage with respect to speed was assumed to be a regression equation. Such an equation, however, does not fit very well with the observations. A more realistic approach would be to form a hypothesis that the visible kernel damage is an exponential function with respect to flail speed. Too little data are presented to permit the drawing of such a conclusion at this time.

No observations were taken of the moisture content in the grain, but the crop was dry and well suited for combining when the test at 1,300 rpm was conducted. Six out of seven observations at 1,200 rpm were carried out the same day and at a higher moisture content in the grain than the observations at 1,300 rpm. An equation for percent visible damage of the kernels would only be appropriate at a certain moisture content of the crop or if a parameter for the influence of moisture content was incorporated.

Regardless of these objections, the observations showed that a flail speed above 1,300 rpm or 5,500 fpm should not be used for harvesting wheat plots under average harvesting conditions because of the high percent of visible kernel damage.

A few plots were harvested with a flail speed of 1,400 and 1,500 rpm. No observations were taken, but the kernel damage increased rapidly and were considerably higher than can be accepted for harvesting plant breeding plots of wheat.

Splitting of the wheat kernels was the most common form for visible kernel damage.

The Swirl-Chamber Efficiency

An evaluation of the swirl-chamber efficiency must deal with the percent losses of grain and the percent straw separation.

No attempts were made to take samples of sufficient size to determine the means and standard deviations for different adjustments with accuracy. The tests indicated a relatively strong relationship between swirl-chamber efficiency and the amount of grain and straw entering the swirl-chamber. For shape 1 of the swirl-chamber, Test 6 showed that the percent swirl-chamber losses of threshed grain decreased from increased yield of grain. A corresponding decrease in straw separation with increased straw load was also observed.

The most logical explanation to this reaction was that the higher yields "overloaded" the swirl-chamber by decreasing the speed of the air and thus decreased the percent separation. Test 7, however, showed a relationship between shape 1 of the swirl-chamber and the separation which backed up the general picture for shape 2 of the swirl-chamber.

This relationship was best demonstrated in Test 5. The percent swirl-chamber losses of threshed grain increased with increased plot yield. A corresponding increase in straw separation with increased yield of straw was also observed. The difference in shape 1 and shape 2 of the swirl-chamber can be observed in Figures 7 and 8. The swirl-chamber is set at shape 1, but a line marked 2 can be observed on the plastic wall. The difference in operation caused by the shape of the swirl-chamber was that shape 1 returned more grain and straw to the swirl (had a smaller radius of curvature) than shape 2 and this overloaded the swirl-chamber at high yields.

In shape 2 the grain and straw was directed more upwards toward the outlet of the swirl-chamber. The increase in losses of threshed grain with increased yield was also probably due to overloading. It must be assumed that the difficulty for the kernels to be separated from the straw increased with increased density of material in the swirl-chamber.

The available observations were not considered suited for forming regression equations for swirl-chamber losses versus grain yield, but the following illustration was considered useful.

Shape 1 of the swirl-chamber

If plot 10 in Test 6 and plot 12 in Test 7 were excepted from the calculation, the remaining seven plots, together with the two plots of Test 4, yielded these averages:

2.34 percent losses of threshed grain.

0.46 percent losses of unthreshed grain.

92.1 percent separation of straw.

The range of these observations are as follows:

0.4 to 6.7 percent losses of threshed grain.

Nil to 1.0 percent losses of unthreshed grain.

80.5 to 97.2 percent separation of straw.

In plot 10, 21 percent threshed grain was lost in the swirl-chamber. The corresponding straw separation was 98.7 percent. In plot 12 the corresponding numbers were, respectively, 5.1 and 99.1 percent.

Shape 2 of the swirl-chamber

The four plots from Test 5 yielded these averages:

1.9 percent losses of threshed grain.

0.3 percent losses of unthreshed grain.

77.9 percent straw separation.

The range of these observations are as follows:

0.2 to 3.3 percent losses of threshed grain.

Nil to 0.7 percent losses of unthreshed grain.

70.7 to 86.3 percent straw separation.

A comparison between shapes 1 and 2 of the swirl-chamber are difficult because the losses were also affected by the flail speed, the setting of the fan shutters, and the air deflector.

The maximum capacity of the fan was used with shape 2 of the swirl-chamber and, in spite of that, the straw separation was inferior to that required of a plot combine.

Shape 1 gave a better solution in spite of the relatively large losses of threshed grain. The losses of unthreshed grain in the swirl-chamber were considered as a part of the cylinder losses and will not influence the swirl-chamber losses of threshed grain. This means that the swirl-chamber had 2.34 percent losses of grain at a straw separation of 92.1 percent. It should be remembered that the average losses for wheat, barley, and oats with the German experimental cyclone-thresher were 2.9 percent.

The tests indicated that a swirl-chamber principle design of proper size should provide an efficient self-cleaning separator for a variety plot combine for grain.

Field Results of Self-Cleaning Efficiency

The combine was designed to be 100 percent self-cleaning. The tests showed, however, that the relatively long straw produced by the flails tended to clog the duct and the swirl-chamber. These elements were definitely too small for harvesting two rows simultaneously. For one row harvesting the duct and swirl-chamber together clogged in about 30 percent of the total number of harvested plots. The swirl-chamber clogged more easily than the duct. In some cases the straw which the swirl-chamber did not separate clogged in the duct to the grain box, and in other cases, some straw was long enough to clog across the swirl-chamber itself.

The source of clogging in the duct was the bend at the inlet to the swirl-chamber.

Complete self-cleaning with respect to the straw seems to be possible with proper construction and dimension of the duct and the swirl-chamber.

Some kernels remained in the swirl-chamber at the end of the plots because they were in equilibrium with the air from the fan. By reducing the throttle these kernels slid into the grain box by their own weight.

Reducing the air speed in the swirl-chamber between the plots by one or another means would be necessary for obtaining a self-cleaning combine when this particular model of the swirl-chamber is used.

LABORATORY TEST FOR SELF-CLEANING EFFICIENCY

In order to determine the self-cleaning ability of the combine, the following tests were conducted in the laboratory after the harvest season.

The Cutterhead Fan

Three handsful of wheat were introduced in the fan when operated at a speed of 1,000 rpm. The fan was stopped and checked for remaining kernels after each run. This procedure was repeated five times. No kernels were left in the fan.

This test would have to be repeated several hundred times in order to state the fan to be completely self-cleaning. An absolute test for the self-cleaning ability of the fan was, therefore, designed to save labor.

One handful of wheat was placed in the bottom of the fan housing when the fan was stationary. Then the fan was started and the speed was gradually increased to 1,000 rpm. An inspection after stopping showed that no kernels were left in the fan housing. Two replications of this test were performed with the same results.

Since the fan must be operated at 1,100 to 1,300 rpm, the fan was considered to be completely self-cleaning.

The Air Duct

The duct between the cutterhead and the swirl-chamber was inspected between each of seven runs and no kernels were found. Even with the small number of replications it was stated that the air duct was self-cleaning with respect to lodging of grain.

The Swirl-Chamber

The swirl-chamber was inspected between each of seven runs. The result was in agreement with the field tests. It was necessary to reduce the throttle setting in order to allow the kernels left in the swirl-chamber to slide down into the grain box. This model of the swirl-chamber design was, therefore, considered to be self-cleaning with proper construction when an air reducing technique is utilized between varieties.

PROPOSALS FOR FURTHER INVESTIGATIONS

This research is considered as a preliminary investigation to determine the design parameters of a plot combine for plant breeding. Various ideas were tested and design parameters gained.

The suggestions presented in this chapter were based on the experiments conducted and previous experience with the threshing of small grain in plant breeding plots.

The Suction Cutterhead

To prevent cutterhead losses the cutterhead should be constructed according to the following specifications.

A centrifugal fan 7 to 8 inches wide, 24 to 30 inches in diameter, and with a 4 or 6 blade impeller should be used for harvesting 2-row plots in small grains. To reduce the kernel damage to a minimum the fan wings should be faced with rubber. The corrugated concave should be solid. To keep the power requirement small, an auger should be mounted on each side of the fan to auger the standing plants into the fan.

For plots consisting of more than two rows, it is suggested that a series of centrifugal fans 5 inches wide, about 24 to 30 inches in diameter, and with crop intake on one side of the fan housing are placed along the same shaft. The space between each fan for entrance of the crop should be about 3 inches. A straw divider at least 18 inches long should be placed in front of each fan. The fan shaft should rotate clockwise when looking at the combine from the right side.

The Duct

It is assumed that the proposed fan would deliver enough air at a peripheral speed of 5,000 fpm to blow the grain and straw in any desired direction to the separating and cleaning device. The duct area should be approximately 70 to 80 square inches.

The Swirl-Chamber

The swirl-chamber should be constructed so the seeds deflected across the outlet from the swirl-chamber will not re-enter the stream of grain and straw coming from the cutterhead. Several methods for accomplishing this are possible. The most rewarding seems to be to use a series of modified swirl-chambers to deflect the grain and straw towards combs of ¼-inch rods placed ½-inch center to center. The grain and some short straw coming with the end first will pass through the combs while the longer straw and the grain, not seperated, will be deflected to the next swirl for further separation. Two or three swirls and combs mounted in series should be used for efficient separation of the grain from the straw and chaff.

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