ACTION OF A CONICAL ROTARY STRIPPER-BEATER EMPLOYED IN HARVESTING STANDING GRAIN

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ABSTRACT

ACTION OF A CONICAL ROTARY STRIPPER-BEATER
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by Robert Emerson Strohman

Many authors feel that increased mechanization in the production of rice in Southeast Asia will increase the supplies of this crop, which are greatly needed by the rapidly expanding population. The purpose of this study was to make a contribution, if possible, to the solution of one of the problems encountered in bringing the benefits of mechanization to Southeast Asia.

Information concerning the present situation was gathered from many sources and analyzed. It was found that the greatest need for mechanization was in the harvesting of rice grown in irrigated fields. The varying degrees of success of the many attempts to increase the mechanization of the harvesting of this crop over the past two decades was noted. The most popular approach has been the modification of existing machines. Recently a few machines were designed specifically to meet the requirements for harvesting irrigated rice. The two major requirements for mechanized harvesting are complete water control and a variety of rice with short straw, erect nonlodging habit, nonshattering

grain and even ripening.

The conditions in Taiwan are more favorable for increased mechanization than in any of the other countries studied. The design criteria for a harvester to be used under Taiwanese conditions were established.

Since these requirements could not be met with existing means of threshing, a new principle of grain harvesting was formulated. In this method a section of straw immediately below the head is fed between a rotor and concave without severing the straw from the ground. The grain is then stripped from the straw starting at the base of the head. A machine was built to evaluate this principle.

Tests were conducted on oats and rice. When the machine was properly adjusted, total losses of rice were less than 2.5 per cent. Eighty-six to 92 per cent of the grain was completely threshed, the remainder being unthreshed heads or branches. No damage to kernels was found. These results compare favorably with standard commercial combines now in operation.

Power requirements are very low. They can be supplied by the small hand tractors now used in much of Asia. Where mechanical power is not available, power for the rotor can be supplied by a man, while the machine can be pulled by a single draft animal.

Approved H. F. McColly
Major Professor

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By

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This thesis is dedicated to the author's wife, Dorothy, for keeping the home fires burning while it was being written.

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I. INTRODUCTION

Basis for the Problem

The FAO (Food and Agriculture Organization of the United Nations) (1963) estimated that 300 to 500 million people out of 3,000 million in the world are underfed and that up to one-half of the world population--perhaps even more--suffer from hunger or malnutrition.

For future calorie and protein targets for the Far East they have set as a high or long term target, 2,400 calories and 20 grams of animal protein per person daily. By comparison the current average daily diets of Europe and North America contain over 3,000 calories and 44 grams of animal protein.

If these targets are to be met by the year 2000, when the world population is expected to exceed 6,000 million, then four times the present food supplies will be needed in the Far East at that time. Since the food supplies per capita are higher in Japan than in the rest of the Far East, the situation in Southeast Asia is even more acute.

Objectives

1. To determine from a literature survey if increased mechanization could increase food production in Southeast Asia.
2. To determine from the literature survey the crop for which increased mechanization of production could have the greatest positive effect on food supplies in Southeast Asia.
3. Of the basic operational functions required to produce this crop, to select one for which increased mechanization is most likely to be feasible and fruitful.
4. To determine a country where the introduction of machines is most likely to be accepted.
5. To determine the requirements for a machine which will perform the selected basic operational function.
6. To find a principle on which a machine might operate in order to meet these requirements.
7. To determine, both in the laboratory and the field, if a machine based on this principle will perform the selected function.
8. To determine from field tests the operational characteristics of a machine based on this principle.

II. REVIEW OF LITERATURE

Benefits of Increased Mechanization

A number of writers have commented on the importance of mechanization or the benefits to be gained from it. It should be remembered that mechanization can be improved and increased without the introduction of engines or motors (Davies, 1954). In this thesis the term "mechanization" is used in its broadest sense to include improved hand and animal powered tools as well as motorized machines.

Liang and Peng (1960) mentioned that 1,127 man hours per hectare are required to produce a crop of rice in Taiwan. Between 5 and 7 hours of labor are required to produce a bushel of rice in Asia while 5 to 7 minutes are required in the more highly mechanized countries (FAO, 1960a). This is a ratio of 60 to 1 for the average but when the least mechanized countries are compared to the most mechanized, the ratio is 200 to 1 (Rice Council for Market Development, no date). Reporting on mechanization in Europe, Lodigiani (1956) pointed out that 140 hours per hectare were required to harvest by hand and thresh with a stationary thresher, while only 12 hours were required when a combine was used. These figures become more significant in view of the fact that 80 per cent of the world's crops are produced by hand or animal power (FAO, no date).

Japan has the highest degree of mechanization of any of the countries in the Far East. In 1962 there were 300 farm machinery manufacturers in Japan. The use of machines has reduced the labor requirement per hectare of rice by more than 50 per cent. Several factors have tended to promote rapid mechanization. There has been a minimum of labor management trouble in the farm machinery industry. Farmers can borrow money at 6 per cent to buy machines. The labor force on the farms has been reduced by a migration of farm workers to urban areas (Stout, 1962).

In addition to the benefit gained by the reduction in labor per hectare, Motz (1960) observed that Japanese farm production has increased 30 per cent due to improved practices. Mechanization is given some credit directly and also indirectly since labor saved by mechanization made possible better control of insects and pests.

Some possible benefits of mechanization mentioned by Davies (1954) are saving crops before a storm strikes and getting all of the land plowed before the season is over. Vaugh (1960) considered mechanization worthwhile if it just allows more time for education, homemaking and leisure. Farrall and Esmay (1961) and Randhawa (1960) gave mechanization credit for achieving a high ratio of total population to the number of farm workers. Hall (1960) in discussing the prospects for increased mechanization of wet-field agriculture in Asia, stated:

> In terms of costs and the technological levels of the populations concerned probably no other development could so speedily and effectively alleviate the immediate great problem of Monsoon Asia--hunger.
>
> . . . .
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> The Niiike study has proved conclusively that the mechanization of wet field agriculture is possible and profitable. It increases yields, encourages diversification, makes possible some land reclamation, and allows for a better life for the farmer. Conditions in Niiike are similar to those in the densely populated lands of Monsoon Asia.
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> The feed formerly required to maintain the work animals is available for the support of commercial livestock. The man labor hours saved can be employed in diversifying and expanding commercial crop production, in the building of household industries and in improving the cultural and material life of the farmer and his family. This does not mean that all of the machines necessary for complete mechanization have been perfected. For example, in Japan there are still no satisfactory small machines for rice transplanting and harvesting.

Importance of Rice

"Rice has been the most commonly used grain product since ancient times" (Rice Council for Market Development, no date). The world production of rice is slightly higher than the world production of wheat (U.S.D.A. Agricultural Marketing Service, 1961; and U.S.D.A. Economic Research Service, 1961). About 93 per cent of the total land area used for rice production throughout the world is located in Asia (U.S.D.A. Agricultural Marketing Service, 1961). Both the area and the yield are increasing in the Far East while the area is being reduced in the rest of the world (FAO, 1960b). According to Hall (1960) the people living in Asia who depend on rice cultivation for their livelihood represent 26 per cent of the world's population. It also happens that these areas where the production and consumption of rice are the highest are the areas where the food supplies are most critical. Thus, it appears as though an increase in the rice production in Asia is needed.

Most of the rice grown in Asia is produced using very simple tools with manual workers and draft animals providing the main source of power (FAO, 1961). According to the United States Department of Commerce (1959) 0.5 per cent of the world's tractors were in Asia, which has 22 per cent of the world's agricultural land.

Unless unlimited funds and enough personnel are available to attack all phases of the problem at one time, it seems best to concentrate research efforts in those areas where increases in production will make the biggest contribution. Since the production of rice in upland fields without the use of irrigation is relatively unimportant (Grist, 1959), even a large percentage increase in this crop would not have much effect on the world food supply. In addition, the methods of production and the machines used for upland rice are similar to those used for wheat, barley, and other upland grains. On the other hand, rice grown on land which is flooded during most of the growing period is produced under conditions and using methods that are not common to any other crop. Thus, it appears that the greatest contribution to increasing world food supplies which can be made by agricultural engineers is in the area of the production of irrigated rice.

Need for Mechanization in the Harvesting of Rice

As noted previously Liang and Peng (1960) found that 1,127 man hours per hectare were required on the average to produce a crop of rice in Taiwan. Of this total, 81 per cent was required for the four major operations; 14 per cent for nursery work, 19 per cent for transplanting, 25 per cent for weeding and 23 per cent for harvesting. On the basis only of labor requirement it might appear that weeding should receive attention first. A closer study reveals several other factors which should also be considered.

First, weeding takes place over a period of 20 days so that only 15 man hours per day are required for each hectare. "The period of harvest is rather limited. When the crop is ripe it should be harvested as quickly as possible to avoid lodging and undue loss by shattering" (FAO, 1961). To reduce complications in the drying process, the crop should ideally be harvested in a single day, never more than three days. Thus, the peak demand for labor at harvest is greater than for weeding.

Second, the hours required for weeding can be reduced by methods already available. Weed control with selective herbicides is now widely practiced (FAO, 1961). The Japanese have a wide variety of sprayers and dusters and a number of mechanical weeders for hand and animal power are available. They also have several weeding attachments for power tillers (Kishida, 1958).

Thus, it appears as though the immediate objective of research aimed at increasing the use of mechanization in rice production should be the harvesting operation.

Prospects for Increasing Mechanization in the Harvesting of Rice

Conventional Methods of Harvesting Rice

Harvesting varies from cutting individual heads with a small knife held in the palm of the hand, up to large self-propelled combines, although practically the entire crop in Asia is cut with the sickle (FAO, 1961).

The great variety of threshing methods can be classified as abrasion or impulse. The abrasion group includes treading by animals or humans and the use of such devices as rollers and sleds on threshing platforms. The impulse method can be further subdivided into two groups depending on whether the impulse is imparted by striking the grain against a solid object such as a threshing ladder, platform or tub, or by a moving object striking the grain as in the pedal thresher or flail.

There are as many ways of harvesting irrigated rice as there are countries in which it is grown. In the United States the combination of grain binders and stationary threshers, pull-type combines and self-propelled combines have all been successful. Combines have been used to some extent in Europe but Lodigiani (1956) related that 80 to 85 per cent of European rice is still cut with a sickle. The reasons given for the lack of acceptance of the combines are the small fields and low bearing pressure of the wet soil.

Allen and Haynes (1951) tried to measure bearing pressures in wet rice fields without success.

In Japan the crop is harvested when the leaves, stems and two-thirds of the heads are still green. Plants are cut with a sickle and tied into bundles. If threshing follows immediately, the grain must be dried in the sun to reduce the moisture content from 20 or 25 per cent down to 15 per cent. The usual practice is to cure the grain in the bundles on a rack for about ten days before threshing.

The crop is threshed by holding the bundles so that the heads contact a rotating drum having projecting wire loops which knock the grain out of the straw. This machine takes many forms. In the simplest the drum is powered by a foot pedal. The operator supplies the power and holds the bundle on the drum at the same time. The grain is collected on a mat and cleaned later. The most complex form is a complete thresher and separator which is power driven and has an automatic chain feeder that holds individual bunches of straw and moves them parallel to the axis of the cylinder so that the grain is removed from the straw but the straw is undamaged and can be used for various industries (Central Commercial Company, no date).

In Taiwan a small, lightweight, hand sickle is practically the only tool used for reaping (Ma and Lee, 1960). To change this practice will require either a new variety of rice, a change in field size, or a machine of different design principles from any now available. Such a machine will have to be compact enough to operate in small fields and within the economic range of Taiwanese farmers. Present varieties of rice were developed for easy threshing by hand methods. The straw is very tough and flexible and the grain shatters very easily. This prevents the use of the small mowers, reapers and binders which have been developed in Europe for other small grains. Even a simple cradle cannot be used because the grain will be shattered by the impact of the fingers (FAO, 1960a).

Pedal operated threshing cylinders mounted on skids are used for most of the threshing. These are pulled around the field following the reapers. In this way, as fast as the rice is cut it is threshed and there is no need to bind it into bundles or handle it more than is necessary. This cuts down the losses due to shattering. One man can cut about one-half acre per day with a sickle, and two men with a pedal thresher can thresh two or three tons of rice in a day. In the southern and eastern parts of the island, threshing tubs are still used, while near Taipei and Taichung some Japanese type, power-driven threshers are found.

After threshing, the grain is carried to the courtyard where it is winnowed either with natural wind by tossing it into the air, or with a fanning mill. After cleaning, it is dried on concrete platforms in the sun and stirred by hand using special rakes (Ma and Lee, 1960; and JCRR, 1961).

Obstacles to the Mechanization of Harvesting Irrigated Rice

Harvesting of any crop presents problems but there are a number of difficulties in harvesting which are peculiar to rice, especially if it is grown in flooded fields. Hopfen (1960) noted that the grains shatter very easily so that any means of cutting or gathering which is not gentle will result in lost grain. This has prevented the introduction of such simple tools as the grain cradle and the grain binder which are used for other small grains. The tendency of the crop to lodge (FAO, 1961) requires any mechanical harvesting means to be equipped with complex gathering mechanisms such as pick-up reels. Modern combines have overcome these two problems but in many areas they still cannot be used because of four other common conditions.

Many of the fields are too soft at harvest time to support heavy machines. In much of Asia most of the fields are too small or inaccessible for practical use of large machines. Straw which has passed through a combine is no longer suitable for many of its present uses. Access roads to the fields are poorly surfaced and narrow.

In many areas where machines have been introduced, it has been found that lack of mechanical ability on the part of the operators has reduced the effectiveness of the machines and shortened their life. Lack of service and repair facilities have had similar effects (Grist, 1959).

Coleman (1953) summarized the two major stumbling blocks to increasing mechanization of harvesting rice. The first need is complete water control. This would eliminate all the problems mentioned from machines bogging down in the field and in field transportation. The second need is for a variety of rice with short strong straw, erect nonlodging habit, nonshattering grain, and even ripening.

Recent Developments in the Mechanization of Rice Harvesting

Since over 93 per cent of the world's rice acreage is in Asia, the degree of mechanization outside of Asia is of little consequence as far as the total crop is concerned. While there are many difficulties encountered in the production of irrigated rice, still efforts have been made to mechanize some or all of the basic operations. Some of these have been successful and have been accepted. Others are still in the experimental stage.

Allen and Haynes (1953) reported a series of trials with mowers, binders, stationary threshers and trailed combines, none of which were successful. The cutter bar of the mower tangled the swath so that more time was required to sort out the stalks than was required to cut and bunch with a sickle. The binders and trailed combines were easily bogged down. The Turner Economy Thresher performed its role satisfactorily but the system failed because of difficulties in getting the crop from the field to the machine. This failure illustrates the necessity of evaluating any proposal for improving production as a part of a system and not on an individual basis.

Jones (1949) found that a McCormick Deering rice binder worked fairly well on erect rice, but would not work when the rice was lodged. Allen and Bewley (1949), testing the same binder on bog soils, found that even a 14 x 30 inch main wheel did not give enough flotation. They also found that this method of cutting resulted in large grain losses through shattering from the bundles. In this particular experiment the bundles were placed in shocks without caps and allowed to dry in the sun. This practice caused cracked grain because the drying was too rapid.

In British Guiana, binders, threshers, and pull-type combines were all tried and abandoned. However, track mounted self-propelled combines were very successful. These machines cut a swath fourteen feet wide. Pick-up reels and auger tables were used (Giglioli, no date).

Haynes (1954) gave a good account of tests conducted in Malaya with a Massey-Harris No. 80 SP Rice Special combine. One of the biggest difficulties encountered was the training of drivers. It was found that the combine would not operate well if the moisture content of the grain was above 20 per cent. Under Malayan conditions this meant that they could operate from about 10:00 a.m. to 8:00 p.m. After each shower, work was delayed until the straw was dry. When the combine was used, artificial drying was needed because the output per day was more than could be handled by drying platforms. This machine was mounted on tracks and performed well in all but the wettest conditions. However, the steering wheels left very deep ruts which could be undesirable for later operations. The machine climbed the bunds between fields with no difficulty. It was found that a pick-up reel was necessary but even with the pick-up reel the output in lodged grain was less than half that where the straw was erect. Grain losses were less than 3.5 per cent. Work was satisfactory in fields of 0.4 acres and larger. While this machine gave excellent performance, it had one peculiar characteristic; the "dividers" did not divide the crop but rather mashed it down to the ground.

FAO (1961) made the following remarks concerning the harvesting of irrigated rice:

> Mowers of the standard animal-drawn type used for fodder and to some extent grain harvest in the western countries are not suitable to harvest paddy [rice] even under good soil and crop conditions. When the crop is transplanted, the bunched nature of growth at ground level and the soil adhering to the plant tends to clog the cutter-bar. Considerable shattering may also occur. These machines cannot be used to harvest lodged crops as in this case it is necessary to have extension guards and pick-up reel to bring the stalk over the cutter-bar. Fields must be opened by hand to prevent trampling and, in addition, a large crew is required to clear each cut swath so that it will not be trampled in the succeeding round.
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> Power machines can be used only after some development in plant breeding or variety selection where a type of paddy which will have a stiff straw and less tendency to lodge as well as less tendency to shatter is being used. Paddy has been largely selected for easy hand threshing so that very little effort is required to rub the kernels out of the head. Very high rates of shattering occur even with the use of hand sickles and particularly with the mower and the combine.

All combines which have been satisfactory for harvesting rice have proved too expensive for the average Asian farmer, and too large for some fields and access roads. Poynter (1961) has developed a small stripper harvester weighing 200 pounds which harvests a two foot swath. This machine works well in the upland crops for which it was designed. There is a possibility that a modified version may prove successful in rice although the original model did not perform well in limited tests.

In Japan intensive studies on small harvesting machines are in progress. Three types have been developed:

1. A machine which cuts the plant at the bottom of the stem and lays it perpendicular to the direction of travel.
2. A reaper which leaves the plants in bunches.
3. A binder which leaves the stalks in bundles bound with straw rope.

Development of a small combine is underway (Kaburaki, 1960). Small power-driven automatic threshers which thresh the grain but retain the straw undamaged are very popular in Japan (Kishida, 1961).

At the NIAE (National Institute of Agricultural Engineering) in England, specifications were drawn up for a thresher for small scale rice growers (Marsden, 1959). Briefly, the result was a thresher weighing 336 pounds including the gasoline engine which furnished the power. The threshing was done in the field, the five men required to operate the machine carrying it with them as they followed the reapers. The output was between 1,200 to 1,500 pounds of threshed rice per hour. Of course, the machine could also be used to thresh from stacks if this method was preferred. If it was desired to retain the straw in an undamaged condition the machine was used as a head stripper only. While this was a big step in increasing the efficiency of labor at harvest, the reaping was still done by hand, and the crop gathered and carried to the thresher by hand.

Because of the peculiarities of the rice plant and the conditions under which it is grown, it seemed unlikely that existing machines could be successfully modified or adapted for the conditions of Southeast Asia. Therefore, it was decided that an attempt should be made to design a harvesting machine which would fit into the present system of production and which would overcome some of the current obstacles to mechanization.

Selecting an Area for the Introduction of a New Harvesting Machine

Harvest conditions vary widely throughout Southeast Asia. There are variations in soils, varieties of rice grown, weather, amount of water on the field, methods of handling the crop after harvest, local customs and many other factors. It seems highly improbable that a single machine can be designed which will be successful and acceptable to the farmers in all of these regions at the same time. On the other hand, if a successful machine is introduced in one area it can be modified and adapted to extend its application.

When considering the introduction of mechanization in any area, it is well to remember these conditions given by Faunce (1961).

1. Machines must be adapted to area.
2. Operators must have mechanical know-how.
3. Service centers must be provided.
4. Improper or poorly adapted machines can increase costs.
5. Handicaps to mechanization are:
    a. Low income
    b. Handling and maintenance difficulties
    c. Small irregular fields
    d. Surplus labor.

In Japan many new systems and machines for harvesting are competing for the farmer's attention. This reduces the likelihood that further innovations, especially of foreign origin, will be accepted.

Geographically, Taiwan is located between Japan and the balance of Southeast Asia. Taiwan is also somewhere between Japan and her southern neighbors in scientific farming methods, extent of farm mechanization, and problems encountered (JCRR, 1957). In Taiwan the farmers have been introduced to mechanization of tillage, are acquiring mechanical skills, have demonstrated a willingness to accept new farming methods and are building up the capital reserves needed to buy new machines. However, as was noted in the previous section, they are still using the old hand methods for harvesting.

Although the NIAE thresher described in the previous section is now in production, there has been no indication that it has been introduced in Taiwan. The self-propelled combines with pick-up reels, which gather the crop so successfully in the United States, are too expensive for the individual farmer in Taiwan and require large fields for economical operation.

From a consideration of the foregoing factors, it was decided to design the first harvesting machine for Taiwanese conditions and make modifications as needed for other parts of Southeast Asia at a later date.

III. DETERMINING THE DESIGN CRITERIA FOR A SMALL RICE HARVESTER

Information from the Literature Survey

As a first step in selecting the features to be incorporated in the design of a machine to harvest rice under Taiwanese conditions, it was decided to take a second look at the literature to determine what type of machine would be most likely to fit into the present production practices and would be most likely to be accepted by the farmers.

Many attempts have been made, and many are still being made, to miniaturize the conventional rice combines, which have been so successful in the West. Considerable progress has been made, and some of these machines look promising. However, there is no indication that manufacturing costs can be reduced to a point where the use of one of these machines can be justified on a single farm. Either cooperative ownership or custom work would seem to offer the only sound methods by which they could be introduced.

In replacing draft animals for tillage operations, farmers have overwhelmingly accepted tiny walking tractors and power tillers in preference to either cooperative ownership or custom work with standard sized machines. Judging from this, it appears that farmers will prefer harvesting machines cheap enough for individual ownership, or at least within the reach of two or three close neighbors or relatives.

Many of the fields in Taiwan are no larger than 0.1 hectare (JCRR, 1960) and may be under water at harvest, so any machine must not only be compact but also light in weight. In the present harvesting method, which is described in more detail in the previous section, the grain is cut with a sickle and threshed immediately with a pedal thresher. The thresher is pulled through the field, following the reapers. The mixture of leaves, trash, chaff, unthreshed heads, broken branches and threshed grain, which is produced by the thresher, is carried to the farm yard for further cleaning, drying and finishing operations. In order to reduce the size, weight and power requirements of the harvester, it was decided to leave the cleaning operation in the farm yard, at least for the first model, rather than to make the cleaning equipment an integral part of the machine and transport it around the field in the manner of a conventional combine.

In some parts of Taiwan, straw is left in the fields and is plowed under. This operation is much easier if the straw is attached to the ground. In other areas straw is removed from the field for various uses. After the grain is removed from the straw there is no concern about shattering, and the straw can easily be cut by existing rotary or reciprocating cutters, with or without binding attachments. Thus a further reduction in weight and cost of the machine was made possible by eliminating the cutting mechanism and leaving the straw attached to the ground. Now of the original five operations performed by the combine, namely: cutting, elevating, threshing, separating and cleaning, only one remains: threshing. This is not a new concept. The Australian strippers are more or less conventional cylinders operating close enough to the ground to catch the heads and thresh off the grain, leaving the straw attached to the ground. The problem here is that shatter losses are high when a cylinder is operated above the row and perpendicular to it.

It is interesting to note that the requirements for equipment needed by research workers and seed growers for harvesting experimental and seed increase plots are very similar to those of Taiwan. The machines must be small, lightweight and economical. The only additional requirements being, that they must be self-cleaning between plots and that the sample can be quickly and easily removed. This possible alternate use of the machine must be kept in mind for further development when making modified versions.

Results of Testing Machines and Components in Michigan State University Rice Plots

Even though the design criteria for the harvester were reasonably well established by the literature survey, it was felt that existing machines should be examined for possible modification or for components to be used in the final machine or system. Units considered were both experimental and production models of machines intended either for Southeast Asia or for plot work. It was also decided that a first hand knowledge of the environments and conditions under which rice is produced and harvested would be helpful.

Since it was not feasible to transfer the project to the Orient for this part of the work, a field of irrigated rice was planted on an area of low ground on the Botany Farm at Michigan State University.

Financial and temporal limitations prevented an exhaustive study of this nature but a few machines were obtained and tested. The rice, not being adapted to the cool Michigan summers, did not mature. Thus, actual threshing tests of rice were not possible. Wheat, oats and barley were used to obtain indications of threshing characteristics, while ability to cut and handle straw, as well as traction and mobility, were studied in the experimental rice plots.

Poynter Pneumatic Stripper Harvester

This machine (Figure 1) was purchased from the manufacturer, Poynter Products, 5 Montrose Street, Surrey Hills, Victoria, Australia. It was designed by Mr. Gilbert E. Poynter to harvest the seeds of wild grasses. The shatter losses were high, although they were less in oats than in wheat and barley. Heads are removed from the straw by beaters and threshed as they pass over a concave. Broken straw and chaff is mixed with the grain. Every few feet the machine must be stopped, the front hood raised to increase the air blast, and the contents of the grain pan stirred by hand to clear out the trash. About two quarts of clean grain is obtained per cleaning. If the leaves are still green (which they normally are at harvest time on the rice plants), they choke the discharge very quickly.

A dry soil surface is required for satisfactory traction. If the tires are wet the drive rollers slip on the tires.

NIAE Midget Thresher

This machine (Figure 2) was purchased from the manufacturer, R. G. Garvie & Sons, 2 Canal Road, Aberdeen, Scotland. It was designed at the National Institute of Agricultural Engineering in England (Marsden, 1959) especially for rice and worked very well on oats which has a

Figure 1. Poynter pneumatic stripper harvester from Australia. (631785-7)

Figure 2. NIAE midget thresher from Scotland. (641488-5)

similar panicle. To obtain good results when threshing wheat it was necessary to change the angle of feeding to one that was more nearly tangential. This machine is simple, rugged and does not damage the grain. It can be used as a head stripper if there is reason to save the straw. It has a very high capacity for such a small machine.

Standard Jari Mower

This machine was borrowed from the Soils department. When there was no wind it cut the plants evenly and placed them in neat windrows with the stalks parallel, whether the crop was planted in rows or broadcast. Traction and mobility were better than for the Poynter, but the clearance was only about three inches so this machine could operate only on firm soil. The Jari would make an excellent teammate for the NIAE thresher.

Modified Jari Mower

This mower (Figure 3) had smaller drive wheels than the one described above. These wheels were too small for rough ground and carried sticky mud into the working parts of the machine, forcing the drive belts off the pulleys. It could only be used on smooth dry fields. The Farm Crops department had modified this mower by the addition of sheet metal gathering and collecting attachments. It cuts clean and gathers in neat bunches when the plants are either erect r i

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or leaning toward the machine and are in parallel rows of correct width. The sheet metal is a worthwhile addition, but should be applied to the high wheeled version, described above, for use in wet fields.

Experimental Plot Harvester

This machine (Figure 4) was designed and built at Michigan State University for the purpose of harvesting experimental plots (Oyjord, 1962). It was thought that with some modification it could be used as a small rice harvester. A nose wheel was added, ground clearance was increased for work in soft ground and a guide was added to bring the heads of grain into the threshing fan.

This device proved to be heavy, awkward and difficult to handle. It cannot be used in soft mud. Threshing and feeding characteristics were observed using wheat. The feed was not positive and some of the heads did not enter the threshing fan. No shatter losses were noted. All of the heads that entered the fan housing were completely threshed, but about 10 per cent of the grain was cracked and about one-third went out with the straw.

Figure 3. Modified Jari mower. (631785-5)

Figure 4. Experimental plot harvester. (641488-3)

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IV. THE STANDING GRAIN HARVESTER

Selection of a Design for the Harvesting Means

There was no indication that any of the machines, whose performance has been described in the previous section, could be modified to meet the design criteria as outlined in Chapter III. The next step was to develop a machine using a new threshing principle to meet these requirements. In the new method, a section of the stalk immediately below the head is fed into the space between a rotor and a concave without severing the plant from the ground. By leaving the straw attached to the ground, the head is pulled through this space by the forward motion of the machine, and the grain is removed from the straw by the action of the beaters. As the motion of the head is opposed to that of the beaters, the removal of kernels starts at the base of the head. In conventional threshers the removal starts at the tip since the head is traveling in the same direction as the beaters (Figure 5).

It was felt that this new threshing principle should be evaluated in the field before any attempt was made to incorporate it into a complete operational machine. The

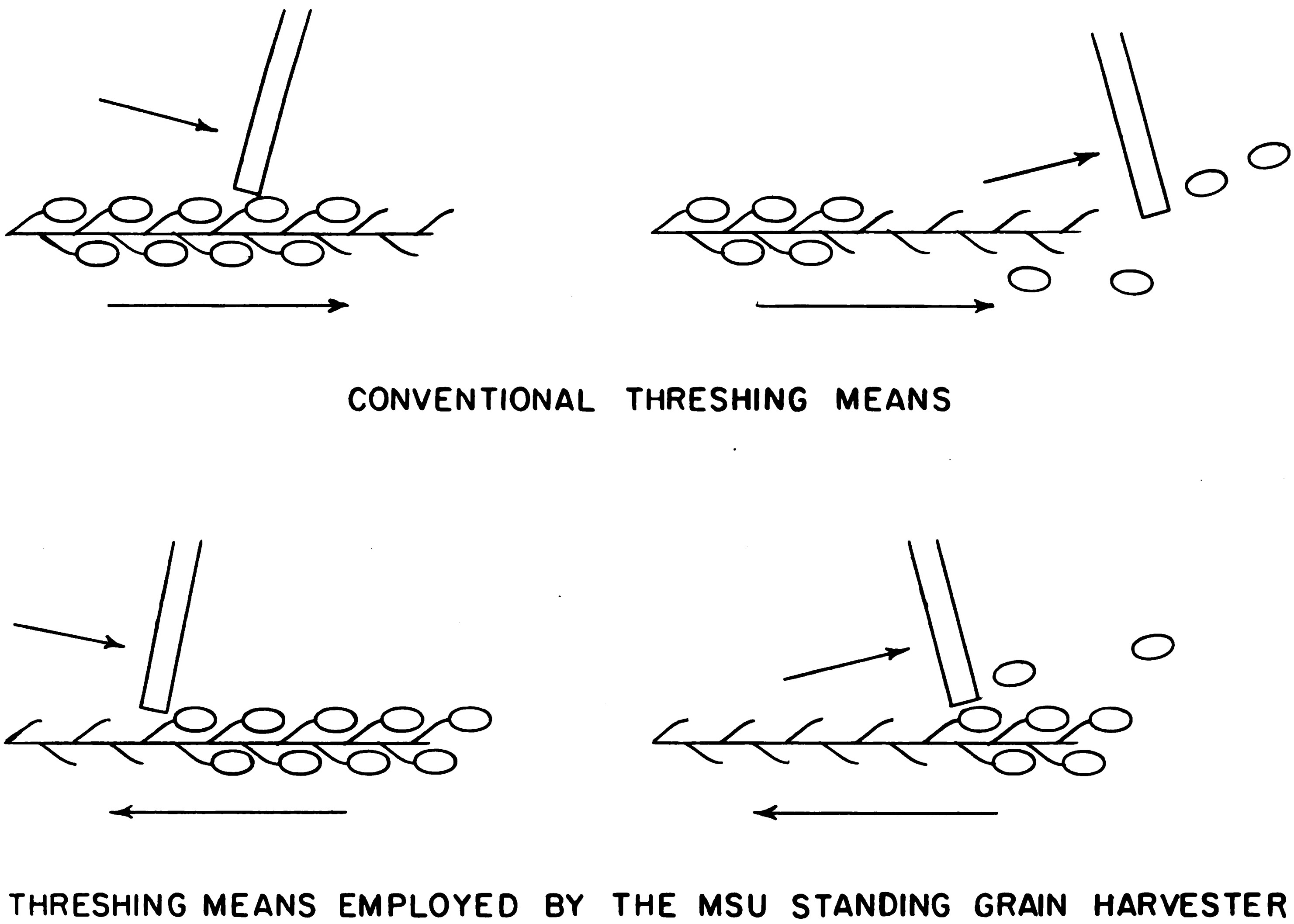

Figure 5. Comparison of two means of threshing.

first observations on the functioning of the components were made with a 1/12th scale model (Figure 6). By using strips of paper to simulate a row of grain the model was adjusted and modified until it seemed to have the correct action. The next step was to build a full sized machine which could be used to test the threshing principle in the field.

While the ultimate size of the commercial machines will be dictated by economic and operating characteristics, the feasibility of the harvesting system can be confirmed and demonstrated with a device of minimum complexity and cost if the device is designed to operate on a single row. Of course, it is possible that for harvesting experimental plots or even small fields commercial harvesters using this threshing principle will be built in the one row size.

Since a high impact velocity not only tends to break off complete heads without threshing, but also may cause kernel damage, the lowest possible peripheral speed is desired. However, there are always some kernels in every head with a tight attachment which require higher velocities for separation. In order to subject the heads to continuously variable peripheral speeds as they move across the concave, the rotor was made with a conical shape. The axis of the rotor is set at an angle, both with the surface of the ground and the row being harvested.

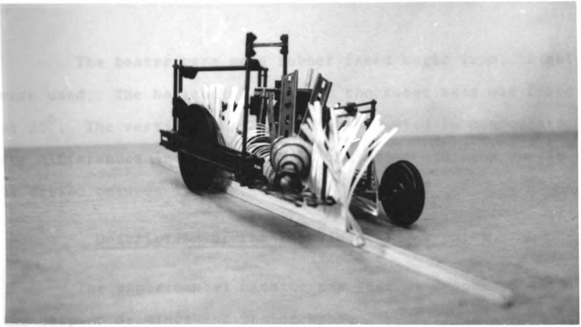

Figure 6. Scale model of standing grain harvester. (641488-7)

Figure 7. Prototype of harvester in rice field near Stuttgart, Arkansas on August 29, 1963. (631785-19)

The beater bars were rubber faced angle iron. Eight were used. The horizontal angle of the rotor axis was fixed at 30°. The vertical angle could be adjusted to compensate for differences in the sinkage of the front and rear wheels. It varied between 17° and 19°.

Description of the Experimental Harvester

The experimental machine can best be described with the help of drawings and photographs.

Figure 5 shows the difference between the action of a conventional thresher and the new threshing principle.

Figure 7 is a view of the complete machine from the left side.

Figure 8 is a top view of the machine with the power supply for the rotor and the means of providing locomotion omitted.

Figure 9 is a sectional view through section A-A of Figure 8 and shows the general arrangement of the rotor bars, concave bars, lower baffle, screen and grain pans.

Figure 10 is a sectional view through section B - B of Figure 8 and shows the general arrangement of the rotor, concave, upper baffle, left grain pan and screen.

Figure 11 is a view of the complete machine from the right side showing the manner in which the unthreshed grain is fed under the rotor by the auger, and the angle of the straw as it is pulled through the opening between the rotor and the concave.

Figure 12 is a view from the left side showing details of rotor, concave, and grain pan.

Figure 13 is a perspective view of the complete machine showing the general arrangement of dividers, feeder bars, auger, auger wings, rotor, concave, grain pans, and screens.

Figure 14 is a front view showing in general the dividers, feeder bars, and auger. The lower grain pans are temporary for experimental use. They should be eliminated and the regular grain pans extended to cover the same area.

Figure 15 is a diagram showing the passage of the panicle through sections of the concave and rotor.

Figure 16 is a schematic developed view of the concave.

Figure 17 is a schematic developed view of the concave showing the theoretical path of a point of attachment of a kernel of grain.

In these figures the numbers refer to the following parts:

1 - rotor	9 - auger flight
2 - rotor bar	10 - auger wing
3 - concave	11 - grain pan, left
4 - concave bar	12 - grain pan, right
5 - feeder bar	13 - baffle, lower
6 - grain divider, left	14 - baffle, upper
7 - grain divider, right	15 - screen
8 - auger	16 - stalk of grain

The gathering device for the machine consists of conventional grain dividers commonly employed on grain harvesters, 6 and 7, which separate the stalks in the row being harvested from adjacent rows, bring them into an upright position, slightly compress the row and feed it into the auger, 8. The diagonally disposed auger and the auger wing, 10, working together with the feeder bars, 5, move the central portion of the stalks into the space between the rotor, 1, and the concave, 3.

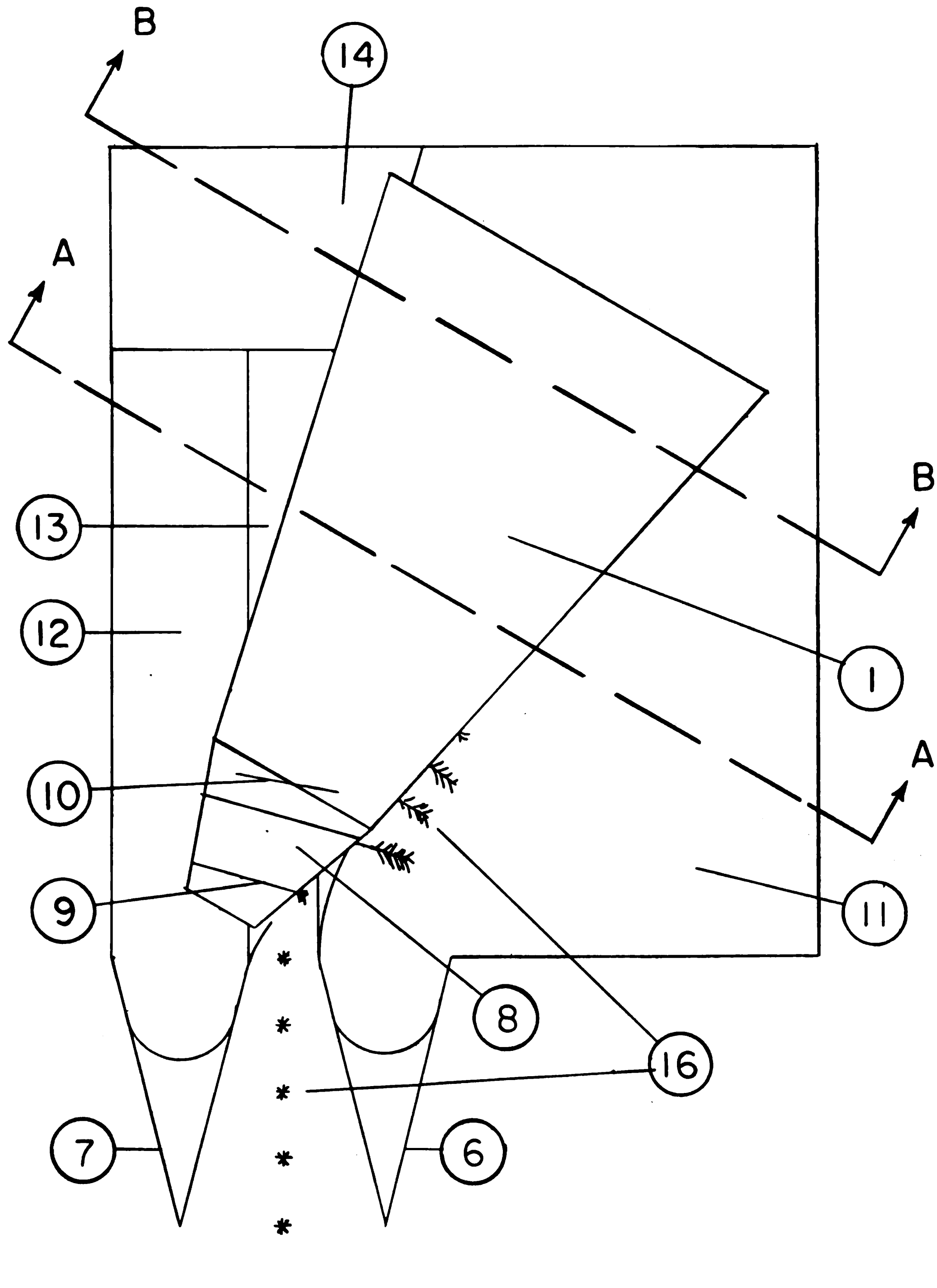

Figure 8. Schematic top view of harvester.

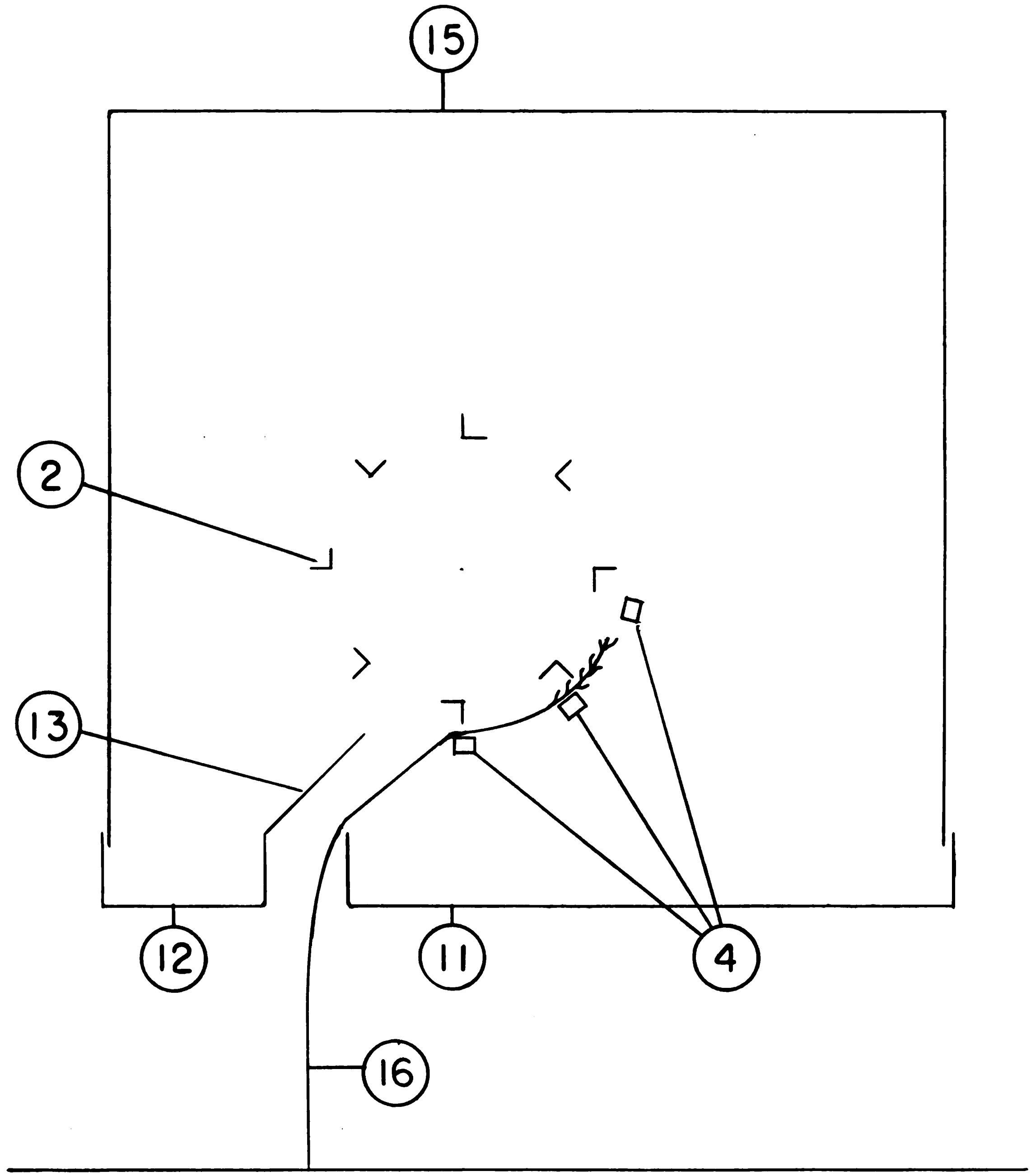

Figure 9. Section A - A of Figure 8.

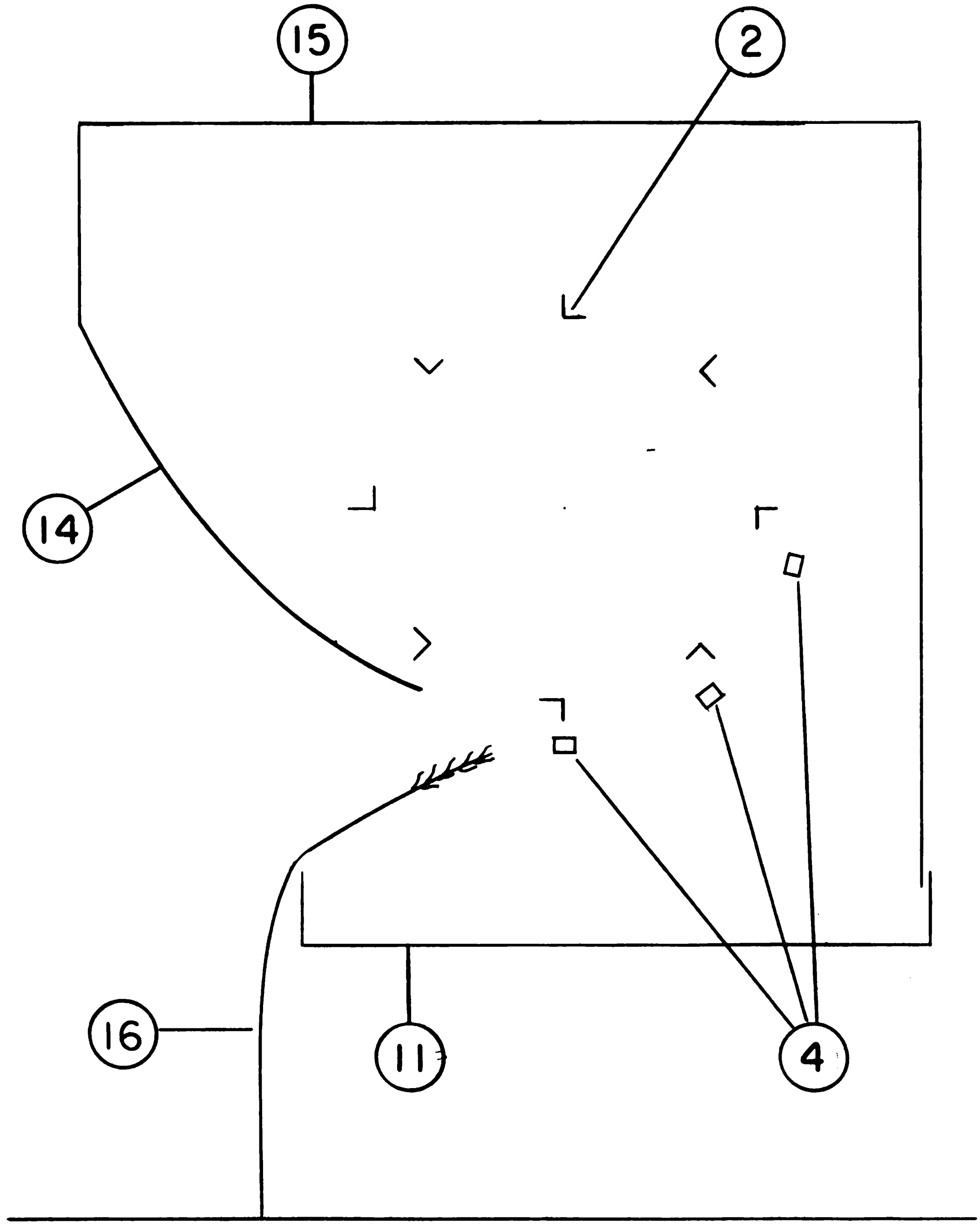

Figure 10. Section B - B of Figure 8.

Figure 11. Prototype of harvester in oat field near East Lansing, Michigan in August, 1963. (631785-17)

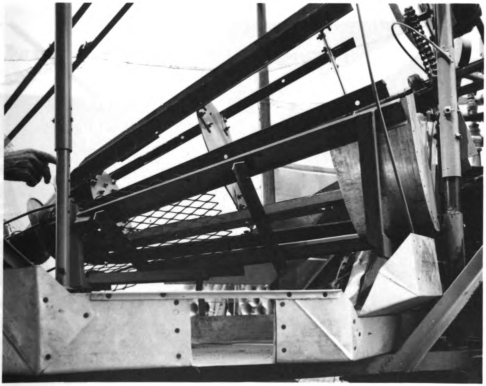

Figure 12. Rotor and concave of standing grain harvester. (631785-15)

Figure 13. Perspective of prototype with screens removed, showing arrangement of dividers, feeder bars, auger, auger wings, rotor and grain pans. (632195-3)

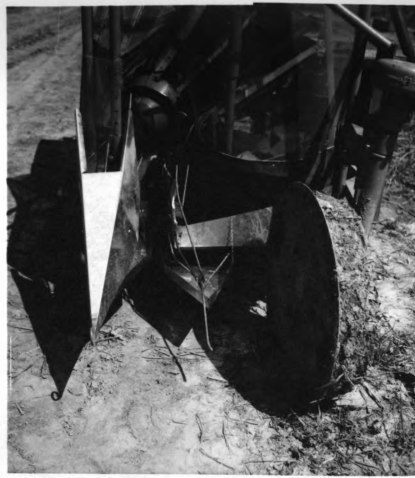

Figure 14. Front view of machine. (631785-16)

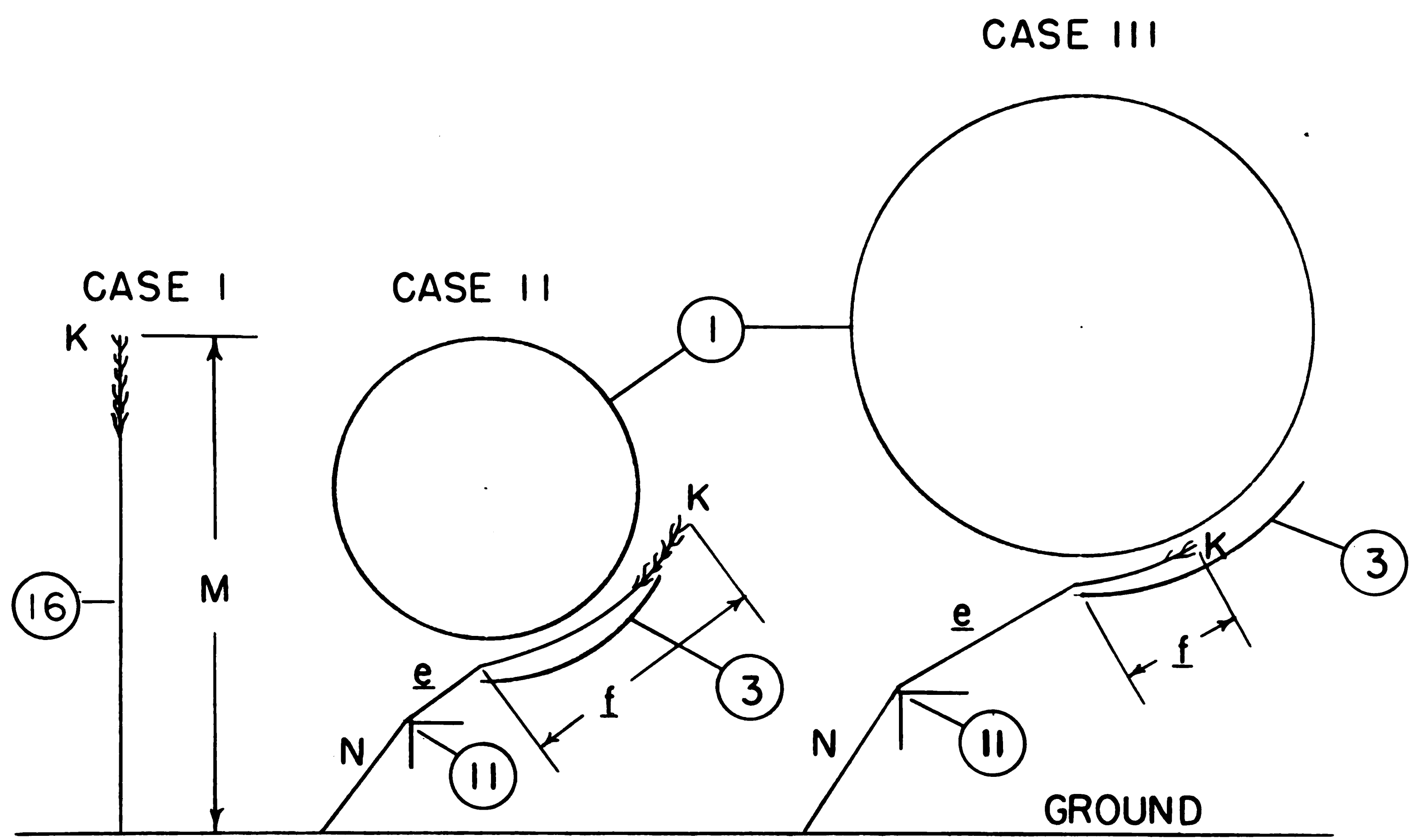

Figure 15. Diagram of passage of panicle through thresher.

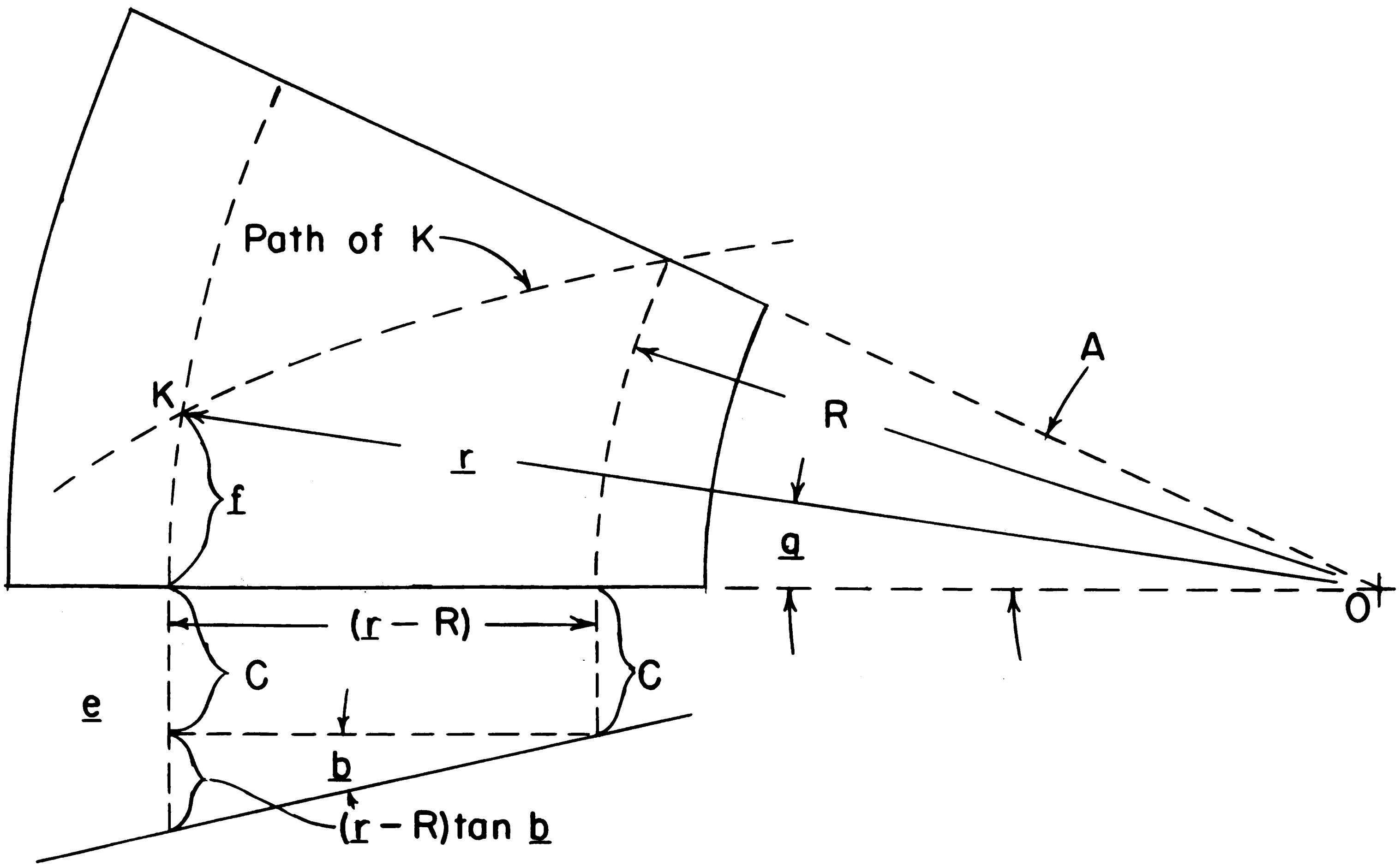

Figure 16. Schematic developed view of the concave.

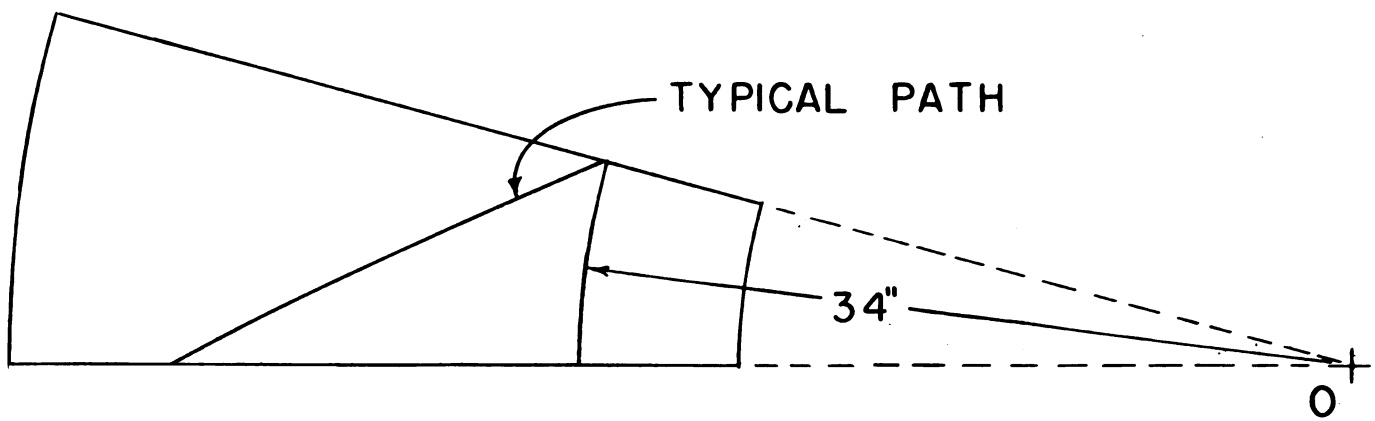

Figure 17. Theoretical path of the threshing action.

The auger is mounted on the same shaft as the rotor and turns with the same angular velocity, $\underline{w}$. The outer edge of the auger flight follows a path in space which is formed by the intersection of a right circular cone and a right helicoid having a common axis. To locate this path in space, consider a set of nonrotating, right hand rectangular coordinate axes in translatory motion with the origin of coordinates fixed to the apex of the cone, oriented in such a way that the Z axis is parallel to the row, with the positive direction being toward the rear of the machine, and the X axis is upward. The velocity vector of the row, relative to these axes is then parallel to the Z axis. Let this vector be $\overline{M}$.

The projection of the axis of the cone on the Y,Z plane makes an azimuth angle $\underline{a}$ with the Z axis while the axis itself makes a latitude angle $\underline{b}$ with the Y,Z plane as the equatorial plane. Both angles are acute, and $\underline{a}$ is measured from the Z axis toward the Y axis. Let the axis of the cone coincide with the Z' axis of a transformed coordinate system, also nonrotating, with the same origin, and with the Y' axis in the Y,Z plane. See Figure 18. The direction cosines for the change of axes can then be written in terms of angles $\underline{a}$ and $\underline{b}$ as shown below.

	X	Y	Z
X'	cos $\underline{b}$	- sin $\underline{a}$ sin $\underline{b}$	- cos $\underline{a}$ sin $\underline{b}$
Y'	0	cos $\underline{a}$	- sin $\underline{a}$
Z'	sin $\underline{b}$	sin $\underline{a}$ cos $\underline{b}$	cos $\underline{a}$ cos $\underline{b}$

As the stalk moves into the machine, the central portion is in contact not only with one or more feeder bars but also with the outer portion of the auger flight. To analyze the motion, consider a model with a single feeder bar, on which the successive points of contact with the stalk form a straight line. This line is an element of the same conical surface which contains the outer edge of the auger flight. It is also the path of the intersection of the stalk and the feeder bar.

If the stalk is to enter the space between the rotor and concave, the upper part must have a lateral motion relative to the row. If the stalk is to move into the machine without bending either forward or backward, then the component of the velocity of each point on the stalk relative to the frame of the machine, in the direction parallel to the row, must be equal in magnitude and opposite in direction to the velocity of the frame relative to the ground. To meet this requirement, in the mathematical model, the point on the stalk at the intersection of the edge of the auger flight and the feeder bar must have a velocity relative to

the X,Y,Z system whose Z component (backward, parallel to the row) is equal to $\overline{M}$. Call this point on the stalk $\underline{h}$.

Let the velocity of $\underline{h}$ be $\overline{V}$. The velocity vector $\overline{V}$ is directed along the feeder bar and makes an angle $\underline{c}$ with with the Z' axis, and its projection into the X',Y' plane makes azimuth angle $\underline{d}$ with the X' axis. The angle $\underline{c}$ is the angle between the rectilinear elements of the cone and the axis.

The direction cosines for the velocity vector $\overline{V}$ can be written in terms of $\underline{c}$ and $\underline{d}$ as shown below.

	X'	Y'	Z'
$\overline{V}$	$\sin \underline{c} \cos \underline{d}$	$\sin \underline{c} \sin \underline{d}$	$\cos \underline{c}$

$\overline{V}$ can be expressed in terms of its components in the directions of the transformed axes.

$$V_{x'} = \overline{V}(\sin \underline{c} \cos \underline{d})$$
$$V_{y'} = \overline{V}(\sin \underline{c} \sin \underline{d})$$
$$V_{z'} = \overline{V}(\cos \underline{c})$$

Each of these components makes a contribution to the component of $\overline{V}$ in the Z direction.

$$V_z = \overline{V}(\cos \underline{a} \cos \underline{b} \cos \underline{c} - \sin \underline{a} \sin \underline{c} \sin \underline{d} - \cos \underline{a} \sin \underline{b} \sin \underline{c} \cos \underline{d})$$

In the mathematical model, the expression enclosed in the above parentheses is a constant. Let this constant be G. Then

$$V_z = \overline{V}G \qquad (1)$$

The transverse component of the velocity of h relative to the rotating cone is equal in magnitude, but opposite in direction, to the transverse velocity component r w of a point on the cone surface. Relative to the nonrotating X',Y',Z' system, h has a zero velocity component in the transverse direction. (The transverse direction lies in the tangent plane to the cone and is perpendicular to the cone element along which the tangent plane makes contact.)

Thus, the vector $\overline{V}$ lies in the longitudinal section plane containing the cone axis and the cone element through h. Since h remains on the conical surface, the vector $\overline{V}$ is in fact directed along the cone element.

For a point moving along the outer edge of the auger flight, let d s be the incremental displacement component along the edge of the auger flight, let d u be the component along the cone element (parallel to $\overline{V}$) and let d p be the incremental angle of rotation of the cone about the Z' axis. Then the transverse component of the moving point's displacement relative to the cone surface (in the direction opposite to that of the motion of a point fixed to the cone surface) is $\underline{r}\,d\,p$, where $\underline{r}$ is the radial coordinate measured from the Z' axis. Denote the velocity relative to the cone (along the auger flight) by V_s, the angular velocity of the cone by $\underline{w}$, the transverse velocity component by V_w, and the angle in the tangent plane between the path and the transverse direction by $\underline{q}$. The component along the cone element of the velocity relative to the cone surface is the same as the velocity $\overline{V}$ relative to the nonrotating X',Y',Z' system. See Figure 19.

$$\frac{\overline{V}}{V_{\underline{w}}} = \tan \underline{q} = \frac{du}{\underline{r}\,dp} = \frac{dz'}{\underline{r}\,dp\cos\underline{c}}$$

Also $V_{\underline{w}} = \underline{r}\,\underline{w}$, hence $\dfrac{\overline{V}}{\underline{r}\,\underline{w}} = \dfrac{dz'}{\underline{r}\,dp\cos\underline{c}}$

or $dz' = \dfrac{\overline{V}(\cos\underline{c})dp}{\underline{w}}$

Let L = the lead of the helicoid (the distance which the generatrix of the helicoid moves in the direction of the axis while making one complete revolution).

Then $$L = \int_0^{2\pi} \frac{\overline{V}(\cos\underline{c})}{\underline{w}}\,dp \quad .$$

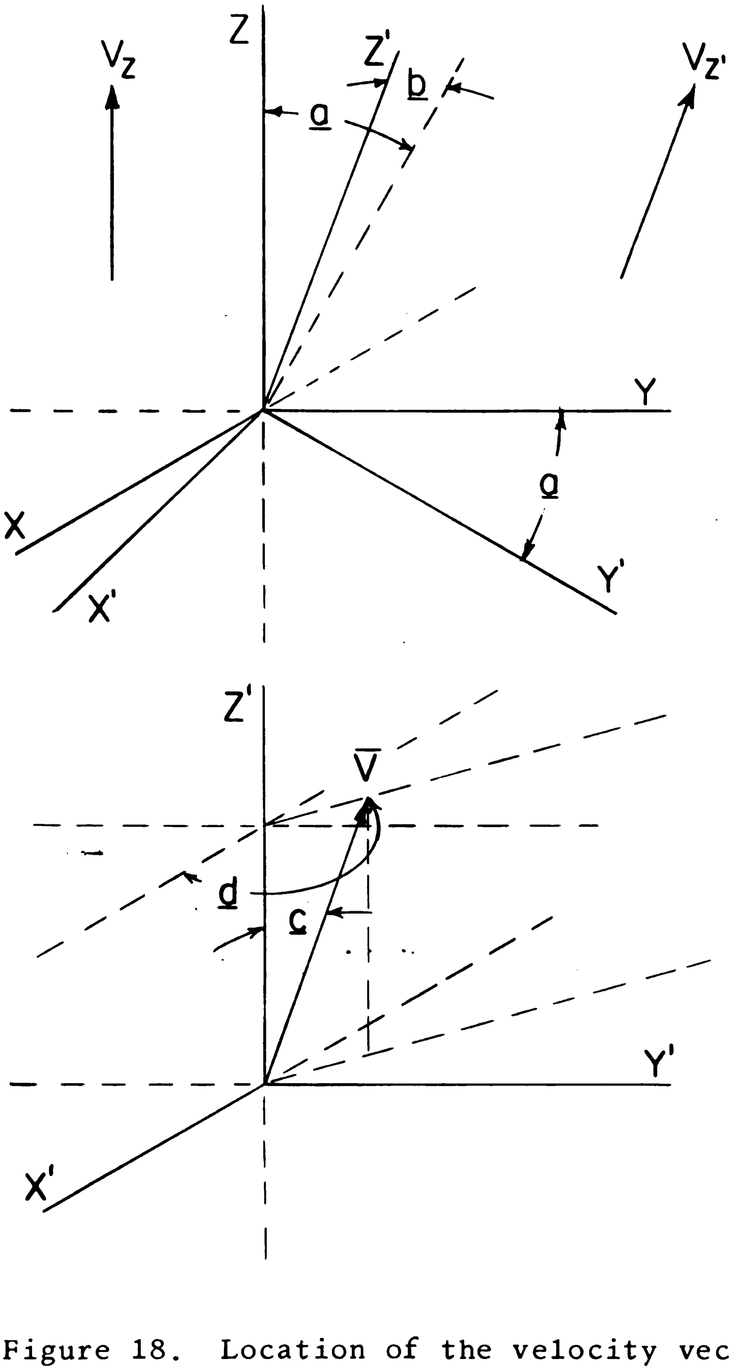

Figure 18. Location of the velocity vector $\overline{V}$.

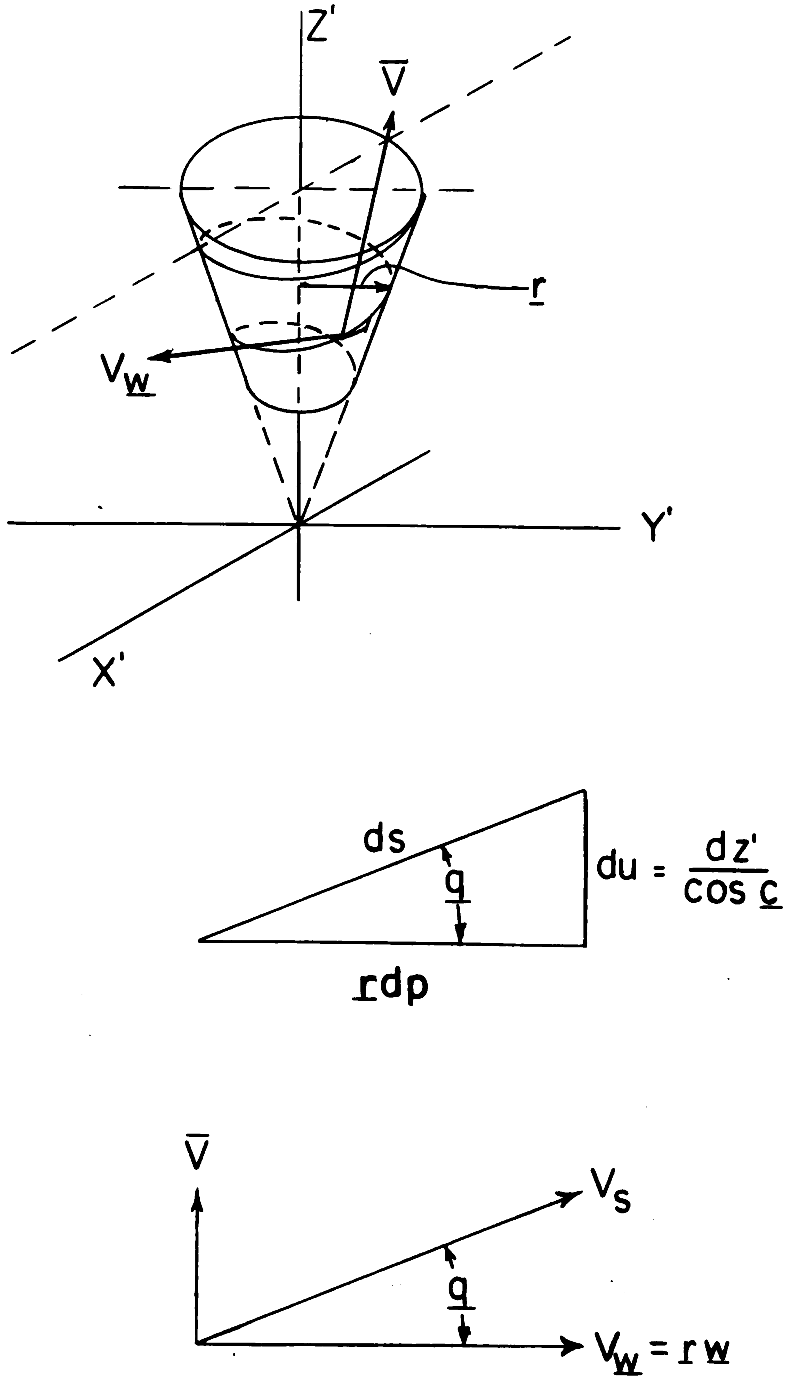

Figure 19. Schematic representation of the auger flight.

Since $\frac{\overline{V}(\cos \underline{c})}{\underline{w}}$ is independent of z' and p, this integrates

to
$$L = \frac{\overline{V}}{\underline{w}} 2\pi(\cos \underline{c}) \tag{2}$$

or
$$\overline{V} = \frac{\underline{w}L}{2\pi(\cos \underline{c})} \tag{3}$$

Substituting this value of $\overline{V}$ in equation (1)

$$V_z = \frac{\underline{w}L}{2\pi}\left[\frac{G}{\cos \underline{c}}\right] \tag{4}$$

In the mathematical model, the expression enclosed in the square brackets in equation (4) is a constant, Let this constant be C. Then

$$V_z = \frac{CL\underline{w}}{2\pi} \tag{5}$$

If the condition that the stalk leans neither forward nor backward is maintained, then $V_z = \overline{M}$. If $V_z > \overline{M}$ the stalk leans toward the concave as it moves in. If $V_z < \overline{M}$ the stalk is bent forward or away from the concave. Once the stalk is between the rotor and concave, it has a tendency to lean toward the front of the machine. See Figure 11. This tendency will be partially overcome if $V_z > \overline{M}$. It will be increased if $V_z < \overline{M}$. Therefore, the design values were taken, for the range of velocities expected in the field,

so that

$$V_z \geq \overline{M}. \tag{6}$$

Substituting the value of V_z from (5) into (6)

$$\frac{CL}{2\pi} \underline{w} \geq \overline{M} \tag{7}$$

or

$$L \geq \frac{2\pi \overline{M}}{C\underline{w}}$$

If $\overline{M}_{max}$ is the maximum value of $\overline{M}$ expected, and $\underline{w}_{min}$ is the minimum value of $\underline{w}$ expected, then

$$\frac{2\pi \overline{M}_{max}}{C\underline{w}_{min}} \geq \frac{2\pi \overline{M}}{C\underline{w}_{min}}$$ for the range of velocities

expected in the field, and

$$L = \frac{2\pi \overline{M}_{max}}{C\underline{w}_{min}} \tag{8}$$

gives a "safe" value for L.

The following values were used to design the auger.

$\underline{a}$ = 30 deg.; $\underline{b}$ = 17.5 deg.; $\underline{c}$ = 20 deg.; $\underline{d}$ = 135 deg.;

$\overline{M}_{max}$ = 16 in./sec. (approximately 0.9 mph)

$\underline{w}_{min}$ = 10 rad./sec. (300 rpm).

Substituting these values in equation (8), L was calculated to be 4.21 inches. The auger flight made two revolutions so that the total length was 8.42 inches.

The concave is formed by three bars spaced about 34° apart, each bar being coplanar with the axis of the rotor. The clearance between the rotor bars and concave bars is adjusted so as to keep as much of each head as possible in contact with the rotor bars without breaking off complete heads. The clearance may vary between bars and also from one end to the other of the same bar.

As the machine moves forward, the heads are pulled down and enter the clearance space between the rotor, 1, and the concave, 3. The clearance is adjusted so that as the heads pass over each of the concave bars, 4, in turn, the kernels are struck near the point of attachment to the straw by the rotor bars, 2. It is this action which separates the grain from the straw.

Since the actual path followed by a kernel of grain suddenly changes direction when the kernel is removed from the panicle by the impact of the rotor bars, no attempt was made to plot the path of such a kernel. What is of greater interest in the analysis of the threshing action is the path along which this separation could take place. This is the path of a point of attachment of a kernel to the panicle, or, more simply, the path of a kernel which passes completely through the machine without being separated from the head. Such a hypothetical kernel, which was called K, was followed through the machine and its path across the concave was plotted.

Figure 15 is a schematic representation of the stalk at three points in the threshing process. In Case I the plant has not yet contacted the machine. In Case II the stem is between the rotor and concave, but threshing has not yet started. In Case III the kernel whose path is being plotted is between the rotor and the concave.

The actual path will vary a great deal depending on the shape and location of the various parts of the machine. In the experimental machine the concave was a section cut from a cone. The developed surface of the cone is shown in Figure 16. A portion of a possible path of K across the concave is shown as a dotted line.

Since Figure 16 shows the developed surface of the cone, all points in the path of K across this surface lie in a plane in this figure. Let each point in this path have plane polar coordinates $\underline{r}$ and $\underline{a}$, where $\underline{r}$ is the distance from the apex of the cone, 0, and $\underline{a}$ is the angle measured in the plane from the lower edge of the concave, which is an element of the cone. Let the value of $\underline{r}$ at the point where the path of K intersects the upper edge of the concave be R.

Let the value of a at this point be A, which is the angle included between the edges of the developed surface of the concave.

For the mathematical model the edge of the grain pan is assumed to be a straight line parallel to, and a fixed distance from, the row, which is also assumed to be a straight line. It is further assumed that the angle between these parallel lines and the portion of the straw which extends from the ground to the edge of the grain pan has a constant value. Then, for the mathematical model, the length of that portion of the straw which extends from the ground to the grain pan is a constant. Let this length be N. See Figure 15.

Let e be the length of that portion of the straw which extends from the edge of the grain pan to the edge of the concave. See Figure 15 and Figure 16. Let f be the length of that portion of the straw which extends from the lower edge of the concave to K.

Observations made with the scale model using pieces of string and further observations of the full sized machine in the field, indicated that this portion of the straw followed a smooth contour which could be roughly approximated by a section of the thread of a wood screw with a comparatively small lead. Since the actual lead could not be determined, the mathematical model was constructed as though it were zero. That is, in the developed surface, $\underline{f}$ is measured along a circular arc. Let M be the total length of the straw from the ground to K.

Then $M = N + \underline{e} + \underline{f}$ or $\underline{e} + \underline{f} = M - N$. Let the angle between the edge of the grain pan and the lower edge of the concave be $\underline{b}$. When the stalk is in the position where the path of K starts across the concave, the value of $\underline{f}$ is RA. Let the value of $\underline{e}$ when the stalk is in this position be C. Then, at any later position, $\underline{e} = (\underline{r} - R) \tan \underline{b} + C$, and $\underline{f} = \underline{r}\,\underline{a} = M - N - \underline{e} = RA + C - \underline{e}$.
Substituting the value of $\underline{e}$ from above,

$$\underline{r}\,\underline{a} = RA + C - [C + (\underline{r} - R) \tan \underline{b}].$$

Therefore, $\underline{r}\,\underline{a} = RA - (\underline{r} - R) \tan \underline{b}$

$$\text{or } \underline{a} = \frac{RA}{\underline{r}} - \frac{(\underline{r} - R)\tan \underline{b}}{\underline{r}}$$

Since $\underline{a}$ is now expressed as a function only of $\underline{r}$ and known constants, the path of a kernel can be plotted by choosing values of $\underline{r}$ and computing the corresponding value of $\underline{a}$.

When the experimental machine was adjusted for grain with M approximately 42 inches, A was 0.265 radians and tan $\underline{b}$ was 1/2. In a typical example when R was 34 inches,

$$\underline{a} = \frac{34 \times 0.265}{\underline{r}} - \frac{1}{2}\,\frac{(\underline{r} - 34)}{\underline{r}}$$

The values obtained from this equation are plotted in Figure 17. From the figure it can be seen that in the developed surface this curve is almost a straight line. Observations made in the field indicate that actual paths are quite similar to the theoretical, indicating that the error caused by plotting the path as though the portion of the stalk between the rotor and concave was in the form of a circular arc in a plane parallel to the base of the cone is not too great.

Two grain pans, 11 and 12, are provided to collect the grain. One pan is placed on each side of the row with a space between them wide enough to allow the straw to pass through. As the threshed grain leaves the rotor it is deflected into the grain pans by the screen, 15, and the baffles, 13 and 14. The baffles follow above the straw as it bends away from the row and prevent loss of grain through the space between the pans.

Power Supply and Instrumentation of the Test Machine

To design a commercial machine the speed and power requirements of each component must be known. Power requirements of a machine are also a factor to consider in determining if its use is justified on an economic basis.

A tachometer mounted directly on the upper end of the rotor shaft was used to indicate the rotor speed. The forward speed of the machine was obtained by noting the time required to traverse a measured distance.

Measuring the power requirements was simplified by using hydraulic motors to drive the rotor and the propelling axle. All drives were by chain so that exact ratios were obtained. The drive systems were kept separate, one pump, set of valves, pressure gauge and motor for the rotor, and another complete system for the axle. Both pumps were driven by a gasoline engine using a single chain. Engine speed was obtained at no load with a revolution counter.

The arrangement of these parts is shown in Figure 20. Since the pressure in each system and the speed of each unit were known, it was possible to obtain either the power output of a pump or the power input to a motor from the manufacturer's specifications.

Measurement of Variables

Wind

The direction and velocity of the wind were not measured accurately since their effect was felt only on the operation of the feeding mechanism which was not being tested directly, and they did not influence the performance of the threshing means which was the subject of this investigation. An approximate value for wind velocity was obtained by recording the reading, in miles, on a wind gauge near the field and the time of the reading, before starting

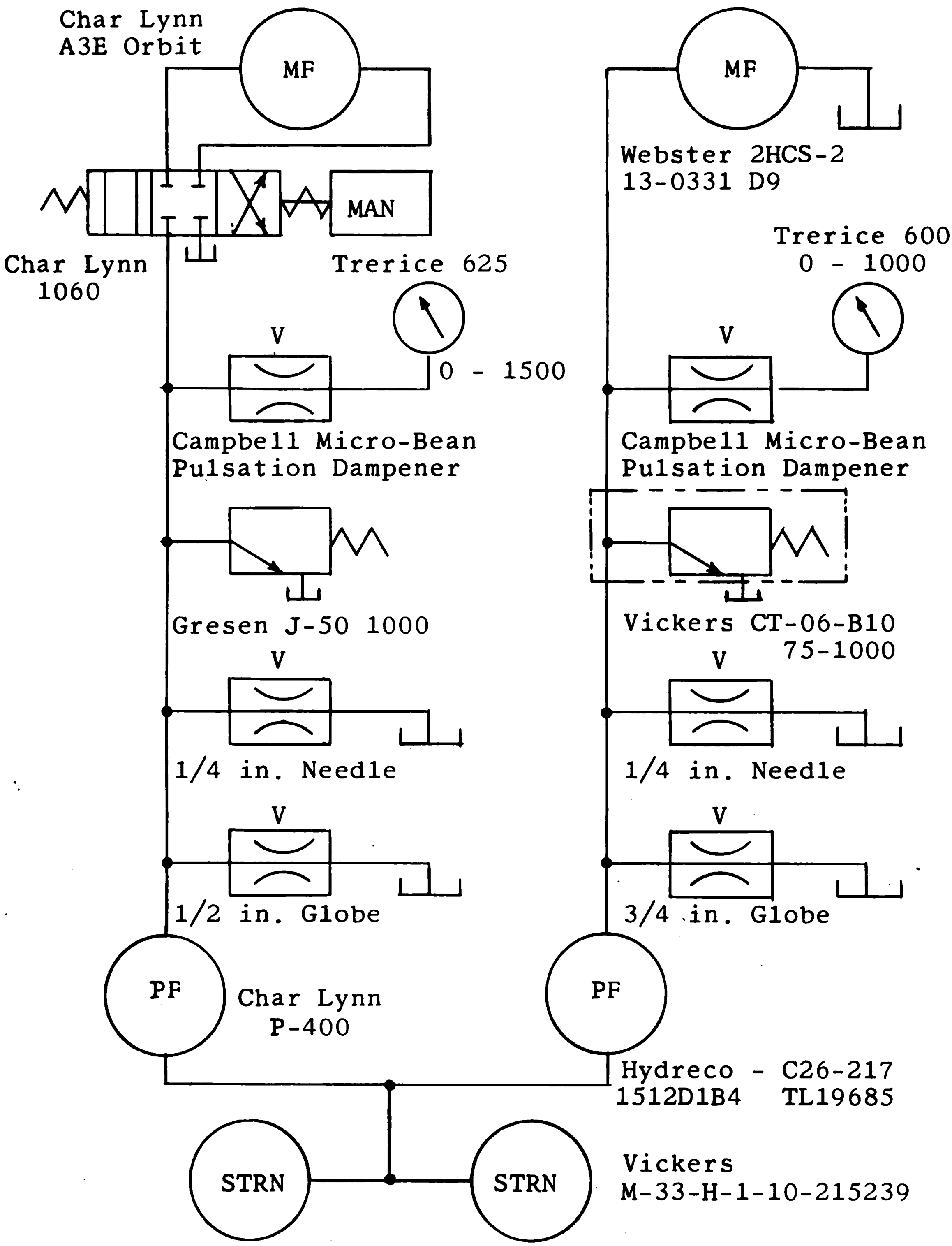

Figure 20. Diagram of hydraulic circuits.

a series of tests and again after the series was completed. The average wind velocity during the series was calculated from these values. Since the winds were rather steady and light, the average was used for all tests in the series. The wind direction was estimated for each test using a bit of dust. The direction recorded is that from which the wind was blowing relative to the direction of travel of the machine. A watch was placed with 12 o'clock pointing in the direction of travel of the machine and the number on the watch face closest to the direction from which the wind was blowing was recorded as the wind direction.

Humidity

Wet and dry bulb temperatures were measured with an ordinary sling psychrometer. Barometric pressure was not measured. Values of relative humidity were taken directly from the chart assuming that the barometric pressures were normal atmospheric pressures.

Moisture

Moisture content of the grain was determined by using capacitance-type moisture meters. Most of the samples were checked on both the Steinlite and Radson meters. Some were checked only on the Radson. Both meters were calibrated using the oven method.

Moisture content of the straw was obtained by the oven method.

Weights

For the data on oats, three instruments were used. The Mettler multiple range, indicating analytical scale was used for straw moisture content samples. For the other samples two indicating spring scales were used, one weighing in pounds and ounces, the other in ounces and sixteenths. These were adjusted and checked using fixed weights. For the data on rice the Mettler multiple range, indicating analytical scale was used for samples expected to be less than 100 grams while a double pan Toledo indicating scale was used for samples expected to be 100 grams or more.

Length of Row

Seven steel rods 1/4 inch in diameter and 4 inches long were bolted at 2 foot intervals along an aluminum tube. These rods were sharpened and adjusted so that the points came as close as possible to the corresponding 2 foot marks on a steel tape. Increments of row in any multiple of 2 feet could thus be measured by sliding this "comb" into the row. Since the "teeth" made a division in the row there was never any question as to whether a particular stalk was included or not.

Other Variables

General condition of the soil and the crop were noted and recorded. The approximate height of the crop was obtained by measuring a few typical stalks. The distance from the soil surface to the point where the axis of the rotor crosses the row, and the vertical angle of the rotor were also recorded. The latter varies with the distance the rear wheels sink in the mud.

Preliminary Observations and Testing at Michigan State University

While the main motivating force which prompted this research was the needs of the rice farmer in Southeast Asia, a second possible use for the machine might be a plot harvester for experiment stations and seed growers throughout the world. Such a harvester would not be limited to rice but could be used for any variety of small grain. For this reason it was deemed desirable to observe the action on several of the more common varieties of small grain.

It was also possible by making preliminary observations to detect weak spots, make modifications and adjustments, and finalize the testing procedures before the rice was ready to harvest so that the most effective use could be made of the limited amount of time available for testing on rice.

No quantitative measurements were made when threshing wheat and barley. Observations of the action were made and noted in the laboratory note book.

Of the varieties of small grain available, oats were considered to be the best substitute for rice because of the similarity of the spreading panicles on these two cereals. Several testing procedures were tried in an attempt to find a system that would be practical and give usable results. In the first system it was planned to evaluate the performance of the machine by comparing the amount of grain which it harvested in each of a number of trials with the amount harvested by hand methods in the same number of trials. Several variations of this method were used on August 5, 7 and 8.

On August 5, a 12-foot section of row which looked fairly uniform was selected and divided into 6 equal parts. By tossing a die, 3 of these parts were selected and carefully cut by hand and tied in a canvas. The process was then repeated for another 12-foot section leaving a total of 12 feet of row standing. The total weight of the material cut by hand was recorded, and after it was carefully threshed, the weight of grain was recorded.

The 12 feet of row left standing was harvested with the machine. The mixture of clean grain, unthreshed heads, straw and chaff collected in the grain pans was separated into components and weighed. The straw was cut by hand, weighed and then rethreshed in the same way as the control. Grain recovered from the straw was called straw loss. While this method probably gave the least chance of variations in actual yield between the grain harvested by the machine and the control, the machine was not being presented a normal row because of the breaks where the sections were removed by hand. On August 7, twelve rows each 24 feet long were selected. Six of these were picked at random for controls and the other six were harvested with the machine. The grain left on the standing straw after the machine had passed was stripped by hand since this was quicker and more positive than cutting and threshing.

The same procedure was followed on August 8 as on August 7 except that in order to more properly evaluate the threshing mechanism, the grain left on the standing straw was divided into two parts. Grain on heads which for some reason did not enter the space between rotor and concave was considered feeder loss, while grain which was not removed from a head which did pass through the space was called rotor loss. The results of these tests are given in Table 1.

The confidence interval estimates of the differences between the means of the grain harvested by hand and by machine for August 5 and 7, which are given in Table 3, gave no new information since the differences were assumed to be positive. However, the feeder and rotor losses which were actually weighed and are shown in Table 2 were appreciable. It was also observed in the field that a real quantity of grain was lost on the ground.

In other words, considering the limited time available for testing, it was impossible to obtain a large enough sample to give an accurate indication of the machine's capabilities using this system.

In the second system the entire yield on the area harvested by the machine was accounted for. Ground loss was estimated by dropping a small frame at random on each row and picking up the kernels inside the frame for a sample of the loss on that row. Unthreshed heads, clean grain, feeder loss and rotor loss were measured as in the first system. With the second system, a hand harvested control was not needed, but was taken for comparison with the first system. In order to save time, three 24 foot rows were included in each trial. Two trials were made with the machine, and two were harvested by hand for controls. This system was used only on August 14. After comparing the two methods, it was decided to use the second for the tests on rice.

Rice Harvesting Tests at the University of Arkansas

Through the cooperation of the University of Arkansas, it was possible to make a series of tests in which rice was harvested under field conditions at the Rice Branch Experiment Station located near Stuttgart, Arkansas.

On the experiment station the rice fields are kept under water until a few days before harvest. When the water is drained the soil surface is left relatively smooth and weed free. On this smooth surface it was rather easy to obtain the ground loss by counting the number of kernels per foot of row before the harvesting trial was started and again after it was completed. The difference in the two counts was then the ground loss in kernels per foot of row. The sample for each row consisted of four observations taken at random, each observation being one-sixteenth of the length of the row. A typical observation is shown in Figure 21. From the grain harvested in each trial, two hundred kernels were selected at random and weighed to give the average weight per kernel. This figure was then used to convert loss in kernels to loss in grams for each test.

By obtaining ground loss in the above manner, the entire yield was accounted for and all percentages were obtained without the use of a hand harvested control.

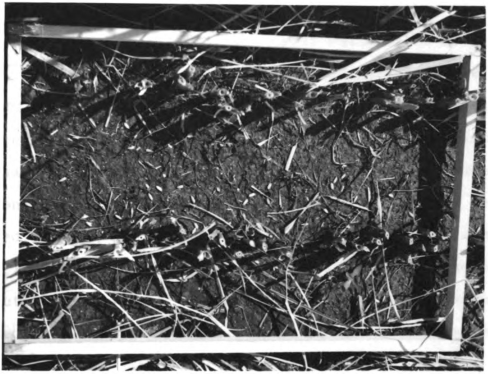

Figure 21. Ground loss when harvesting rice. (632371)

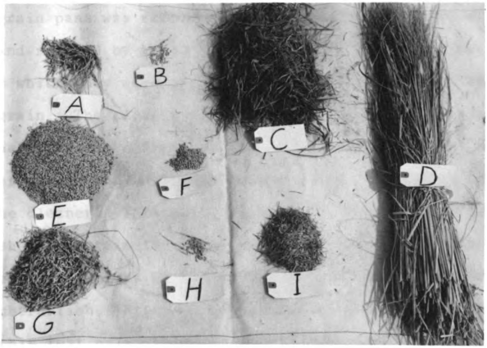

Figure 22. Results of test No. 8 at Stuttgart.
(631785-14)

For each test, after measuring the portion of the row which was to be harvested by the machine, an adjacent section at each end was cut away by hand to allow the machine to enter and leave in a straight line. The test portion was then harvested with the machine. See Figure 23 and Figure 24. The contents of the grain pans were put in paper bags and labeled. After the ground loss was obtained, feeder and rotor losses were stripped by hand and bagged. The straw was cut by hand and tied in a bundle. After the straw was weighed, a few typical stalks were chopped up and the moisture content was determined by the oven method.

After the total weight of the material obtained from the grain pans was recorded, the unthreshed heads were sorted out and removed by hand. The number of heads was recorded after which they were put through a head thresher to recover the grain. The clean grain was removed from the remainder of the grain pan contents with a Clipper seed cleaner. Leaves, trash and unthreshed spikes went over the top screen of the cleaner. This material was also run through the head thresher to obtain the weight of grain in the unthreshed spikes. The weight of leaves, trash and chaff was obtained by subtraction. Figure 22 shows the results of test No. 8. For this test only, the spikes were sorted by hand. The components shown in Figure 22 are as follows:

A - Unthreshed heads
B - Feeder loss
C - Leaves and trash
D - Straw
E - Clean grain
F - Ground loss
G - Unthreshed spikes
H - Rotor loss
I - Chaff and light grain.

Results of Tests

Testing at Michigan State University

The tests at Michigan State University were conducted from July 16 to August 14, 1963. The original data for these tests are recorded in Laboratory Book No. 1, Project 669, pp. 61 to 71.

The trials on barley and wheat were of an exploratory nature. No weights were recorded and no attempts made to determine the efficiency of the machine at this point. By observing the general quality of the work it was possible to determine which parts of the machine needed modifications or adjustments. The barley was quite ripe. Most of the heads were snapped off without being threshed. This trouble was not noted on wheat which was also quite ripe. The wheat was standing erect and no trouble was experienced in feeding it under the rotor. Threshing was nearly complete.

Figure 23. Front view of machine harvesting rice. (631785-9)

Figure 24. Rear view showing condition of straw after rice is harvested. (631785-12)

The averages for oats are given in Table 1. In each test several complete stalks were sheared off near a node by the auger. A few unthreshed heads were also broken off by the rotor bars. In recording weights and percentages, the grain from the sheared stalks was included with that from the broken heads.

In the first two series of tests, August 5 and August 7, the feeder losses and rotor losses were not separated. In the first three series, August 5, 7 and 8, the ground losses were only estimates based on the assumption that the total yield of the rows harvested with the machine was the same as that of the hand harvested controls.

It was noted that for each series of tests, the mean weight of the grain harvested by hand, which was presumed to be the total yield, was greater than that harvested with the machine. This result was expected if the yields were reasonably uniform.

For the purpose of making comparisons, observations from hand harvesting (total yield) were called X and those from the machine, Y. For August 14, total loss was also obtained. This value was called L. The analysis was carried out as if these values had normal distributions. A summary of the results is given in Table 2. A two-sided F test with a level of significance of 0.05 was used to test for equal variances. This test is outlined in Table 3.

Table 1. Averages for Garry oats

	Aug. 5	Aug. 7	Aug. 8	Aug. 14
Percentage of total grain				
Heads	9.28	3.59	4.55	6.12
Clean grain	79.05	83.18	69.26	71.12
Total in pan	88.13	86.78	73.81	77.24
Ground loss	4.20	9.12	22.53	8.69
Straw loss	7.47	4.10		
Feeder loss			2.93	13.27
Rotor loss			0.73	0.80
Total losses	11.67	13.22	26.19	22.76
Number of runs	5	6	6	2
Length of run (feet)	12	24	24	72
Relative humidity	54%	56%	43%	65%
Moisture content				
Percentage of grain	13	10	9	11.5
Percentage of straw	51	50	36	17
Rotor speed (rpm)	500	500	500	500
Forward speed (mph)	0.9	0.9	0.9	0.9

Table 2. Comparison of two methods of harvesting oats

	August 5		August 7		August 8		August 14		
	X	Y	X	Y	X	Y	X	Y	L
	0.5977	0.5078	1.8750	1.0664	1.3750	0.7343	2.5156	2.1295	0.5073
	0.7500	0.5988	1.8750	1.1797	1.0938	1.0352	3.3438	1.9960	0.7166
	0.6328	0.5429	1.1250	1.1328	1.3125	0.8125			
	0.4375	0.5743	1.0625	1.0117	1.1875	0.9843			
	0.6132	0.4727	1.2500	0.8867	1.1250	0.8438			
			1.2500	0.8516	1.1250	0.9180			
Sum	3.0312	2.6875	7.0625	6.1289	7.2188	5.3281	5.8594	4.1250	1.2239
Mean	0.6062	0.5375	1.1771	1.0215	1.2031	0.8880	2.9297	2.0625	0.6119
Sum of squares	1.8876	1.4537	8.3398	6.3471	8.7511	4.7854	17.5092	8.5166	0.7709
$\frac{(sum)^2}{N}$	1.8376	1.4445	8.3131	6.2595	8.6852	4.7315	17.1663	8.5078	0.7490
Diff.	0.0500	0.0092	0.0267	0.0876	0.0659	0.0539	0.3429	0.0088	0.0219
S^2	0.0125	0.0023	0.0053	0.0175	0.0132	0.0108	0.3429	0.0088	0.0219

X - pounds of grain harvested by hand; Y - pounds harvested with machine; L - total losses in pounds of grain.

Table 3. Analysis of results with oats

Date	August 5	August 7	August 8	August 14
N	5	6	6	2
S_x^2	0.01249	0.00534	0.01318	0.34296
S_y^2	0.00230	0.01752	0.01079	0.00882
F	5.43	3.29	1.2218	38.893
$F_{.975}$	9.60	7.15	7.15	648
d.f. on t	8	10	10	2
$t_{.95}$	1.86	1.81	1.81	2.92
S_p	0.086	0.1511	0.1095	0.419
$S_p\sqrt{2/N}\ t$	.1010	.1580	.115	1.440
$(\bar{X} - \bar{Y})$	0.0687	0.1556	0.3151	0.8672
$\underline{\theta}$	-0.0323	-.0024	+0.2001	-.5728

In the table: F is S_{max}^2/S_{min}^2; $\underline{\theta}$ is the lower confidence limit.

In each case, the hypothesis of equal variances was accepted. Thus, it was possible to use a pooled estimate of variance in finding confidence intervals. It was assumed that the machine method was faster and cheaper and would be adopted unless there was definite reason to believe that the hand method was better.

To compare the two methods a 95 per cent lower confidence interval on $\mu_x - \mu_y$ was found. In every test N_x was equal to N_y. Therefore,

$$\frac{(\bar{X}-\bar{Y}) - (\mu_x - \mu_y)}{S_p \sqrt{2/N}}$$

has a t distribution with 2N - 2 degrees of freedom. The 95 per cent confidence limits on the difference in means are then $[(\bar{X}-\bar{Y}) - S_p \sqrt{2/N}\ t_{.95};\ +\infty]$. The results are given in Table 3.

On August 14, the total losses were measured. These are recorded as L in Table 2. The pivotal quantity used to find the 95 per cent lower confidence interval on the mean of L was $\dfrac{\bar{L} - \mu_L}{S/\sqrt{N}}$ which has a t distribution with N - 1 degrees of freedom. The 95 per cent confidence limits are then

$$(\bar{L} - \frac{St_{.95}}{\sqrt{N}};\ +\infty) \text{ or } (-.059;\ +\infty).$$

On August 8, the confidence interval estimate was that the difference in means was at least 0.2 pounds. For the other days the confidence interval added no information since it was already known that the difference in means was positive.

Both the relative humidity and grain moisture content were lower on August 8 than any of the other days. This caused more shattering and increased the ground losses. On August 14, about one-half of the oats was lodged. This caused a sharp increase in feeder losses as shown in Table 1.

Testing at the University of Arkansas

The harvesting trials at Stuttgart were made between August 30 and September 14, 1963. The original data are recorded in Laboratory Book No. 2, pp. 7 to 15. All of the tests were conducted in a field of Northrose rice except for tests numbers 31 through 36 which were made in a field of Nova rice. The purpose of the short series in the Nova was to determine if the machine would function in varieties of rice other than Northrose.

A summary of the results for rice is given in Table 4.

Table 4. Data for rice, 1963

Test Number	Rotor Rpm	Drive Mph	Relative Humidity %	Grain Moisture %	Straw Moisture %	Bushels Per Acre	Percentages of Total Grain							
							Heads	Spikes	Clean Grain	In Pan	Ground Loss	Feeder Loss	Rotor Loss	Total Losses
1	580	0.45	79	26	75	131	3.7	12.7	79.1	95.5	4.1	0.4	0.0	4.5
2	360	0.45	79	26	75	168	2.3	12.7	79.6	94.6	4.5	0.5	0.4	5.4
3	580	0.45	79	26	75	137	5.4	12.2	76.6	94.2	4.5	1.2	0.1	5.8
4	580	0.9	49	23	73	116	1.3	13.0	82.2	96.5	3.0	0.5	0.0	3.5
5	580	0.9	49	23	73	149	4.4	17.1	74.5	96.0	3.5	0.4	0.1	4.0
6	360	0.9	49	23	73	134	3.5	12.0	77.9	93.4	3.5	2.7	0.4	6.6
7	600	0.9	57	22	71	115	1.4	10.0	81.0	92.4	3.4	4.0	0.2	7.6
8	500	0.9	57	22	71	153	3.6	14.0	79.7	97.3	2.3	0.2	0.2	2.7
9	500	0.9	57	22	71	121	0.9	12.4	82.5	95.8	2.6	1.4	0.3	4.3
10	600	0.45	71	23	69	136	2.1	12.3	43.0	57.4	2.4	39.5	0.7	42.6
11	600	0.45	71	23	69	178	1.8	9.1	57.1	68.0	2.1	28.5	1.4	32.0
12	600	0.45	71	23	69	108	1.1	10.5	47.4	59.0	1.6	38.8	0.6	41.0
13	600	0.45	71	23	69	156	1.9	15.5	74.3	91.7	3.4	4.4	0.5	8.3

Table 4--Continued

Test Number	Rotor Rpm	Drive Mph	Relative Humidity %	Grain Moisture %	Straw Moisture %	Bushels Per Acre	Percentages of Total Grain							
							Heads	Spikes	Clean Grain	In Pan	Ground Loss	Feeder Loss	Rotor Loss	Total Losses
14	600	0.45	71	23	69	176	1.3	6.7	40.3	49.3	1.4	48.7	0.6	50.7
15	600	0.45	71	23	69	145	1.2	16.6	77.1	94.9	3.2	1.9	0.0	5.1
16	460	0.9	68	21	74	170	0.4	10.0	85.9	96.3	2.4	0.2	1.1	3.7
17	460	0.9	68	21	74	153	0.2	8.4	86.4	95.0	2.1	0.0	2.9	5.0
18	460	0.9	68	21	74	155	0.7	10.2	86.2	97.1	1.4	0.5	1.0	2.9
19	460	0.9	68	21	74	182	1.0	9.6	85.0	95.6	2.9	0.2	1.3	4.4
20	460	0.9	68	21	74	159	1.2	8.0	86.9	96.1	2.1	0.0	1.8	3.9
21	460	0.9	68	21	74	170	0.0	8.3	88.6	96.9	1.5	0.6	1.0	3.1
22	460	0.9	61	19	71	139	0.3	10.1	87.6	98.0	1.3	0.4	0.3	2.0
23	460	0.9	61	19	71	145	0.0	11.3	86.5	97.8	1.4	0.2	0.6	2.2
24	460	0.45	61	19	71	186	0.0	9.6	88.8	98.4	1.0	0.1	0.5	1.6
25	460	0.45	61	19	71	181	0.3	9.9	87.0	97.2	0.4	1.9	0.5	2.8
26	800	0.9	61	19	73	151	14.3	12.7	69.4	96.4	1.1	2.4	0.1	3.6

Table 4--Continued

Test Number	Rotor Rpm	Drive Mph	Relative Humidity %	Grain Moisture %	Straw Moisture %	Bushels Per Acre	Percentages of Total Grain							
							Heads	Spikes	Clean Grain	In Pan	Ground Loss	Feeder Loss	Rotor Loss	Total Losses
27	700	0.9	61	19	73	132	1.4	12.8	82.2	96.4	0.7	2.6	0.3	3.6
28	560	0.9	61	19	73	118	0.2	8.2	88.5	96.9	1.3	1.0	0.8	3.1
29	460	0.9	61	19	73	140	0.0	12.8	85.3	98.1	0.9	0.1	0.9	1.9
30	320	0.9	61	19	73	147	0.0	7.5	82.5	90.0	0.8	3.5	5.7	10.0
31	345	0.66	82	20	64	97	1.8	4.0	91.0	96.8	1.2	0.8	1.2	3.2
32	345	0.66	82	20	64	72	3.7	2.7	89.3	95.7	1.9	0.9	1.5	4.3
33	345	0.66	82	20	64	80	2.6	3.5	89.3	95.4	2.3	0.3	2.0	4.6
34	368	0.72	82	20	64	80	3.0	1.2	93.2	97.4	2.3	0.0	0.3	2.6
35	368	0.72	82	20	64	76	3.0	3.0	92.4	98.4	1.2	0.0	0.4	1.6
36	368	0.72	82	20	64	82	3.0	4.8	89.2	97.0	2.0	0.2	0.8	3.0
37	540	0.54	81	20	71	146	3.9	12.3	82.4	98.6	0.9	0.2	0.3	1.4
38	540	0.54	81	20	71	156	1.2	11.4	85.5	98.1	0.6	0.6	0.7	1.9
39	540	0.54	81	20	71	207	2.6	11.7	84.8	99.1	0.4	0.0	0.5	0.9
40	540	0.54	81	20	71	178	2.0	12.2	83.6	97.8	1.1	0.4	0.7	2.2

When harvesting rice, the auger did not shear off complete stalks as it did in the oats. It was noted that the rice straw was somewhat tougher than that of oats and the nodes were much less prominent. These differences may explain the improvement in the action. During the preliminary trials, for which no data was recorded, the straw was not fed under the rotor properly. This resulted in a feeder loss which appeared to be about one-half of the crop. The solution to this problem was found to be the addition of two wings or extensions on the auger which forced the straw under the rotor.

All of the tests were made on reasonably erect rice except for tests numbers 10 through 15. These trials were made the day following a wind storm and the straw was lodged. In tests 10, 12 and 14 the machine was operated in normal fashion, but for 11, 13 and 15 the action of a pick-up reel was simulated with a pitch fork. The average feeder loss was over 42 per cent with no assistance. With the fork, on the first trial it was 28.5 per cent; the second, 4.4 per cent and the third, 1.9 per cent. There was some indication then that with a little practice a man could soon develop enough skill to reduce the feeder losses to acceptable levels in lodged grain. In areas where labor costs are low, lodging is infrequent and the crop is systematically pushed down in one direction before a storm, this method might be more economical than the addition of the pick-up reel.

In tests 1 through 15, excessive ground losses were noted. The area covered by the grain pans was increased and the space between them was reduced. In tests 16 through 21, some reduction in ground losses was obtained. Further improvement was made by adding two new baffles which covered the space between the pans. In the remaining tests on Northrose rice the ground losses were acceptable.

All samples of grain harvested with the machine were checked for visible physical damage to kernels but none was found. Tests 26 through 30 were run at a range of speeds which extended above and below the normal range. At the same time a sample was stripped by hand from the same row. Two hundred kernels from each of these observations were treated with fast green stain to check for cracks in the seed coat. Another sample from each observation was used for a germination test. The results are shown in Table 5.

To test for the independence of X and Y, simple linear regression was assumed of the form:

$$Y = A + BX + e$$

Using $\underline{b}$ as the symbol for the least squares estimate of B, the value of $\underline{b}$ was found to be -2.71×10^{-3}.

Table 5. Damage to kernels during harvest

	Hand Stripped	Machine Harvested				
Rotor speed rpm (X)	..	320	460	560	700	800
Number with cracked seed coat (Y)	10	7	10	3	8	6
Percentage germination (W)	92	89	82	94	85	82

The hypothesis that B was equal to zero was tested at the 5 per cent level.

$\frac{(\underline{b}-B)\ S_x \sqrt{N-1}}{S_{yx}}$ has a *t* distribution with N - 2 degrees of freedom. If the hypothesis is true, then $T = \frac{(\underline{b})\ S_x \sqrt{N-1}}{S_{yx}}$ has a *t* distribution with N - 2 degrees of freedom.

$(N-1)S_x^2 = 144{,}480$; $S_{yx}^2 = 8.58$; $T = -0.352$.

$\underline{t}_{.025}(3df) = -3.182$. Therefore, the hypothesis that X and Y are independent was accepted. In other words, there is no evidence that the number of kernels with cracked coats is affected by rotor speed.

The independence of X and W was tested in the same manner. $\underline{b} = -.01$; $S_{wx} = 5.5$; $T = 0.69$

$\underline{t}_{.975}(3df) = 3.182$.

Therefore, the hypothesis that X and W are independent was accepted. In other words, there is no evidence that germination is affected by rotor speed.

The results of this same series of tests indicated that there was a relationship between rotor speed and both rotor loss and number of unthreshed heads. This relationship is shown in Figure 25 which indicates that the relationship is not linear.

When all factors were considered, the best results for the Northrose rice were obtained with a rotor speed of 460 rpm. Five tests were run at this speed after the machine was modified. Averages for these five tests are shown in the first line of Table 6. The best rotor speed for the Nova rice was 368 rpm. Three tests were run at this speed, and averages are shown in the second line of Table 6.

Table 6. Averages for best rotor speeds for rice, 1963

	Percentage of Total Grain								
	Heads	Spikes	Clean Grain	In Pan	Ground Loss	Feeder Loss	Rotor Loss	Total Losses	θ
Northrose	0.1	10.7	86.9	97.9	1.0	.5	.6	2.1	2.5
Nova	3.0	3.0	91.6	97.6	1.8	.1	.5	2.4	3.6

$\overline{\theta}$ is the upper 95 per cent confidence limit on the mean value of total losses.

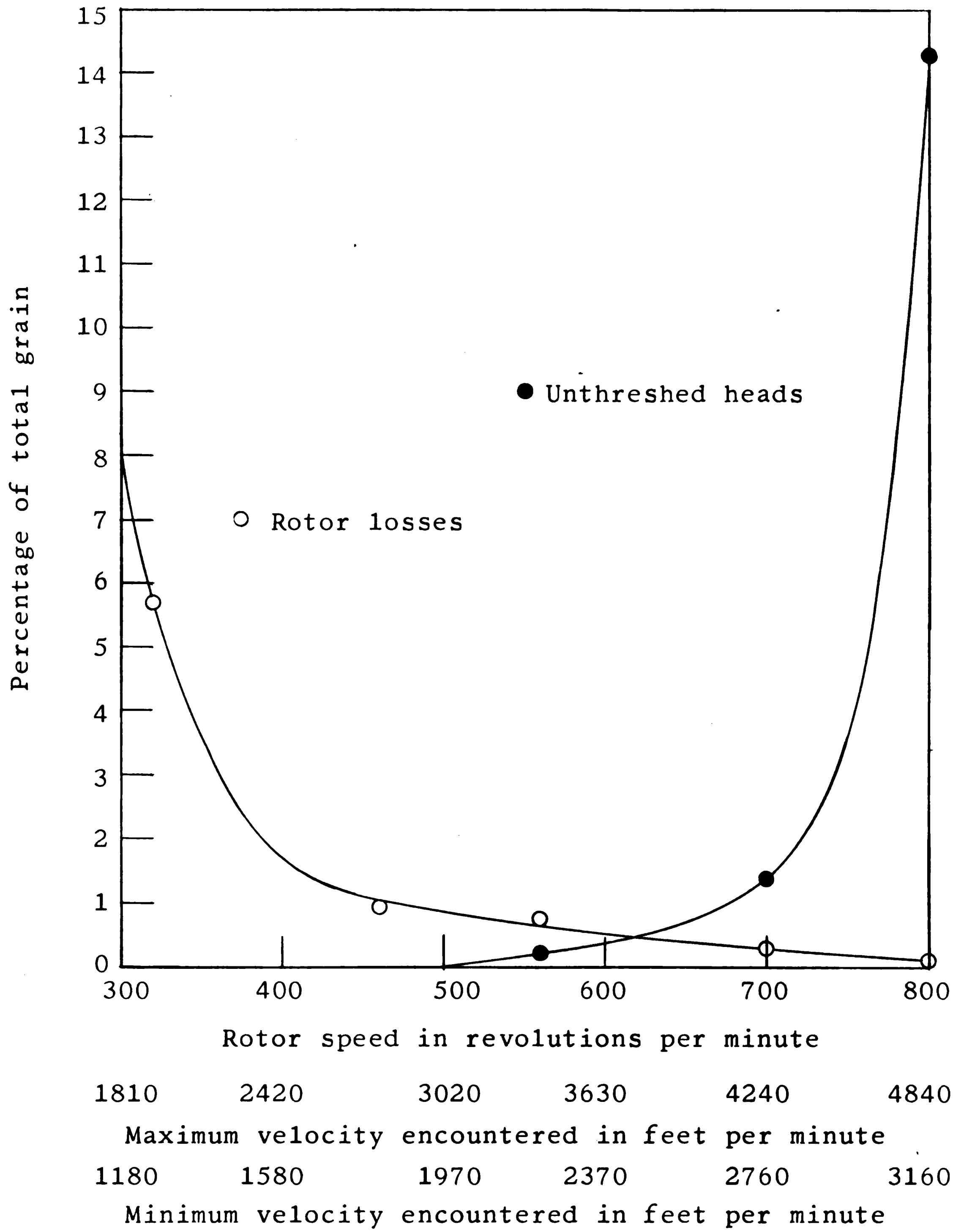

Figure 25. The effect of rotor speed and peripheral velocities on rotor losses and number of unthreshed heads.

While the standing grain harvester in its present form is not intended to compete with conventional grain combines, a brief comparison may have some value in evaluating the performance of the former. In Chapter II, tests of a conventional rice combine in Malaya were mentioned in which grain losses were under 3.5 per cent. The averages shown in Table 6 are under 2.5 per cent. The comparison has little meaning because there is no reason to believe that there was any similarity in the conditions under which the tests were made.

Two IHC 403 Rice Special combines in first class condition were used to harvest the same field of Nova rice in which observations 31 through 36 were made. These machines were cutting 12 foot swaths and were operated by thoroughly experienced drivers. Ground loss for these machines was estimated by counting the kernels on a strip of ground 1 foot wide and 12 feet long perpendicular to the direction in which the combines had traveled. On the basis of a single observation, the indicated ground loss was 4.5 per cent. A thoroughly mixed sample from the truck, into which grain from both combines was emptied, showed visible kernel damage of 9.6 per cent. Because of bad weather it was not possible to bring the conventional combines into the Northrose field in time to make a similar comparison on that variety.

The maximum speed of the hydraulic motor used to drive the rotor was less than 1800 rpm for all tests. The maximum pressure was less than 100 psi. From the chart supplied by the manufacturer it was determined that less than one-fourth horsepower was required to drive the rotor. In the same manner it was found that less than two horsepower was needed for the forward drive. This has little meaning, however, since most of the weight of the machine was in the bulky hydraulic system which would not be used on a commercial machine. In any case, a commercial model could be pulled by a lightweight hand tractor, and in most cases by a single draft animal.

V. SUMMARY, DISCUSSION AND CONCLUSIONS

Summary

It has been estimated that over four times the present food supplies will be needed in Southeast Asia by the year 2000 if the average daily diets there are to reach acceptable levels by that time. The purposes of this study were to determine how increased mechanization can help in the solution of this problem and, if possible, to make a contribution toward finding the answer.

Many authors feel that greater mechanization of rice harvesting will help to solve this problem. Throughout the world harvesting practices vary from the practice of cutting individual heads with a small knife to the use of large combines designed specifically for rice. It was found that the salient obstacles to the mechanization of irrigated rice were the following:

1. The grains shatter easily so that any means of cutting or gathering which is not gentle will result in lost grain.
2. There is a tendency for the crop to lodge.
3. Many of the fields are soft at harvest time.

4. Straw which has been damaged by machinery is no longer suitable for many of its present uses.
5. It is difficult to get machines into the fields.
6. Farmers in much of Southeast Asia lack mechanical ability.

During the past two decades many attempts have been made to increase the mechanization of the harvesting of irrigated rice. In Malaya large machines were adapted for use on soft ground. In South America a system evolved making use of standard farm machines with very little modification.

Because of the tendency of rice to lodge and shatter, the only successful alternative to hand harvesting has been the self-propelled combine with a pick-up reel. These machines are too large and expensive for most of Asia. The two major stumbling blocks to mechanization of harvesting with conventional machines are the lack of complete water control and the need for a variety of rice with short strong straw, erect nonlodging habit, nonshattering grain and even ripening.

Most of the research reported over the last twenty years consisted of testing, modifying and retesting of existing machines. More recently there have been several reports of basic research where machines were designed specifically for the requirements of rice production.

The conditions in Taiwan are more favorable for increased mechanization of harvesting than in any of the other countries studied. Accordingly, it was decided to design the first machine for Taiwanese conditions and make modifications as needed for other parts of Southeast Asia at a later date.

From the literature survey, from discussions with native Taiwanese and others who have lived or studied in Taiwan, and from experience gained by planting several plots of rice at Michigan State University, the design criteria for a small harvester were established. Several existing machines were examined, but none of them met the requirements.

A machine was built to test a new principle of grain harvesting in which a section of straw immediately below the head is fed between a rotor and a concave in such a way that the grain is stripped from the straw starting at the base of the head. The straw is not cut but is left standing in the field (Figure 24).

Tests were conducted on oats and rice. When the machine was properly adjusted, total losses of rice were less than 2.5 per cent. Eighty-six to ninety-two per cent of the grain was completely threshed, the remainder being unthreshed heads or branches. No damage to kernels was found. These results compare favorably with standard commercial combines now in operation.

Power requirements are very low. They can be supplied by the small hand tractors now used in much of Asia. Where mechanical power is not available, power for the rotor can be supplied by foot treadle or hand crank, while the machine can be pulled by a single draft animal.

Discussion

The results of the tests on rice indicate that this method of harvesting has definite possibilities of being successful. One of the remaining problems is that sometimes heads are broken off without being threshed. Unthreshed heads can be eliminated by reducing rotor speed, but this increases rotor loss (Figure 25).

It was observed that in grain of uniform height, less than two-thirds of the rotor was actually used for threshing. The useful portion of the rotor has a maximum diameter of 26 inches and a minimum diameter of 12 inches. The useful length of the beater bars is 32 inches. For the typical path shown in Figure 17, only 18 of the possible 32 inches are used.

If the azimuth angle between the axis of the rotor and the row were reduced, the entire rotor could be used for each head. This would increase the range of peripheral velocities to which each head is subjected. The maximum and minimum peripheral velocities encountered at the ends of the path in Figure 17 were calculated and shown below the corresponding rotor speeds in Figure 25. In Figure 26, the percentages of grain are plotted against the same velocities calculated for the ends of the rotor. These curves show that both rotor losses and unthreshed heads could have been held below 0.3 per cent with a rotor speed of a little less than 700 rpm.

In order to more properly evaluate some of the other factors involved in the operation of the machine, the clearance between the rotor and the concave was held constant at 3/16 of an inch for all of the trials on rice. During initial observations, it was noted that decreasing the clearance increased the number of unthreshed heads and decreased the rotor loss. Independent adjustments which are easily made should be provided at each end of the concave so that a large clearance can be provided at the entrance to reduce the tendency to snap off heads while a small clearance at the exit will reduce rotor loss.

Since the only purpose in building and testing the experimental machine was to evaluate the new threshing principle, no formal attempt was made to evaluate the drive wheels. The Nova field was under several inches of water when the harvesting trials were conducted there, and the Northrose field had some standing water part of the time

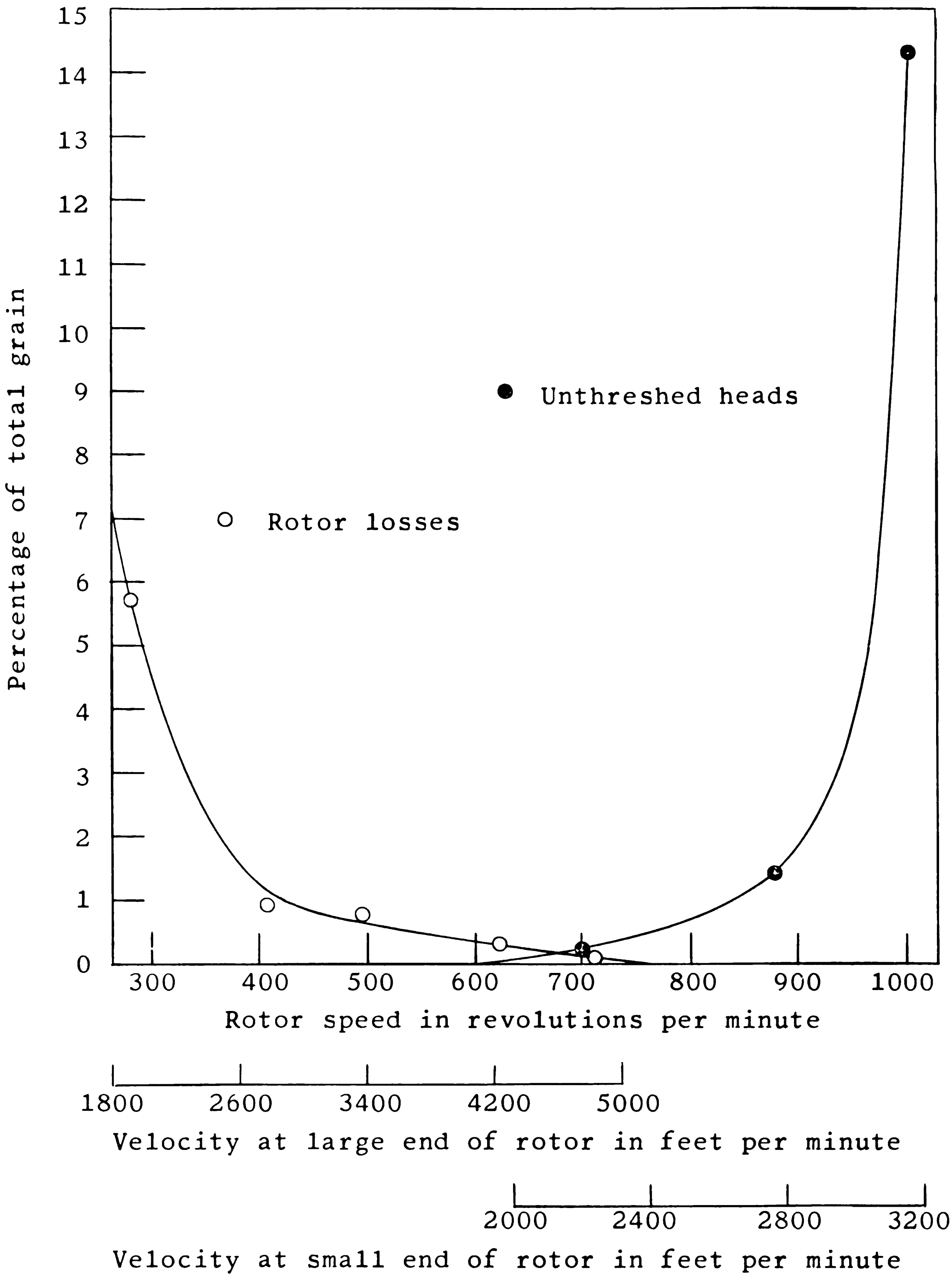

Figure 26. Rotor losses and unthreshed heads for velocities at the ends of the rotor.

(Figure 11). No difficulties were experienced with traction in either of the fields.

Conclusions

From the Review of Literature

1. Increased mechanization will increase food production in Southeast Asia.
2. The increase in food supplies which can be achieved through increased mechanization of rice production is greater than the increase which can be expected from greater mechanization of any of the other crops grown in Southeast Asia.
3. There is a greater need for increased mechanization in harvesting than in any of the other basic operational functions required for rice production.
4. The conditions in Taiwan are more favorable for increased mechanization than in any of the other countries studied.
5. The desirable features for a machine to harvest rice in Taiwan were found to be:
   a. A selling price low enough to permit ownership by individual farmers.
   b. A size compact enough to allow operation in fields with an area of 0.1 hectare.

c. A weight light enough to allow operation over soft surfaces.

d. An arrangement of parts such that straw does not pass through the machine.

e. An arrangement of parts such that straw is not cut until after the grain is removed.

<u>From the Work at Michigan State University</u>

1. To provide the features listed under a, b and c above; the cleaning and finishing operations should not be incorporated in the field machine.
2. To provide the features listed under d and e above; the grain should be stripped from the straw while the straw is still attached to the ground.
3. Cereal grains can be harvested without cutting the straw by using the principle of the conical rotary stripper-beater.
4. Total losses can be held below those of conventional combines.
5. Kernel damage will be nil.
6. Rotor losses can be minimized by high rotor speeds.
7. Unthreshed heads can be minimized by low rotor speeds.

8. A range of peripheral speeds which will keep both rotor losses and unthreshed heads at reasonable levels can be obtained by correct adjustment of rotor angle.
9. Power requirements for the rotor will be less than 1/4 hp when threshing up to ten bushels of rice per hour.

VI. SUGGESTIONS FOR FURTHER WORK

The threshing principle for a small-grain harvester has been established in this thesis. A practical field machine will need a gathering mechanism to handle lodged as well as erect grain. Easily emptied grain pans must be designed. Optimum dimensions and adjustments such as the rotor azimuth angle and clearance mentioned in the discussion section, as well as others, must be determined for best operation and lowest cost. Weight should be reduced as much as possible by the use of aluminum and plastic in construction. The machine should be constructed so that the motive power can be supplied by either the draft animals or the hand tractors already available in Southeast Asia. Rotors could be ground driven using V-belts, mule sheaves, and variable-speed pulleys, or they could be driven by small mounted engines with variable-speed drives. The larger, multiple-row models may be self-propelled with one engine supplying power for all needs.

Another version of this machine should be developed for harvesting experimental and seed-increase plots. This model should be self-cleaning between plots and designed in such a way that the sample can be quickly and easily removed.

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