Design requirements of an experimental combine-harvester

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SEMINAR

DESIGN REQUIREMENTS OF AN EXPERIMENTAL
COMBINE-HARVESTER

- 1964 -

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SYNOPSIS
This seminar begins by outlining the history of wheat cutting and threshing, briefly tracing these operations from early primitive methods to to-day's modern combine-harvester. An equally brief description is then given of the principal components of a combine-harvester.

Following this, several trials conducted to evaluate the performance of combine-harvesters are discussed in relative detail. From this it was revealed that the major cause of damage to grain during threshing was high threshing drum speeds.

An analysis of the characteristics of some experimental machines is then made, followed by a discussion of the design features that would be preferable when considering the building of an experimental combine-harvester.

A summary of the more unusual threshing methods is then presented together with several experimental methods at present in the stage of research. A conclusion was drawn from these, that possibly the best value of further investigations would be gained in perfecting the method most commonly used at present, that is, of the rasp-bar
cylinder and concave method of threshing, since, taken all round, there does not appear to be any superior method at present in use, or is there likely to be in the immediate future.

(ii)
SECTION 1

INTRODUCTION
When an investigation is to be carried out into some problem, and further research is to follow, it is essential that that problem's background should be thoroughly understood. By this it is meant, that a complete history of the problem should be known, together with an awareness of findings established by other people or bodies.

It is in this regard that this seminar has its purpose.

Ever since grain has been prepared, damage has been incurred during threshing. Whilst at the present day, relatively little damage is done compared with that incurred yesteryear, the problem of reducing the percentage damage will remain a problem until no damage is inflicted during its preparation.

It must be understood that there will always be some grain which is damaged, since in the final product, there includes that grain which is damaged in the field because of the natural elements. This source of damage will be dealt with more thoroughly further on.

However, damage produced by machinery can be reduced to an absolute minimum.
2.

Staff at the Wollongong University College are soon to carry out a research programme with the aim to reduce the loss of grain due to damage during threshing to this absolute minimum.

The writer hopes that part of the groundwork, mentioned previously, for the research programme will be covered in the course of this seminar, and that it may be of some value to the staff in their investigations.

Should the reader, upon perusal of this seminar, think the title has been poorly chosen, he may find comfort in the fact that the seminar has its purpose in the preparation, rather than the actual design, of an experimental combine-harvester.
SECTION 2

HISTORY AND COMPONENTS OF THE

COMBINE-HARVESTER
2.1 The History of Wheat Cutting and Threshing

Farm labour, prior to the early 1800s, was considerably cheaper than urban labour, and in being so, did not promote invention pertaining to the land to such an extent as it did in the urban areas. However, this cheap labour position gradually deteriorated and mechanical innovations started to make their presence felt throughout the countryside.

The crop was originally cut manually with the aid of scythes, whereupon it was transported to a barn and spread on the floor. Here threshermen, using a flail, threshed the grain from the ear. The flail consisted of two sticks joined together with a leather thong. The straw was removed leaving a mass of grain, chaff and little pieces of straw and dirt on the barn floor.

The lighter chaff and small pieces of straw were winnowed by opening doors at both ends of the barn thereby setting up a natural draught through the barn. This served as a crude cleaning operation.

The first improvements that came were centred on the threshing. For example, as early as 1636 a thresher was patented which consisted of a series of flails operated by
cranks. The forerunner to the modern thresher was produced by Andrew Meikle in 1786 (Fig. 2.1). His thresher consisted of a revolving drum provided with four beaters which threshed the grain against a concave surface. In 1789 he made an improved machine which made an attempt to sieve the grain at the same time.

The machines were not yet able to cope with any great quantity.

By the turn of the century, threshing machines were being built which had an output such that they were a practical proposition. Initially they were driven manually, but a large step forward was made in 1842 when Messrs. Ransomes, Sims and Jefferies exhibited the first portable steam engine and in the same year combined it with the thresher.

Basically, the thresher has not changed radically from this early machine, although many important minor improvements have been made.

The scythe was succeeded by the reaper, the first of which to be used successfully was produced by the Reverend Patrick Bell. However, conditions did not promote the use of this machine, and it was not until 1860 when mowers were being extensively used that mechanical
equipment could be said to have largely succeeded manual methods of cutting crops.

It is interesting to note that Bell's machine was pushed by horses whereas the mowers, and later the reapers, were pulled by horses.

It is said that the greatest achievement of agricultural engineers is the binder, the first of which was introduced in the early eighteen fifties. This machine cut the crop and bound it into sheafs. Initially they were bound with wire but this was succeeded by twine when in 1879 Appleby introduced the knotter.

All these machines were the forerunners for the combine-harvester. This machine combined the work of the thresher and the reaper. Actually, the first combine type of machine was produced over one hundred years ago, being pushed by horses. This machine, known as a stripper was invented by Ridley, an Australian. It was called a stripper since it did not cut but stripped the grain from the ear. These machines were later drawn by horses as was the case with the reaper. The grain, together with chaff, was stored in a tank on the machine which was later winnowed in a separate machine.
FIGURE 2.2

A Modern Combine Harvester.

a. Reel
b. Cutter Bar
c. Conveyor
d. Threshing Drum
e. Concave
f. Beater Drum
g. Straw Walker
h. Cleaning Shoes
i. Fan
j. Tailings Auger
k. Clean Grain Auger
6.

In 1884, H.V. McKay added a winnower to the stripper thus providing dressed grain in one operation.

The stripper was succeeded by the header, which in Australia was produced by E. Taylor in 1910. This machine cut the plant below the ear, wormed it to the centre of the cutter bar, and then elevated the ears to a single threshing drum.

Having passed through the threshing drum the grain was singled out by winnowing and sieving.

The most modern of to-day's combine-harvesters still employ the basic principles of the Taylor machine although efficiency has been considerably increased by many technical improvements.

2.2 The Principal Mechanical Components of Combine-Harvesters

The following is a summary of the principal mechanical components of a combine-harvester.

(i) The Reel

The reel, item (a) in Fig. 2.2, serves to feed the crop into the harvester, and revolves in the same direction as the ground wheels of the machine.

By far, the majority of combine-harvesters use a reel. It has many adjustments, and if improperly adjusted, can be responsible for costly loss of grain ahead of the cutter bar.
7.

If run too fast, it can thresh grain from the heads, but too slow, it can push grain ahead to the point where the cutter bar cannot cut it. If set too high it can miss down grain whilst if set too low it can carry over straw and drop it ahead of the cutter bar.

The best speed for the reel is about 1-1/4 times the forward travel and the best setting for the slat reel is slightly ahead of the guard or fingers and high enough on the straw to just miss the lowest heads.

In general, the reel has its primary use in down crops, in which case the added cost is payed for in a very short time.

(ii) **The Cutter Bar**

The cutter bar consists principally of a coarsely toothed blade sliding on wearing plates, indicated by item (b) in Fig. 2.2.

Incorrect adjustment of wearing plates and knife clips, and/or a dulled blade will seriously effect the efficiency of the cutter bar. It is necessary that it be properly adjusted and kept clean otherwise wedging will be induced. This increases cutter bar loads, eventually resulting in complete clogging and causing damage to the cutter drive parts.
(iii) **The Platform Auger**

This part of the combine-harvester serves to transport the crop heads and straw cut by the cutter bar to the feeder conveyor. When cut, the crop heads and straw are deposited on a platform and the auger screws it from both ends to the centrally located conveyor in the case of a self-propelled harvester, or to the off-set conveyor in the case of a tractor drawn harvester.

Whilst Fig. 2.2 does not show a platform auger, most harvesters have one installed on them. They are necessary on harvesters whose cutting width is greater than the width of the threshing drum.

The auger can be adjusted up or down to suit the volume of harvested material. For example, it should be raised as high as possible for a heavy volume of dry harvested material, and it should be lowered as much as possible for a very light volume of harvested material, to keep the straw moving to the feeder conveyor.

The auger can also be adjusted fore and aft. For example, in a heavy crop, the auger should be moved to the rear to allow more room onto which the harvested material may fall. The auger should be moved to the front for a light short crop in order to get the material to the centre of the auger.
(iv) **The Feeder Conveyor**

The feeder conveyor, Item (c) Fig. 2.2, takes the harvested material from the platform and feeds it into the threshing drum. The conveyor has adjustment up and down allowing it to conform to the volume of harvested material entering the drum.

(v) **The Threshing Drum and Concave**

There are two principal types of threshing units. One is known as a rasp bar cylinder and concave, and the other a spike-tooth cylinder and concave. Whilst the former is the most common, considerable use is made of the spike-tooth cylinder and concave in America, and in areas in which rice is harvested.

Although the rasp bar unit requires more power than the spike-tooth unit, better results are achieved with the rasp bar type, particularly in handling damp weeds and in that it produces less tearing up of the stems.

The spike-tooth thresher tends to tear up the straw and weeds, resulting in greater separating and cleaning problems.

The concave is provided with adjustments so that the gap between the periphery of the drum and surface of the concave may be set to suit the conditions of the crop being harvested.
In Fig. 2.2, the threshing drum is Item (d), and the concave is shown as Item (e).

It is in this threshing process that most grain is either damaged or lost due to improper settings of drum speed and concave clearance. Thus, the threshing unit will be the item upon which most attention will be focused in designing an experimental combine-harvester.

(vi) **Beater Drum**

This drum lies beside, and on the outgoing side of, the threshing drum, as illustrated by Item (f), Fig. 2.2.

It is normally equipped with four rows of spikes which strip the straw from the threshing drum so that no threshed straw is carried around the threshing drum and hence into the concave again.

Whilst it is not designed to help separate the grain from the straw and other impurities, it does serve this useful purpose.

The drum beaters do a good job of slowing down the crop, since it comes from the threshing drum at quite a speed.

The basic speed of the entire machine, excluding the cylinder, is usually determined by the speed of the beater.
If set too fast, grain loss is likely since the fan speed is increased, resulting in possible blowing out of grain, and also because the straw walkers will "walk" too fast, thus ejecting the straw before complete separation is possible.

(vii) Separating Mechanism

About 90% of the separation of the grain from foreign material is achieved at the instant of threshing, with the aid of the beater drum. This grain, plus relatively minor impurities, goes straight to the cleaning mechanism.

The other 10% of separation is done on what was previously referred to as a straw walker, Item (g), Fig. 2.2. This is a grated platform with its surface covered in a maze of saw tooth sections. It reciprocates back and forth, "walking" the straw to the rear of the machine where it is ejected. As the straw is walked, the grain, and ears which have not been properly threshed, called tailings, fall through the walkers and are transported by conveyor to the cleaning mechanism.

(viii) The Cleaning Mechanism, or Shoes

The semi-clean grain now drops onto a chaffer, Item (h), Fig. 2.2. This is another grate, and on the average,
its openings should be rather wide. Here it is desired to save all the clean grain and tailings.

The broken straw and chaff should not fall through.

The cleaning fan, Item (i) Fig. 2.2, blows the chaff out the rear of the machine, as is the case with the odd lengths of straw which skid over the surface of the grate.

Now only clean grain and unthreshed ears remain. These are dropped onto a sieve (shoe) which only allows the grain to fall through whilst the tailings slide to an auger, Item (j) Fig. 2.2, which transports them back to the threshing drum for rethreshing.

The clean grain is gravity fed to the bottom of the machine to an auger, Item (k) Fig. 2.2, which delivers it to a grain tank on the machine. From here it is either bagged or augered out to a bulk-top moving along beside the harvester. A bulk-top is a grain "tank" on the tray of a truck.

_ix_ **Power Plant**

Various combinations are available for the provision of power to drive the mechanism.

The early horse drawn harvesters obtained power from the road wheels. Tractor drawn harvesters either
gain their power from the tractor itself or by a separate engine on the harvester. Self-propelled harvesters have one engine which serves to drive the machine and its mechanism simultaneously.
SECTION 3

DAMAGE TO GRAIN DUE TO THRESHING
3.1 General

There are two basic types of damage inflicted upon grain during threshing.

Firstly, and the most obvious, is visible damage, that is broken on cracked grain. The second type of damage is invisible damage. In this type, the kernel of the grain is damaged.

Many trials have been made by various people and in general, consideration is given to, firstly drum speed and concave clearance of the machine, and secondly the moisture content of the particular grain to be harvested.

Grain damage is a very serious problem since it renders grain useless as far as germination is concerned.

There are two standard germination tests conducted on visibly undamaged grain. These are the sand test and acid test. The acid test is more sensitive than the sand test since some grain which fails in the acid test will germinate in the sand test.

The sand test is carried out in the following way. The grain chosen for the test is put in a container of moist sand and placed in a refrigerator for five days, regulated to 5°C. At the end of this time the grains are removed and placed
in a "germination room" regulated to 60°F where they remain for the duration of the test. Counts of the germinated grains are usually made after say seven days.

The following is the basic procedure for testing grain by the acid test. A quantity of 50 cc of 1/2% solution of tetrazolium chloride is put in a 250 cc flask and heated to 45°C. The grains to be tested are introduced to the solution and the flask is connected to a vacuum whereupon the pressure is reduced until the solution just boils. After 10 to 15 minutes the grains are removed and a record of the number of grains whose embryos turn red is made.

In order that figures produced by various bodies are relative, all tests carried out should abide by the rules laid down by the International Seed Testing Association(12).

The procedures for sand and acid testing described above conform to these rules.

From the results obtained from various trials, certain drum speeds, concave settings and desirable moisture contents have been determined to produce the least amount of wastage.

However, as mentioned previously the least wastage should not necessarily be considered to be entirely caused
by the machine. Grain may be damaged in the field by such elements as weather and insects. These already damaged grains are normally included in the figures obtained after threshing. Much time would have to be spent in hand rubbing sections of a crop and determining the percentage wastage before threshing, prior to the crop being harvested.

This is generally impracticable, and hence results given usually include this damage not due to the threshing machine.

3.2 Drum Speed Vs Concave Clearance

One particular trial(16) which endeavoured to establish a relationship between grain damage and varying drum speeds and concave settings was conducted in New Zealand with quite pointed results. For this trial the moisture content was the constant, it being fairly low at from 14.0% to 14.8%. It was intended that ordinary production machinery would be used in the trial. However it was found that this had several drawbacks, such as cleaning after each test. So a special machine was produced which simulated the production machines but incorporated those aspects which because of their absence in the production machines, rendered them unsuitable.
<table>
<thead>
<tr>
<th>Concave Clearance, inch.</th>
<th>1400</th>
<th>1350</th>
<th>1300</th>
<th>1250</th>
<th>1200</th>
<th>1150</th>
<th>1000</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8</td>
<td>16.0</td>
<td>12.2</td>
<td>5.7</td>
<td>6.3</td>
<td>9.5</td>
<td>6.8</td>
<td>2.3</td>
<td>8.4</td>
</tr>
<tr>
<td>5/32</td>
<td>13.3</td>
<td>5.5</td>
<td>6.7</td>
<td>5.7</td>
<td>3.0</td>
<td>4.5</td>
<td>2.8</td>
<td>5.9</td>
</tr>
<tr>
<td>3/16</td>
<td>12.5</td>
<td>6.2</td>
<td>6.5</td>
<td>4.2</td>
<td>5.0</td>
<td>6.2</td>
<td>4.2</td>
<td>6.4</td>
</tr>
<tr>
<td>7/32</td>
<td>11.7</td>
<td>3.0</td>
<td>6.2</td>
<td>5.2</td>
<td>3.0</td>
<td>6.3</td>
<td>2.2</td>
<td>5.4</td>
</tr>
<tr>
<td>1/4</td>
<td>11.2</td>
<td>5.0</td>
<td>6.5</td>
<td>4.5</td>
<td>2.5</td>
<td>4.0</td>
<td>1.8</td>
<td>5.1</td>
</tr>
<tr>
<td>Mean</td>
<td>12.9</td>
<td>6.4</td>
<td>6.3</td>
<td>5.2</td>
<td>4.6</td>
<td>5.6</td>
<td>2.7</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 3.1**

Visible Damage to Wheat Seed, %.
Details of this machine are included in Section 4. One quarter of an acre of cross seven wheat was used in the trial over a three year period, there being three samples taken at each setting. Mean values were then taken as the result for each setting.

This procedure was repeated over the range of settings as shown in Table 3.1 for the first test of the trial.

These results indicate that for every 50 r.p.m. increase in drum speed, the percentage visible damage increases by $0.95 \pm 0.32$. It is noted that in this test only visible damage was considered.

In the second test of the trial, the threshed grain was also checked for invisible damage.

The total effect of visible damage and invisible damage is known as wastage.

It should be noted that invisible damage is expressed as the percentage germination of visibly undamaged grain.

Percentage wastage is derived from the following formula:

\[
\text{Percentage wastage} = x + \frac{(100-y)(100-x)}{100}
\]
### FIGURE 3.1

**Effect of Drum Speed and Concave Clearance.**

![Graph showing visible damage and germination of visibly undamaged seed as a function of concave clearance and drum speed.]

<table>
<thead>
<tr>
<th>Concave Clearance, in.</th>
<th>1/8</th>
<th>5/32</th>
<th>3/16</th>
<th>7/32</th>
<th>1/4</th>
<th>9/32</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible Damage, %</strong></td>
<td>12.3</td>
<td>10.3</td>
<td>8.9</td>
<td>8.0</td>
<td>7.6</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Germination of Visibly Undamaged Seed, %</strong></td>
<td>93.7</td>
<td>94.1</td>
<td>94.9</td>
<td>95.0</td>
<td>94.7</td>
<td>95.7</td>
</tr>
<tr>
<td><strong>Wastage, %</strong></td>
<td>17.6</td>
<td>15.4</td>
<td>13.5</td>
<td>12.4</td>
<td>12.5</td>
<td>11.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drum Speed, R.P.M</th>
<th>1200</th>
<th>1100</th>
<th>1000</th>
<th>900</th>
<th>800</th>
<th>700</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Visible Damage %</strong></td>
<td>18.8</td>
<td>19.1</td>
<td>12.0</td>
<td>8.2</td>
<td>2.5</td>
<td>2.5</td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Germination of Visibly Undamaged Seed, %</strong></td>
<td>94.6</td>
<td>90.9</td>
<td>92.7</td>
<td>94.2</td>
<td>96.9</td>
<td>94.9</td>
<td>98.5</td>
</tr>
<tr>
<td><strong>Wastage, %</strong></td>
<td>23.2</td>
<td>26.4</td>
<td>18.4</td>
<td>13.6</td>
<td>5.5</td>
<td>7.4</td>
<td>2.2</td>
</tr>
</tbody>
</table>

### TABLE 3.2

*Wheat Threshing Trials*
**Effect of Drum Speed and Concave Clearance**

**TABLE 3.3**

<table>
<thead>
<tr>
<th>Visible Damage, %</th>
<th>7.7</th>
<th>8.3</th>
<th>8.5</th>
<th>7.2</th>
<th>6.0</th>
<th>6.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination of Visibly Undamaged Seed, %</td>
<td>90.4</td>
<td>89.9</td>
<td>90.6</td>
<td>90.9</td>
<td>93.0</td>
<td>93.3</td>
</tr>
<tr>
<td>Wastage, %</td>
<td>16.0</td>
<td>16.9</td>
<td>16.8</td>
<td>15.2</td>
<td>12.3</td>
<td>12.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drum Speed R.P.M.</th>
<th>1100</th>
<th>1000</th>
<th>900</th>
<th>800</th>
<th>700</th>
<th>600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Damage %</td>
<td>19.9</td>
<td>10.0</td>
<td>8.1</td>
<td>5.0</td>
<td>0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>Germination of Visibly Undamaged Seed, %</td>
<td>78.7</td>
<td>88.0</td>
<td>92.6</td>
<td>92.6</td>
<td>97.3</td>
<td>98.6</td>
</tr>
<tr>
<td>Wastage, %</td>
<td>36.9</td>
<td>20.9</td>
<td>14.9</td>
<td>11.9</td>
<td>3.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>
where \( x = \) percentage of visibly damaged seed.

and \( y = \) percentage germination of visibly undamaged seed.

The results for the second test are shown in Table 3.2 and Fig. 3.1.

It can be seen that for each \( \frac{1}{32} \) inch decrease in concave clearance, the percentage wastage increased by \( 1.16 \pm 0.29 \) and the percentage visible damage by \( 0.93 \pm 0.20 \). For each 100 R.P.M. increase in drum speed, the percentage visible damage increased by \( 3.51 \pm 0.42 \), the percentage germination decreased by \( 0.85 \pm 0.35 \) and the percentage wastage increased by \( 4.07 \pm 0.59 \).

The third test of the trial, executed the following year (moisture content of 14.8\%), gave the results as outlined in Table 3.3 and Fig. 3.2.

For each 100 R.P.M. increase in drum speed in this test, the percentage visible damage increased by \( 3.66 \pm 0.62 \), the percentage germination decreased by \( 3.67 \pm 0.67 \) and the percentage wastage increased by \( 6.85 \pm 1.11 \).

From the trial as a whole, it can be seen that high speeds are the main cause of wastage. Concave clearances only influenced visible damage at high drum speeds and poor germination was only given at high drum speeds. Varying concave clearances had little effect on visible and invisible damage at low drum speeds.
A check was made, during the trial, of the threshing efficiency by rethreshing the straw with the machine adjusted so that the remaining seed was removed. This was weighed and expressed as a percentage of the total weight of seed obtained from the original sample.

It was found in these checks that the loss of seed was negligible over 700 R.P.M. Even at 600 R.P.M. and the widest clearance, it did not exceed 7.1/2%. This indicated that a low damage rate was not being obtained at the expense of unduly low threshing efficiency.

To get some indication of maximum values of visible damage and germination loss due to causes other than threshing, an inspection of the magnitude of the quantities recorded for less severe combinations of speed and clearances was made.

Examination showed that visible damage due to other causes was probably not more than 2.5% in the first test, 1% in the second and 1% in the third test of the trial. Similarly it showed that the germination of the unthreshed sample was probably not less than 98% in the second and third tests.

The general conclusion that can therefore be drawn from this trial is that to get the necessary severity of threshing in a low moisture content wheat crop, reduce the
FIGURE 3:3
Effect of Drum Speed and Moisture Content.
concave clearance. Do not gain this end by increasing the drum speed too much.

3.3 Drum Speed Vs Moisture Content

Having established that the concave clearance has little effect on grain wastage the same body in New Zealand carried out a trial(15) which constituted varying the drum speed and moisture content but maintaining a constant concave clearance of 3/16", and again the grain tested was wheat.

For this trial, it was found that direct threshing was impracticable due to uncertain weather conditions and, possibly, uneven drying of the seed.

The method used was to cut random sections of the crop with a binder and to bring it in to undercover storage, allowing it to dry naturally to an equilibrium moisture content. Then samples were artificially moistened in a humidity room which allowed the samples to be raised in moisture content to between 12 and 26%.

Six or seven samples each weighing two pound were taken at each moisture content for each drum speed employed. The percentage wastage was again determined as previously indicated.

Graphs drawn from results obtained in the trial, which constituted two tests - one test being made in each of two consecutive years - are as shown in Fig. 3.3.
From these results it can be seen that the drum speed, as was the case with the previous trial, is the main cause of wastage.

Whilst inconsistent results were obtained for visible damage in the two tests as far as moisture content was concerned, a very definite trend was noticed for germination.

In the first test of this trial a very significant drop in visible damage was observed in reduction of drum speed. The single check at 1000 R.P.M. confirmed the trend. In the test the following year the characteristic of reduced visible damage with increased moisture content (as was the case in the first test) was not significant. However, with reduced drum speed the visible damage was again reduced.

Germination decreased with both increasing drum speed and moisture content in both tests.

The overall effect in terms of wastage was that with increasing drum speed and moisture content the percentage wastage was also increased.

For this trial, the conclusion is, that best results are obtained at low drum speeds and low moisture contents, the severity in threshing being obtained by reducing the concave clearance as established in the previous trial.
In a trial carried out by staff of the N.I.A.E.\textsuperscript{(1)} in which a survey was made to investigate the influence of drum speeds, concave clearances and moisture content, the trend observed closely matched that which was established in the trials discussed on the previous pages.

For this survey conducted by staff of the N.I.A.E., samples were taken from commercial machinery actually at work, the working conditions being those under which the farmers would normally operate.

Numerous trials have been carried out to establish these relationships and the findings have been unanimous particularly as far as wheat is concerned.
SECTION 4

SOME EXISTING EXPERIMENTAL MACHINES
Successful field trial results, using standard production combine-harvesters, are obtained only after slow and painstaking setting and cleaning operations. Therefore, special machines have been built to enable quick and accurate settings of the adjustable parts, and to enable quick cleaning.

4.1 Tractor Drawn Machine

One such machine\(^{14}\) which has been built, was used in the trials from which the results given in Section 3.2 and 3.3 were obtained.

This machine did not have a reel and the cutter bar was relatively narrow at 5'/4 inches. The feeder conveyor was of the chain and slat type and discharged the harvested material into an 18 inch wide, 18 inch diameter, 8 rasp bar threshing drum.

The drum was driven by an infinitely variable double-belt drive which gave a range of drum speeds from 0.36 to 1.4 times the engine speed, that is, from 350 to 1800 R.P.M.

A transmitting type electrical tachometer was fitted to show the drum speeds at any given instant.

The drum being fixed, required that the concave clearance should be obtained by shifting the concave itself. The front and rear of the concave was moved simultaneously by the same amount by means of a screw and crank mechanism.
The concave clearance was easily read by means of a graduated scale attached to the mechanism, the calibration of the scale being determined with the aid of feeler gauges to ensure accurate adjustment.

A fixed baffle plate at the rear of the threshing drum reduced the velocity of the material that was discharged from the drum and allowed it to fall on to a set of four straw walkers of 24" in width and 84" in length. A reciprocating tray underneath the walkers was used to convey the material that passed through the straw walkers to the front of the riddle through an adjustable opening. The sloping bottom of the riddle box caused seed to flow toward one point and then fall into a tray underneath.

The machine was self-cleaning, since its grain conveyor consisted of a reciprocating tray, previously mentioned, which had no ledges or places to retain any seed. By replacing the cross auger with a sloping riddle, cleaning problems were further reduced.

Since there was no returns auger, and that the flow of material was reduced to ensure thorough collecting of grain (thereby inducing impurities), the collected grain was not as clean as that collected in production machines. However, this must be accepted since further cleaning was possible later, and the emphasis was to be on reclaiming as close as possible to 100% of the harvested grain.
The only place where seed and other material remained, was in the bottom of the concave against the concave bars. The power for the machine was provided by a 17 H.P. air-cooled petrol engine.

4.2 Self-Propelled Machine

A self-propelled combine-harvester has also been built. This machine incorporated a reel with height and lateral adjustments and was driven from the threshing mechanism, thus rendering its speed relative to the speed of the mechanism. Since best reel speeds are relative to the ground speed of the harvester, it would be preferable to drive the reel from, say, one of the front wheels.

The effective cutting width of the cutter bar was 5 feet and adjustment of the cutter bar for height (from ground level to 3 feet) was provided hydraulically.

A platform auger was provided with removable end covers to facilitate cleaning. The feeder conveyor was of the conventional slat type.

The threshing drum was 16 inches in diameter and fitted with eight rubber-faced bars; metal rasp bars could also be fitted if required.

The concave was also rubber-faced. The concave clearance was attained by changing the position of the drum shaft bearings, which allowed a clearance from zero to 2 inches.
Drum speeds were not infinitely variable, but rather, were obtained by using different drive sprockets.

The drum and concave were easily exposed for cleaning by means of a hinged cover over the drum and by hinging one end of the concave.

Semi-conventional separation was incorporated. For cleaning, no tailings return mechanism was provided, instead, they were delivered to a tray and kept for research purposes or manually re-fed through the threshing drum.

The cleaned grain was collected in trays at the base of the harvester, so designed to facilitate easy pouring into bags, whilst covers over the straw walkers and sieves were easily removed to enable easy cleaning.

A conventional fan was fitted with adjustments for amount and direction of air flow.

A Ford 4-cylinder, 12 H.P., water cooled petrol engine provided the power for the entire machine.

The ground speed of the machine was infinitely variable between zero and 4 miles per hour, being attained by transmitting the drive between two differentials by means of a roller chain.

This particular experimental combine-harvester was able to be cleaned by two men in 10 minutes and generally proved quite successful.
4.3 A Rethresher Machine

Another interesting machine has also been developed. It was called a rethresher$^{(9, 10)}$ and was used in combine-harvester testing.

During a combine-harvester test it is necessary to measure grain loss. In order to estimate those parts of the total loss caused by incomplete threshing at the drum and by incomplete separation at the straw walkers and sieves, samples of efflux from the test combine-harvester have to be obtained. These samples are then sorted for loose grains and incompletely threshed heads. Previously, these operations involved hand feeding of a small threshing machine and it was for the purpose of speeding up this work and making possible the handling of larger samples, that a rethresher was designed.

It was a self-propelled machine, fitted with a hydraulic crane for weighing (to estimate yields) straw and grain samples with a minimum of movement from the point where they were delivered.

To collect the straw and chaff leaving the combine-harvester for testing in the rethresher, the combine-harvester was fitted with two 6 foot wide calico rolls. One roll was situated just below the straw ejection opening and the other below the chaff ejection opening. The rolls were 50 yards long
Operation 1.
½ Mile per Hour.

Operation 2.
Stationary

Operation 3.
Stationary

FIGURE 4.1
The Paths of Material through the Thresher in the Three Operations for Which it is Used.
and at the commencement of the test, two men, one at each end of the spools, pulled the ends of the two sheets onto the ground and held them there. Simultaneously a third man at the grain delivery point, commenced to collect the grain in a special sack. The run terminated when the ends of the sheets left the spools and correspondingly, at that instant the grain sample was terminated.

The rethresher then came to the start of the calico sheets and proceeded to wind the two sheets in as it moved slowly forward (Operation 1, Fig. 4.1). The material off the top sheet (straw) was passed direct to the straw walkers and the chaff on the bottom sheet fell into a large trough suspended beneath the feeding head. The straw leaving the rethresher was allowed to fall onto a third calico sheet suspended at the rear and which was allowed to unwind as the rethresher moved forward.

When the two sheets had been wound in, the grain in the drawer beneath the rethresher was emptied into sacks. This grain represented the fraction of the total loss due to loose grain having been carried over with the straw.

With the rethresher stationary, the chaff was then poured from the collecting trough into the feed aperture above the straw walkers (Operation 2, Fig. 4.1). The grain
thus recovered represented the loss due to grain having been carried over the sieves with the chaff. The chaff leaving the rethresher was collected in a large hessian sheet and was subsequently poured onto the straw lying behind the rethresher on the third calico sheet. With the rethresher still stationary, the straw on the third sheet was then passed through the drum of the rethresher and allowed to fall onto a large square canvas sheet placed beneath the rear of the machine (Operation 3, Fig. 4.1). The grain collected in the drum was that which was contained in the unthreshed heads (or part heads) and was regarded as drum loss.

All grain samples and straw samples were weighed and the percentage losses due to the various components calculated.
SECTION 5

DESIGN FEATURES OF AN EXPERIMENTAL COMBINE-HARVESTER
In this section an attempt will be made to isolate some of the features which directly concern the building and performance of an experimental harvester, and to discuss the principles of operation of some non conventional experimental methods of threshing.

5.1 Design Features of an Experimental Conventional Combine-Harvester

In practically every article published which deals with carrying out trials to evaluate the performance of combine-harvesters, particular mention is made of the ease of cleaning of the machine after each individual test, so that the next test's efficiency figures are as near as possible, an accurate evaluation of its performance. In fact this is the reason why several experimental machines have been built in preference to doing trials with ordinary production machinery. In almost all cases the body concerned would have preferred to carry out the trials under the most natural conditions possible.

This means that the experimental harvester should be as self-cleaning as possible, supported by provision of easily removable cover plates around those parts of the machine that are likely to retain material at the conclusion of a test. These parts would be the concave, platform, walkers and cleaning sieves (or shoes).
Discharge augers are usually replaced by pans, as is the case of the tailings auger. Damage inflicted by these augers could be the subject of a separate investigation. On the whole, damage due to this cause accounts for a very small percentage of the total damage incurred by the machine.

The machine should have a means of quickly and accurately adjusting the drum speed, the best method would probably be to incorporate an infinitely variable gearbox. Correspondingly, a direct reading indicator should be attached to show the correct drum speed at all times.

The machine should also be provided with a means for quickly adjusting the clearance between the drum and concave, in such a manner that both the front and rear of the concave are moved and the clearance is kept equal at each end of the concave. A further direct reading indicator to show the concave clearance should be incorporated.

For maximum versatility, the experimental machine should be equally suitable for direct heading and stationary work.

Consideration should be given to include in the design, a method of quick removal and replacement of the drum and concave, so that time is not lost in changing drums and concaves of different design.
FIGURE 5.1


Pounds Straw Per Minute.
Experiments (6) have revealed that the best reel speed ratios under all operating conditions are achieved by driving the reel from a ground wheel or from some shaft whose speed is proportional to forward speed. With this in view the experimental machine would be best equipped in this way.

5.2 Power Requirements of Combine-Drives

The following is a summary of the power requirements of combine-harvesters (14). Whilst the figures pertain to production rather than experimental machines, they give an indication of relative power requirements of the various components.

In wheat, about 50% of the power required to drive a combine-harvester is absorbed by the threshing drum. The rate of flow of material into the drum has a distinct effect on the power requirements as can be seen in Fig. 5.1. The machine on which these figures were established, had a 6'8" width of cut, together with a 5 ft. drum of the rasp bar type, operating at 1000 R.P.M. and requiring friction power of 0.5 H.P.

At a rate of 30 lb. per minute flow of threshed straw, the power had increased to 1 H.P. When the rate was 60 lb. per min., the power required was 2.9 H.P.
FIGURE 5.2

Power Distribution for a 7ft. Combine in Wheat.
This indicates a rapidly increasing power requirement as the speed of travel is increased, or rather as the rate of flow is increased. In other words, if the cutter bar was increased from 5 ft. to 7 ft., and all other factors remained the same, the power required would not increase as the ratio of cut but would double. This relationship needs to be considered when the cutter bar is to be increased without appropriate changes in the cylinder.

Fig. 5.2 outlines the requirements of all the components of a harvester. The harvester on which these figures were established was not a self-propelled type and therefore no allowance has been made for traction.

The cutting, cleaning and separating mechanisms together with the reel and elevator all required relatively very little power and their requirements did not increase greatly with increasing flow rate.

The estimated total horsepower curve allows for frictional losses throughout the machine.

5.3 Non-Conventional Threshing Methods

This section can be further sub-divided into, firstly, uncommon methods that are in use and secondly, methods that are in the experimental stages.
5.3(1) Existing Uncommon Threshing Methods

Mention has already been made of the very common rasp bar cylinder and concave. To a lesser extent mention has been made to the spike-tooth cylinder and concave, and it has been indicated that this type of threshing unit is especially suitable to the harvesting of rice. It is also quite useful in the harvesting of windrowed beans.

One type that has not yet been mentioned is the angle-bar cylinder and concave. The cylinder is equipped with helically mounted, rubber faced, angle-iron bars rather than corrugated bars as in the rasp bar type. The concave of the angle-bar type is ordinarily fitted with a rubber-faced "shelling plate" and steel-jacketed rubber bars. Of later years, however, the angle-bar arrangement has faded from the scene since it is basically similar to the rasp-bar cylinder and concave but is not quite as effective.

With some podded crops, a large part of the threshing can be done with a squeezing action, a rubbing action, or a combination of the two. Rubber covered steel rolls have been used to a limited extent for threshing beans. An experimental bean combine (2) developed in America, had a
series of three pairs of rubber-covered rolls, operating at peripheral speeds of 250 to 300 F.P.M., instead of a conventional cylinder. Threshing in this machine was entirely due to squeezing and rubbing of bean pods. Satisfactory threshing was obtained without appreciable seed damage (3). A combination of one rubber-covered roll and one steel roll (known as flax rolls) is sometimes installed just ahead of the conventional cylinder when harvesting podded crops such as flax and alfalfa. The upper roll is spring loaded and is driven about 10% faster than the lower roll to give a rubbing action in addition to the squeezing effect. In addition to their threshing action, flax rolls tend to hold the material against the pulling action of the cylinder, thus promoting more uniform feeding.

Wear on the rubber faced components seems to have made this type of threshing quite expensive.

5.3(2) Threshing Methods in the Experimental Stages

The first method that will be discussed will be that using two cylinders. It has been shown that the main mass, including the better grain, becomes separated from the ear with relative ease. High speeds are not, therefore, needed for the first drum, but the grain coming from it must be eliminated from the threshing process before the grain
mass passes to a second drum, which must have a considerable speed in order to ensure complete threshing.

These ideas have not so far been put into practice although investigations\(^{17}\) have been carried out that suggest the idea is quite sound. The principal problem preventing the idea being put into practice is, as mentioned, that there is extreme difficulty in effectively preventing all the grain threshed in the first cylinder from passing to the second.

Because of the evidence that high peripheral speeds lead to excessive grain damage, this method has far reaching possibilities. In fact, it has been found that the total damage for both stages of threshing is 1.5 to 2 times less than in conventional one-stage threshing.

A second method in the experimental stages is that which employs two co-axial truncated cones, one within the other\(^{18}\). This arrangement has produced a threshing efficiency of over 99% at all rotor speeds and the separating efficiency was comparable to that accomplished with conventional threshers.

The outer cone of a threshing unit of this type built for experimental purposes, was fabricated.
perforated sheet metal and was the stationary member. The inner cone, which was the rotating member, consisted of eight rubber-covered angle-bar beaters of the type discussed earlier in Section 5. The clearance between the rotor and the stationary member was of the order of 1/2 inch, but could be varied. The material was fed from the truncated end, into the annular space between the cones, and moved along a helical path on the inner surface of the stationary cone towards the base of the cones where it was discharged by centrifugal force. The seed passed through the perforations in the outer cone.

It is difficult to imagine, however, how a unit of this type could be adapted to a combine-harvester, and in fact this is the main reason why it still remains in the experimental stages.

A further method which has undergone experimentation is that type of threshing produced by centrifugal force as provided by non-impulsive acceleration which would result if a head of grain were suddenly accelerated without impact.

In the experiment\(^{(19)}\), a batch-type centrifugal thresher that was capable of threshing 50 to 100 heads at the
one time was built. It was designed to permit both the exertion of high forces on the heads and the continuous collection of threshed grain.

The rotating threshing head was completely enclosed by plywood which was lined with rubber padding. An electric motor driving through a variable-speed transmission was capable of rotating the threshing head at from 600 to 4500 R.P.M. The housing bottom was tapered down the centre to allow the threshed grain to drain to the outside and be collected.

In the tests, it was found that complete threshing could be accomplished with only minor visual kernel damage for wheat under 35% kernel moisture content. At high moisture contents, this method was found to be lacking.

Time prevented the procuration of literature on yet another type of threshing, that of the endless band threshing(7). This method appears to have concentrated on the concept of integral threshing and separation. It makes use of a rubberised canvas belt carrying rubber rasp bars, which is passed over two rollers and close to an open metal concave of considerably greater than normal length. Largely
due to this long concave and the vibration of the belt, its separation qualities are of a high order. In wheat, only 2% of the total grain remained in the straw when it left the concave. However output was on the low side and the rate of wear was rather high.

5.4 Photography of the Threshing Process

Theories on the way the threshing drum worked were originally based on simple observation of its action and its effects on the crop being threshed.

In view of the speed at which the drum works, it is not surprising that comprehension was incomplete and some of the conclusions incorrect.

Perhaps the most important mistake was the assumption that the beater bars rubbed the grain out against the concave, and that the ribs, alternating in direction on the bars, rubbed first one way and then the other to produce an action similar to rubbing grain from an ear by hand. It was also commonly held that the crop was threshed against a mat of straw moving between the beaters and the concave.

However neither of these theories is completely true as has been verified by high speed cinephotography (3,200 frames per second).

In the first place the drum will work if the clearance between the beaters and concave is too wide for an
ear to make contact with both at the same time, and, in
the second, the mat of straw in the drum during threshing
is frequently too thin to provide an effective backing
against which the beaters can work.

The basic principle on which the drum relies is
the shattering action of the fast-moving beaters on the
relatively slow-moving crop. This is a random process,
each ear receiving an indefinite number of impacts before
threshing is complete.

An appreciation of the principle, due largely to
cinephotography, has gone a long way to explain why
particular adjustments to the drum have the effects they do.
SECTION 6

CONCLUSIONS
From trials and investigations carried out all over the world, there seems to be little doubt that the major cause of damage imparted to grain during threshing is closely related to drum speed, accentuated by certain conditions of concave clearance and grain moisture content.

Since this damage can be kept at quite a low minimum under optimum operating conditions, plus the fact that alternate methods of threshing to the conventional single-stage system are still far from being economical methods, it appears that most benefit would be gained in further research and improvement of the conventional rasp-bar cylinder and concave threshing operation.

There is room for improvement too, in the effectiveness of separation and cleaning of the grain in combine-harvesters.

Threshing is always most pronounced in the early part of the concave of a rasp-bar drum, and, in the case of cereals and other easily threshed crops, is frequently completed in the first few inches. At this point the crop is moving more slowly relative to the beaters and consequently the shattering action is more pronounced than later on when it approaches beater speed more closely.
TABLE 6.1

The Effect on Separation Efficiency of Changing Concave "Wrap" (Length)

<table>
<thead>
<tr>
<th>Concave Length in.</th>
<th>6 1/2</th>
<th>13</th>
<th>19 1/2</th>
<th>26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of total grain Separated %</td>
<td>57.4</td>
<td>71.6</td>
<td>84.0</td>
<td>90.7</td>
</tr>
</tbody>
</table>
In these cases the extra length of concave usually fitted is unnecessary for threshing, and in that it breaks straw, uses power, is a disadvantage, but it is most important in separation (8).

This can be seen clearly in Table 6.1. Although the grain should be removed from the path of the beaters as early as possible in order to reduce damage, it is clearly desirable to take advantage of the open state of the crop in the drum to achieve separation.

In order to exploit this feature to the full, the aim in concave design should be to get the crop threshed as early in its passage through the drum as possible and then obtain maximum separation.

One can see that there still remains scope for research on the conventional machines and thus justification for building an experimental combine-harvester to assist in these investigations.
APPENDIX 1

Bibliography


11. Hutchison, T.; "Machinery on the Farm."


APPENDIX 2

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