A PROTOTYPE COMBINE FOR GRAIN HARVESTING

BASED ON INTERNAL PNEUMATIC TRANSFER

by

Ian Gilbert Ridgway

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Department of Agronomy and Farming Systems
The University of Adelaide, Australia

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DECLARATION

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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Ian Gilbert Ridgway

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PATENTS APPLICABLE

The following Patents apply to machines described in this thesis

"Resilient Tapered Thresher", I.G. Ridgway and The University of Adelaide,

Australian Letters Patent No: 1592117 dated 13/3/81

British Letters Patent No: 1592117 dated 21/2/78

U.S. Patent App. No: 4,185,692 dated 22/2/78

Canadian Patent App. No: 1,068,577 dated 23/2/78

German Letters Patent No: 2807945.0 granted 24/2/78

Japan Patent No: 1160116 dated 24/2/78

"Articulated Side Draft Implement", I.G. Ridgway and The University of Adelaide,

Australian Letters Patent No: 541022 granted 16/12/1981

"Crop Cutter", I.G. Ridgway and The University of Adelaide,

Complete Specification lodged in the Commonwealth of Australia on 20/5/82

ABSTRACT

Development of improved methods of harvesting standing crops *in situ* has been a major challenge to farmers since the Vallus was first used around 70 AD in Gaul. Mechanical harvesting has been developed to the current large, cumbersome combines with electronic controls and numerous components and moving parts. These are still very dependent on dry stems and heads to harvest, thresh and clean grain crops, which are cut no lower than 150 mm above ground level. Conventional combines are relatively complex, heavy and difficult to clean and, despite significant design for safety, are still the causes of many farm accidents.

The aim of this project was to build a combine with a reduced number of components, a maximum of five moving parts, which could reap most if not all crops from ground level upwards and be self-cleaning. The threshing action could be compared to a human hand picking heads of grain wherever they were growing, threshing the heads as gently as two hands rubbing the grain from the chaff, and cleaning the chaff from the grain as gently as a puff of human breath, so carefully that all the grain is retained.

This thesis begins by tracing some of the history of grain harvesting methods and the search for a simpler, safer and more efficient combine design is described through an account of the development of working prototypes. This account is spread over three chapters that describes the materials and methods used in the process (Chapter 3), the various tests undertaken and their results (Chapter 4), and a final discussion of the prototype and the likelihood of its commercialisation (Chapter 5), which is a summary of this project and a look into the future.

In summary the development process began with first developing a soft thresh conical thresher, the Resilient Tapered Thresher (RTT), which separated grain from heads, and an air aspirator, which drew away the dust and chaff. The next stage was to use a Ridley type harvesting front to pick the ripe heads and convey them by throwing and blowing the harvested and partly threshed material to the RTT. This concept could reap cereal breeders' plots at around 80 plots per hour with low losses of grain. The discovery, by serendipity, of the Silsoe stripping header principle and the application of it to the combine, in place of the Ridley front, has made possible the building of

three plot combines which are able to combine up to 300 4m^2 plots per hour for wheat breeders.

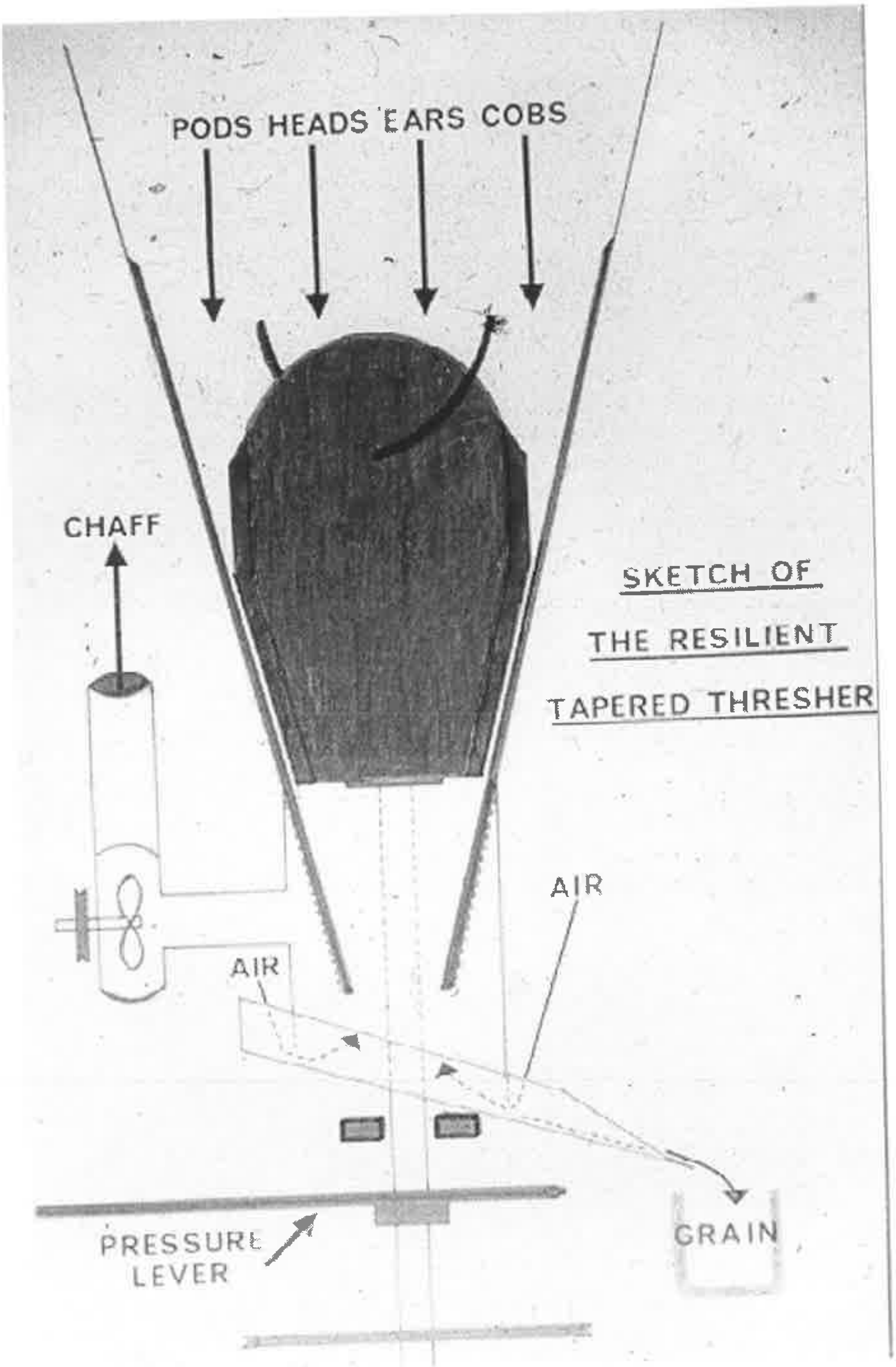

Figure 0.a The RTT and cleaning concepts.

GLOSSARY

1. *Binder* - A reaper which takes the cut material away from the crop, packs and ties it in sheaves automatically when a predetermined sheaf size has been reached.
2. *Chute* - The enclosed air space between the stripping/header and RTT.
3. *Comb* - Divides the standing crop into rows which are held while the knife cuts or beaters strip the crop at the required height.
4. *Combine* - A combination machine which harvests, threshes and cleans grain.
5. *Elevators* - Take the harvested crop from the auger to the thresher and later grain up from below the sieves to be released into the grain tank.
6. *Fan* - The high speed extractor fan which draws the chaff and dust away from the grain.
7. *Fingers* - The comb units which divide the standing crop.
8. *Heading stripper* - The upward and backward rotating drum with five spokes, on which are carried plastic arrowhead fingers (developed at Silsoe Research Institute, UK) looking from the front, the rotation is upward.
9. *Knife* - The knife has many triangular serrated blades which cut the heads off the straw.
10. *Machine A* - 4 row plot harvester, 3 moving parts built in 1978-79, incorporating a Ridley type stripper/header with forward, down rotating beaters plus an RTT and fan.
11. *Machine B* - 6 row plot harvester incorporating a Silsoe plastic arrowhead, backward rotating heading stripper an RTT and a fan.
12. *Mono construction* - Chassis and body are built as one inseparable unit.
13. *Pump* - Hydraulic pump which provides oil at high pressure to drive hydraulic motors.
14. *Reaper* - Now called a mower with an oscillating knife, it left the cut crop behind or away from the crop in a row.
15. *Rotor* - Main moving component of the Pneuflo with the tapered thresher, air and straw extractor on one shaft.

16. *RTT* - Resilient Tapered Thresher, a thresher of grain seeds, cobs, kernels and all other seed heads where the conical, slow moving, soft rubber faced rotor rolls the unthreshed heads, pods, kernels in shells, corn on the cob and other seed pods against the hard rubber face of the internally lined stator. The result is a soft thresh, similar to two human hands, causing minimal damage to the threshed material. The vertical floating action of the rotor allows threshing pressure to be maintained for varying crop amounts by varying the weights on the pressure lever. (See Figure a).
17. *Scutcher* - The revolving component which strikes the ears from the stem.
18. *Separation* - Cleaning the grain by removing the chaff, straw and weed seeds from the grain.
19. *Sieves* - Trays with holes in them on to which the grain falls. The sieves oscillate and the fan blows or sucks away the chaff and dust.
20. *Stator* - The fixed outer truncated conical sheath of metal, lined with resilient material in the threshing area, which enclosed the air and straw extractors above and the resilient tapered thresher below.
21. *Stooks* - A group of vertically arranged sheaves (from a binder) standing as close together as possible to facilitate drying, ripening, curing and to reduce weather damage.
22. *Straw walkers* - A set of long narrow members (harps) for removing grain from straw. They are mounted behind the thresher and have a lifting/carrying action which allows the straw to be discharged along the harps alternating with a retraction that opens the straw mat so the grain falls out.
23. *Stripper* - A harvester having a comb like front which is driven into the crop just below the heads which are stripped from the straw by a downward rotating steel rotor with up to eight bars.
24. *Stripping header* - A rotor with up to 8 bars, each bar containing radially aligned plastic stripping fingers which are rotated upwards as they are driven into the crop, stripping heads from straw – there is no associated comb.

25. *Threshing* - The action by whatever means of separating the grain from its fixed position on the head, or in the pod and/or from the chaff which surrounds it or from the awn such as for barley or from the husk and the cob as in maize.
26. *Threshing drum* - A revolving frame which carries the threshing bars.
27. *White head* - A grain of wheat separated from the head but still encased in the chaff.

1 Introduction

"A significant proportion of farmers in Australia have been bound by the burden of inheritance, social strata and tradition" Cooke, (1994)

1.1 The case for a more efficient combine

Note: In this thesis a combine is a machine that harvests, threshes and cleans grain, as in American terminology.

A Glossary of terms is provided at the front of this thesis.

1.1.1 The Innovators

Inventors and innovators from the Industrial Revolution till today, including Bell and Miekle (Scotland), Hussey and McCormick (USA), Ridley, Bull, McKay and Taylor (Australia), Ferguson (England) and Massey and Harris (Canada), have all contributed to the mechanisation of grain harvesting. A major contribution of the early inventors was that they developed and built machines that worked and provided a practical solution, but more importantly broke through the tradition of the day to see their machines adopted.

1.1.2 The Ridley Stripper

An efficient and reliable harvester was introduced into South Australia by John Ridley and his team in 1843 (Reddin, 1992). The concept, initially of one moving part, for harvesting standing cereal crops dominated the local harvest scene and possibly other parts of Australia for over 50 years. In fact, a modified and improved version of the Ridley-type stripper was used well into the 1960s in the Tatiara and nearby Wimmera wheat growing areas of Australia.

1.1.3 Current Combines

Machinery development since Ridley has been diverse, culminating in large, expensive machines with thousands of components, many moving parts and limited accessibility to them. A range of factors has required these developments and refinements to early machines. With the increased production of wheat lands, due to the widespread use of fertilizer, medics and subterranean clover in rotations (Donald, 1960) and heavier yielding crops which tended to lodge, especially in stormy weather, required a harvester which could collect and thresh the whole crop. Another influence on the design of harvesting machinery was the diversification by cereal growers into other cash crops such as faba beans, field and chick peas, lupins and also oilseed crops such as canola, linseed and safflower, and especially seed crops such as kale, radish, coriander, phalaris, shaftal clover, sub-clover and lucerne. Some of these crops also required winnowing so that the threshing capacity had to match the total crop intake and separate straw and chaff from seed. In summer rainfall areas, crops such as maize, soy beans and rice, as well as cereals, needed harvesters not only capable of handling the whole crop but doing so at high moisture content. This required high powered combines due to the tough threshing of the crop and in some cases the need to thresh grain from green straw called for even more power.

1.1.4 Combine problems

As a result of these modifications modern combines are large, powerful, complex machines with complicated control systems. The machines are built by teams producing complex machines to do a simple job. There is no accountability by the person who designs a component from a remote position. If the component fails or is inaccessible for repairs, lubrication or replacement that designer may not even know of the problem, it becomes the purchaser's job to rectify. These current machines are expensive, (up to A$450,000), noisy, dusty and dangerous. The complexity has resulted in increased risk of failure and increased cost. These are some of the factors motivating the search for alternative grain harvesting systems. Over 80 percent of combine harvesters sold are of traditional design but more harvesting capacity, less costs, less weight, less width, smaller size, simpler design and serviceability are bringing changes (Klinner *et al.,* 1987). Other problems include restricted range of crops that can be harvested, inability of rotary axial flow combines to handle damp straw and windrows, the difficulty of baling straw from axial flow combines, the need to chop and/or spread straw and the extra power needed.

The basic material flow path for modern combine harvesters is as follows: the crop is cut at the required height not lower than 150 mm above the ground with a sickle bar then taken into the steel thresher by a reel, a cross auger and a conveyer, all of which are steel moving parts working within steel chutes and/or troughs. The threshers are either tangential (across the flow) as in a drum thresher or axial (in line with the flow) as in the rotary type threshers. Drum threshers use a single pass of approximately 90° of the circumference in the cross flow, compared to multiple passes of 360° contact in the in-line rotary threshers. One company makes a rotary cross flow thresher (an axial flow) which is enclosed in a long mesh threshing cylinder in which the crop rotates several times to extract the grain from the heads chaff and straw. All of these machines thresh the total intake before any grain is removed from the flow. They all have many moving parts, more than 20 in each case. See Appendix No. 27 for a flow chart.

1.1.5 Combine Investment

These modern combines are getting bigger, more powerful, more complex, have more complicated control systems and more moving parts which increases the cost and the risk of failure. Combines have become very expensive. In 1982 Bloomfield found that the most expensive item of farm machinery, averaging 20% of the investment, was the combine (quoted by Tun Tin, 1990). It is unlikely that the situation has changed for the better since this study was carried out.

1.1.6 The Demise of the Tractor Drawn Combine

In the 1990s only one Australian company, Horwood Bagshaw, was manufacturing commercial size Power Take Off (PTO) combines and was one of the few remaining manufacturers of PTO machines in the world. However, these combines have largely gone out of favour: total sales have decreased from 1057 units in 1985 to 220 in 1991 (Kondinin, 1993). The Horwood Bagshaw company has now ceased production of combines, therefore Australian farmers have to rely entirely on combines of European and North American origin, which have not been designed specifically for unique Australian conditions. In the circumstances it is not surprising that two comprehensive Australian surveys have revealed many shortcomings in these combines.

1.1.6.1 The Kondinin Group Survey 1980-81

The Header (Combine) Reliability Survey in 1980/81, published by Kondinin and District Farm Improvement Group (1981), reports on the reliability of 306 combines on farmers' properties including 31 models by 8 different makers. The study found faults in drive belts, fatigue in comb fabrication, unreliable electric motors, bearing failures, inadequate feed-in mechanisms, grain tank inadequacies, and tyre failures. Access to the machine for inspection, cleaning and servicing was difficult or impossible without dismantling parts of the machine. Lack of capacity and too much grain loss were also listed as problems.

1.1.6.2 The Kondinin Group Survey 1993

In a similar report by the Kondinin Group in 1993 (*loc cit*) at least as many deficiencies are pinpointed as in the 1981 report, and many local modifications are listed to make these machines more suitable for Australian conditions. Seemingly over a period of 12 years little if any progress was made in supplying more efficient combine harvesters to Australian farmers.

1.2 Combines built in USA and Europe

Northern Hemisphere combines are designed to harvest large volumes of moist crops. They must therefore be modified to handle the low volume, dry crops of Australia. According to a survey done by Rickman in Queensland (in Tun Tin, *loc cit*) the performance of these combines was less than 50% of their grain processing capacity. For them to perform at full capacity in Australia means having either twice the width or twice the speed and as yet neither is feasible. In view of this problem, Australian farmers are obliged to buy combines, which need adapting before being used, which means extra cost to the farmer. Some of these modifications listed by the Kondinin Group in 1993 (*loc cit*) are the following.

- wire netting behind the reel to prevent heads being flicked out of the machine
- fitting of Harvestaire/blowers to combat the loss of short crop falling out over the cutter bars
- double cut short fingers
- light crop fingers
- double knife cut
- fitting a vibra mat
- fitting the Aussie-Air front horizontal air blast to shift cut material back to the auger
- rubber wipers fitted to the reels to sweep cut material to the auger
- a lupin breaker – a serrated addition to the auger
- a coarse pitch auger

- different settings for fingers on the reel from 12 o'clock to 2 o'clock (viewed from the left end) to reduce repeating.

1.3 Objective and hypothesis

This project aims at challenging today's traditions of complex harvesting machinery with a back-to-basics approach to combine design to produce an efficient, low cost, self cleaning and relatively safe combine, quickly serviced and requiring less maintenance. It is based on the hypothesis that simpler and more efficient combines are feasible by building, testing and documenting models that are:

- self cleaning
- use air and gravity for internal transport of harvested material
- have minimal moving parts
- able to have some plastic components
- have shafts driven directly with direct coupled motors (electric or hydraulic)
- sealed between inlet and outlet to prevent dust escaping
- able to harvest from ground level upwards
- available at an acceptable price.

1.4 Structure of this document

This thesis begins by tracing some of the history of grain harvesting methods (Chapter 2) and the search for a simpler, safer and more efficient combine design is described through an account of the development of a working prototype. This account is spread over three chapters that describes the materials and methods used in the process (Chapter 3), the various tests undertaken and their results (Chapter 4), and a final discussion of the prototype and the likelihood of its commercialisation (Chapter 5).

It should be made clear from the outset that development of the Pneuflo combine was a long- term action learning process. The author was engaged in this project over 25 years with only a few periods of funding. As such it was never conceived as a conventional academic thesis, and statistically rigorous comparisons between the various prototypes and conventional machines were not made at every stage of the process.

Action learning methodology has a long pedigree and has been used across a very wide range of disciplines, including engineering. The action learning process has four stages. It begins with the learner / researcher having an objective experience, which in this case may be for example testing a prototype combine; then reflecting on that experience in the light of his own experience-based knowledge; he then forms new concepts which are the basis of future actions (eg improved combine design) and returns to the beginning of the process. This process can be seen in the thesis as the author moves from one model to the next on the basis of his experience.

This thesis has been written without the general concept of comparisons between two combines of different designs on specifically designed plots of various crops being possible since it concentrates on the development of a workable unit that can be more fairly compared to machines that have had over 100 years of development by many individuals and teams of engineers, costing many millions of dollars.

1.5 Conclusion

From early in the history of South Australia significant farm machinery manufacture has occurred. Only one major company remains, with an unknown number of small factories making components such as harrows, slashers, augers, tubulators, press wheels and plot combines.

The demonstration of a viable tractor powered Pneuflo combine could prepare the way for a South Australian re-entry into local and worldwide combine markets, especially in the developing countries.

2 Historial background leading to the development of the Pneuflo Combine Concept

2.1 Introduction

The evolution of mechanical grain harvesting and threshing has been long in process and varied in form. Above all, this history has been very interesting. Many innovations have had significant social impact while many others have not been adopted. This lack of adoption was often not because the innovation was not practical and worthy but because of social reasons such as lack of capital for their development. This historical review traces the evolution leading to the development of the conventional modern combine through its many stages. It does this by first describing pre-industrial harvesting and the evolution of cutting, threshing, winnowing and combining concepts. Then follows a description of some of the historical and cultural factors affecting the development of harvesting machinery. The technology that is the foundation of the modern combine harvestor is then presented. Importantly, attention will be drawn to early work on pneumatic threshing systems.

The review then presents some surveys of combine harvesters by the Kondinin Group to illustrate that there are still many deficiencies in the modern combine. In short, they are relatively dangerous and expensive, and they are very difficult to repair, service and clean. The aim of the current work is to show that harvesters can be simpler, self cleaning, safer and more efficient. Recent work on conical threshers and then arrowhead stripping headers is presented as it supports and complements the development of the Pneuflo combine.

2.2 Harvesting concepts

Seeds and fruit have been a major component of the diet of the human race for a very long time. It is likely that in the early days of human evolution most of these were collected or harvested by hand in an opportunistic way, by humans for their own consumption. However as the society became more organised the harvesting of seeds or grains would have developed into a major seasonal activity. Many of these seeds could be stored for a long time and provide highly nutritious food. Because of the importance of such seeds in human survival, more efficient harvesting systems began to be developed rather than relying solely on hand picking.

Human hands were originally used not only to pick or harvest but also to separate the grain from the heads by rubbing the heads between the hands. The next step would have to be the separating of the chaff from the grain using either the wind or a puff of human breath (See Figure 2.a).

Hand threshing was a gentle process and would not have damaged ripe grain nor resulted in grain loss, it is suggested the degree of mechanisation was in the inverse ratio to the percentage of the population available to harvest grain for food. The mechanical evolution of this process has continued and as the population increased there was a need for specialisation. Consequently less and less people were available for harvesting and threshing the grain. The once labour intensive processes have now become highly mechanised.

2.2.1 Evolution of Grain Harvesting

Development of harvesting machinery is reviewed in this section. Particular emphasis is devoted to the review in Quick and Buchele (1978) ''THE GRAIN HARVESTERS'', which took the authors ten years and to five continents for their study. Data and or quotes in this section are from this reference unless stated otherwise.

The simple hunter/gatherer process of collecting grain and removing unwanted husks, or winnowing, can be broken into the five main processes of a modern combine – cutting/gathering the crop, threshing grain from heads/cobs, separating grain from long straw, cleaning dust and chaff from the grain and finally delivering grain ready for market, either in bags or bulk hoppers. Each of these processes will be described in this section

2.2.2 Cutting and gathering – knife to cutterbar

Grain knives have been made by primitive people from bone. These tools have been found in the pyramids, caves and excavations in the Middle East. Next came sickles of various shapes and scythes with long handles fixed to beaten metal blades to which could be added cradles to hold the cut crop so it could be laid in rows to dry or tied in small bundles for drying and threshing. Carter (pers comm), after a visit to Russia in 1979, suggested more grain was harvested with sickles than with combines in the world at that time.

The cutting or reaping of wild crops and sown crops evolved slowly until the industrial revolution. With better metals, horse power and steam power industrious farmers and engineers developed tools such as mechanical shears, oscillating knives, rotary cutters and over shot revolving beaters to the most recent development, arrowhead under shot strippers (see Figure 2.b).

Cutting the standing crops needed to be done before the crop was ripe and likely to shed. Hand tying of sheaves was one means of assisting the transport of the crop to a central threshing site. However as the cutting process became more efficient binders were developed to deliver the cut crop to a position where it could be tied, first with strands of crop, then wire and later with string.

In some cereal production areas, crops could be left on the straw until ripe then direct headed. This was a much quicker process and with a harvester, thresher and a winnower in the same machine, a sample ready for sale could be obtained in the field. These machines were called headers and had oscillating knives to cut the crop, which was conveyed to a thresher, then to a winnowing process where the chaff and the straw were blown and shaken from the grain. This way of harvesting allowed most of the straw to be left standing and used later for animal feeding, bedding, fuel for steam production, roofing for houses and sheds as well as binding for earthen walls and mud bricks.

2.2.3 Threshing

Effective and primitive threshing tools include human hands, animals treading on a prepared floor and threshing devices made from timber such as a tapered log tethered to a slip ring fixed to a post and then pulled around in a circle, threshing as it rolls (See Figure 2.c). Other threshing devices, primitive but still in use, are blocks of granite sitting on a sheet of animal skins or fertilizer sacks stitched together. Small bundles of dried crop can then be threshed by banging them on the granite. A block of wood or a wooden frame also make suitable threshing blocks.

Threshing sledges pulled by a draft animal over layers of dried crop were also used. One such sledge used in Turkey was called a "*dovern*" and could be pulled by a horse, donkey, mule, cow, or maybe a couple of sheep. A tablet, found in southern Iraq and thought to be over 5000 years old, also depicted a threshing sledge, in this case called a "*tribulum*". In Ethiopia a device called an "*olpad*", made from an axle with steel discs bolted together 15 cm apart, was pulled over the layered crop. A threshing cart called a "*noreg*"is still being used in parts of Asia. Other threshing techniques such as human held flails are still used where human labour is plentiful.

Leckie, a Scot, is believed to have made the first threshing drum but Meikle, another Scot, is credited with inventing the threshing drum and cylinder combination and patented it in 1756. Power could be obtained from a water wheel or horse works and threshing beaters revolved to give speeds up to approx 1000 m per minute for the beaters, scutchers or rub bars. Some were under shot, the crop to be threshed was presented to the bottom of the beaters. Others were over shot with the crop presented to the top of the beaters which rotated in the opposite direction. They were driven by a long leather belt or strap, which acted as a clutch in case of a blockage or over load. Many transportable threshers were towed from farm to farm by horses, some had steam traction engines and the same engine drove the threshers once they were in the field where the crop had been harvested.

There has been a variety of threshing modes used in the past. Few of these modes are used now. The transverse undershot, the single longitudinal rotary, the double rotary and the axial or transverse are the most common. Within these main principles are a variety of threshing surfaces, all of them are made of steel, very aggressive, rugged and strong to cope with large volumes of material other than grain passing through them. Because most of the crop passes through the combine and high speeds are required there is an excessive amount of power needed. This adds to the cost and over all weight of the components. None of these threshers have a vertically orientated axis of rotation.

Herbsthofer (1974), working with Massey Ferguson, developed a combine incorporating a conical thresher. It had no walkers and weighed one tonne less than a convential combine of similar capacity. Herbsthofer also describes a conical thresher built by J.K. Wise of Toronto, Canada. This was vertically mounted with the outer cone sheath rotating and the inner component stationary. The thresher was fed from the small end, at the bottom.

Ridgway (1978A) describes a vertical conical thresher (Patent Numbers are given in the front of this thesis) with soft threshing surfaces fed from the top, the large end and driven at speeds less than 100 RPM (see Figure 2.d).

2.2.4 Winnowing

After reaping with a binder or other cutting methods the dried crop had to be threshed and then winnowed. Winnowing using the natural wind is still a very cheap and effective grain cleaning concept. In some countries women do the winnowing using a cleaning dish as well as the wind to produce grain clean enough to eat or grain can be thrown into the air or dropped from sufficient height when there is enough breeze to blow the chaff and dust away (See Figure 2.e).

Initially the mechanical winnower was hand turned by one or two men. Some winnowers had large four bladed fans and sieves which vibrated or oscillated to keep the mixture moving to assist the separation by wind, gravity and motion. By the skill of the tradesman and the needs of farmers to speed the threshing and the cleaning, combination threshers and winnowers were built. Most small farmers would engage a contractor to bring the machine to the field to thresh and clean the crop (see Figure 2.f).

2.2.5 Combining

As the three components of harvesting, reaping, threshing and winnowing, developed separately machines were also being built containing the three actions in a combined unit. The Combine had to have a cutter bar or reaping front, a thresher, a winnower and straw walkers to keep the long straw from contaminating the sample and over loading the sieves. A combine could only be used in a crop which was ripe and dry enough to prevent contamination with insects or mould in the stored grain. Driers for stored grain came later and they enabled grain crops to be combined much sooner and stored without rotting or being eaten by insects.

An immense amount of work has been put into designing, manufacturing, testing and improving combines. Two of the early models were built for use in the Sacromento Valley, USA, one in 1886 on the farm of G.S. Berry and the other on the same farm in 1888. These combines were huge even compared to today's models. The 1886 model had an open front 22 feet wide, was the first self-propelled combine and could harvest and clean the grain from 50 acres in a day. The second had a 40 ft front and could harvest 100 acres in a day. They were both driven by steam engines which used straw from the crop to fire the steam boilers. The later model could work after dark as it had a lighting system (See Figure 2.g).

Many different companies have built combines since those first models. There have been comb fronts taking heads only, open fronts to collect lodged crops, Ridley stripper fronts also taking heads only and leaving the entire straw using an over shot or over the top rotor and arrowhead stripping fronts which stripped, and threshed the heads with an undershot rotor and plastic fingers (Hobson et al, 1986) (See Figure 2b).

Some big changes have taken place in the diversity of combines in the last 100 years. Self propelled combines are flooding the market and now have the total new market in Australia. Tractor drawn combines, although much cheaper to buy and slower to depreciate, have lost favour or have been squeezed out of the market. It has been suggested that the ownership of a self propelled combine has a status symbol and many farmers are prepared to buy big, whereas the cash conscious farmer is a potential customer for a tractor drawn power driven combine.

2.3 Cultural context of machinery development

2.3.1 Harvesting progress

Mechanical development was progressing rapidly in the USA and around 1820 700 different machines were either patented or on the USA market. Power was supplied to these machines in many ways - by men, horseworks and steam power. In circular horseworks horses either walked on the ground harnessed to a long pole which was fixed to a large pulley or cog (above or below the horse) or were restrained and walked on circular platforms which turned the machinery. Tread mills where the horse walked in a raised box turning an endless mat over a roller on which was a large pulley or cog were also used.

From 1788 to 1880 'Combined Threshers' are described by 35 different patents, some with winnowers and some with two horse tread mills for a power source. These innovations of the early 1800 era were all built in the UK or USA. Possibly the only name to survive in the agricultural machinery business was Jerome Increase Case whose company is now amalgamated with Case-International multi-national manufacturer. Reapers were still a big part of the mechanisation development as binders had yet to be invented, but the various stages of cutting the crop, shifting it to one side, then conveying the cut crop over the drive wheel had been accomplished. Samuel Lane from Maine patented the first combine on the 8th of August, 1828. Achmore and Peck in 1835 and Briggs and Carpenter in 1836 also patented combines. Unfortunately the 1836 US Patent Office fire destroyed the details both of construction and performance. The first large working combine was the Michigan machine built by Hiram Moore in 1839 and is discussed in a later section.

One setback to harvesting development was the threshing machine riots of 1830. In England farming boomed during the Napoleonic Wars and when the soldiers returned home to find jobs were very hard to get, due in part to the mechanisation on farms, they took direct action. 400 threshers were destroyed in 2 years, some rioters brought to trial, 19 executed and 481 transported to Australia as convicts. Even the district Magistrates supported the unemployed, and issued a request that farmers employ labourers and pay them 10 shillings per week.

2.3.2 The first Australian wheat crops.

Wheat was first planted in N.S.W. during 1786 near where Sydney now is by James Ruse, a convict. In 1823 gold was discovered, bringing many more people to Australia, and in 1836 South Australia was proclaimed a state. Wheat was grown on the Adelaide Plains and nearby hills. Another gold rush, in early 1840s at Ballarat, drained the manpower from SA such that the wheat harvest was desperately short of labour. The Corn Exchange Committee offered a prize for a harvesting machine suited to the area. Although seventeen models were submitted none received the award, but much effort was being aimed at developing a machine. Reddin (*loc cit*), after extensive research, showed that John Ridley was the man most responsible for mechanising the wheat harvests from 1843 onwards, with the Ridley Stripper (See Figures 2.h and 2.i). This simple harvester with one basic moving part gave the wheat industry a new outlook, and within a few years 30,000 of them had been built (Wheelhouse, 1966; Reddin, *loc cit*). The original Ridley designed reaper, see Figure 2.h, harvested only the heads of wheat, providing the crop was standing. This reaper consisted of a set of fingers bolted to a metal bar specially designed to allow the fingers to be clamped to the bar. This allowed an adjustment of the space between the fingers to be sure the standing straw could pass through the fingers just below the heads on the straw. The heads were presented to the down swept beaters which stripped the grain and the chaff taking in very little if any straw. Some of the was grain separated from the chaff the rest was separated by a secondary in built thresher or in a mobile thresher. The concept was in general use for over 100 years and its efficiency in standing crops, taking heads only with a steel beater above steel fingers, has never been matched, especially when later complemented with a simple and effective secondary thresher, cleaning sieves, and a winnower in the one machine loosely called a "harvester". However, this simple and very efficient reaper was unable to handle straw. Ridley is also credited with designing a stripper with a rear cutter bar for mowing the stripped straw close to the ground.

In 1848 1200 acres of wheat were sown at Camden near Sydney and a yield of 40,000 bushels was obtained. All of the harvesting was done by hand labour and G.R. Quick (1988) estimates 100 people were needed for the harvest, 12 acres per person. A similar crop now would require one contractor and a large combine. Labour costs since then have increased 400 times but the gross return from wheat to the farmer has only increased 5 or 6 times. Quick suggests wheat is marginally more profitable to grow now than in 1848 and that without modern machinery all of the Australian population would be required to harvest the crop. People persevering with wheat growing need modern machinery to maintain quantity and quality of the wheat and reduce losses.

Could one argue the need for a more efficient cheaper and faster combine has arrived?

2.3.3 The world scene

Cyrus McCormick from Virginia, USA, patented his reaping machine in 1834 for a fee of $30.00. A similar reaper mower was marketed about the same time by Obed Hussey, who had successfully harvested 186 acres of oats on a farm in Maryland in 1836 and patented it in 1847. The McCormick reaper had a cutter bar and a reel but the Hussey reaper had no reel and worked better at trotting speed. McCormick and Hussey demonstrated their reapers in England in 1851 and soon after McCormick arranged for 500 of his reapers to be built in England. By 1852 the British press was vigorously admonishing farmers to mechanise for their economic survival.

The two inventors staged competitions and had a long running campaign. Eventually McCormick went on to establish his company, which built reapers, and in 1848 sold over 800 machines. Companies were licensed to make reapers, some at $20.00 per machine. McCormick established a factory near Chicago. He began advertising and initiated a credit sales system. By 1849 he had made 2800 units and his competitors only several hundred. There were many attempts to build reapers but mostly they were unsuccessful.

George Esterly in 1844 patented a push header which cut the heads from the crop and held them in a bin for bulk delivery to a thresher, then as demand required also built into his header a side delivery unit for farmers who preferred their crop to dry in a row before threshing.

Around 1858 steam power was becoming available to drive the threshers and this allowed them to move or be moved from farm to farm more readily. By 1890 two thirds of California's 2.5 million acres of wheat were being harvested by combines!

Specialist harvesting crews were cutting up to 6,000 acres per season and contract prices were: 1887 - $1.50/acre, 1892 - $1.15/acre, 1893 - $1.50/acre, 1900 - $1.75/acre compared to $3.00/acre for horse drawn machines.

2.3.4 The Gold Rush Effect

Gold was discovered in California in 1848 very soon the rush put 300,000 people there but after 12 years the gold was exhausted and people turned to farming in a big way. Farms were large and so were the fields, some were hundreds of acres, and by the 1860s wheat was extensively cultivated and at $3 per 100 lb sack or $60 US per ton, wheat growing was very lucrative. Push type headers became the most sought after harvesters. They had wide fronts and as the horse or mule team walked behind there was no side draft or crop damage. Headers only cut the heads of wheat since in California (with its Mediterranean climate) wheat ripened and dried on the stalk, so there was no need to cut, bind and cure in the stook. By 1869 2500 headers were produced while reapers (binders) exceeded 60,000. The headers gathered the heads and as little straw as possible. The harvested material was elevated into 'barges' or wagons, with high sides, pulled alongside. These loads were then taken to the stationary thresher-winnower for threshing and cleaning before the grain could be bagged. If the thresher was unable to receive the headed straw it was stacked loosely in selected sites to minimise the distance travelled by the bulk wagons from header to the stack. Headers in this concept required less power than a combine. They were steered and driven from the 3rd wheel site at the rear. The driver "header-puncher" held the tiller between his knees for minor corrections, control of the horses did the major steering. At least two barges (Palouse Wagons or bulk wagons) were needed for each header. Each barge needed a driver and a forker, who levelled and placed the unthreshed heads.

2.3.5 The first big combines

The Hiram Moore and Hascall combine which was built around 1839 used a large rotary screen for the final cleaning of the grain and it could harvest at the rate of 20 acres per day, further it was described as *"a gigantic invention well adapted to meet the necessities of a gigantic country*" (Quick and Buchele, *loc cit*: p 89). Despite the success of the Moore combine in Michigan in 1847 or 1848 and the success of it in California in 1854 fifty years passed before combines were used again in Michigan, due in part to the inability to renew the patents (which then expired after 14 years) and the lack of financial support.

A photograph of the Michigan Combine shows a team of 16 horses in 8 rows of two with a rider-driver-jockey for each 4 horses. The combine machinery was driven by a 5'6" diameter drive wheel with a 2 ft wide rim. Early reaping costs of the combine were less than one dollar per acre compared to $3 per acre for the normal handling of the crops.

Using a team of 56 men 96 horses and mules, 21 Palouse Wagons (barges) and 7 headers and a locally built thresher and winnower, 6,750 bushels of wheat were processed in one day. This happened in the Napa Valley, California, in 1878 on the property of a Dr Glenn, the biggest wheat farmer at the time. He owned 100 square miles of Colusi County and in 1880 harvested 1,000,000 bushels of wheat. 600 men and 800 draft animals did the work. When wheat dropped to $20.00 per US ton he switched to combines to save cost. In 30 years 1858 to 1888, some 21 combine manufacturing ventures were begun in the Pacific region. Davis Brothers 1862 combine had 4 horses pushing, 6 pulling and was claimed to be able to cut, thresh and clean 1500 bushels per day with a 3 man crew. The first engine functioned combine was built by B.F. Cook and exhibited in 1871 California State Fair in Napa. It had a steam engine to drive the machinery, a horse team pulled it along. In the Sacramento Valley in 1888 a combine owned by G.S. Berry appeared with more firsts than any combine before or since. This machine was the first;

- Straw-burning steam combine "fuelled off the land" as it went along.
- Tractor to work forwards and backwards.
- Combine to harvest 100 acres in 1 day.
- To have lights to allow night work.
- To have a 40 ft cutter bar.

In 1893 a Holt steam traction engine was used to pull a 50 ft wide combine. It had a 26 ft. main cutter bar and two 12 ft. extensions. In 1925 the Holt and Best Combine manufacturers amalgamated to form the Caterpillar Tractor Company which continued making combines until 1935, when the combine business was sold to Deere and Company.

2.4 Foundation of the modern combine

2.4.1 The importance of clean seed

In 1852 the necessity for seed cleaning was appreciated by farmers who recognised that a single wild oat seed could produce 200 others a mustard plant 10,000 of its kind and that crops would produce better when graded seed was used. Winnowing by the wind and by many varied shapes and sizes of fans were used from early Chinese farm yards until now and examples of the 18th and 19th century winnowers are to be seen in the Henry Ford Museum in Michigan. Next came the combined winnowers and sieving devices which took the light chaff and dust by air and the larger pieces of straw would have been removed from the grain by sieves, which could have slots, grooves, round holes, oblong holes and eventually woven wire to help the separation.

2.4.2 Threshing

The first rasp bar thresher was patented in 1848 by John Goucher in York but acceptance was slow.

2.4.2.1 Rotary threshers

Bennet Woodcroft in 1853 classified and illustrated some 33 different rotary threshers, among them were some parallel to the ground but most were vertical - none of them appear to have had sustained use. The Revered Patrick Bell developed a reaping machine in 1868 near Carmyllie in Scotland. It was pushed by two horses and for its era was carefully planned and appeared to work well - these machines were exported to the USA, Australia and Europe. A model is held in the London Science Museum. Between 1786 and 1831 over 50 reapers with different concepts were reported in England, Scotland, Europe and the USA.

2.4.3 Separation

John Morton is believed to have developed straw walkers, initially called 'harps', in about 1858. Morton's walkers were 6 feet long and were made of 30 pieces of 2 x 0.75 inch timber 0.75 inches apart and were mounted on diametrically opposite cranks such that every second walker would lift while those adjacent would go down. The cranks had 3.5 inch amplitude. A cross auger was fitted beneath the walker tray and, after cleaning on the sieves, transfered the grain to the grain bin.

2.4.4 Self rakers

Vertical axis Self Rakers patented by Owen Dorsey in 1856 were called an "improved harvester rake". It had the appearance of the side show device where chairs are fixed to the end of long radial arms rotating on a plane 45^{o} to the vertical. On this machine these radial arms swept past the drivers head and would have been a hazard similar to the guillotine. These vertical axis rakers also called "pigeon-wing" reapers, stayed in vogue for 50 years, each one took the place of 5 labourers. By 1864 harvesting machinery was big business with 203 manufacturers making 87,000 reapers harvesters and mowers annually in USA.

2.4.5 The first vee belts

Holt Bros in the U.S.A. began making combines in 1885 and dispensed in part with tight fitting toothed cogs, introducing hook link chain and segmented vee belts to transmit power. Holts first export combine was shipped to Melbourne in 1894. (Holts, later part of the Caterpillar company, also made crawler tractors which were exported to Australia).

2.4.6 Harvesters and Binders

"Without a doubt the greatest reformer of the age in the agricultural world has been the American harvester and binder" (quote from British Colonial Trade Journal, 1888 in Quick and Buchele, *loc cit*). McCormick's Riding Binder of 1875 allowed two men (bandsters) to ride on the machine to tie the sheaves with straw bands. John E. Heath of Warren Ohio was the first to bind sheaves mechanically and he obtained a patent on July 22, 1850 for a device which compressed the straw wrapped twine around it and tied a knot in the twine.

2.4.6.1 The string tie binders

The acceptability of the new string tie binders boosted the sales of harvesting machinery to 250,000 by 1885. McCormick had, by 1884, sold 54,841 machines including 15000 twine binders. At this point the spread of mechanical harvesters had reached a stage where in England, Scotland and USA the dependence on harvest labour had reduced and the degree of development had reached a plateau.

By 1888 the level of mechanisation on the farms was requiring 100,000 self binders and 15,000 reapers and mowers using 30,000 tons of binder twine annually. The manufacturers were employing some 30,000 workers and no doubt most of them were displaced farm workers. The basic Appleby knotter design is still used on hay balers with the ability to tie both vegetable based and plastic based twine.

This patent was remarkable for its originality and the directness. It included the first use of a twine spool, a cord holder, sheaf compressor, a knotter to tie the knot and a knife to cut the string. Despite this achievement the first commercially successful mechanical binders tied with wire, but this took many years to become commercial and in fact not until 1873 was the first fully automatic wire tie binder sold. There were also automatic self-tying straw binders. William Douglas possibly had the longest US patent, No. 789010 May 2 1905 for an automatic self tying straw binder that took him 26 years to develop, from 1879.

50,000 McCormick Harvesters and Wire Binders were sold between 1877 and 1885. The availability of suitable twine at a reasonable cost delayed the introduction of twine tie binders till 1881.

2.4.7 Blowers and extractors

A 'blower', mentioned on page 105 and pictured on page 108 of Quick and Buchele (*loc cit*), is the exhaust tube directing the dust and chaff. By 1900 most contractors' threshing rigs had self feeders, straw blowers, bag weighing and counting apparatus. By 1918 the Russell thresher had a dust removing fan over the walkers.

2.4.8 Spare parts

Walter A Wood 1861 and his company were the first to provide interchangeable spare parts for their reapers, the 'chain rake' reaper. By this time Cyrus McCormick had become a millionaire and a few years later his workers made 6000 'Advance' reapers in one year and in 1874 sold 8445 machines despite a fire which caused them to shift and rebuild just before the 'self binder' became the next evolutionary stage in mechanised harvesting.

2.4.9 Hedlie Shipard Taylor

The header combine built by Hedlie Shipard Taylor in 1913, was able to handle every condition of crop, light, heavy, storm tangled or weed infested. Later his design was changed to be able to harvest many different types of seeds, even a rice combine, followed by a full self-propelled (auto header). Taylor had little education and was mostly self taught, his inventions included harvesters, pasture renovators, bagging machines, pea harvesters, rice headers and war implements. He was probably the most prolific inventor of farm machinery in Australia (Wheelhouse, *loc cit*).

2.5 Kondinin Group Header Reliability Surveys,

The source of manufacture of Australia's harvest machinery has changed dramatically over the years. The trend in purchase of Power Take Off (PTO) machines compared to Self Propelled in 1970 was 50% by 1989 only 19% were PTO, three years later only 7%. Total sales of machines have gone from 1057 units in 1985 to 220 in 1991. In 1997 manufacture in Australia of PTO machines was non existent. The last company to make combines[1] in Australia was Horwood Bagshaw, one of the few power take off combine makers. Combines made in Europe and North America are designed to harvest volumes of moist crop and therefore must be modified to handle the low volume dry crops of Australia. This suggests Australian farmers are obliged to buy a machine which needs adapting before it is used. The extra cost naturally is passed on to the farmer.

Aware of the fact that there are problems with combines on the market, the Kondinin Group regularly undertakes surveys of this technology. The results of these surveys are important because they illustrate how often technology that was designed outside of Australia presents problems and needs modification after they have been purchased by farmers. These surveys will be discussed at length here because they provide evidence for the need for a versatile and flexible Australian designed combine.

2.5.1 Kondinin header survey 1980-81

The first survey of header reliability was undertaken in 1980-81 (Kondinin, *loc cit*). The aims were:

[1] The words 'header' and 'combine' are, for practical purposes interchangeable. In reality a 'combine' is a machine that heads, threshes and cleans, whereas historically a 'header' just cuts off heads. Rgardless of this distinction, the word 'header' is the colloquial use.

"To provide farmers with more information on machinery both new and secondhand. To make manufacturers more aware of the problems farmers are having with their machines, with the aim of enabling improvements to be made to current models and to assist them to design future machines to meet farmers requirements. To improve the liaison between farmers, dealers and manufacturers for the mutual advancement of the grain industry."

This survey reports on the reliability of 306 headers on farmers' properties including 31 models and 8 different makers. Faults in drive belts, fatigue in comb fabrication, unreliable electric motors, bearing failures, inadequate feed-in mechanisms, grain tank inadequacies, tyre failures, difficult or impossible access for inspection, cleaning and servicing, lack of capacity and too much grain loss were listed.

2.5.2 Kondinin header survey 1986

The first survey highlighted many short comings of headers currently on the market and a follow up survey in 1986 went into even greater detail. Listing the significant finds of this survey:

In this survey 19% of open front machines in 1986 survey were fitted with air assisted fronts. Uneven feeding of cut crop from the comb to the thresher was a problem in 22% of open front and 13% of comb fronts. Wheat and barley threshed by the reel fingers was difficult to shift to and by the auger. Grain loss over the walkers was also a regular problem. There were also many other problems listed with cleaning fans, grain tank and unloading auger, cabin air conditioner, engine and power train.

Another common problem was over-loading of sieves caused by

- excessive repeating of unthreshed grain;
- uneven distribution of material on the sieve;
- over-threshed straw in hot weather; and
- operator misjudgement of overall capacity.

Some farmer modifications in response to these problems were:

- a cover over the auger above the mouth of the elevator;

- extending the auger flights straight across the centre section to act as paddles to throw crop into the elevator;
- reverse flighting on the auger to prevent uneven feeding
- fitting a stripper plate along the platform floor to assist even feeding;
- numerous adaptations to cope with either light or heavy crops uneven feeding to the left or the right of the elevators;
- filler plates on the concave (these plates created problems by reducing separation at the concave);
- open filler bars on the concave;
- reverse wedge concave setting;
- reducing drum speed;
- removing concave wires;
- adding special dressing to thresher drive belts because they are inadequate for the job.

All of these alterations and additions had to be done after the farmers had purchased expensive machines and at the farmers expense.

2.5.3 Kondinin header survey 1993 (The 'Reapers Digest' Survey)

Even by 1993 farmers were still needing to make significant modifications to their combines such as:

- wire netting behind the reel to prevent heads being flicked out of the machine;
- loss of short crop simply falling out over the cutter bars, fitting of Harvestaire/blowers to combat this loss;
- doublecut short fingers;
- light crop fingers;
- double knife cut;
- fitting a "VIBRA" mat;
- fitting the "Aussie-Air" front horizontal air blast to shift cut material back to the auger;
- rubber wipers fitted to the reels to sweep cut material to the auger;
- a lupin breaker - a serrated addition to the auger;
- a coarse pitch auger;

- different settings for fingers from 12 o'clock to 2 o'clock viewed from the left end to reduce repeating;
- stiff rubber paddles on the centre section of the augers.

The most common problem with Self Propelled and PTO combines surveyed was the breakdown of the tyre systems and this was first noticed in 1981, then 1986 and finally 1992. A continuing example of field experience being disregarded by the manufacturers.

The Kondinin report also noted *"The high level of down time can be attributed to routine servicing and maintenance plus the time taken to access the threshing components. Self Propelled versus Power Take Off comparison draws the conclusion that there is huge potential for any machine which can efficiently take the best of both while eliminating the disadvantages*"(Kondinin, *loc cit*: Page 41).

The problem of harvest fires has not diminished in recent years as machinery becomes more sophisticated with more moving parts to create heat and sparks. The message from many farmers who have had fires in harvesting machinery is that not enough time was directed to keeping <u>straw</u>, <u>chaff</u> and <u>dust</u> off dangerous areas. There are also suggestions that over heated hydraulic lines have caused fire. A cleaner, cooler and simpler machine would obviously reduce the fure risk.

Tullberg, quoted in Tun Tin (*loc cit*), suggests that in some, if not most, Australian reaping conditions the northern hemisphere combines cannot be economically loaded, either because the crops are lighter or it is not possible to drive fast enough to fill them adequately. This is an important problem because the crop processing components of a combine account for most of the cost. John Deere installed "independent carriage suspension" on their 1051 PTO machines for faster ground speed. However, this did not completely solve the problem. Tullberg suggests a temporary solution may be to swathe 2 x 9m windrows together and driving faster. Eventually he concludes that the stripping-header principle will provide the solution to this problem.

2.6 The History of Conical Thresher Development

2.6.1 Lalor's thresher

Lalor (1962) in discussing the design of a rotor for a conical thresher states, "Considerable air movement will occur as a result of the fanning action of the rotor and this air movement will consume some of the power supplied to the rotor. In designing a threshing cone, therefore, every effort should be made to utilize the air movement for conveying and cleaning the grain".

The dimensions of the cone for Lalor's thresher were 406 mm diameter at small end, 1513 mm at the large end and the length 1219 mm and it was made of 3.2mm thick sheet steel. It was made in four sections, bolted together. The material appears excessively thick and with the reinforcement strips and flanges would have required special rolling and bending to fabricate.

The clearance between the cone and the rotor was 25 mm at the small end 13 mm at the large end. The clearance at the large end varied due to the base of the cone not being a perfect circle. This is similar to the Resilient Tapered Thresher rotor and stator fit Ridgway (1978A) (See Figure 2.d).

2.6.2 Threshing site observation

Lalor (*loc cit*) describes the results obtained from high speed camera pictures taken at 2000 frames/second. "Little impact between the material and the beaters was observed. Grains in the path of the beaters were struck, but the straw was not, since the centrifugal force threw it free of the beaters, with the result that there was little contact between the straw and the beaters. The straw was rubbed slightly by the beaters due to the relative motion between the two". The amount of relative motion is indicated in the data presented in Table 2.1.

Table 2.1 Speed (in revolutions per minute RPM) of beaters, straw and grain as calculated from high-speed motion pictures (Lalor, *loc cit*)

	Site 1 RPM	Site 2 RPM
Beaters	450	450
Straw	150	130
Grain	180	180

Table 2.2 Relationship between rotor speed of an 8 bar rubber coated cone and threshing efficiency (Lalor, *loc cit*)

RPM	Threshing Efficiency %
300	99.08
350	99.56
400	99.60
450	99.78
500	99.84

2.6.3 Grain damage in Barley

Lalor (*loc cit*) stated that 75% of large grain can be ruptured by impact with a cylinder bar at a speed of 35 m/s. Rubber-faced angle bars have an advantage in that they accomplish adequate threshing without causing excessive kernel damage. Rasp-bar cylinder caused up to 3 times the damage caused by the angle bar types. In small seed legumes seed damage was found to decrease when the cylinder load was increased; when the straw was leafy and had high moisture content similar results were obtained.

2.6.4 Pathways in a conical thresher

Lalor and Buchele (1963) describe the theory of helical path of grain and straw in a conical thresher of 54^{o} apical angle. Their conclusion is that in a horizontal conical thresher, material will travel through it, providing the angle is greater than zero. How this principle relates to a vertical conical thresher used in the Plot Harvester is discussed. To have movement in a conical thresher in a helical path needs an initial motion, displayed in the Buchele machine when the grain moves down the cone angle overcoming friction. This infers that when grain is fed into the thresher it begins to move, by the force of gravity applying to it on the cone surface, overcoming friction whereupon it assumes a helical path imparted to it by the cone bars.

In the vertical concept the initial motion is provided by the velocity of the incoming material as it well may be by the auger feed of the horizontal aspect. The speed of the drum bars (impellers) at a point on the inner side of the cone is directly related to the radius at that point and may be defined as RPM x Point Diameter (PD).

Lalor and Buchele (*loc cit*), using a horizontal conical thresher with 8 rubber beater bars, cone angle of 54^{o}, cone length 48 inches, found that threshing took place mostly in the first half of the cone length. Tests were performed at 300, 350, 400, 450 and 500 RPM and threshing efficiency was over 99% at all speeds. This finding is very relevant today because, contrary to current practice, **THRESHING DOES NOT REQUIRE HIGH ROTATIONAL SPEED.**

2.6.5 Combine technology

Herbsthofer, F. J. (*loc cit*) suggests there has been little change in combine technology in 100 years. He claims the conical thresher was still on the drawing board in 1973. He draws the conclusion that, because there has been no change, the system of beaters and concave or pin rotor and peg concave could not be improved, single and multiple drum mechanism were the basic threshing mechanisms.

He goes on to describe some 30 different complicated concepts for more efficient threshing of grain, including five conical systems. Even these five methods are complicated, the first patented in Germany in 1930 by Curtis was horizontally arranged and fed from the small end. A vacuum combine similar to the Curtis design was built in Russia in 1929 and failed to be viable because of the high power requirements. Total losses were around 5% in ideal conditions.

Experiments were done at Ohio Experiment Station with a conical threshing and centrifuge separation system. Outer and inner cones revolved at different speeds. An extractor was used to suck the chaff and straw away. Under optimal conditions total losses of 1% were recorded. **However, the amount of chaff and straw was twice that of harvester mechanisms with a transverse thresher, walkers and sieves.**

At Michigan Experiment Station, Lalor and Buchele (*loc cit*) built a conical thresher for experimental uses. It had an outer fixed sieving cone and rubber coated beater. Threshing losses were under 1% but to achieve 98% separation the sieving conical stator would have needed to be 2.130m long.

Herbsthofer (*loc cit*) directed the building of several combines for Massey Ferguson containing rotary conical threshers, again horizontal but fed from the side. These machines were smaller in size and weighed almost 1000 kg or 25% less than comparable conventional combines.

Another conical thresher proposed by Joseph Wire, Toronto, had a vertical axle. It had 14 components, was fed from the small end, the bottom, and the cone rotated around the fixed conical drum. No mention is made of performance, Quick and Buchele (*loc cit*).

2.6.6 Design and testing of a threshing and separating cone

The factors affecting cone performance are:

- apical angle
- length of cone entrance to exit along the surface
- length of slots in the stator
- RPM of rotor

Slots had to be such a length that the seed could pass through them without striking the edge of the opening, this meant that the seed had to pass through the slot in the time that it took to pass over it. If the acceleration of the seed in the radial direction is $r\omega^2$ where r is the radius of the cone at that point and ω the angular velocity of the seed. The required slot length can be found by equating the time for the seed to pass through the opening to the time for it to traverse the length of the slot. In this manner the slot length is found to be a function of the radius of the cone as follows:

Z (slot length) = $\sqrt{2ry}$

where r is the cone diameter at the slot and y is the screen thickness through which the seed must pass in order to clear the outside edge of the screen (Lalor and Buchele, *loc cit*).

Buchele's cone was 406 mm at the small end and 1524 mm in diameter at the large end. The rotor test speeds were 300, 350, 400, 450 and 500 RPM and straw was removed through a chute at a tangent to the base, at a velocity high enough to load it directly on to a wagon.

- threshing was above 99% for all speeds
- the cone was made of 8 sections of sheet steel
- the four at apical end had slot length 51mm
- the four at base end had slot length 76mm

Cost of cone was prohibitive but there was no cost given or indication of how the cone was put together.

2.6.7 Radical threshing

Conical threshing research was reported by Wessel, a German engineer, whose work was translated by W. Klinner, of Silsoe Research Institute. Wessel called the process "radical threshing" and listed four distinct phases:

- separation in the feed tube
- separation due to the change in momentum
- separation due to oscillating motion of material laterally slipping on the beaters
- impact against the surrounding casing.

The clearance between the beaters and the feed tube outlet was significant. The peripheral speed of the rotors was at least 40 m/s and up to 51 m/sec. Threshing efficiency was similar compared to conventional combines. Damage to seed was also similar, but threshing efficiency and damage increased as clearance reduced. The conical thresher described was assumed to be made of steel. Later Buchele developed a conical thresher with flaps (presumably rubber) rubbing against the inside of a perforated cone for threshing small seeds and hard to thresh grain. A cone thresher has been used (but not described) by the Pioneer Hybrid Seed Corn Company of Johnson Iowa since 1955. Damaged barley not only has reduced germination it also does not keep in storage as well as if it is undamaged. One test on barley showed

74% of grain undamaged 26% damaged. At threshing speeds of 25 m per second, threshing efficiency was low but seed was not damaged.

2.6.8 Grain loss of wheat, maize, sorghum and soybean

Brown and Vassey (1967) in their survey showed that wheat harvesting machines in current use in the Victorian wheat belt are reasonably successful in meeting their functional objective in regard to grain losses which are relatively low as a proportion of production. Most farmers appear to accept these losses as not excessive, however they are significant, varying from about 1% to 5 or 6% with occasional values higher, averaging about 3% of the potential yield.

Losses of 5 or 6% on a farm may not become a big financial loss to individual farmers, but on a national scale 5% of 20 million tonnes is 1 million tonnes of grain. This is a huge loss and related to an international crop of 1 billion tonnes 3% becomes 30 million tonnes, which is significant.

During a maize shelling demonstration using a working model of the Resilient Tapered Thresher at the Grain and Forage Harvesting Conference, Ames, Iowa 1977, an observer (corn grower) noted the threshed grains retained their caruncle which conventional combines remove. This represents 4% increase in saleable grain, in 1994 this was approximately 1,000,000 tons per year increase to USA corn growers, (Ridgway, unpublished).

Grain Sorghum losses from conventional combines can be as high as 16% and as low as 6%. The lowest losses were at cylinder speed of 16.9 ms^{-1}, moisture content 20.4% and cylinder/concave clearance at 6 mm. The highest losses of ≥16% were at moisture content 16.1%, 19.83 m/s cylinder speed and 11 mm clearance (Fairbanks *et al.*, 1979 in Tun Tin, 1990)

Soybean losses averaged greater than 8.5% of total yield. The cutter bar caused 81% of the average total loss (Dunn *et al.*, 1975 in Tun Tin, 1990).

2.7 The development of the Arrowhead Stripping Header (Silsoe)

The arrowhead polyurethane stripping/header concept was developed in the 1980s by a team of researchers led by Klinner and Hale at AFRC Institute of Engineering

Research, Silsoe, UK (Klinner *et al.*, 1986; Hale, 1990). A standard combine was modified so that a stripping header front could be quickly exchanged for a conventional cutter bar front. In the harvest period, August to November in 1985, an area of 19.3 ha was harvested in wheat, oats, barley, peas and linseed in 44 experimental tests. Straw intake was always less with the stripping/header than with the conventional front. Moisture content of straw was up to 30.7% and grain up to 20.6%. The combine output was up to 80% greater using the stripping/header front compared to the cutter bar or conventional front.

Grain losses in most of the tests were less with stripping header than the conventional front. The potential benefits of a stripping header front were not defined but indicated. There were no indications of losses from the stripping header as it left the crops at full speed. This has little if any significance in a commercial situation but could be very important when reaping plant breeder plots.

At Silsoe, U.K. encouraging trials of the arrowhead stripping fingers stripping header were held in 1984, during 1985 it was used to harvest barley, oats, wheat, linseed and peas. Losses were not unreasonable. Straw intake was only a few percent in early standing crops to around 50% in over-mature and lodged crops, Klinner and Hale (1985). A modified stripping header 3.6m wide was evaluated in 1986 Hobson *et al.* (*loc cit*). Evaluations were compared to conventional systems. Stripping header losses ranged from 32 to 100 kg/ha in cereals and combine through put increased significantly, for example 54% gain at 1% grain loss and 50% increase at 100 kg/ha grain loss. Trials with a New Holland TR85 in Victoria with the arrowhead finger in 180 ha of barley, had grain loss of 49 kg/ha compared to 120 kg/ha with the conventional front (Francis, pers com). Work on 25 ha of rice in NSW with a 6m stripping header front on a New Holland 8070 found a negligible grain loss compared to conventional machines working at the same speeds. Because of reduced intake of straw, wear and tear on the machine was expected to be reduced.

An effective and efficient stripping header system for existing combine-harvesters needs to be given highest priority to achieve early commercialisation, which appears to be justified, especially if an efficient, simple cleaning mechanism can be evolved.

Cooperation with the manufacturers of combine-harvesters will be essential to minimise problems of attaching and driving the new headers.

Depending on the quantities of material other than grain, which more refined designs of stripping header will remove with the grain, it may become possible to reduce the size and complexity of the combine-harvesters, or to develop machine systems based on collecting the crop in the field, taking it to a processing station for separating any re-threshing, cleaning, grading, drying if necessary, and storing. Crop residues may be used as fuel for a drier or be pelleted or cubed with or without additives to yield another saleable bi-product of cereal growing for mixing into animal rations. Centralised processing can operate around the clock, if necessary, compared with the limited number of hours daily during which the field equipment can perform its harvesting function. It must be noted that a stripping header can work earlier and later in the day than conventional combines. This is possible because the stripping header can handle higher moisture contents.

The potential advantages of *in situ* grain stripping for the disposal and utilisation of the straw needs to be thoroughly investigated and quantified. New techniques may become necessary, requiring the adaptation of existing machinery and probably some new developments which can speed the harvesting techniques.

Further work at Silsoe Research Centre between 1984 and 1989 (Hale, *loc cit*) indicated an increasing development and widespread use of the stripping header concept of harvesting. By 1990 units were purchased in 23 countries including Australia, USA and USSR as well as in a number of European and Eastern Bloc states.

2.7.1 Performance of arrowhead stripping headers

Header losses are always very difficult to measure and therefore the data obtained may only be used as an indication of the performance of both the cutterbar and the grain stripping systems. Grain losses for both types of harvesting header are given in Table 2. 3.

Table 2.3 Combine Grain losses, kg/ha (Hale 1990)

		Wheat	Barley	Oats	Rice
Cutterbar	Average	150	235	22	29
	Maximum	634	491	37	45
	Minimum	7	8	10	14
Stripper	Average	86	106	50	48
	Maximum	105	141	58	83
	Minimum	65	71	37	21

From the data, the header losses made by the grain stripping system are in the range of losses *normally* accepted by farmers when a cutterbar system is in operation.

2.7.1.1 Power requirements of arrowhead stripping headers

Due to the harvesting and threshing abilities of a stripping header front, power requirements are from 1.0 to 4.5 kW/m at 7.5 km/h in a standing crop. In lodged cereal crop conditions, the power requirement may be 7.0 kW/m and in lodged rice conditions power requirements may be 9.0 kW/m.

Other work done by Tun Tin (*loc cit*), Douthwaite, Quick and Tado (1993), Quick and Douthwaite (1994) has indicated advantages in harvesting and threshing of grain sorghum, soybean, and rice with a stripping header front. Together with the early Silsoe results. these indicate a new era has arrived in harvesting most crops. Some more work on standing and windrowed faba beans and other windrowed crops such as canola need to be published. Even without published results, progressive farmers will soon adapt the stripping header to suit their special needs. This has begun in several Asian countries where International Rice Research Institute and Sisloe workers have demonstrated that an adapted machine, a stripper-gatherer, can harvest cheaper than traditional systems on small farms.

In summary, the stripper-gatherer system now commercially available can harvest with less expense than any existing system on small farms in Asia. It has a simple design, can be made locally and is suited to the region's rice farmers. It should prove important in helping small area farmers survive under difficult economic conditions.

2.8 Conclusion: the grounds for a change to the Pneuflo concept

This review has outlined the development of the modern combine harvester. It has also shown the great limitations of current combines. The recent work on conical threshers and arrowhead strippers was presented as an indication of ideas being developed to improve this technology.

It is interesting that no sustained viable *vertical* threshing system was found in this literature. The only exception is a vertical threshing cylinder patented in the USA December 3, 1922. It was driven by one horse walking on a circular driving platform which transferred the power with a leather (belt) strap to the thresher. The concept of vertical threshing has great merit for the ease of cleaning, so it is curious that this idea was not propogated further until 1986, Figure 2.k, when a patent was filed in Finland. Figure 2.l indicates the complexity of this device compared to the simple Resilient Tapered Thresher shown earlier (Figure 2.d and Figure 2.j).

The chapters that follow describe the development of the Pneuflo concept which integrates the concepts vertical, conical threshing, arrowhead strippers and air separation.

Figure 2.a Hand Threshing.

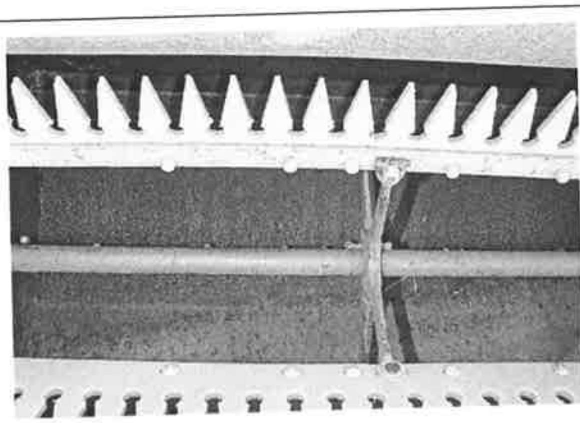

Figure 2.b Arrowhead harvesting fingers developed at Silsoe Agricultural Research Institute, UK.

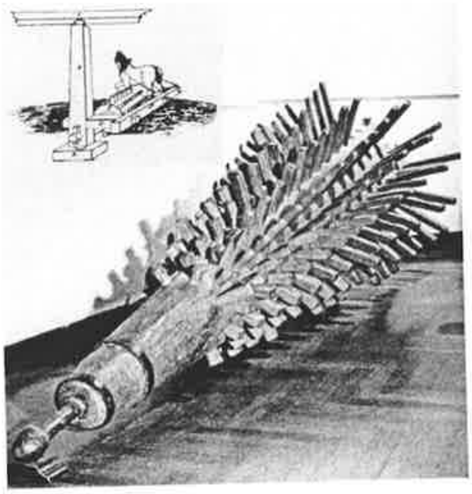

Figure 2.c Porcupine thresher used in New York State in the early 1800s. (Quick and Buchele 1978).

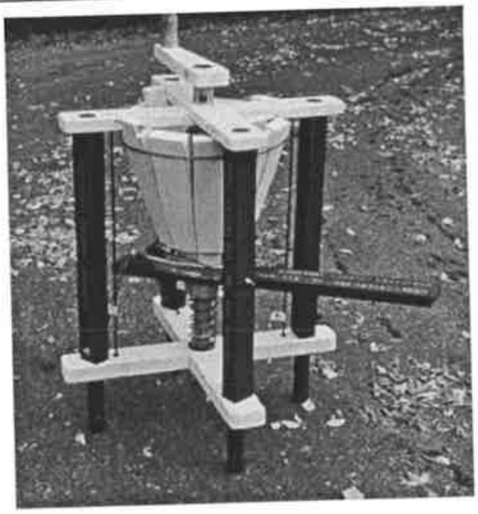

Figure 2.d Wooden Resilient Tapered Thresher developed by the author for demonstration at Grain and Forage Harvesting Conference, Ames Iowa, 1977.

Figure 2.e Traditional winnowing of rice as still practiced widely around the world. This photo is from Sri Lanka (source: I Nuberg)

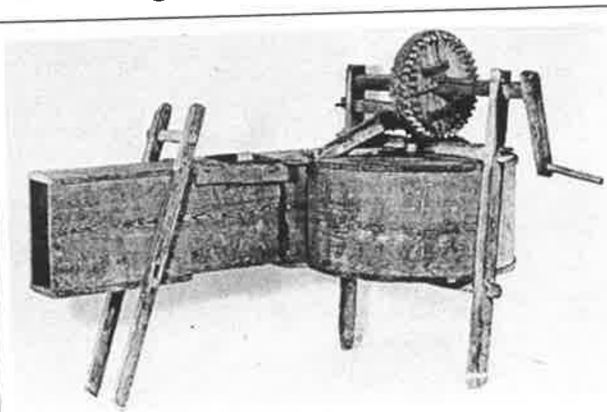

Figure 2.f Hand-turned horizontal winnower for cleaning chaff from grain, ca 1840. The grain was fed through the hole at the top and the clean grain collected underneath (Quick & Buchele 1978)

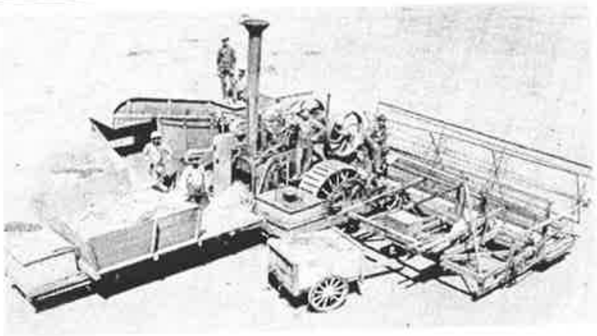

Figure 2.g The first self-propelled combine made in 1886 in California. It had a 22-foot cut and 50 acres of grain could be cleaned and sacked per day (Quick & Buchele, 1978)

Figure 2.h Ridley's Stripper, his third model, 1846. (Redden 1992)

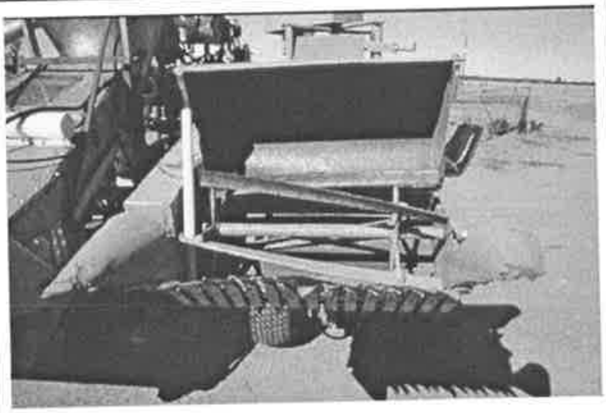

Figure 2.i A modern (1978) version of a Ridley type harvester constructed by the author at Hannaford's Seedmaster factory, Adelaide.

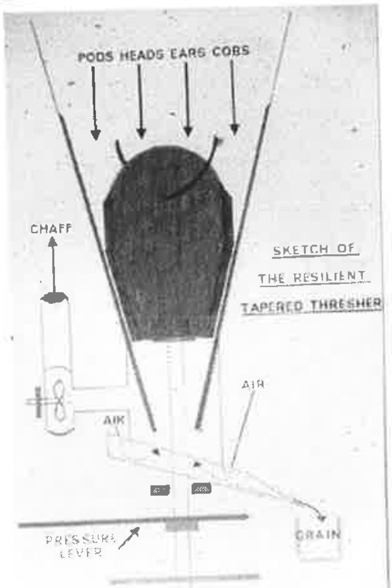

Figure 2.j Sketch of RTT

Figure 2.k Vertical thresher from Finland

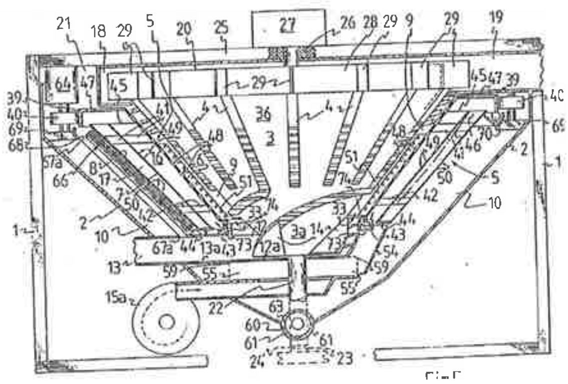

Figure 2.l The patent drawing of a vertical conical thresher number 893,315 filed in Finland July 1986 has been sent from Silsoe College.

3 MATERIAL, COMPONENTS, DESIGN AND CONSTRUCTION

3.1 Introduction

The Pneuflo concept is a radical departure from conventional harvesting technology. It depends on air flow to transport material from the stripping header to the thresher and for the removal of dust, chaff and straw from the grain. It took several decades to develop, with many working models in the process. To detail every drawing and test result made over this period would be beyond the scope of this thesis and the patience of the reader.

In this chapter only the main models are described and the results of their performance is presented in Chapter 4. The first model is the Resilient Tapered Thresher laboratory model which was developed in 1976 as a prototype: a vertical, tapered threshing unit with a built-in chaff extractor, see Figure 3.a, 3.b and 3.c. The next models to be discussed are the wooden hand operated concepts, one made to take to the Ames Grain and Forage Harvesting Conference and the other made for the Philippines Workshop and the Mission Farm in Ecuador, shown in Figure 3.d. The third model (which was the first self propelled unit) is described as the Pneuflo Ridley Front, built in 1978 and shown in Figures 3.e and 3.f. The fourth model detailed here is the Pneuflo Silsoe Front, Figures 3.g, 3.h and 3.i, built in 1994-95. The fifth unit described is the first commercial Pneuflo Combine, made by Irvine Engineering at Tintinara and shown in Figure 3.j. Other combines mentioned in Chapters 3 & 4 are one taken to Queensland (Figure 3.l) and one built at the Roseworthy Campus (Figure 3.m). A description of the design and construction of these models is given in this chapter after a short history of the development process.

3.2 History of the development process

3.2.1 The very early days

The development of the Pneuflo concept began when the author was a young man. The first combine on my father's farm was a Massey Harris 8 ft open front comb header having a reel with built in choke cutters. Ground speed was about 2 miles per hour and it was pulled by 6 Clydesdale horses. Father purchased it, possibly as a new machine, around 1920. When the crops were ripe, the weather hot and the cogs bearings and chains oiled with special stringy harvester oil it produced a perfect sample. The driver sat on a cast iron seat covered with a jute sack to stop some of the heat transfer to the driver. He could see the sieves and walkers working due to the machine having a material flow direction change of 90° from the rasp bar thresher via the walkers and the sieves toward the unharvested crop. This vantage point also caused a certain amount of physical discomfort if there was a wind blowing from the dust outlet toward the driver.

In 1941 Father purchased a John Deere Model D petrol/kerosene tractor fitted with rubber tyres and a three speed gear box with a top speed of 5 mph. Bottom gear at 2 mph was ideal to pull the header, this was done until 1945 when Father bought a new Horwood Bagshaw 10 ft comb header on steel wheels but with a power drive from the tractor. This unit could reap a ton to the acre crop at 3.5 mph. Now 200 bags (600 bushels) could be reaped in a day of about 10 hours but there were some side effects. First the combine had to be greased every two hours. Second the machine settings were more critical and the samples produced were seldom as good as the Massey Harris. This was due mainly to the thresher rotor having fixed lugs which threshed the crop through a series of slots made by the pegs, which could be raised and lowered as necessary. Resetting required two large spanners and a hammer to change the settings sometimes two or three times per day depending on the ambient temperature and the crop moisture content. If the thresher pegs were kept too high the straw tended to be pulverised and overload the sieves causing grain loss initially and a blocked thresher, if not corrected. The combinations of settings including those of the thresher, internal wind speed, sieve position, hole size and shape, number of sieves fitted, internal wind direction and height of the tail gate came to well over 1.5 million.

At this point the desire to build a combine with a slow soft thresher in a self-cleaning sealed combine was conceived. However the opportunity to work on this concept did not occur until 1975.

3.2.2 Waite Agricultural Research Institute

In 1975 the author was employed as Laboratory Technician in the Agronomy Department of the Waite Agricultural Research Institute (WARI), Adelaide. Work on *the Pneuflo* concept began with the development of the Resilient Tapered Thresher while attached to the Grain Legume Research Project of Dr Roland Laurence. The problem of the day was that conventional threshing machinery smashed too many seeds. The Resilient Tapered Thresher was developed in response to this need. In addition, a cleaning function was added by allowing the threshed mixture to fall through an up-draft of air which lifted the chaff and dust from the grain. A lever was fitted to the rotor spindle to allow the threshing pressure to be adjusted by loading the lever with a weight. The threshing pressure remained constant but the volume could vary due to the rotor lifting in the tapered housing. This simple concept was the foundation for all the models developed subsequently. See Figures 3.a – 3.c.

The first use of the RTT was to thresh and clean over 50000 samples of grain legumes, cereals and grasses grown for the Agronomy Department at the Waite Institute, beginning in 1976. In 1977 a wooden, hand-turned model, shown in Figure 2.d, was made to demonstrate the RTT concept at the Grain and Forage Harvesting Conference in Ames at the Iowa State University (Ridgway 1978A). The RTT Ecuador model, Figure 3.d, was also taken onto the ABC-TV program *The Inventors* in 1978 and was awarded the prize for the inventor of the week. The next day the SA Minister of Agriculture, Brian Chatterton, arrived at the Waite Institute offering his help in developing the concept. He offered salary to pay someone else to do my regular job while I concentrated on developing the RTT. Demonstrations of the concept were given to interested people, one of whom noted that the RTT did not remove the peduncle from maize to the same degree that commercial combines did and this represents 4 % of the crop.

A grant from the Rural Credits Department of the Reserve Bank in 1978 financed the building of a self propelled combine on a Bolens 16 HP hydrostatically driven power unit ride on lawn mower, as a mobile plot harvester with a Ridley harvesting front, the RTT concept for threshing and with cleaning provided by an updraft of air (Figures

3.e and 3.f) to harvest four rows of breeder's plots up to 5 m in length. This combine had a 600 mm wide crop intake with a down swept beater rotating above a comb with 15 teeth initially, Fig 3e. However, comb losses were too high so an extra tooth was added. See tables of results in Chapter 4. The combine, called the *Ridgway Pneuflo with Ridley Front*, was used to harvest research plots of wheat, triticale and uniculm barley, with a narrow track so that plots could be harvested without damage to adjacent plots.

The beater imparted enough velocity to the harvested heads and a current of air strong enough to move the crop to the RTT where threshing was completed. The threshed mixture fell across a 45° updraft current of air that extracted the Material Other than Grain (M.O.G.). The clean grain fell into a collecting bin. Clear Perspex tube 100 mm diameter was used so that the driver could check the separation and adjust the air flow accordingly, shown in Figure 3.k. The air flow was produced by a mechanically driven 100mm fan. The driver sat on the left side and the bagger sat on the right. This combine was used for harvesting postgraduate plots of triticale and wheat, research plots of uniculm barley and dry land lucerne.

This model was further modified by: replacing the mechanical lift with an hydraulic cylinder fitting a perforated screen at the top of the chute to vent excess air and replacing straight beater bars with curved bars to create a screwing head removal instead of a series of direct hits. Replacing the Ridley bars with arrowheads fixed on the bars (Figure 3.n) indicated the huge potential of a replacement self cleaning simple combine for harvesting most, if not all, grains and seeds.

Further modifications of this machine included the extractor fan being mounted on a 45° angle clear tube with speed control rather than flow control to vary the flow and the fitting of a top lip and a bottom lip to minimise grain losses at the end of the breeder's plots.

A special feature of this machine is that it is capable of reaping at ground level. See Figure 4.d on page 72, where a sample of oats reaped from the ground. The sample was not perfectly clean because the total crop, approximately 1m tall, was reaped.

The next development of the wooden concept included wooden models professionally made at the Waite Institute and two steel models for sale made by Alf Hannaford & Co. Pty Ltd who were licensed by the University and the author (see brochures in Appendix 11 and 12). These hand turned models were very useful for small samples of grain legumes. A wooden model was made for demonstration at the Regional Grains Post Harvest Workshop in The Philippines (Ridgway, 1981). This model (Figure 3.d) was sent to a mission station in Ecuador and was used there for six years (See Chapter 4). Using the RTT to shell soft-shelled almonds further demonstrated the versatility of the concept.

In 1978, a 12 FT open-front Massey Harris self-propelled combine was converted by removing the thresher and the walkers and replacing them with a 1m diameter RTT as shown in Figure 3.l. An endless slatted plastic ribbed conveyor belt replaced the steel crop elevator. This combine was taken to Queensland to test it harvesting navy beans but the crop was infested with green weeds, which did not pass through the thresher. On return to WARI this combine was used to harvest research plots of faba beans. See appendix.

Due to complications with the licensee the next model, see Figures 3.o and 3.p, a 2m wide intake field combine was built at another engineering factory. This combine was built with a Ridley comb, a down-swept beater and a patented crop cutter beneath the fingers of the comb and was mounted on the drawbar of an MF35 tractor on an articulating frame. The tractor drove the components hydraulically via a PTO hydraulic pump and hydraulic motors. This combine was tested in 1980 but problems with the hydraulic system were unresolved due to financial problems.

Over the period 1975-80, two other legume combines, Figures 3.q and 3.r, were built with open front combs 1m wide and fitted with 1m diameter RTTs. They were electrically driven and did the bean plot harvests as required.

The Department of Plant Pathology at the WARI was investigating diseases with orchid plants, which do not germinate easily unless scarified or treated to remove the testa. Dr J. Warcup asked me to make an RTT to remove testa from 0.2 to 0.3 mm diameter seed. The RTT was made using a 25mm diameter rubber stopper fixed to a 6 mm drill shank for the rotor and GSS lined with tough sponge for the stator, as shown in Figure 3.s. The stator was fixed to a 30 cm lever, pivoted so it could assume the right position to fit the rotor as the lever was loaded to complete the threshing. Dr Warcup was satisfied with the performance.

A similar unit was made for Emeritus Professor C. M. Donald. The main difference was that the unit had to be big enough to hold one head of wheat. Also the load was applied to the rotor in this model, rather than the stator, by pulling down on the lever, see Figure 3.t. The rotor was a spherical plastic ball (off a boat trailer) with rubber impellers fixed to the circumference. The rotor was fixed on a threaded spindle, clamped between nuts. Professor Donald was very satisfied with the thresher.

In 1980 the RTT project was suspended due to lack of financial support. The project was not revived until 1989 when I met Professor R. Godwin from Silsoe College, Cranfield University, UK, at a meeting of the American Society of Agricultural Engineers in New Orleans. He invited me to visit Silsoe where the stripping header concept shown in Figure 3.u was demonstrated. In 1991 *Luminis,* the company responsible for commercial development of Adelaide University intellectual property, raised money for shipping this combine and myself to Silsoe for further development work (see Appendix 26 for report). This spurred me to incorporate the stripping header, the RTT and an air separation in a field combine. By 1995 the *Ridgway Pneuflo Combine with Silsoe Front,* Figure 3.g – 3.i, was developed on the Bolens mower using my own physical resources, financial help from Luminis and with the assistance of an engineering graduate, Paul van Wezel (Reid and van Wezel, 1993).

This combine was awarded First Prize for Inventions at the 1995 South East Field Days at Lucindale, SA.

On return from England, this combine was developed into a working model financed by Grains Research and Development Corporation. Dr Rathjen, wheat breeder at WARI received a report from his technicians after this combine had produced acceptable samples of seed increase plots. A plan for a commercial combine was prepared for harvesting 1.25 m breeder's plots. This was built by Irvine Engineering at Tintinara, see Figure 3.j, and was capable of harvesting up to 300 plots per hour compared to other combines that only harvested 80-100 plots/h. (results in Chapter 4). Two more commercial combines were built for Dr Rathjen's team in 1999-2000 and are giving very satisfactory service (see Rathjen letter in Appendix 13).

Currently (2002), *Luminus* is interested in supporting the development of a commercial model that would be suitable for farmers.

3.3 Pneuflo – Roseworthy with Silsoe Front

The substantive difference between the Ridley Type machine and the Roseworthy machine, Fig 3.m, is that the latter machine uses arrowhead stripping header fingers which rotate upwards through the crop, taking mainly heads in a standing crop. The Ridley machine moves downward through the crop.

3.3.1 Design of basic unit at Roseworthy 1992-93

Certain parameters were required to allow the combine harvester to gather 6 rows of cereals, for Roseworthy Plant Breeders and to thresh and clean an unknown range of experimental plots which were six rows wide and approximately four metres long. The machine had to be self-cleaning and to be able to deliver a cleaned sample of grain into paper or plastic bags ready for weighing. The maximum width was to be not more than 1.25 m, length was to be not more than 4m. The height had to be less than three metres total for stability and to be able to drive the combine from the shed in which it was being built.

This combine will now be described under headings: design of mono-construction, design of the chassis, stripping header and chute design, grain thresher and dust extraction and design of nose cone lips.

3.3.2 Design of the mono-construction

The Stripping Header, the chute from it to the threshing chamber and straw extractor were built to be in fixed relationship with each other and the fabrication was to be airtight when working to prevent loss of air pressure, and to prevent dust from escaping. The construction also needed to be lifted at the front to suit different height crops.

The lifting component used was the comb lift hydraulic cylinder and pump unit obtained from a MF31 plot harvester. To give a range of crop intake heights from ground level to approximately 2 m the rear hinge pin had four different anchor positions. Galvanised Sheet Steel (GSS) 1.6mm or 1.4mm or 1.27mm thickness was used, as needed, to fabricate the stripping header housing, the chute, the body of the threshers and straw extractor. Reinforcing of the chute to take the hydraulic ram fixing required some framework which was 2mm thick 10mm x 20mm and a plate 10 x 30 x 100 mm.

The straw thresher housing was rolled and assembled at R.A.E. workshop from 1.6mm GSS the same material was used for the top on the rotor, which was 800 mm diameter. The top kept the thresher bars stabilized and the same material was used for the top of the thresher housing and the straw extractor outlet, Figure 3.v.

The stripping header cowling and the ends were fabricated at the RAE workshop from 1.6 mm GSS, as was the cowling and sides which were strong enough to carry the self aligning bearings for the stripping header and the hydraulic motor drive.

The chute was fabricated at R.A.E. workshops from 16 gauge (1.6 mm) galvanised sheet on a framework made from 75mm x 25mm x 3mm and 50mm x 25mm x 3mm rectangular steel tube and 25mm x 25mm x 3mm square plate assembled so that the delivery of the harvested materials to the threshers was initially radial, but later modified to tangential.

3.3.3 Design of the Chassis

A 1970s Suzuki Stockman 4WD chassis was used as the base unit. Its dimensions were width 1.38 m and length 2.9 m, on 6.00x 15 inch tyres. The engine and gear box of the Suzuki were discarded. This was replaced with a Perkins P4.108 diesel motor developing 33 kW or 45 bhp at 3000 RPM from a 6' self propelled Massey Ferguson combine was mounted in transverse position above the front wheels with radiator to the new right.

The ground drive of the unit was driven by an hydraulic motor (Char-lynn model 309 101 1011 007), directly coupled to the transfer case and connected to a bi-directional control valve to give forward and reverse motion and braking. This was mounted on the input side of the transfer case for the ground drive. The proportional control valve was mounted on the floor beside the driver.

Two hydraulic pumps were needed, one for the ground drive and one for the stripping header, thresher and fan, which was a Shimaosh model 25a-32r-784-38-7063. The three hydraulic motors for the stripping/header, thresher and extractor fan were Dowty model t29-7484-hm90r-2-9-76, Char-lynn model 458-101-1033-007, and Dowty model t45r 7481-hm-30r-4-10-77 respectively. These were mounted on the left of the chassis and driven by vee belts from the motor which had the original flat pulley removed and a 4-groove, B section, vee pulley fitted.

An A-section pulley was mounted on the outer end of the main pulley to drive the pump for the two hydraulic cylinders. These were taken from the MF Combine and were mounted to provide height adjustment controls for the stripping header and the top lip. The control levers were on the left of the driver's seat.

The steering column was re-sited to the rear of the chassis and a long drag link connected so that the steering wheel turned in sympathy with direction required.

3.3.4 Stripping Header and Chute Design

A five-spoked stripper rotor was used as the basis of the prototype plot combine incorporating a Silsoe Stripping Header built in 1992. Arrowhead stripping fingers, made by Shelbourne Reynolds England, were purchased from Cutts Machinery Melbourne, to build the stripper header 1.200m wide. The arrowhead fingers, Figure 3m, were supplied in 0.60m lengths and were fastened to the spokes after being bolted to steel support bars 25mm x 6mm x 1200mm. When the rotor was completed 5 rows of stripping fingers were arranged on radius lines compared to the Silsoe and Tun Tin designs of 8 row with fingers arranged at 15^{o} and 20^{o} ahead of the radius line. The rotor plus fingers had a radius of 0.300 m.

The cowling over the stripping header was designed to give a clearance 65 mm above the finger tips and a cut off plate was fitted on the bottom of the delivery chute at 55^{o} past the vertical. Initially the cowling continued to 180^{o} past the vertical but this was found impractical and when field tests were begun this lower section was cut back 30^{o} to allow the fingers earlier and lower access to the crop being stripped. The cut off plate had to be altered to 50^{o} past vertical to match the modified chute, which was found to be too deep and too wide.

The cowling front opening was at 270^{o} from the vertical in the direction of rotation of the rotor. An adjustable top lip was fitted externally, Figure 3.w. The lip position was controlled by an hydraulic ram and rotated through 45^{o}, from 270^{o} back to 225^{o}, giving control of crop inlet and reducing losses if the forward speed was inadequate or the crop inflow was reduced below a critical point. The critical point is defined as that which prevents grain loss forward of the cowling.

Due to a limit on the width of the stripping header a direct drive motor could not be used on it. An hydraulic motor mounted above the cowling drove the rotor via vee belts at selected speeds between 400 and 1100 RPM. In operation the stripping fingers were able to collect herbage material from ground level. This could enable heads of grain, fallen to the ground prior to harvest, to be retrieved when harvesting lodged crops.

Initially, the chute from the stripping header to the thresher was built with a constant cross section area, but as shown in Figure 3.x this tended to block. The entry to the chute for the reaped material was 150mm high and 1250mm wide = 187500 mm^2. After extensive tests and modification the chute was redesigned to have an inlet from the stripping header of 1250mm x 75mm = 93750mm^2 (50% of the original size) and a reducing cross section to the exit, which was reduced to 250mm x 750mm = 46750 mm^2 or 25% of the original outlet size. These continuing design changes and modifications were part of the evolution of the concept and the action learning process.

The access of the chute to the threshers was designed to be radial and direct but eventually it was tangential, several other options were considered, radial upswept, down swept, radial divided, with a lip, and tangentially with a lip.

3.3.5 Design of Thresher and Straw Extractor Housing

The thresher needed adequate capacity to handle the crop load. The measurements of the conical thresher and circular extractor housing were 1200mm high, 960mm top diameter, and 152mm bottom diameter. The top 200mm of the housing was circular and housed the straw thresher (Figure 3.v) and the straw extractor fan, shown in Fig 3.y. The cone angle was 54^o after Lalor and Buchele (*loc cit*).

The inside of the straw threshing section of the housing was designed to be lined with a 25mm square woven mesh made of 3mm diameter zinc coated rod. This was supported 30mm inside the housing to act as a threshing grid, it was later replaced by four hollow rubber bars 50mm wide and 50mm high with 3 flat sides rounded top and bolted vertically. Several clear perspex windows were planned around the housing for observation and service. The top of the housing was sealed in place by a rubber seal and over centre fasteners.

The straw outlet from the extractor housing was designed to allow the straw to be ejected tangentially through a 180mm x 180mm sheet metal tube 700mm long to which a jute sack could be attached to collect samples. The chaff and dust extractor tube was attached to the bottom of the threshing housing using a 150mm plastic sewer pipe Y piece. The clear perspex extractor tube 150mm external diameter and 1000mm long had a slope of 60^{o} from the horizontal. A 150mm extractor fan was arranged to pull air up the inclined tube at a speed, less than that which would extract the grain as well, about 6m/s. The design of the dust and chaff extractor allowed for speed control of the fan to adjust the airflow. Discharge from the extractor fan was to the right of the harvester through a clear perspex 150mm diameter tube 1m long, to which could be attached a jute sack for sample collection, Figure 3.f.

To separate the grain which was threshed by the arrowhead polyurethane fingers at the front intake of the machine, the inlet from the chute, was designed to allow that grain to pass down through a Resilient Tapered Thresher, to rub out any white heads before entering the dust and chaff extraction tube. The intake from chute to thresher was also designed so that the unthreshed heads and heads still on the straw would be taken upward, by the up draft of air created by the straw extractor fan, the impetus from the chute air flow, and the increasing velocity of the conical threshing rotor as that material was impelled by the rotor.

The Resilient Tapered Thresher Stator was a commercially made unit supplied from Hannaford Seed Master Services. This unit was used as the basis to plan the upper thresher to remove grain from straw or the straw threshing and extraction component. The same angle was used and the fabricated unit was built vertically above the manufactured unit. The thresher had four bars of 1.6mm galvanised sheet steel made in pairs each with two blades of the straw extractor, cut out of 1 piece of steel. See Figure 3.y. A sheet steel top on the bars stabilised them at that point. This arrangement was expected to cope with all crops except corn (maize) as the clearance between the bars and the mesh was to be no less than 10mm. The threshing needed was expected to be done by impact and the shearing effect of straw on mesh. The vertical air speed within the thresher was not expected to be above 6m/sec but the ejected straw was expected to be accelerated by the fan blades at the top of the thresher bars. The concept was to remove the grain before the updraft reached 6m/sec. As the empty straw was lifted higher its speed increased until ejection.

The spindle on which the threshers bars were mounted was 36mm hollow tube for the RTT section and the straw thresher section had two pieces of 40mm angle iron welded along it making a square shaft to which the thresher bars could be bolted making them readily mounted and demounted.

The spindle was carried in two wooden red gum bearings, one between the threshers and one on an angle iron frame above the housing. The direct drive hydraulic motor was coupled to the shaft by using a standard tractor power shaft spline welded to the spindle and the female section fitted to the hydraulic motor spindle, this was designed to give quick release of the motor for access to the thresher. The design of these threshers includes a spring, fitted around the shaft and above the top bearing in this case, to carry the total weight of the spindle threshers, extractor and drive motor. This allows the unloaded spindle to turn freely and also prevents cannibalisation of the opposing surfaces. To bring the threshing surfaces in the threshing mode a floating downward pressure was needed this was done via a lever across the top end of the drive motor having a moveable weight to vary the pressure. This concept allows the volume of threshed material to alter while retaining constant threshing pressure.

The access point to the thresher was designed to allow grain and unthreshed material to enter at a point where the centrifugal velocities of the threshers would, on the lower RTT, be slow enough to let grain go down and, on the upper RTT, fast enough to take the straw up. A retaining bracket in which the pressure lever could move vertically but not horizontally allowed the rotor to be turned and maintain a pre-determined threshing pressure. The separation tubes below the thresher were 150 mm polycarbonate tubing as was the dust and chaff exhaust tube.

3.3.6 Nose Cone or Top Lip, and Bottom Lip

In the combine for this project a top lip was included initially, followed by a matching bottom lip, both being controlled by the driver. The bottom lip was spring loaded to give fast mouth closing when released by the driver at the end of a plot and was returned by a rope pull. The need for these lips to be included was to prevent grain loss from the stripping header at the end of the cereal plots for which it was being built. This was achieved by fitting two segments of sheet steel shaped to fit the outside of heading stripper housing, the top lip included a rolled circle of GSS moving about 45^{o} of the housing circle and the bottom lip about 90^{o} of the housing circle. Both lips were to be attached to the heading stripper shaft ends by a 90^{o} quadrant of sheet steel and a suitable bush. The top lip was to be lowered hydraulically and returned by coil springs such that it could touch the ground when the fingertips were rotating at ground level and be raised about 45^{o} above that position. The circular shape of the top lip was to prevent damage to incoming heads and prevent the fingers flicking heads forward if the forward speed was too slow or the crop too light to prevent the forward loss.

The bottom lip was designed to be manually controlled by the driver. As the crop intake was finishing it was to be closed against the top lip as fast as possible. The leading edge to be a strip of rubber insert 1cm thick to give a seal and prevent metal to metal contact and damage. As the bottom lip was to be closed air access to the rotors was to be maintained by a 25 mm gap in the overlap of the top and bottom lips when closed. When the losses were measured the losses were found to be insignificant. This compared favourably with the results obtained by the Silsoe workers (Klinner *et al* 1987).

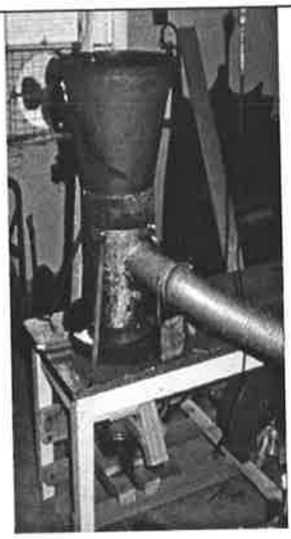

Figure 3.a The first laboratory thresher and cleaner (1976)

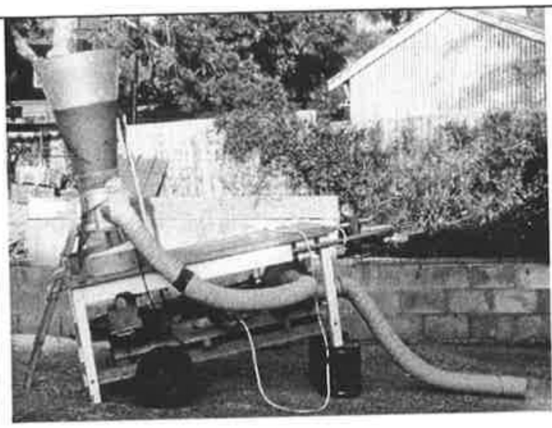

Figure 3.b The first laboratory thresher and cleaner (1976)

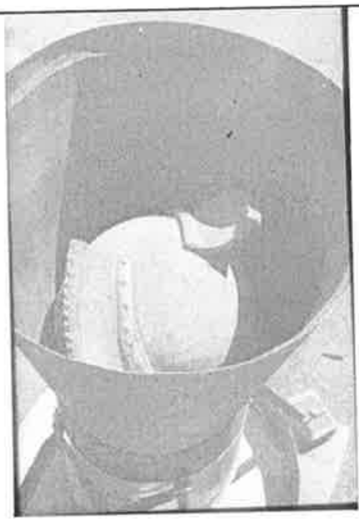

Figure 3.c Rotor and Stator of laboratory thresher

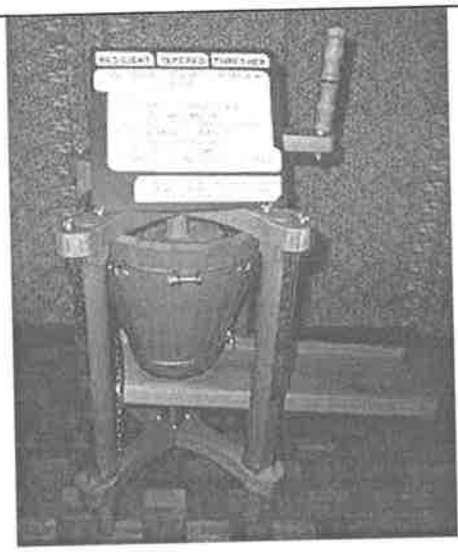

Figure 3.d Ecuador model

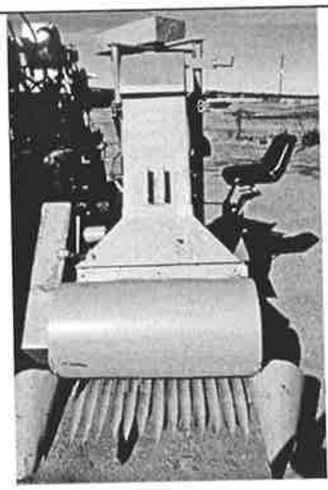

Figure 3.e Ridley Comb, telescopic lift (Bolens)

Figure 3.f Ridley Comb, telescopic lift (Bolens)

Figure 3.g Ridgway Pneuflo with Silsoe front

Figure 3.h Ridgway Pneuflo with Silsoe front

Figure 3.i Ridgway Pneuflo with Silsoe front

Figure 3.j First commercial unit made by Irvine Engineering, Tintinara

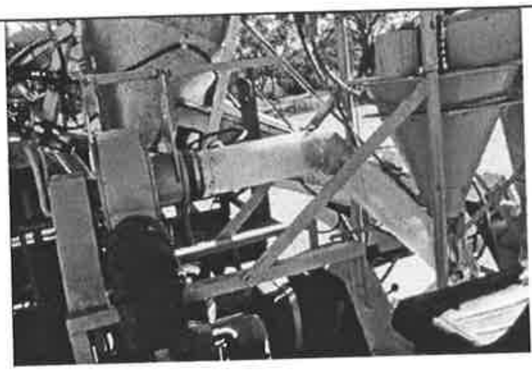

Figure 3.k Aspiration tube

Figure 3.l Massey Harris SR conversion taken to Queensland

Figure 3.m Roseworthy Pneuflo

Figure 3.n Curved steel beater bars

Figure 3.o 2m comb field type with Ridley front working

Figure 3.p 2m comb field type with Ridley front, patented belt cutter and articulated drawbar

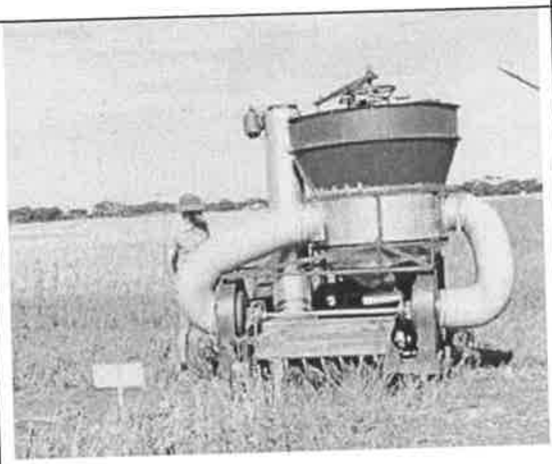

Figure 3.q First mobile legume combine (electrically driven, on MF35 tractor)

Figure 3.r Second mobile legume combine (electrically driven)

Figure 3.s Single cereal head model

Figure 3.t Orchid seed testa remover

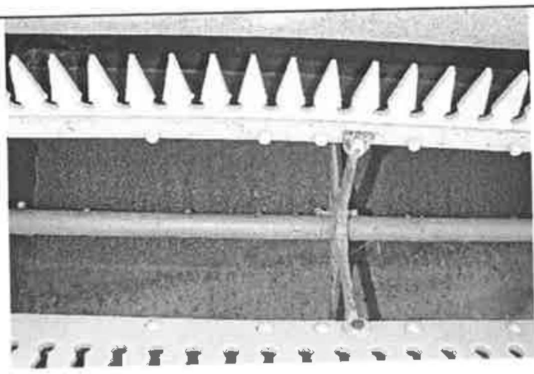

Figure 3.u Silsoe stripping header for Roseworthy unit

Figure 3.v Threshing Rotor, Roseworthy machine

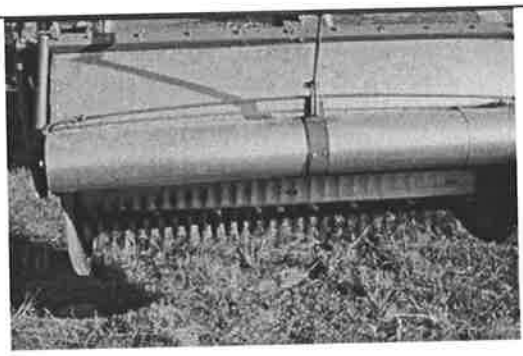

Figure 3.w Top lip of Roseworthy Machine

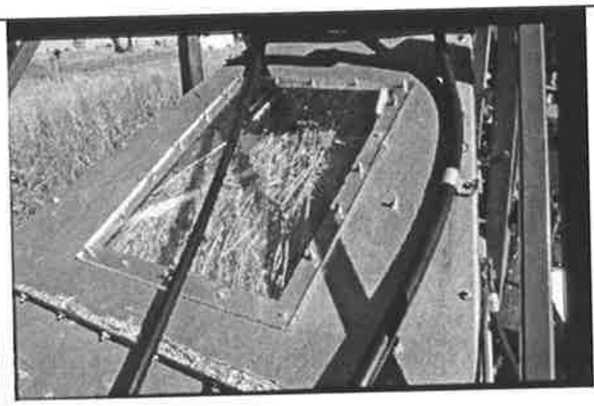

Figure 3.x Partly Blocked Chute

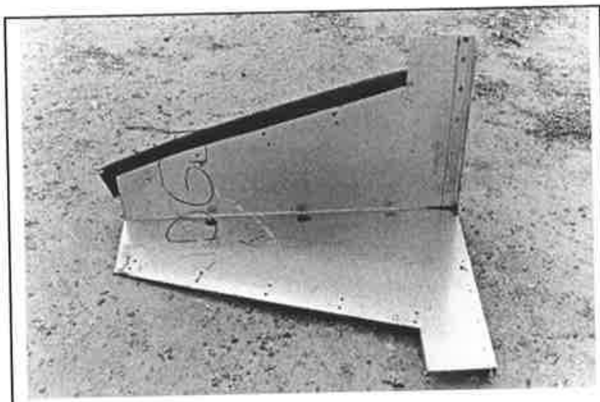

Figure 3.y Thresher and extractor fan

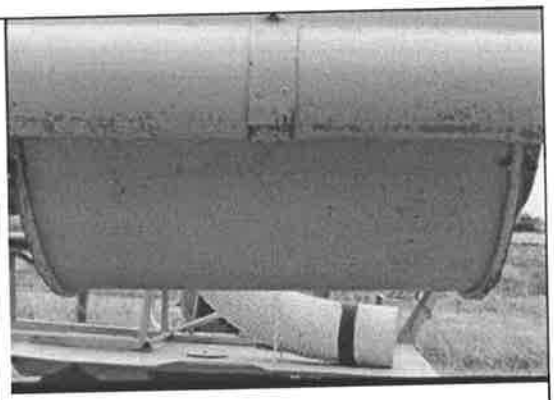

Figure 3.z Closed top and bottom lips

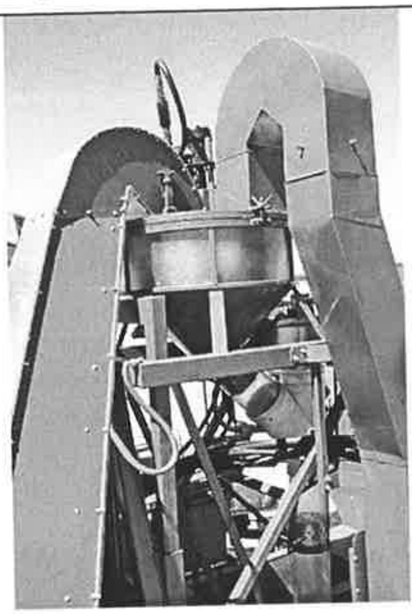

Figure 3.aa Top of Irvine showing fasteners and chute

Figure 3.bb Hybrid over the top unit

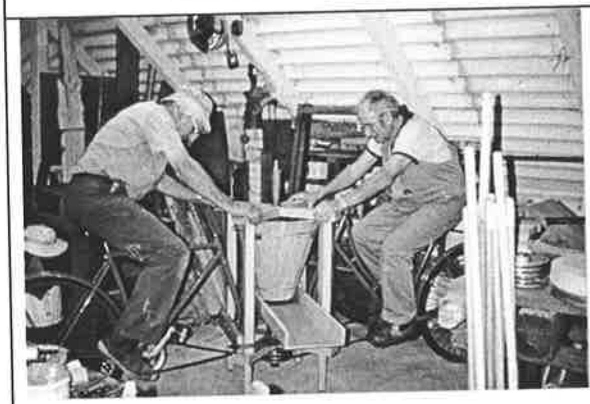

Figure 3.cc Two person pedal powered Ecuador type

Figure 3.dd Ridgway designed, Hannaford manufactured hand model

4 TEST RESULTS OF SIX MACHINES

4.1 Introduction

The Pneuflo concept has been under development since 1976 with repeated testing at each stage. Only the key test results are presented here of the main machines developed. Some of the results presented here have been published.

For the purpose of this work and to note why these results may appear to be out of a systematic order. The reason is the various models were made as the need arose. The first unit was made on a shoestring budget and the components were mostly obtained from surplus stores at the Waite Institute. However $70 was needed to have the rotor turned on a wood lathe and to have the stator made from sheet steel with sheet rubber vulcanised on the inside. Having got this model to thresh heads of wheat the next step was to build the aspiration hood, which also worked. This was the first working concept of the RTT.

Because the patent attorney suggested a working model was the best way to introduce a new concept, the first wooden hand operated RTT was conceived and made out of salvaged material. This unit was built on the keg principle, wooden staves held together by steel bands, this allowed the components to be packed in a carton and carried as luggage on an aircraft. This unit was the basis for designing and building the Ecuador model, which is the second model to provide results for this chapter, as well as the first steel models made by Hannafords.

4.2 The First RTT

When the confirmation to give a paper at the Ames Conference was received urgent decisions were made. In the Agronomy Department at the Waite Institute Professor Emeritus Colin Donald encouraged the author to prepare a paper, a copy of which is in Appendix 1. A working model, Figure 2.d on p 36, was made to take for actual demonstration.

The first test results of the Resilient Tapered Thresher were published in the proceedings of the First International Grain and Forage Harvesting Conference, held in Ames, Iowa in

1977, see Appendix 1. These results show the ability of the laboratory RTT and the aspiration method of cleaning grain of wheat, barley and faba beans. Over 50000 samples of various crops were threshed and cleaned in subsequent years in this machine.

4.2.1 The first critical observations of performance of the RESILIENT TAPERED THRESHER

To indicate the performance of the prototype, three species of grain were used, namely wheat stored as whole plants from the 1976 harvest, barley scythed at ground level from a 1976 farm crop and a small seeded faba bean harvested as mature whole plants which had been air dried. All samples were oven dried at 43°C prior to threshing to simulate normal dryness at harvest time. These results are summarised in Tables 4.1, 4.2 and 4.3.

Table 4.1 Wheat: Resilient Tapered Thresher Table model

Sample	Number of samples	Time per sample (means in seconds)	Broken grain	Percent grain with glumes attached	Percent of total grain in chaff *
Single ears	100	24	0	0.6	0.14 *
5 ears	100	37	0	1.5	0.19 *
Hill plots	200	46	0	N/A	N/A

* These values are unusually high. The air flow was excessive in these tests.

N/A = not available.

Hill Plot is the grain grown from one head of parent, planted in a cluster.

Table 4.2 Barley: A comparison of three threshers

Thresher	Number of samples	Sample	Time per sample (sec.)	Grain missing, broken or damaged (percent)	Grain with awns (percent)	Percent of total grain in chaff
Resilient tapered thresher	100	Single tillers	31	0	3.2	0
Resilient tapered thresher	50	5 tillers	46	0	0.8	0
Bench type centrifugal thresher	50	Single tillers	31	30	5.7	N/A
Bench type centrifugal thresher	50	5 tillers	27	38	7.4	N/A
No. 6 Sunshine header	50	Sub sample ex bulk sample	N/A	2.5	1.2	N/A

These figures demonstrate the difference in broken grain and grain with awns attached using the RTT compared to the current machinery being used. The figures are means, with no SD or range information available.

Table 4.3 Faba beans: Resilient Tapered Thresher (310 mg per seed)

Sample	Number of samples	Broken grains per sample *	Unthreshed grain	Percent of total grain in chaff
Single pods	100	0.05	0	0
5 pods	100	0.23	0	0.08
10 pods	100	0.24	0	0

4.3 The Second RTT

4.3.1 Resilient Tapered Thresher made of wood, rubber and steel

This RTT was made at Waite Institute for a demonstration at the Regional Grains Post Harvest Workshop held January 20-22 1981 in the Philippines. After the conference this thresher was sent to a Mission Farm in Ecuador where Peter and Ann Clarke, both graduates of the Agricultural Science Faculty, used it to shell nuts and corn during the next 6 years. The results were obtained before they left Adelaide in 1980. They were interested in using this device for threshing nuts and corn cobs under the conditions of low-input village agriculture at the mission and determining how many people were needed to operate the system. The tests involved only one person to turn the rotor but it was fitted with a two-person handle so that continuous turning would be possible at about 100 rpm.

The RTT was demonstrated at the conference where a paper was presented on how to make and use a wooden RTT (Ridgway, 1981). There is a copy of this paper in the Appendix 3, where some results of testing a wooden RTT are also presented.

Table 4.4 Test of performance of a wooden, hand powered RTT shelling peanuts

	Kernel weight (g)	Kernel %	Damaged Kernel weight (g)	Damaged Kernel %	Unshelled peanuts (g)	% Unshelled
Mean	168.1	58.2	118.9	41.8	42.4	9.5
Standard Deviation	46.43	15.20	48.29	14.71	50.84	10.26
Max	230	77	210	68	170	34
Min	100	32	70	26	0	0

These tests indicate a RTT may have a place in areas where an increase in efficient use of time is beneficial. Preliminary testing indicated that the RTT can double the production of peanuts shelled and corn threshed from the cob, is this sociably acceptable? Clark (pers com) in 6 years work at the mission station in Equator the RTT was very useful but was not readily accepted by the local people. For example corn shelling was a communal job done by the ladies who would be denied the social experience if a machine was to replace them. This attitude was obvious from experience in Indonesia at a research station several ladies were seen sitting around a pile of peas hand picking split peas and engaging in conversation at the same time. Introducing mechanisation where there is an abundance of labour can mean the loss of a job and income derived there from as well as missing a social occasion.

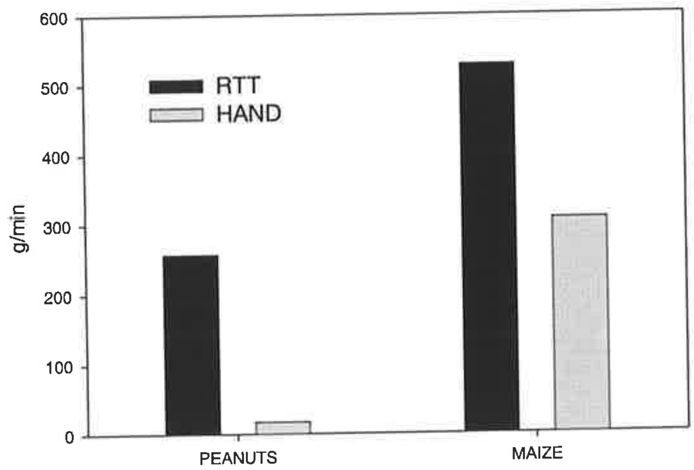

Figure 4.a Threshing rates (grams/min) of RTT vs Hand-threshing for Peanuts and Maize

Two tests made:

- threshing corn from the cob in the RTT compared to hand threshing
- threshing and shelling peanuts by hand and in the RTT.

Threshing with bare hands takes 67% longer than with RTT. Although no more grain is shucked under the RTT per cob, it clearly will allow for more grain to be shucked per hour. In addition, the fatigue and damage to the hand under the hand method would be hard to measure.

The data presented was obtained prior to the Manilla Conference and a summary follows. Thirty-seven cobs of corn were threshed, seventeen by hand and twenty by the RTT, selected at random.

Table 4.5 Comparison RTT vs Hand threshing of corn (mean values)

	Cob length	Cob weight	Diam. largest (mm)	Thresh time (secs.)	No. of turns	Grain (gm)	Cob weight (gm)	Cob + grain weight (gm)
RTT	212	280	46	27	18	235	44	279
Hand	215	283	48	45		232	47	279
P value				0.001		0.860		

4.4 The Ridgway Pneuflo Plot Combine with a Ridley Front

Originally this combine was built at the Hannaford Seedmaster Factory, on the body of a Bolens ride on lawn mower which had a hydrostatic bi -directional drive. This combine was first used to reap wheat barley and triticale trial plots before being field tested at the Roseworthy Campus to establish performance data. The plots were reaped from south to north in March 1979. The temperature, wind speed and wind direction were recorded each day and losses were measured pre harvest, from the comb and from the chaff extractor. The space between the comb teeth which was determined by the number of teeth in the comb. For example 16 teeth in the comb, which was 600mm wide, meant a space of 8mm whereas 15 teeth had 10.7mm spaces. Losses at the comb with 16 teeth ranged from 3.67% to 5.68% averaging 4.64 % of a total loss of 5.0 %. The 15 teeth comb losses ranged from 10.4 % to 17.0 % to average 13.6 % of a total loss of 14.2%.

Data collected included wind strength and direction and minimum and maximum temperature. Comb losses including shatter losses prior to harvest and aspirator losses.

Comb and shatter losses were measured by counting the grains on the ground in a wire quadrat of area 250mm by 400mm. To get a weight of grain the weight of the wheat was assumed to be 40g/1000 grains. The aspirator losses were collected in a steel oven tray the grains counted and assumed to be same weight per 1000 as the grains from the comb. The aim of the tests was to get a basis of the performance of this combine to ascertain its potential compared to the combines used by the wheat breeders.

Table 4.6 Results 1979 in RAC West 9

RIDLEY FRONT - Estimates of losses at the comb in Condor Wheat, 90 plots reaped on 5 different days

Date	Max. temp.	No. of teeth	Comb loss % of yield *	SD**	Aspirator loss % of yield *	SD	Tonnes ha *	SD
9.3.79	28.3	15	13.6	2.4	0.8	0.4	1.57	0.1
13.3.79	30.8	16	6.2	2.2	0.4	0.1	2.03	0.3
14.3.79	25.9	16	6.3	0.9	0.5	0.3	2.4	0.2
14.3.79			7.0	1.2	0.9	0.6	2.7	0.1
16.3.79	28.2	16	4.6	0.7	0.4	0.2	2.5	0.2
16.3.79			5.2	1.2	0.6	0.2	2.6	0.2
20.3.79	33.5	16	7.6	1.8	0.4	0.1	2.6	0.3
20.3.79			7.6	1.4	0.4	0.2	2.3	0.3

* Mean of 10 plots 4.35m^2

** SD = Standard Deviation

4.5 Discussion of Plot Type

These results were the first test in a set of 80 plots, each 4.35 m^2, with a Ridley type comb and beater harvest method. The beater rotor contained 4 bars; one set were straight steel, the others straight steel, rubber coated. The number of teeth in the comb was either 15 with spacing of 10.7 mm in between the teeth, or 16 with 8 mm between the teeth. All 80 plots were Condor wheat, which by early March would have been ripe for at least three months. The rotor of the Resilient Tapered Thresher incorporated in this combine was driven at the same speed for all plots, about 200 RPM, and the front beater at 1000 RPM. The chaff extractor fan was driven at a constant speed, but the inlet to it was varied; either partly open on 3 or fully open on 5, depending on the quantity of chaff to be removed.

The figures indicate that increasing the number of teeth in the comb from 15 to 16 decreased the losses at the comb from 13.6% of yield to 6.3%. There appears to be no significant different in the losses from the other treatments. Losses from the dust extractor and broken grains are consistently low.

4.5.1 Further testing of the Pneuflo with a Ridley front at Mortlock

This combine was also tested at the Mortlock Experimental Research Station in 1980, reaping plots of condor wheat in two replications of 9 plots in each treatment on the 10-3-80. The time was between 42 seconds and 46 seconds per plot, which translates to 86 and 76 plots per hour respectively. These times were for one person and the combine. In 2002 the rates of harvesting for two persons using combines costing around $100000 are less than 100 plots per hour.

Table 4.7 Effect of throttle speed of Pneuflo Ridley Front combine on plot yield and losses at Mortlock Experiment Station, March 1980

	Full Throttle	¾ Throttle
Time taken (sec)	41.7	46.7
Yield (g/plot)	725	628
Comb & pre-harvest loss (g/plot)	150.0	186.3
Loss from dust and chaff extractor	42.0	20.7

Given these data and the time taken to reap the plots this combine was capable of acceptable performance for trial plots. However the use made of it was for the difficult crops, tall triticale and ultra short uniculm barley and long wheat plots for a PhD student. This was in 1979 and the results were an incentive to continue improving the concept.

4.6 The Third RTT Concept, a Silsoe front replacing the Ridley front

From the foregoing data which gave more confidence in the potential of the threshing scope of the RTT and more information on performance. See the range of species threshed in Chapter 5.1, p 73. Later the decision was taken to develop a plot harvester, which would be able to test the Silsoe concept on the plot combine, which had been originally fitted with a Ridley front. Accordingly funds were sought from Luminus Pty Ltd to convert it to a Silsoe front combine. This was done early in 1995 with the help of P van Wezel, B.Mech.Eng. This combine won the first price for the invention competition at the Lucindale Field Days in 1995.

4.6.1 Report of using the Plot Type converted from a Ridley to a Silsoe front

22.6.95

A neighbour of the author agreed to be the second body to balance the plot harvester and we reaped the lucerne left on an old tennis court site. The biggest problem was the chute blocking with small sticks not broken by the fingers but thrown to the narrow part of the chute. Some seed was ejected through the straw extractor, some was thrown forward because the top lip was not low enough, crop not thick enough, or forward speed too slow, or a combination of all three. There were no seeds visible in the dust and chaff extraction. The straw extractor blocked because the sack attached was vertically over the end. The removal of pods from stems, now dry, was satisfactory.

This combine was used to reap some seed increase crops for cereal breeders from the Waite Institute during the autumn of 1995. These crops were growing in the Tatiara, on J & J Arney's farm, near where the newest version of the Pneuflo had been rebuilt with a Silsoe Front fitted to replace the Ridley comb.

The sample produced impressed the breeders who then sought the necessary funds to have a plot combine built for their wheat plots. Before this could happen however one of the breeders' Ridley style reapers was converted by fitting it with a Pneuflo body. The following tables indicate the potential of this concept which further increased the desire for a custom built Pneuflo for the wheat breeders.

4.7 The Fourth Model With The Pneuflo Concept

Table 4.8 1996 test of pathway losses and time to reap plots 6 rows by 3.8m long

Harvesting 6 row x 3.8 m long plots of Condor Wheat, 20/3/96 at Roseworthy

Plot	Sample Reaped (g)	Loss in pathway (g)	Total Yield (g)	Loss %
1	253.2	25.7	278.9	9.2%
2	526.8	43.8	570.6	7.7%
3	603.7	21.2	624.9	3.4%
4	397	48.7	445.7	10.9%
5	190.4	45.6	236	19.3%
6	660.4	44.9	705.3	6.4%
7	424.9	49.8	474.7	10.5%
8	363.1	15.9	379	4.2%
9	638.8	50.5	689.3	7.3%
10	150.7	21.4	172.1	12.4%
11	70.7	16.4	87.1	18.8%
12	443	54.2	497.2	10.9%
Total	4722.7	438.1	5160.8	8.5%

Plot	Reap (sec)	Cleaning (sec)	Total (sec)
1	6	28	34
2	6	25	31
3	6	7	13
4	5	10	15
5	6	8	14
6	6	14	20
7	6	25	31
8	6	23	29
9	6	14	20
10	7	32	39
11	7	25	32
12	8	20	28
Total	75	231	306
Mean	6.25	19.25	25.5

4.8 The Fifth Model With The Pneuflo Concept

4.8.1 The first comercially built plot combine

This combine was built by Irvine Engineering at Tintinara in South Australia. Before being field tested at Roseworthy Campus this combine was used to reap trial plots at Coonalpyn where it out performed all previous plot combines by being able to begin reaping earlier and finish later because it was able to reap grain with a higher moisture content compared to other plot combines. This combine was able to reap over 250 plots per hour compared to less than 100 plots per hour for the older combines. At the Roseworthy Campus in 1998 this combine was used to reap field sites of wheat, oats, barley, peas, cereal rye and lentils.

Harvest date 3-2-1998 using the Irvine Pneuflo with a 6 row Silsoe front in an unnamed variety of wheat gave a mean harvesting time for 19 plots of 6.6 seconds, mean clean-out time 7.8 seconds and mean total time 14.2 seconds. This equates to about 190 plots per hour. However further experience indicated this combine had a potential of reaping up to 300 plots per hour, but the system of sample collection is inadequate.

Further tests to determine the losses from the stripping header were conducted at Roseworthy in 1999, whilst not conclusive the indications of losses at this time were under 5 %.

The arrowhead stripping rotor could take just the heads or if the crop had lodged the total crop could be harvested but at a reduced ground speed. This required much more power for the rotor. The arrowhead reaper has no comb, only upward rotating fingers which thresh up to 80 % of wheat, 100% of oats and 40% of barley at the point of harvest.

A special feature of these combines is that they are capable of reaping at ground level. See Figure 4.d, where oats have been reaped from the ground. The sample is not clean because the total crop approximately 1m tall was reaped from relatively rough ground.

Table 4.9 Harvest of five cereal crops using Pneuflo Silsoe Front combine, March 1998 Roseworthy Campus

Crop	Field Sample	Cleaned	Chaff		Cracked		Moisture
	wt(g)	wt(g)	wt(g)	%	wt(g)	%	%
Wheat	1091	932	1.5	0.14	151.9	13.9	12.5
Triticale	957.6	894.8	0.8	0.08	56.1	5.9	13.4
Rye	777.5	671.8	3.2	0.41	3.2	0.41	11.8
Oats	681.6	493.7	8.5	1.2	123.6	18.5	12.0
Barley	889.6	855	5.6	0.63	21.3	2.4	12.3

Table 4.10 Performance test of the Pneuflo Silsoe front made by Irvine Engineering Sample size 37

	Sample weight	Chaff %	Screening %	Moisture %
Mean	660	1.42	6.20	11.36
Standard Deviation	244.8	1.30	4.96	0.39
Maximum	1182	6.58	17.5	12.40
Minimum	226	0.00	2.16	10.50

The above summary in Table 4.10 indicates a higher than may be expected quantity of screenings, which indicates the ability of the Pneuflo to retain all of the grain instead of discarding the screenings on to the ground. The quantity of chaff is within the limits of the specifications laid down by the Ausbulk receival agents. This combine is also capable of reaping wheat which is clean enough to resow with out recleaning.

4.9 The Sixth Model

This combine is the one built on the Susuki chassis at Roseworthy Campus in 1992-93. The model had a constant cross section area chute angled at 30 degrees to the horizontal. When tested in the workshop by hand feeding dry bean plants with pods still attached it failed to deliver the herbage to the thresher. The following graphs and table indicate the wind speed patterns measured in the intake duct.

4.9.1 Distribution of air speeds in the chute of the Roseworthy Pneuflo with a Silsoe Front

During early discussions on the format of the chute from the Stripping Header to the RTT the suggestion was made to be sure the cross section of the chute was constant. Studies of physics and earlier work with the first plot combine told me this format was unlikely to carry the harvested material to the thresher. Boyles law (Glasstone and Lewis, 1966) says for a given temperature pressure times volume is constant. In this case with a cross section of constant dimension, 187500mm^2 in this case, friction and swirling would allow the harvested material to be dropped from the air flow. To try and ascertain the pattern of the air speed and hence the flows the decision was taken to measure the air flows.
Anemometer readings were taken on a grid, three levels (bottom, middle and the top) at four sites along the chute and eight positions across the chute (one on the left side and the rest at 100mm intervals across the chute), as shown in Figure 4.c. As expected, there

appears to be a random pattern of air speeds. Using a woollen thread on a piece of wire even the direction of the flows were found to be confused. The plotted data, see Figure 4.b below, realistically support this theory.

To fix this problem the chute was rebuilt internally so that the outlet from the stripping header was reduced to, 93750mm^2 50% of its original cross section and the inlet from the chute to the RTT was reduced to 46750mm^2 25% of the original cross section. The internal dimensions of the chute were reduced to match the adapted size of the end openings and this allowed the harvested crop to reach the RTT perfectly.

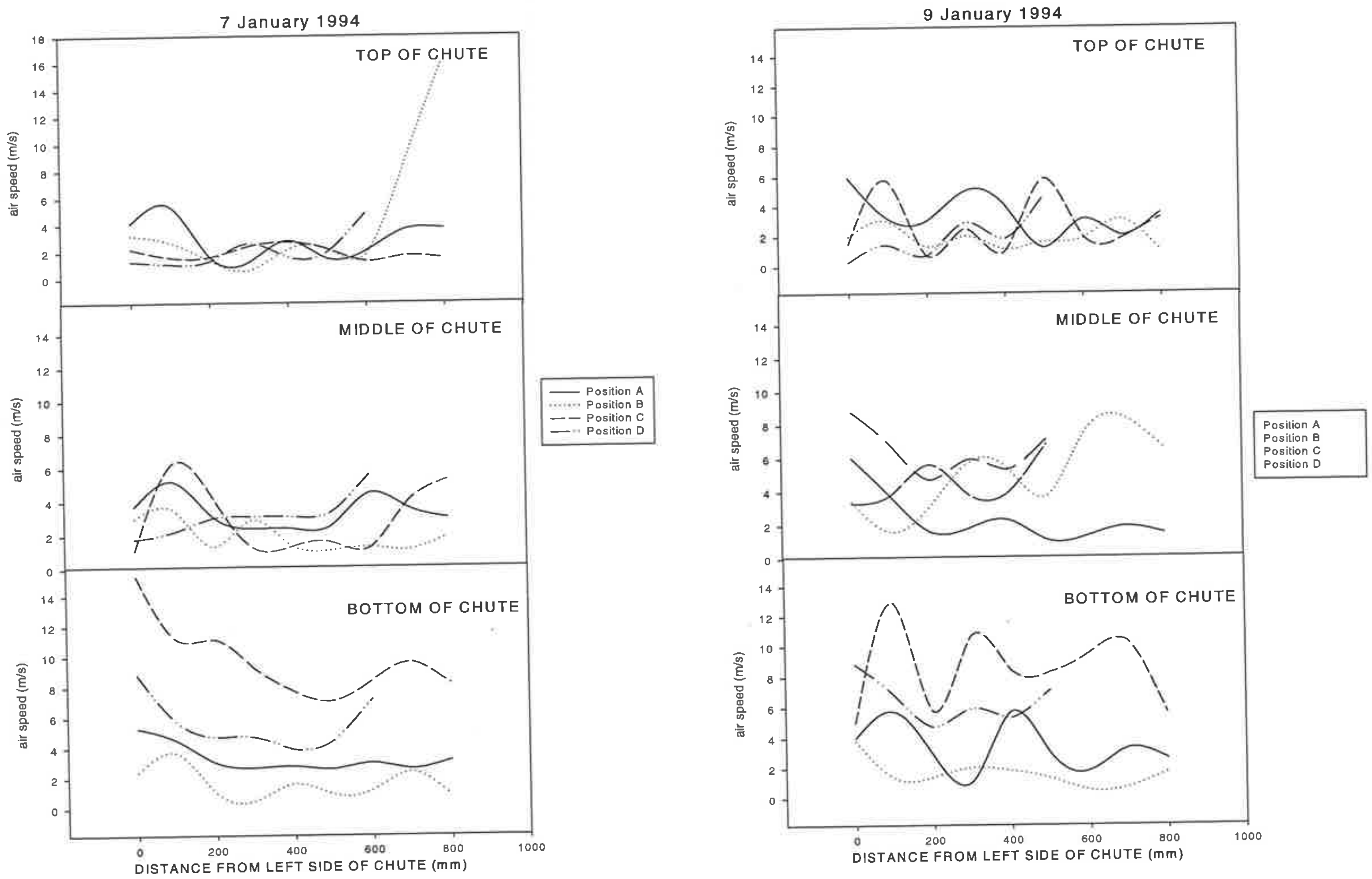

Figure 4.b Tests of Air Speeds in the Roseworthy Pneuflo (to be replaced by later version)

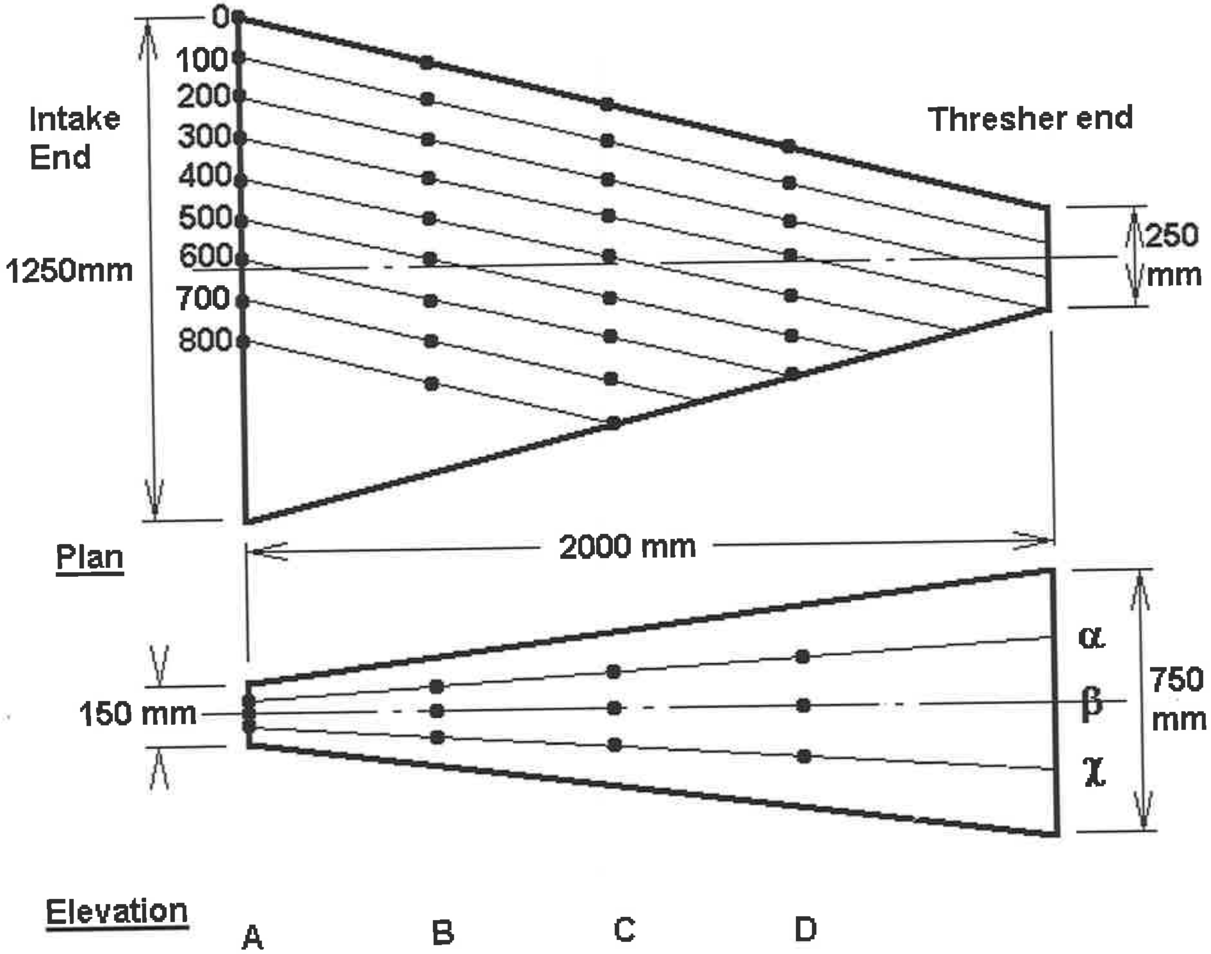

Figure 4.c Layout of air speed sampling points

Table 4.11 Relationship between speed of thresher and stripping front and exhaust speeds (dust and chaff as well as straw)

Target Header speed	Target Thresher speed				100		200		300		400	
	100	200	300	400	Dust	Straw	Dust	Straw	Dust	Straw	Dust	Straw
					F	T	F	T	F	T	F	T
300	116 / 306	201 / 300	286 / 290	390 / 306	10.7	5.6	1.1	8.7	0.5	11.3	0.6	15.3
400	115 / 411	236 / 414	306 / 414	432 / 388	8.6	6.7	2.0	10.3	1.7	12.6	0.8	17.4
500	113 / 498	225 / 520	325 / 495	442 / 490	5.8	7.6	3.4	10.4	2.8	13.9	1.9	18.1
600	112 / 623	233 / 583	317 / 590	436 / 624	6.1	9.3	4.3	11.7	3.3	14.2	3.1	18.6
700	109 / 704	227 / 739	312 / 98	438 / 696	6.6	10.3	5.6	12.9	4.4	14.8	3.7	19.0
800	128 / 818	208 / 814	295 / 804	432 / 824	7.7	12.0	4.7	13.3	6.1	15.3	5.4	19.86
900	109 / 912	202 / 910	307 / 934	388 / 926	9.1	12.8	4.6	14.2	7.4	17.0	6.5	19.2
1000	119 / 940	204 / 936	312 / 1036	370 / 1033	7.1	13.3	4.8	14.7	8.2	18.0	7.8	19.4

Actual thresher speed rpm
Actual header speed rpm

F = air speed out of dust extractor exhaust, ms^{-1}

T = air speed out of straw extractor exhaust, ms^{-1}

Note: Headings are the target figures. The columns show actual measurements. Imposed on these air speeds when reaping is the fan air speed, which creates another interaction within the combine

Table 4.11 illustrates the complex interactions between machine settings and air flows.

Significant results were expected to be obtained in a range of crops using a 6-row Pneuflo. Combine. The Pneuflo Combine consists of three basic components. These are the Silsoe stripping header, where most of the threshing can take place, when the heads are stripped from the straw with the under shot arrowhead fingers, a thresher and a chaff and dust extractor. Observed estimates of threshing were: in Tatiara wheat 80%; Marloo oats 100%; and 105 Uniculm barley 20%. Observations of reaping standing crops of peas and lucerne were also made. Claims of satisfactory combine performance in commercial crops of peas, linseed, rice, wheat, barley, some pasture grass seeds have been reported by Hale (*loc cit*), Hobson (*loc cit*) and Klinner *et al* (*loc cit*). The arrowhead fingers have now been used on commercial combines in thirty different countries. They have been accepted as a very viable replacement for open front combines, especially when crops are high in moisture and grain drying facilities are available. The Silsoe research workers (Hale (*loc cit*), Hobson (*loc cit*), Klinner *et al.* (*loc cit*)) found losses no greater than conventional combines at the cutter bar. The real results of the Pneuflo Combine will be obtained when a working model is operated in a plot harvest program for a full season. Dr A.J. Rathjen reported the harvest of 17000 plots in 1999 with no breakdown time. Then a working system can be developed with a harvest team and objective measurements in time to combine plots; to estimate sample purity, damaged grain and moisture content of grain.

4.10 Conclusion

These results are only a sample of the measurements taken since 1976. Without exception there are no results which have discouraged the continuation of this project. Accordingly, despite the lack of financial assistance and the desire of others to change the design, work has continued. Invitations have been accepted to attend the Adelaide Royal Show and the Yorke Peninsula Field Days. Many people have shown interest and farmers have asked when will there be a model to suit THEM. The answer is always, tell me what size combine is required and pay a deposit! Until there is a working farmer size Pneuflo which farmers can relate to their system, with a support network of service, spare parts, and finance such as J.I. Case made available in the 1800's, marketing of the Pneuflo will not become a reality.

To make comparisons with other combines is not possible until advertising in the printed media can be contested. Accordingly the work published can only be the virtues of the Ridgway Pneuflo and the advantages shown in this work.

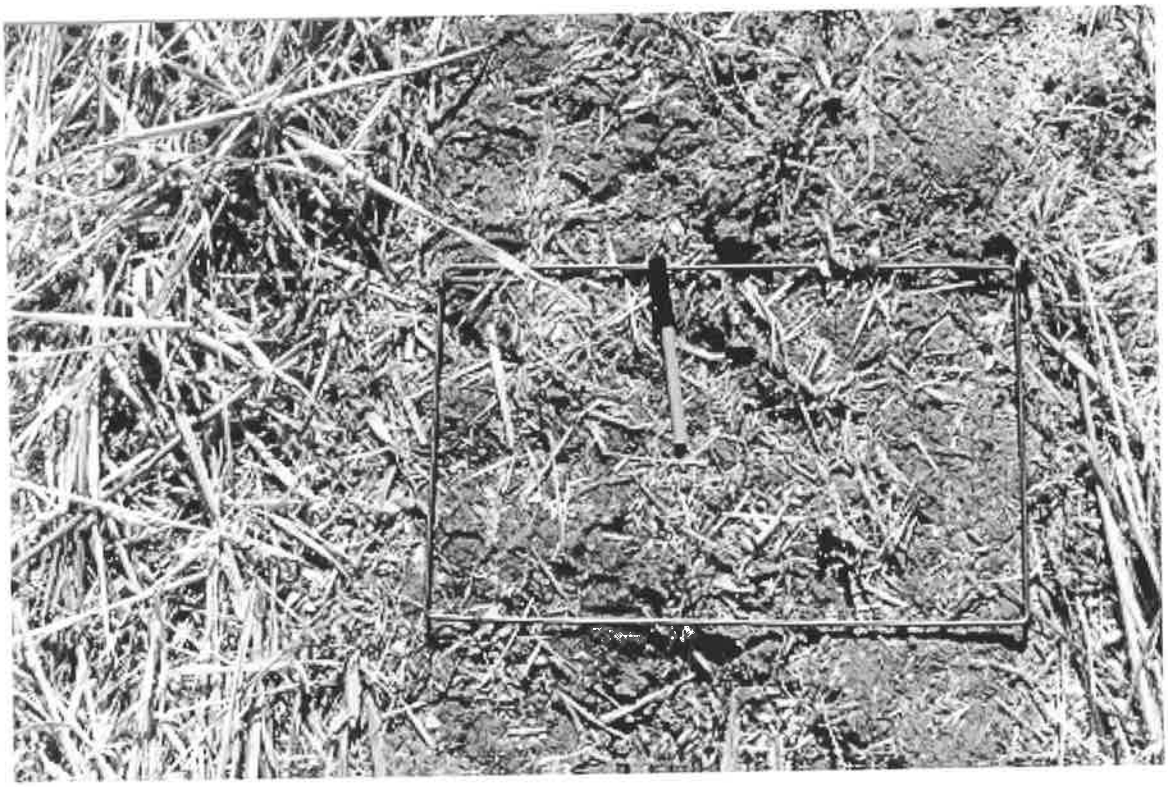

Figure 4.d Lodged oat crop picked up by stripping header front

5 Final Discussion and Conclusions

5.1 Present state of development

Concepts such as the Pneuflo Combine will continue to evolve, in that each model built will be improved by using more suitable structural materials, better manufacturing techniques and improved design, The Pneuflo Combine is a combination of very basic techniques for harvesting, threshing and cleaning of cereals, all legumes grasses and other species which are compatible to slow speed threshing shelling crushing and skinning. Depending on the success of the farm model about to be built the list of the scope of the species which will be able to be harvested could be infinite. All of the following have been threshed in the RTT. Adaptation to include a pick up mat or reel will complete the menu of crops that can be harvested threshed and cleaned. Heads, shells and capsules of wheat, oats, barley, rice, maize, sorghum, sunflower, triticale, flax, lucerne, ryegrass, cocksfoot, ryecorn, barrel medic, snail medic sub-clover, faba beans all seed sizes, peas, vetch, lathyrus, lupins, chick peas, lentils, navy beans, cranberry beans, mung beans, soy beans, carrots, upland cress, onions, asters, marsh-mallow, solanum (not all varieties), cosmos, peanuts, paper shell almonds, canola, and kangaroo grass have been processed in the RTT already. Time, space, financial support and human resources have not been available to complete all of the research and development required.

The study of the Pneuflo concept has been somewhat tortuous and has taken much time. The most carefully planned unit, built at the Roseworthy Department of Agricultural Engineering in 1992-3 and modified in our farm workshop, did not reap any plant breeders plots. The most important parts of the study were the lessons from that combine; failures teach more than success. The combine was too big, too heavy and too cumbersome to move about breeder's plots. The angle of the chute was about 40 degrees to the ground, the chute was too long, and the entry from the chute to the RTT was in the wrong place. After modification this combine reaped wheat, oats, barley, peas and lucerne in situ and the chute delivered the harvested crop to the RTT and the straw extractor, which both performed reasonably well but certainly not to degree required for plot work.

After reading the work of Williams (1983) 2 more combines were built with vertical chutes and side delivery to the RTT from the chute. Still there were too many repeats down the chute.

The later models now have vertical or within 10° of vertical delivery into the top of the RTT. via a 180° change in flow direction see Figures 3.a and 3.b, p 55. At the point of delivery the harvested crop has no chance of repeating down the chute. However the excess air going into the threshing area has to be released to prevent interaction with other airflows in the system. This meant an outlet had to be included, large enough to allow any light plant material to be ejected as well.

Despite the early failures, the Pneuflo plot combines now being used by the plant breeders are capable of up to 300 plots per hour.

The Australian tradition of combining was originally developed using locally made combines, which were leaders in their field. John Ridley, Headlie Taylor, John and David Shearer, Horwood Bagshaw and Hugh McKay all made combines to harvest, thresh and clean grain which could be delivered to the market without further cleaning. Not one of these machinery inventors and makers, or even the companies which they developed, are now in business. The last to leave the industry was the Horwood Bagshaw factory at Mannum, it has now ceased production of combines. Consequently, Australian farmers are now entirely dependent on imported combines made by multi-national companies based in Europe and USA.

The Wheat Breeding Group within the Department of Plant Science based at the Waite Campus obtained finance from the Grains Research and Development Corporation to buy the first production model of the Pneuflo 6 row plot combine. This order indicates that a successful stage of the ongoing development has been reached. This group has since obtained two more Pneuflo plot combines but with modified threshers to suit their special needs.

Use of these combines will no doubt result in further improvements being made to these combines and to subsequent models. The experiences described in this thesis should create the incentive for a nucleus to produce Pneuflo combines either tractor propelled and powered or self propelled. While all the dimensions have not been disclosed the author would be able to work with any interested manufacturer.

5.2 Future Possibilities

The Australian Combine manufacturers, except the Kingaroy Engineering Works, have literally been destroyed, their factories either redeveloped or empty. The strength, marketing prowess, financial backing, huge manufacturing infrastructure and physical resources of the multi-nationals will have to be confronted by the Pneuflo Combine concept. The comparison is similar to a hydrogen bomb versus a hand grenade. However, if efficiency in human labour plus capital outlay, prevention of grain loss at combining time, restriction on the spread of weed seeds (especially those which are herbicide resistant) self cleaning and the thrust to use Australian made machines, made for the local conditions, create the required impact on plant breeders first and then farmers, the future of the concept is assured.

The anticipated purchase price, likely to be about half that of similar performing combines, and a machine which, for research workers, can be towed on a trailer behind a one tonne utility saving about 50% of travelling costs, must be strong reasons for purchase. Further strong points for research work are self cleaning, reduced maintenance, accessibility for servicing, dust, chaff and weed seeds collection option for operator comfort, local spare parts availability, the use of relatively unskilled casual labour for drivers and sample collectors, the ability to reap with higher moisture content, faster ground speed, both threshing pressure and spacing readily and infinitely adjustable, threshing sieves readily changeable for different crops, no belts chains or cogs, no exposed moving parts, harvesting at ground level and upwards and the grain sample can be clean enough for re sowing,

Similar advantages should be available for farmers on broad acres, especially if timeliness of combining can reduce losses due to wet weather. Mixing of crops is prevented. lighter combines cost less, faster driving and processing is available. Lower purchase and operating prices will increase viability.

Tullberg, on page 35 of "The Reapers Digest" (Kondinin, 1993), suggests that in some, if not most, Australian reaping conditions the northern hemisphere combines cannot be economically loaded, either because the crops are lighter or it is not possible to drive fast enough to fill them adequately. This is an important problem because the crop processing components of a combine account for most of the cost. He continues suggesting swathing 2 x 9m windrows together or driving faster. John Deere "independent carriage suspension" on their 1051 PTO machines allows faster ground speed. Tullberg concludes "Perhaps Australian producers will find developments of the stripper principle will provide a new solution to the problem".

5.2.1 Pertinent points

After sales service, availability of spare parts and support from the manufacturing company are very important. Without this support the best machine in the world would not be worth the capital outlay. However this requirement would be minimal for the Pneuflo.

5.3 Safety

Accidents are not uncommon with the current combines and associated machinery. Amputations, broken limbs and even death have been caused by careless use of combines. However, when there are exposed vee belts (up to 17 on one plot harvester, see Table 5.1), roller chains, power shafts and exposed gear teeth opportunities exist for serious personal injury. Screw type metal grain augers driven at high speed with no adequate clutches or guards have been responsible for instant amputations.

5.3.1 Safety features

The Ridgway Pneuflo Combine has eliminated the worst features of those combines now on the market. There is no combine with as many safety features, no chains, belts or cogs, elimination of fire risk, self cleaning, soft slow speed threshing, accessibility to components and minimal moving parts. See Table 5.1.

The Pneu Generation Combine has only three moving parts, each one directly driven by an hydraulic motor, in the cereal plot machines. There is no opportunity to be caught in vee belts, roller chains, power shafts or augers on the Pneuflo Combines. Field combines will have a tubulator instead of an auger to shift grain to the following grain trailers. They may also need a slow moving rotary screen.

While harvesting machinery accounts for only some two percent of farm accidents, Farming Ahead September 1977 – Kondinin Group, it must be remembered that combines are used for about one month per year only and this reduces the exposure to the farming personnel.

There is a wide range of crops which have been test threshed in the RTT; all crops which have heads on the top of the stem or those which ripen at ground level will be able to be collected by the Pneuflo with a Silsoe front. The crops with pods along the stem, such as faba beans, and those with branched format and heads on many stems, such as canola will need windrowing prior to combining. Thus a pickup will be required to gather these crops prior to combining with a Pneuflo. The challenge to develop this modification is accepted.

5.4 The Future

The optimistic outlook for commercialisation of the Pneuflo needs realism of the highest level. On the completion of this thesis a farmers model must be made ready to test in the next harvest which is only a few months away. There should be no insurmountable problem stopping this from happening. Parallel to this the next phase should be planned. A business plan needs to be prepared and a professional marketing and financial manager needs to be appointed. Recognition of the very wide application of this concept occurs when the comparison can be seen in the following Table 5.1.

Table 5.1 Comparison of machine simplicity

COMPARE!	MF® 8780XP	DEERE® 9650Conv	DEERE® 9650STS	CASE® 2388	NH® TR99	CAT® 450/480	CAT® 480
Main Belts	11	17	19	11	17	21	18
Chains	5	5	3	9	11	6	6
V/S Pulleys	1	4	4	3	4	6	6
Augers	7	16	9	13	7	8	8
Grease Fittings	31	69	39	55	78	41	53
Gear boxes, Open Drives, U-Joints	4	18	9	12	6	4	5

From Stock Journal, December 20, 2001

LET THERE BE **NO** CONFUSION IN COMPARING THE **PNEUFLO** WHICH HAS

NO MAIN BELTS **NO** CHAINS **NO** VEE / PULLEYS **NO** AUGERS

NO GREASE NIPPLES **NO** OPEN DRIVES **NO** GEAR BOXES **NO** U JOINTS

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APPENDICES

Contained in the Appendix are documents that can be referred to by readers who need to find further evidence of the ability of this concept. The Ridgway Pneuflo Combine, its evolution, its usefulness so far, its projected potential into the farming industry as a safer, more efficient, cheaper, environmentally clean, readily maintained machine with every component accessible within minutes for service and/or repair. The versatility of this concept is beyond the scope of any other known combine and this Appendix will bear support of this by people who have used both the earlier and current models and also those who have expressed the wish to have a farmers model.

The range of documents includes copies of papers written by this author and other supporting documents.

Appendix 1: "The Resilient Tapered Thresher" by Ian G Ridgway, 1978

Ridgway, I. G. (1977). The resilient tapered thresher. In *Grain and forage harvesting : proceedings / first International Grain and Forage Conference, September 25-29, 1977, Scheman Center, Iowa State University, Ames, Iowa*. (pp. 174-177). St. Joseph, Mich., the Society.

NOTE:

This publication is included in the print copy
of the thesis held in the University of Adelaide Library.

Appendix 2: "The Resilient Tapered Thresher – Hand Type Model" by Ian G Ridgway, 1978

Ridgway, I. G. (1978, May). The resilient tapered thresher – hand type model. In *the 3rd Australian Conference on Science Technology*. Conference conducted at the Australian National University, Canberra.

NOTE:

This publication is included in the print copy of the thesis held in the University of Adelaide Library.

Appendix 3: "The Development in Australia of a Simple Low-Cost Resilient Tapered Thresher" by Ian G Ridgway, 1981.

Ridgway, I. (1981, January). The development in Australia of a simple low-cost resilient tapered thresher. In *the Regional Grains Post Harvest Workshop.* Workshop conducted in the Philippines.

NOTE:

This publication is included in the print copy
of the thesis held in the University of Adelaide Library.

Appendix 4: "Seed Cleaning Equipment Evaluation Report for Seedmaster – Alf Hannaford and Co." by Professor Loren Wiesner, 1982.

Wiesner, L. (1982). *Seed cleaning equipment evaluation report for seedmaster – Alf Hannaford and Co.* Montana State University.

NOTE:

This publication is included in the print copy
of the thesis held in the University of Adelaide Library.

Appendix 5: "Improved Handling of Chaffy Grass Seeds through Cone Threshing" by D.S. Loch , the late .W.T. Harding and G.L. Harvey, Proceedings of XV IGC.

Loch, D. S., Harding, W. A. & Harvey, G. L. (1985, August). Improved handling of chaffy grass seeds through cone threshing. In *Proceedings of the Fifteenth International Grassland Congress*, (p. 24-31). Kyoto, Japan.

NOTE:

This publication is included in the print copy
of the thesis held in the University of Adelaide Library.

Appendix 6: Correspondence dated 23 October 1978 from Dr Peter Goodwin, Department of Agronomy and Horticultural Science, University of Sydney, re threshing beans.

Profe[illegible] of Agronomy : M.J.T. NORMAN
Professor of Horticulture : M.G. MULLINS

TELEPHONE: 692 1122.
AUSTRALIAN DOCUMENT EXCHANGE: DX 1154

The University of Sydney

DEPARTMENT OF AGRONOMY
AND HORTICULTURAL SCIENCE

SYDNEY,
NEW SOUTH WALES,
AUSTRALIA. 2006

In reply please quote

23rd October, 1978

Mr. Ian Ridgway,
Waite Agricultural Research Institute,
GLEN OSMOND S.A. 5064

Dear Ian,

Thank you very much for spending the extra two days in this department, making available yourself, and your thresher. I must admit that when I first saw the machine I knew intuitively that it wouldn't work! The bean samples we did are so delicate that we usually hand thresh them, as any of the previous threshers (including a double built thresher) caused seed damage. For the 200 samples, this boring and abrasive job would take about 4 weeks. However, we did it in 2 days, with no obvious seed damage!

We hope to buy a hand machine early in 1979. Meanwhile, I have a lupin project due for harvesting in mid-November. The hand-threshing will be carried out by Eric Corbin, at Wagga Aricultural Research Institute. I think that if you would lend him a demonstration hand machine, he would soon be convinced that it could save him a lot of time in lupin and chickpeas projects. Other people associated with this regional center may also get to see the machine.

Looking forward to seeing you again in the not too distant future.

Thanks again,

Yours sincerely,

PETER GOODWIN

Appendix 7: Resilient Tapered Thresher - Notes on cracking CPS almonds - Dr JF Jackson, 22nd March 1979.

THE UNIVERSITY OF ADELAIDE

WAITE AGRICULTURAL RESEARCH INSTITUTE

GLEN OSMOND
SOUTH AUSTRALIA 5064
Telephone: 79 7901
Telegrams:
WAITINST Adelaide

Resiliant Tapered Thresher(plot type)

1. Notes on its use in cracking CPS almonds

Approximately 930 kg of Nonpareil(otherwise known as Californian papershell or CPS) almonds in the hull were put through the thresher on 17th March, 1979. These nuts were harvested during February, 1979 in a privately owned orchard in the Strathalbyn district. They had been dried and bagged before transport to the Waite Institute, and when put through the thresher contained numerous small sticks, but no leaves, in addition to the nuts.

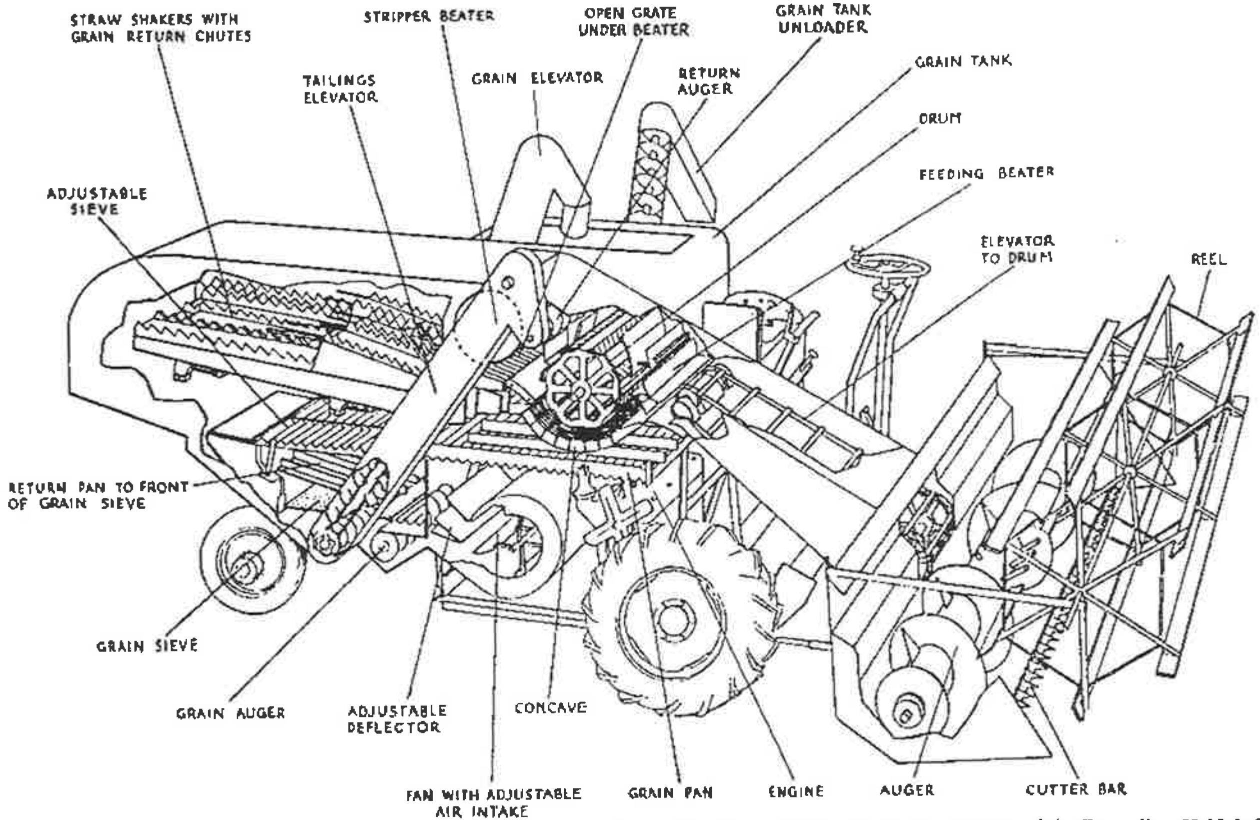
The thresher was found to be capable of handling 6 bags/hour (180 kg/hour) of the supplied nuts. The output from 420 kg of the sample was sorted by a combination of sieves and hand-sorting, and found to yield 22% by weight kernel and 3% by weight kernel in the shell. No uncracked shell in hull were found, and the remainder consisted of hull, broken down, fibrous shell material and sticks, all of which would be suitable for sale as garden mulch. A 500 g sample of kernel was counted and showed an average weight of 1.3 g each. The out turn of kernels as a whole appeared to be less broken and chipped than is the case with conventional commercial crackers; however this is an impression only, and a more accurate figure must await further sorting of the kernels. It is apparent even before this is done that the thresher can successfully crack Nonpareil nuts to produce a kernel at least as good as that from conventional crackers, in good yield, and with a high rate of throughput.

It was observed that several chellaston in the hull inadvertantly mixed with the papershell, came through without hull but uncracked in the shell. It is possible then that the existing thresher could also be used to hull the Chellaston variety.

Dr. J.F.Jackson
Senior Lecturer

22nd March, 1979

Appendix 8: Components of a self-propelled combine (for comparison) from 'Farm Machinery Leaflet No. 3'.



From 'Farm Machinery Leaflet No. 3'. By courtesy of the Controller, H.M.S.O.

FIG. 36.—Components of a self-propelled combine.

Appendix 9: User comments on the Ridgway Pneuflo Combine – A.J. Rathjen, Waite Institute.

User comments on the Ridgway Pneuflo Combine

The Pneuflo is a relatively simple machine. Crops harvested so far include wheat, barley, oats, lupins, peas, dryland lucerne, vetch, lentils, triticale, rye and rice.

The speed of the machine impressed The University of Adelaide's Waite campus wheat breeder Dr Tony Rathjen.

Dr Rathjen said it was much quicker than the plot harvester now in use, It was also cheaper to purchase.

The use of local parts had its advantages, because the cost of importing replacement parts was expensive.

Senior plant breeder at the University of Adelaide's Roseworthy campus, Gill Hollamby, said the cleanliness of the sample and the speed of the machine was fantastic - allowing technicians to harvest up to 250 plots an hour initially.

Dr Rathjen said "it could also handle crops during inclement weather."

Both researchers agreed its ability to harvest in adverse conditions was a positive aspect, particularly when harvesting plots on the Eyre Peninsula where reaping was often delayed because of rain.

Most cereal breeding programs depend upon imported plot combines which have the capability, of harvesting about 80 plots/hour. Our new Ridgway "Pneuflo" has the following advantages:

- Speed - as a two man machine it will harvest about 250 plots/hour.
- Safety - having a low centre of gravity and being hydraulically operated, no belts or chains, it is safer.
- Capital cost, depreciation and maintenance - imported combines cost about $30,000/year. With a lower cost and much greater reliability, the Ridgway Pneuflo will be much cheaper.
- Transport - the 'Pneuflo' can be towed on a trailer at a cost of about 40 cents/km whereas a truck costs about $1.40/km.

Development of the Pneuflo is not complete. Given its speed, there is a need to incorporate a bag folding machine and we have an ambition to reduce the noise level (already below imported combines) and to improve the operator comfort.

Overall, the Ridgway Pneuflo is the most significant development in cereal breeding machinery in the past twenty years and it provides us with an opportunity to move forwards from the 1950s and 1960s technology of the current machines.

Further enquires can be made by e-mail address: *iridgway@roseworthy.adelaide.edu.au*
or by mail to authors address

Appendix 10: "The Experiences of an Innovator", I.G. Ridgway. Patently Obvious Seminar, 25/7/96.

Patently Obvious Seminar – 25/7/96

The Experiences of an Innovator
Ian Ridgway

Most farmers find the need for a tool, an implement or a system which is unavailable from the shelves of commercial suppliers. Most, if not all, machinery needs adapting to individual farm needs. This can be for three reasons: first, the machine may be from the northern hemisphere which it would have been made for a different environment; secondly, the machine may well have been designed by a "shiny bum"; and, thirdly, austerity - the hope to do it cheaper.

My first 'machine' was made when I was 11 years old, a two wheeled 'billy cart' for a wartime fundraising concert. Some of my later homemade items include:

- Building a rubber-tyred horse or tractor drawn trailer using the wheels and axles from a Clyno 2-seater car.
- The same car, having had a gear-box problem, provided a power source for driving a pump jack, green feed cutter and grind wheel.
- The self starter was converted to an electric drill for general use, but mainly for boring fence posts. The generator was driven by a small stationary engine on a transport.
- A slide to fix on the side of a truck to turn small round bales of hay to align with the slide. Once turned the bales could be easily pulled up the slide with a long homemade hook onto the truck and stacked.
- A semi-portable saw bench for cutting building timber from the farm logs.
- A system for unloading cut grass from a flat top truck for silage.
- Designed a turntable for a forage blower chute to give 360° forage delivery.
- Converted a pitchfork for silage handling.
- As finances allowed we purchased a rubbish truck ex the Unley City Council. This truck had a fold up running board for the helpers to stand on to throw rubbish into the truck. Using two long hay hooks I could load square bales of hay standing on the top step as the truck moved along the rows of bales. A strong leather safety belt was needed to keep me on the step.
- Homemade cultivator for TPL Ferguson tractor.
- Built a transport for a portable shearing machine used for pasture plot harvesting.
- Developed the concept of a slow moving conical thresher with resilient threshing surfaces (won the Inventor of the Week in September 1978). Patent number 1592117 AUS.

  In the days prior to Luminis I was encouraged to seek a patent by Emeritus Professor C M Donald. This was successful and royalties eventually paid for patent costs and returned significant income. Patent numbers AUS 512415, UK1592117, USA 4185642, Canada 1068J77, Germany and Japan.
- Designed and built a single head Resilient Tapered Thresher (RTT) for cereals.

- Designed and built a resilient tapered thresher for removing the testa from orchid seeds using 1" rubber stopper for a rotor.
- Designed and built a 4-row cone seeder for planting grain legumes. The same machine planted 2 rows of sterile wheat either side and 4 rows of fertilizer. It was electrically driven from an alternator mounted on the tractor which carried the planter on a three-point linkage system.
- Designed and built a harvesting combine for grain legumes incorporating an RTT and a modified cutter bar. This machine did not perform adequately due to the elevator not lifting cut crop to the RTT.
- Designed the re-modelling of a self propelled combine to encompass an RTT for testing in Queensland reaping, threshing and cleaning navy beans. This trial had to be aborted due to lack of finances.
- Designed and built a combine harvester for legumes incorporating an RTT, a broad elevator and a comb reel built on two cycle wheels to carry the paddles onthe right diameter.
- Designed a 4-row harvester for plant breeders incorporating an RTT and a Ridley type stripping front. This machine was modified several times in the late 70s. Because it could not cope with straw it was modified again by replacing the Ridley front with a set of Silsoe arrowhead reapers.
- An Articulated Side Draft Implement, Patent No. 541022, was a hydraulically articulated draw bar which allowed an offset machine to be articulated behind the towing tractor. This device was incorporated first in a two metre grain combine and allowed the combine to be towed directly behind the tractor. Thus a four metre wide machine could pass through narrow gates and pass along a road without being over-width. This concept was later adapted to a tyned harrow which could be articulated and folded from the tractor seat. This machine took first prize at the 1985 South East Field Days.
- A Crop Cutter Patent Application No. 83861/82, was incorporated into the harvesting front of the two metre combine. It worked well in that concept.
- Adapted in a conventional rotary lawn mower, first as a circular device on a large V pulley but the centrifugal force stretched the belt and even though the belt was bolted in the groove it still stretched and caused imbalance.
- The mower you see here was the next model. This mower was taken to a manufacturer and demonstrated. The factory manager took it home to test the concept on his lawns. The result - he lost the cutting belt and the mower fell from his utility and bent the base plate.
- My current machine project is a radically different grain combine. The current models built for cereals breeders' plots have three moving parts, have no dust or chaff leakage, have hydraulic direct drives for safety and accessibility, plastic arrow head, fingers which harvest the crop and slow moving resilient threshers. The internal surfaces are almost vertical and the crop is conveyed internally by throwing and blowing which enables self cleaning. We are currently seeking venture capital to take this concept to the commercial stage.

An Inventor's Purgatory

- The "Shiny Bum" (inert engineer). "I know better than he does. he is only a bloody farmer".
- The casual onlooker: "That won't work".
- The deceit of commercial hierarchy, or "I'll give you a written promise" then do the opposite.
- "What are you doing that for?" x 1,000.
- The perversion by lawyers of written instructions.
- As you are about to demonstrate to an important supporter there is a melt down or a hydraulic hose burst.
- A helper ruins a demonstration by not keeping to instructions.
- Being balled out by abusive seniors
- The smart arse who asks the unanswerable question or denounces the project before being briefed.
- The person who borrows your machine and tips it off a truck or trailer.
- Obtaining finance in a sea of complacency.
- Being sent down by the Head of Department after 2 years developing the Resilient Tapered Thresher to sweep up radioactive sheep faeces.
- Being told to "throw all that machinery over the cliff into the dump".
- The loss of finance for the Grain Legume project at WARI.

The High Spots

- Being encouraged by the ex-Department Head to apply for a patent.
- Winning the Inventor of the Week competition.
- The immediate response of the Minister of Agriculture (Brian Chatterton) to help with the project by providing 2 years' salary for a replacement for me, allowing full time to the RTT project.
- First ancillary staff person in the University of Adelaide to be granted study leave and a grant to cover costs allowing me to present a paper to the Grain and Forage Harvesting Conference in Ames, Iowa, 1977.
- To receive good written reports on the performance of the laboratory and hand type RTT and the Plot Harvester.
- To work for 1 month at Silsoe College and meet with the Research Group who developed the Arrow Head stripping fingers

Appendix 11: Hannaford Seedmaster Resilient Tapered Thresher Model L.T. (designed by Ian Ridgway).

HANNAFORD SEEDMASTER RESILIENT TAPERED THRESHER MODEL L.T.

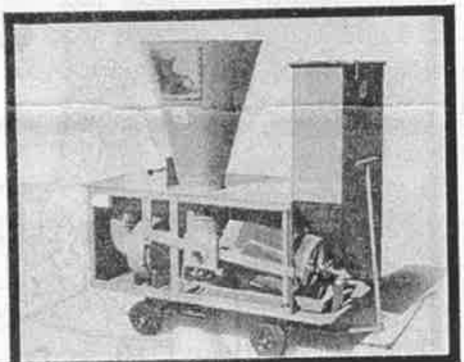
Ian Ridgway

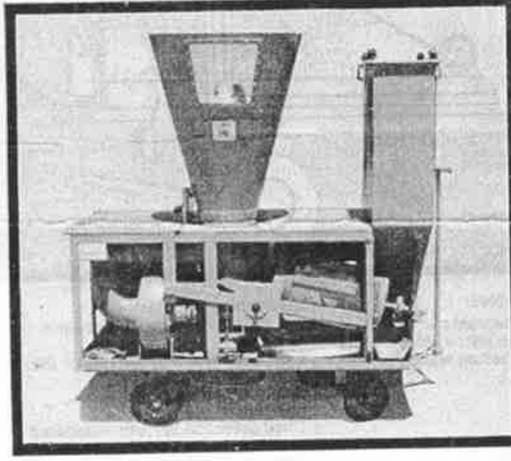
Pat. app.

Seedmaster by Hannaford

The revolutionary new design of the Tapered Thresher incorporates threshing concepts never before seen in conventional type machines.

Developed by Mr. I. Ridgway of the Waite Agricultural Research Institute in South Australia, and manufactured under licence by Alf. Hannaford & Co. Pty. Ltd., the Thresher is ideally suited for laboratory and associated field trial research work, including specialist commercial crops.

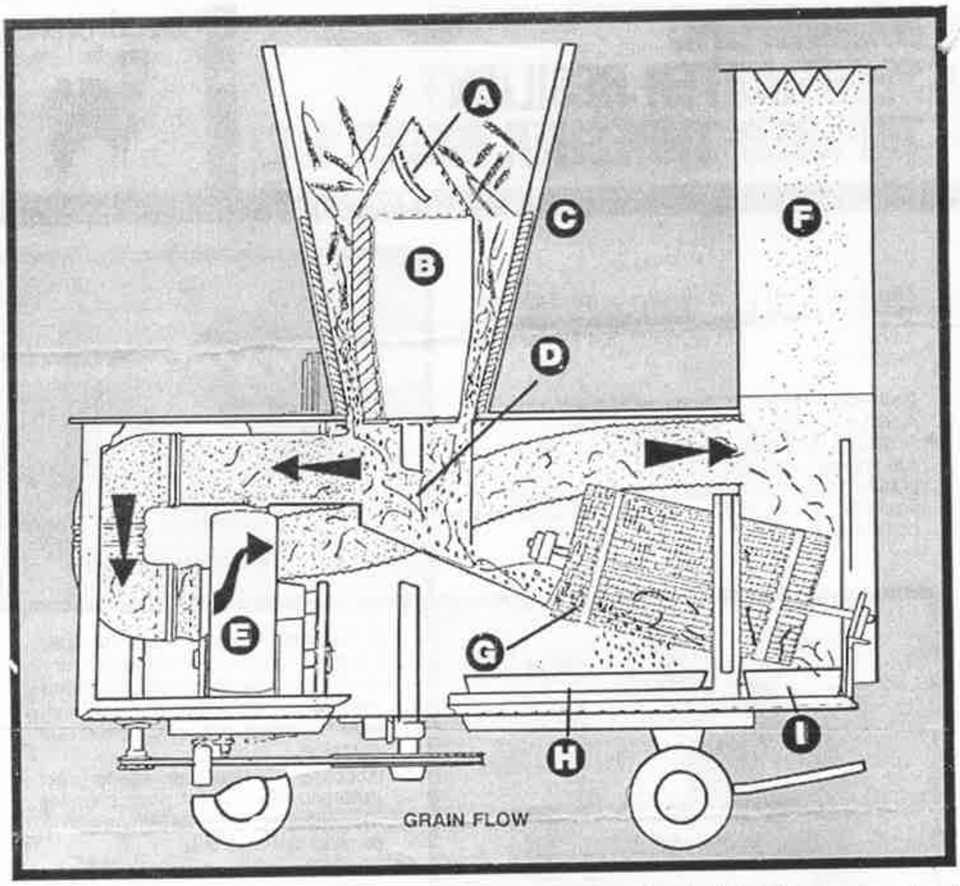




The Resilient Tapered Thresher Model L.T. has six distinct advantages over conventional type threshing machines –

1. Threshing, aspiration, scalping and dust collection are combined in one machine.
2. Absolute minimum damage to grain – dramatic reduction of grain cracking.
3. Threshing surfaces being vertical provide self-cleaning.
4. Flexibility – virtually any variety of seed or grain (coarse grains to small seeds) may be threshed.
5. Dust collector and low noise level enable indoor use.
6. Portability – easily manoeuvred in field or laboratory.

The Resilient Tapered Thresher is also available as a hand operated model for researchers and farmers in Third World developing areas, requiring to thresh smaller samples of grain. Dimensions of this hand machine are 600 mm wide by 600 mm deep by 1200 mm high.



GRAIN FLOW:

Initially the feed vanes (A) feed the material between the rotor (B) and a stator (C).

The action of threshing is achieved by having a relatively resilient surface on the rotor (B), to carry the grain around in contact with the resilient surface of the stator (C). The resilient surface of the rotor rubs the heads and grain against the resilient surface of the stator separating the grain from the heads or plant material.

The threshed material discharges into an area (D) where air separation (aspiration) is effected. Lighter chaff, straw, and dust are drawn off by the fan (E) and blown into the chaff and dust collection chamber (F). The grain, accompanied by the heavier long straws and other large material, not removed by aspiration, flow onto a rotary scalping screen (G).

The required grain sample then passes through the perforations of the screen into the collecting tray (H), while the longer material trails over the end into the scalpings collecting tray (I).

SPECIFICATIONS:

Power Requirements –
240 volt, single phase electric motors. (supplied as standard equipment).

Dimensions –

Length	1770 mm
Width	875 mm
Height	1725 mm
Weight	340 kg
Shipping Weight	426 kg

Shipping Dimensions of Machine crated –

Width	1060 mm
Length	1920 mm
Height	1980 mm

466822

PLEASE NOTE!
Due to technological development our products are being continuously improved, and we reserve all rights to modify any part or parts that may improve the smooth running of this product.

Standard Equipment –
Electric motors wired to individual switches.
Extension lead with standard 3 pin plug.
Scalping Screen – size to be nominated.
Chaff collection bin with associated dust filters.
Trays to collect cleaned sample and scalpings.
Four wheel trolley.

Optional Equipment –
3 phase electric motors or combustion motors.
Scalping screens – round, square, slotted or triangular shaped perforations.

ALF. HANNAFORD & CO. PTY. LTD.
932-942 Port Rd.,
Woodville, S.A. 5011
Phone: 45 6191
A.H.: 45 6192 or 47 5594
Belmont Ave., Belmont W.A. 6104
Phone: 65 2527
Victoria St., Dimboola, Vic. 3414
Phone: Dimboola 84.

Appendix 12: Hannaford Seedmaster Resilient Tapered Thresher Model L.T. Mk II Pamphlet (designed by Hannafords Engineering Department).

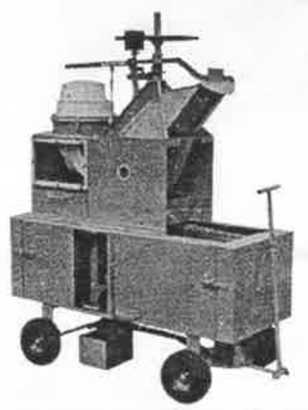
HANNAFORD SEEDMASTER RESILIENT TAPERED THRESHER MODEL L.T. Mk II

Pat. app.

Seedmaster by Hannaford

The revolutionary new design of the Tapered Thresher incorporates threshing concepts never before seen in conventional type machines.

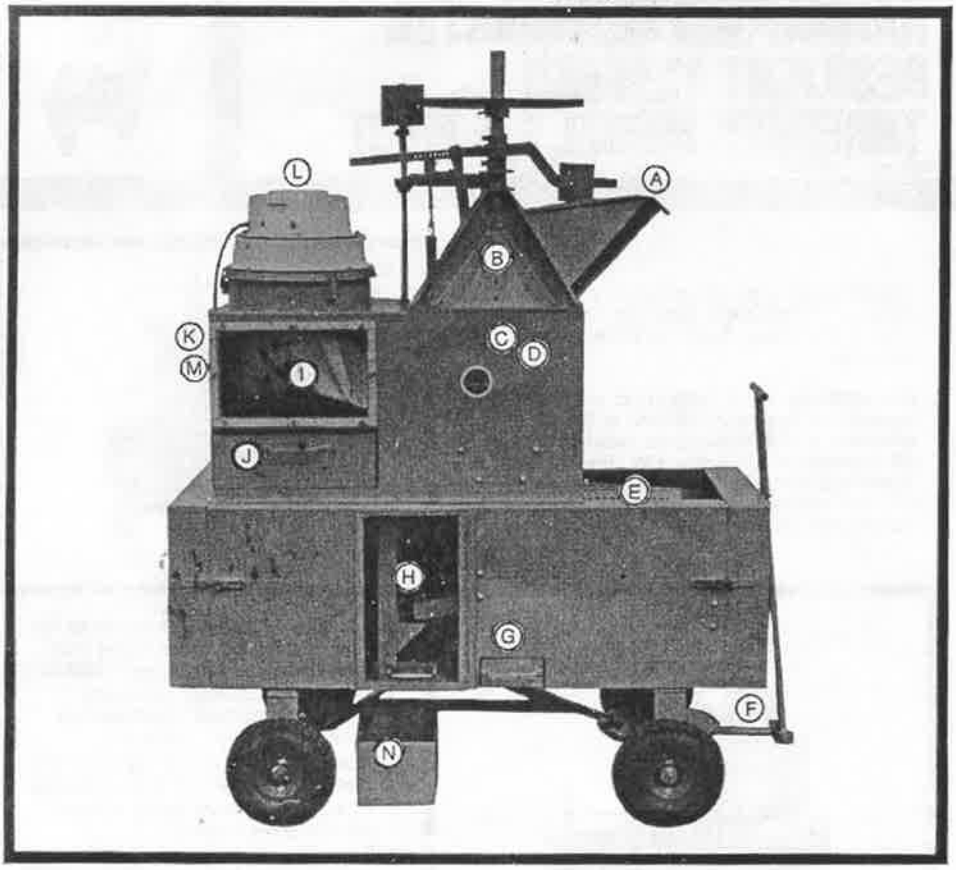
Developed by Mr. I. Ridgway of the Waite Agricultural Research Institute in South Australia, and manufactured under licence by Alf. Hannaford & Co. Pty. Ltd., the Thresher is ideally suited for laboratory and associated field trial research work, including specialist commercial crops.



The Resilient Tapered Thresher Model L.T. has six distinct advantages over conventional type threshing machines –

1. Threshing, scalping, screening, aspiration and dust collection are combined in one machine.
2. Absolute minimum damage to grain – dramatic reduction of grain cracking.
3. Threshing surfaces being vertical provide self-cleaning.
4. Flexibility – virtually any variety of seed or grain (coarse grains to small seeds) may be threshed.
5. Dust collector and low noise level enable indoor use.
6. Portability – easily manoeuvred in field or laboratory.

The Resilient Tapered Thresher is also available as a hand operated model for researchers and farmers in Third World developing areas, requiring to thresh smaller samples of grain. Dimensions of this hand machine are 510mm wide by 650mm deep by 1200mm high.



GRAIN FLOW:
Model L.T. Mk. II

Initially material is directed through intake (A) onto rotor vanes (B) which deliver material between resilient surfaces of rotor (C) and stator (D). The threshed material discharges onto three flat shaking screens (E) which scalp on top two and screen on bottom section. Larger material scalped from sample by top two screens discharged (F). Thinner material screened from sample through perforations of bottom screen discharged into tray (G). Grain which passes over perforations of bottom screen is delivered to aspiration leg (H). By removing top two screens and fitting blank type bottom screen supplied the threshed material can be conveyed directly from thresher to aspiration leg (H). Lighter dust, chaff etc. separated from sample by aspiration into expansion chamber (I) and tray (J). Degree of aspiration regulated by slide (K). Aspiration vacuum suction unit (L). Vacuum hose spigot fitting (M) for use when cleaning machine between varieties. Threshed and cleaned grain collecting tray (N)

SPECIFICATIONS:

Power Requirements –
240 volt, single phase electric motors. (supplied as standard equipment).

Dimensions –

Length	1560 mm
Width	770 mm
Height	1580 mm
Weight	222 kg
Shipping Weight	342 kg

Shipping Dimensions of Machine crated –

Length	1620 mm
Width	820 mm
Height	1765 mm

PLEASE NOTE!
Due to technological development our products are being continuously improved, and we reserve all rights to modify any part or parts that may improve the smooth running of this product.

Standard Equipment
Electric motors wired to individual switches.
Plug socket for standard three pin single phase extension lead.
Three screens – size to be nominated, plus one blank type.
Chaff collection chamber and tray with associated dust filter.
Tray to collect cleaned sample.
Four wheel trolley.
Vacuum hose.

Optional Equipment
Scalping screens – lip, round, slotted or triangular shaped perforations.

ALF. HANNAFORD & CO. PTY. LTD.
(A Crompton Group Company . . . established 1862)
64 East Ave., Beverley, S.A. 5009 Phone 46 6822
A.H. Phone: 47 5594 Telex: AA82167 CROMPTN
Belmont Ave., Belmont, W.A. 6104
Phone: 277 2527
Victoria St., Dimboola, Vic. 3414
Phone: 89.1205
Goondiwindi, Qld.
Phone: 935

EXPORT LEAFLET

Appendix 13: Letter from Dr A.J. Rathjen, listing the important characteristics of the Ridgway Pneuflo Combine.

THE UNIVERSITY OF ADELAIDE
Waite Campus

Despite the hype from molecular biology, the single most serious impediment to genetic improvement of southern Australian crops is the lack of cost-effective, efficient plot harvesting equipment. As forcibly pointed out by the President of Pioneer Seeds (1998 Crop Science Newsletter), varieties are packages of genes and they are only valuable if they perform on farms. Given the complexity of the genome (~ 100,000 genes) and threat of the growing environment, the only way to establish the value of a new variety is to measure its actual performance in farm conditions. And the only way to select effectively among the multitude of genetic variants is to grow very large populations (plots) in farm conditions.

Most breeding programs depend upon the Wintersteiger plot combine which has the capability, when working, of harvesting about 80 plots/hour. Our new Ridgway-Irvine "Pneuflo" has the following advantages.

- Speed - as a two man machine it will harvest about 250 plots/hour.
- Safety - having a low centre of gravity and being hydraulically operated, no belts or chains, it is safer.
- Capital cost, depreciation and maintenance - Wintersteiger probably cost about $30,000/year. With a lower cost and much greater reliability, the Ridgway-Irvine Pneuflo will be much cheaper.
- Transport - the 'Pneuflo' can be towed in a trailer at a cost of about 40 cents/km whereas a truck costs us about $1.40/km.

Development of the Pneuflo is not complete. Given its speed, there is a need to incorporate a bag folding machine and we have an ambition to reduce the noise level (already below the Wintersteiger) and to improve the operator comfort.

Overall, the Ridgway-Irvine Pneuflo is the most significant development in cereal breeding machinery in the past twenty years and it provides us with an opportunity to move forwards from the 1950s and 1960s technology of the current machines.

29.1.99 Dr A.J. Rathjen

Glen Osmond, South Australia 5064
Telephone: (08) 8303 4455 International: +61 8 8303 4455

Appendix 14: Extract from a Crop Science Newsletter February 1998.

Harvesting machinery

Many durum varieties are subject to seed damage during harvest which results in poor emergence and reduced establishment (reference Germination Problems in Durum Wheat, Cooper & Rathjen, Crop Science. See newsletters Feb 1998). This has been a particular problem with our stripper plot harvesters so that our durum yield trials have had uncertain validity. Further, the harvesting has been difficult, with the barbed awns of durum blocking the machines, marked reducing the harvesting speed.

A capital line in a GRDC project has financed the construction of a new plot harvest which we refer to as the Ridgway/Irvine Prenflo Harvester. This incorporates

- a modified Shelbourne stripper front, following the developmental work by Ian Ridgway,
- a secondary thresher
- a winnowing section, again developed by Ridgway
- mounted on the platform of one of our stripper harvesters

All the movement of grain and chaff is pneumatic, as with our stripper harvesters eliminating the need for sieves elevators and walkers, thereby minimising contamination between plots. Hydraulics provide the power for the stripper, hydrostatic drive fans and rams.

Irvine Engineering at Tintinara constructed the machine and contributed heavily to the design. The 1999 harvest was the first full season for the machine and it proved an excellent innovation. Ultimately, we harvested about 17,000 plots with the machine with almost no down time. In contrast to our strippers, it is excellent for harvesting both heavy yielding wheat plots and durums. In fact the heavier the crop, the better the performance as the slight grain loss at the front is reduced in heavier yielding crops. The machine has a very mild threshing action so we expect grain damage to be insignificant.

A number of minor faults remain to be remedied. We require

- more power and better engine cooling
- reduce dust and noise
- a bag folding mechanism

Normal harvesting rate is about 200 plots/hour which is more than double that achieved by the common commercial plot harvesters. Its cost is about $60,000.

Appendix 15: Study Leave Report, 28-11-77

The University of Adelaide
WAITE AGRICULTURAL RESEARCH INSTITUTE
DEPARTMENT OF AGRONOMY

GLEN OSMOND
SOUTH AUSTRALIA 5064
Telephone : 79 7901
Telegrams :
WAITINST Adelaide

STUDY LEAVE REPORT

I.G. Ridgway
Department of Agronomy
Waite Agricultural Research Institute

The aim of my study leave was to present a paper on 'The Resilient Tapered Thresher' at the International Grain and Forage Harvesting Conference at Iowa State University, Ames, Iowa, and to study the faba bean (*Vicia faba* L.) industry in Alberta and Manitoba. An additional purpose was to visit agricultural machinery makers who may be interested in developing the Resilient Tapered Thresher.

My itinerary and main contacts were:- Washington State University, Professor C. Konzak, seed cleaning machinery and harvesters for small plots; Agriculture Canada, Lethbridge, Alberta, Dr A. Johnston, faba beans and new crops; Alberta Agriculture, Edmonton, Mr L. Gareau, faba beans for silage; University of Manitoba, Winnipeg, Professor L. Evans and Dr K. Clark, faba bean research; Manitoba Agriculture, Winnipeg, Mr J. Rogalsky, faba bean uses and marketing, Dr G. Platford, faba beans on farms; Mr P. Pakosh, Chairman, Versatile Manufacturing Company, Winnipeg, discussion and demonstration of 'Resilient Tapered Thresher'; Professor Warren Adams, Intermediate Technology Group, London, discussion and demonstration of Resilient Tapered Thresher as a machine for developing countries; Dr G. Chapman, Wye College (London University), selection and breeding of faba beans; Dr P. Hayes, Queen's University, Belfast, discussion of Resilient Tapered Thresher and willow harvesting.

During my time in Winnipeg I was able to see a cross-section of the faba bean industry. This included work on breeding to produce a small non-toxic white-seeded faba bean, suitable for current farm machinery and able to mature in Western Canada. Other studies were involved with nitrogen fixation; silage making and testing; weed control; disease control; suitability for stock food and human food; marketing; development of machinery for sowing and reaping; and the importance of bees in fertilizing faba beans. These studies are very relevant to the faba bean work being done in South Australia and should be of great value if faba beans are to become a viable crop in Southern Australia.

Report of International Grain and Forage Harvesting Conference at Ames, Iowa from 25-29 September 1977

This meeting was held in the Scheme Center, Iowa State University and was attended by agricultural engineers, machinery manufacturers' representatives and farmers. About 250 people attended the opening sessions. There were 80 papers presented by workers from 14 different countries. A section of space was set aside for working models and exhibits, including electronic monitoring systems, hydraulic drive models, exhibits of crops which can be threshed by combines, and a model of the Resilient Tapered Thresher.

The meetings began at 8 a.m. and finished at 5 p.m. with one evening session of films on the techniques and machines discussed. The Conference was very interesting, especially the panel discussions where farmers provided useful feedback to the manufacturers and designers on the performance of field machines. Especially relevant were the complaints that combines were difficult to repair because of complexity, that grain damage was excessive and that the machines were impossible to clean out between crops or between seasons. My paper on the Resilient Tapered Thresher was well received and a demonstration threshing of maize and soybeans with the model R.R.T. was seen by many.

Everyone at the Conference had the opportunity to visit the National Farm Progress Show in Washington County Iowa State. This was a massive display of new farm machinery coupled with demonstrations of combining, corn silage making, grain handling, feed lotting of cattle, manure disposal, ploughing and seeding, etc. This show, which involved about 1,000 acres of farm land, enabled me to see and price machinery which could be readily adapted to build a field model of a Resilient Tapered Thresher.

The drive by private car from the Farm Progress Show to Chicago through 300 miles of the corn and soybean country completed my visit to North America.

I gratefully acknowledge the financial assistance of:- Australian and Overseas Study Awards - Ancillary Staff, the Hannaford Bequest and Rural Credits Department of the Reserve Bank.

I.G. Ridgway

28 November, 1977.

Appendix 16: Report of an assignment to Universities of Brawjijaya and Udayana, Indonesia, 2-9-80

Report on an Assignment to Universities of Brawijaya and Udayana, Indonesia, by I.G.Ridgway, Waite Agricultural Research Institute, University of Adelaide.

1. PURPOSE OF THE ASSIGNMENT

a). To assist T.S.S.U. members at Unibraw to adjust, modify and evaluate the Resilient Tapered Thresher already there, and the unit carried as hand baggage from Adelaide.

b). To set up a wood turning lathe and demonstrate the use of it in making a Resilient Tapered Thresher out of local materials, and to involve the T.S.S.U. staff as much as possible .

2. ITINERARY

Friday Aug.1st - Adelaide, Melbourne, Sydney, Denpasar, Jakarta.
Sunday " 3rd - Jakarta, Surabaya, Malang.
Sunday " 24th - Malang, Surabaya, Denpasar.
Saturday Aug. 30th - Denpasar, Sydney, Melbourne, Adelaide.

3. AUSTRALIAN CONTRIBUTION

a). The University of Adelaide allowed me leave of absence for my visit and I returned to Waite Agricultural Research Institute on 1 September.

b). The proposed budget of $3,100 was underspent by approximately $200.00 due mainly to saving in air fares, internal travel, excess baggage and purchase of materials.

c). At Jakarta Mr.M.Collins of the Australian Embassy helped with customs formalities, transport and accommodation at the Hotel Indonesia.

4. INDONESIAN CONTRIBUTION

a). The Rector of Unibraw. Dr. Harsono welcomed me to Malang, and on leaving his deputy Professor Baskoro thanked me for working there and asked me for a report on my work after I returned.

b). The Dean of the Faculty of Agriculture, Professor Soetono and his assistant Mr. Lockito were most helpful. I was provided with a freshly painted workshop to set up the wood turning lathe and also the threshers for assembling, testing and modification. Mr. Sumarto, Head of Department of Farm Mechanisation and his staff, including Messrs H.Kini, H.S.Sumardi, R. Wiro'sidarmo, B. Suharto and G.Gito all worked with me in the building, modification and testing of the Resilient Tapered Threshers.

I believe this group could now make and service more Resilient Tapered Threshers, especially when they receive the written instructions which are now awaiting typing. They do not, however, appear to realise that machines can be modified and adjusted as and when the need arises, but I must stress, that a proper assessment was not possible in such a short visit.

c). The Driver of the AAUCS Toyota gave me excellent service. I was driven to and from the University as required and on trips to purchase materials and samples, to visit Bedali Research Centre, Batu apple and vegetable farms, a coffee plantation and factory at Dampit, a cassava factory at Turen and to the Surabaya Airport. I was confused however on the amount and frequency of honoraria due to him, petrol required for the vehicle, and surprised to hear that the vehicle was unregistered.

d). At Udayana the Dean of the Faculty of Agriculture, I.R.Sujatha also Head of the Department of Food Science welcomed me and told me there was no need for me to meet the Rector. ~~His~~ assistant, I.G.S.T.Wisan Purwaday, and his driver took me to the University, the Experimental Farm and to collect a sample of soy-beans for threshing. Dr. Agung of Physics, Professor Winaya, Soil Science, I.R. Made Swara Head of Department of Agronomy, I.R. Nyoman Merit T.S.S.U. & IBU Sri Agung Horticulture discussed the Resilient Tapered Thresher with me. I demonstrated the Wooden Hand Type Resilient Tapered Thresher to all the above except the Dean (who was ill), and about 40 fourth year students of Agriculture.

5. PREPARATIONS

a). A Hand Type Resilient Tapered Thresher was made by me in Adelaide before leaving, packed in kit form and taken to Indonesia as hand baggage (26kg over weight).

b). A Wood turning lathe, 6 chisels, and 2 large wood borers were sent ahead by airfreight and arrived in time and in good order.

c). Although a list of materials and a request to purchase them had been sent to Brawijaya, none had been purchased on my arrival.

d). A desk and chair, as well as a renovated room for a workshop, plus a large bench were provided.

6. ACHIEVEMENT

a). The wood turning lathe was assembled and installed in a day.

b). Purchasing of materials for the R.T.T. to be made in the T.S.S.U. went ahead without difficulty.

6. c). Purchasing of extra tools was more expensive than anticipated.

d). The new thresher was made by the T.S.S.U. group mentioned above and tested briefly threshing peanuts. It was made to be operated by two persons turning a handle.

e). The new thresher made at W.A.R.I. was assembled and used for threshing peanuts, maize, skinning soybeans then modified for threshing I.R. 36 rice. It also crushed tomatoes and an attempt was made to skin coffee beans and crush Batu apples. Further modifications are needed for these fruit.

f). The R.T.T. made of steel was also adapted for IR 36 rice and tested further with maize and peanuts. It was also fitted with a longer handle so that it can be turned by two or three people.

g). The W.A.R.I. R.T.T. was repacked and taken to Udayana and demontrated to 5 members of staff and about 40 fourth year students.

h). IR. Made Swara Head of the Agronomy Department requested that the R.T.T. W.A.R.I. be left at Udayana until the two maize experiments at the farm could be threshed in October. After discussion with Professor Soetono who suggested the thresher could stay at Udayana it was left with Swara after more demonstration and instruction on its use.

CONCLUSIONS

a). At both Universities there appears to be minimal mechanical aids for field experiments and possibly laboratory work.

b). At Unibraw a small workshop serviced the Faculty of Agriculture. However there is a much larger workshop on Campus for presumably Faculty of Engineering.

c). At Udayana the Faculty has no workshop and the main workshop was relatively small and had a limited range of equipment.

d). I believe basic and uncomplicated machinery could be very beneficial if introduced with adequate instructions for workshop upgrading, so that teaching and research equipment could be made and serviced.

RECOMMENDATIONS

a) Early consideration should be given for an exchanging of technicians between Australian and Indonesian Universities. I believe this would have a double advantage in that Indonesians could work in various areas of workshops, research laboratories, and as assistants in practical teaching. On the other side Australian technicians could work in the HUB Universities initially to instal workshop equipment and demonstrate operation and servicing while building the most urgent requirements.

Appendix 17: Power farming extract

Ridgeway, I. G. (n.d.). To cut time and costs. *Power Farming*, 18-19.

NOTE:

This publication is included in the print copy
of the thesis held in the University of Adelaide Library.

Appendix 18: "Peanut Shelling", Dwi Insoepriyantono

Results.

TEST RESULTS REPORT

Thresher Model L.T. Mk. ~~11~~ I

HANNAFORD & Co , Pty. Ltd. Production

by

DWI INSOEPRIYANTONO

Translation

by

HENDRIK KINI

/

TEST RESULTS

Thresher Model L.T. Mk. 11

HANNAFORD & Co , Pty. Ltd. Production

INTODUCTION

Thresher Model L.T. Mk. 11 is anew equipment made by Hannaford & Co. This equipment is designed and developed by Mr. RIDGWAY used for threshing cultivated plant production as peanut, soybean, cereal, sorghum, and Maize.

OBJECT OF THE TEST

To check the ability of the trhesher Model L.T. Mk. 11 for its efficiency of time for threshing and quality of threshing work production.

TOOLS AND MATERIAL USED

I. Tools
1. Thresher Model L.T. Mk. 11
2. Ruler
3. Stop Watch
4. Tampah (wide round tray made of bamboo)
5. Balance

II. Materials
1. Peanut - 60 kg
2. Maize - 60 kg (Maize cob)

PROCEDURE

A. For Peanut

Thresher is fitted by a weight to the scale 13 cm from center hole and peanuts are taken into the thresher step by step from 1 kg to 5 kg for one replication turning.

2

B. For Maize

The weight is liberated from the thresher in order to get some larger space between rotor and stator. 1 kg t0 5 kg of maize is taken into the thresher a little by a little during one replication turning.

Table 1. Testing results for peanut

No.	Time (minute)	Turning Power (man)	Results Unbreakable-shell (kg)	Unbreakable-nut (kg)	Broken-nut (kg)	Shell-weight (kg)
1.	5	1	1.30	2.22	0.20	1.28
2.	5	1	1.45	2.18	0.20	1.25
3.	5	1	1.40	2.25	0.15	1.20
4.	5	1	1.35	2.10	0.15	1.40
5.	5	1	1.40	2.15	0.15	1.30
Average	5	1	1.58	2.16	0.17	-
Percentage		-	31.60	43.20	3.40	-

Table 2. Testing results for Maize

No.	Time (minute)	Turning Power (man)	Results Unthreshed seed on cob (kg)	corn-seed (kg)	Cob - waste (kg)
1.	7	2	0.25	3.97	0.78
2.	7	2	0.25	4.15	0.60
3.	8	2	0.25	4.27	0.48
4.	8	2	0.26	4.06	0.68
5.	9	2	0.26	3.94	0.80
Rata-Average	8	2	0.25	4.08	-
Percentage		-	5.00	81.80	-

DISCUSSIONS

Threshing peanuts using the trhesher needed a short time. Average 5 minutes/5 kg for one replication turning. However, in the aspect of nut quality, it prodused a low quality nut for one replication turning (43.20%)(Table 1). In order to get the complete threshed peanuts, the turning should be replicated 2-3 times, and spend about 15 - 20 minutes to finish them.

For threshing Maize, about 8 minutes/5 kg maize cob is needed for one replication turning, and has produced a high yield of corn seeds (81.80%), that it was not neccessary to repeat the turning (Table 2).

THE COST OF TESTING OPERATION

A. Purchasing Materials

1. 60 kg dry peanuts	a Rp 450,-		Rp 22.500,-
2. 60 kg dry Maize cob à	100,-		5.000,-
		Total	27.500,-

B. Transportation

1. For 60 kg peanuts from KEPANJEN		Rp 1.000,-
2. For 60 kg Maize cob from BATU		1.000,-
3. Petrol for car		500,-
	Total	2.500,-

C. Labour

1. 2 men for turning peanuts	a Rp 750,-	Rp 1.500,-
2. 2 men for sorting peanuts	a 500,-	1.000,-
3. 2 men for turning maize	a 750,-	1.500,-
4. 2 men for sorting maize	a 500,-	1.000,-
		5.000,-

D. Dating (Data)

1. ~~Analyses~~ Analysis and Dating		Rp 1.000,-
2. Typing		1.000,-
3. For operator		1.000,-
	Total	3.000,-

General Total Rp 38.000,-

(Thirty eight thousand Rups)

Supervisor,
Chief of Mechanization Dept.

Ir. C. M SUMARTO

~~In~~
Operator

Ir. DWI INSOEPRIYANTO

THE TAXATION OF THRESHING COST PEF

A. PEANUT

Production per Ha (more or less)	
The rate of Threshing, turned by 2 mer	
Production of 1 Ha can be finished foi	
Effective work per day	
The Cost for threshing/2 men/2 days	........................Rp 3.000
The rate of sorting/2 men/day	: 5 kwintal
Production 1 Ha, can be finished for	: 2 days/8men
Cost of sorting for 8 men/2days	: 8 X 2 X Rp 500,-=Rp 8.000
Total	Rp 11.000

B. MAIZE

Production per Ha (more or less)	: 80 kwintals of Maize cob
The rate of threshing, turned by 2 men	: 30 minutes/kwintal
Production 1 Ha, can be finished for	: 40 hours
Effective work/day	: 5 hours
The cost of threshing/8 men/ 2 days	: 8 X 2 X Rp 750,-=Rp 12.000
The rate of sorting/2 men/ 2 days	: 10 kwintals
Production 1 Ha can be finished for	: 2 days/ 16 men
The cost of sorting/ 2 days/ 16 men	: 2X16X Rp 500,-=-Rp 16.000
Total	Rp 28.000

NOTE :

This calculation written above is not included the cost of maintenace for the Thresher.

Appendix 19: Letter from Dr. Robin Graham, Reader in Plant Science, 4-7-94

THE UNIVERSITY OF ADELAIDE

Waite Campus
Department of Plant Science

4th July, 1994

Mr Ian Ridgway
PO Box 13
BORDERTOWN SA 5268

Dear Ian,

Many thanks for informing us of developments in harvesters based on the resilient tapered thresher. I was impressed with the compatibility of your patented thresher with the "Silsoe" stripper front.

I was not aware than the Silsoe stripper mechanism is so much more efficient than conventual reel-and-cutter bar fronts, allowing much faster harvesting, especially of heavy crops and with lower losses to the ground. I was also surprised to learn they are now in use in 23 countries, and it stands to reason they will come into use in South Australia. This being so, it may be important that breeders note the head and straw characteristics which these headers handle best. It may become important that experimental harvesters also make use of the silsoe stripper front. The one area needing further investigation and development is the recognised losses from these strippers as they come out of a crop. While of no commercial consequence, such losses in small-plot harvesters occur every 5 m or so and are expected to be significant. Ways of preventing or correcting for these losses need to be found before your machine can become a major component of cereal research programs.

I support all efforts to develop your machine further but because of the commercial potential of the stripper principle and because of the most important feature of your thresher - that it is self-cleaning and therefore in breeders' small plots, there is the major improvement of decreasing cross contamination of grain samples by carry over from one plot to the next of seed trapped in the thresher and sieves. I believe this is such an important issue that it alone justifies financial support for the continued development of your conceptually novel design.

I wish you well in seeking this funding; if I can be of any assistance I would be pleased to provide it.

Yours sincerely,

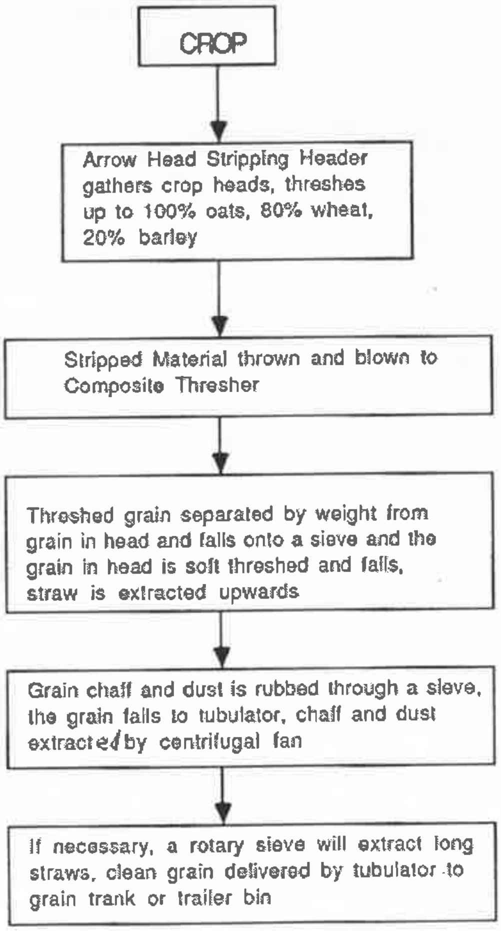
Robin D Graham
Reader in Plant Science

Waite Road, Glen Osmond, South Australia 5064
Tel: (08) 303 7279 International: +61 8 303 7296
Fax: (08) 303 7109 International: +61 8 303 7109
E-mail: plantsc@waite.adelaide.edu.au
Telex: UNIVAD AA 89141

Appendix 20: Flow Chart of Farmers Pneuflo

Flow Chart for a Pneu Generation Combine,

Farmers' Model



Appendix 21: Godwin to Woolhouse re PhD

Silsoe College

Cranfield

Silsoe Campus, Silsoe, Bedford MK45 4DT England
Telephone Silsoe (0525) 60428
Telex 265871 (MONREF G) EUM 300
Fax (0525) 61527

27 August 1991

Professor Harold Woolhouse
Director
Waite Campus
University of Adelaide
Glen Osmond 5069
Adelaide
S.Australia.

Dear Professor Woolhouse,

As you are aware, Ian Ridgway has been with us for three weeks testing and demonstrating the Resilient Tapered Thresher and a straw extractor.

Today we had a group demonstration and discussion on what could be done to further the evaluation of these devices. With us were six staff members from Silsoe Research Institute and six from Silsoe College and after the introduction and demonstration we discussed the best method of forwarding progress with this technology.

We all felt that because the approach was still far away from commercialization yet too useful for AFRC's "non-near market" (pure science approach), that a Ph.D. project would yield the best possible return. Subsequent discussion led to 3 possibilities:

The first is a satisfactory Ph.D. nomination from Australia supported by a Commonwealth Universities Grant. The second, for Silsoe College to apply to (i) The Ministry of Agriculture for a Ph.D. grant and (ii) the Science and Engineering Research Council for a Total Technology grant for a Ph.D. for a U.K. student. This could need an additional Industrial Sponsor input of about $16000 per year from Australia. We would both undertake these submissions as soon as possible and, if neither of the first two are successful, then a U.K. student could be sponsored by an "industrial sponsor", e.g. [illegible] Pty Ltd. This would need around $30000 per year.

In each case we would expect Ridgway to sit on a thesis (steering) committee as a representative of the Industrial Sponsor.

We have no set timetable for the start of a Ph.D. but if a suitable candidate can be found, start could be made as soon as practical, nominally 1st October 1992 for MAFF and SERC. We suggest the main study objective would be to determine the market potential, engineering specifications and design performances of the resilient tapered thresher and the straw extractor.

Yours sincerely,

R.J.Godwin,
Professor and Head
Department of Engineering for Agriculture.
Dean of the Faculty.

Appendix 22: Bilateral Science and Technology Collaborative Program Report - Resilient Tapered Thresher Project

BILATERAL SCIENCE AND TECHNOLOGY COLLABORATIVE PROGRAM REPORT

"RESILIENT TAPERED THRESHER PROJECT"

Abstract

Following the introduction to the harvesting systems of the world of the Shellbourne Reynolds header stripper, the opportunity to combine a Resilient Tapered Thresher (RTT) and a straw extractor to produce a simple, more efficient harvester has become a reality. However, more basic research is needed to be able to define the size of the components and the power needed to drive them. This has been started at Silsoe and awaits a suitable researcher and financial resources to continue.

Report

The object of my work at Silsoe College was to stimulate a bilateral approach to eventually building a new harvesting combine incorporating a RTT with a straw extractor.

I was able to get data of some significance on the time needed to thresh and clean samples of wheat as heads only, heads on 150 mm of straw, heads and straw direct from the Silsoe Research Institute experimental header stripper and the same samples pre-threshed in the Buchele concept. These samples were all fed through an improvised hopper on the top of the RTT component of the Plot Harvester. Also threshed were samples of barley as heads, as total crop from the header stripper and pre-threshed in the Buchele concept. The beans were threshed as heads only and maize as sheathed cobs and desheathed cobs. Neither beans nor maize were pre-threshed in the Buchele concept because of lack of time to prepare a mesh liner of adequate opening size. The testing demonstrated:

(1) The threshing was satisfactory in all cases. Samples pre-threshed in the Buchele concept were threshed much faster than those not, but the aspirator was unable to adequately clean them.

(2) Maize samples were adequately threshed in time, but the format of the RTT in the Plot Harvester is too small for large cobs and there is not enough clearance to pass the threshed cobs between the rotor and the stator.

(3) Bean pods presented no problems nor was the upper limit of capacity to thresh and clean them reached.

(4) The limiting factor of the system appears to be the aspirator at this point.

(5) The aspirator ducting is inadequate in size and layout for the higher capacity of the RTT. The adjusting valve which regulates the flows of air and hence the flow of chaff, corn sheath and bean shells can readily cause bridging across the opening causing total loss of air flow.

Measurements of oil flow and oil pressure to the RTT motor were obtained and an estimate of power required to turn it under load were made.

Estimates using a watt meter were made of electrical power available and used by the Buchele concept. As it was not possible by hand to present a capacity load to it no measurement of capacity was obtained. The outstanding feature of the Ridgway concept of the Buchele principle was the ability to totally thresh the material presented.

The demonstration on Friday 23 was attended by twelve of the fourteen invited, among them Dr. John Chisholm, Dr. Michael Neal, Dr. Jim Price, and Dr. Norris Hobson from the nearby Silsoe Research Institute, which I believe is an indication of the joint interest the equipment has created between the two Institutions. Dr. Roger Arnold, retired from S.R.I., was present also. Indicative of the interest in this project was the length of presentation and discussion which lasted some three and a half hours and continued support has been indicated in the letter of 27 August from Professor Godwin to Professor Woolhouse (copy attached).

I also took the opportunity to visit the U.S.A. on the return journey to Australia and had discussions with Emeritus Professor W. Buchele who patented a conical thresher in the late 1950's. His concept has been modified and is the basis of the straw extraction unit which is part of the current investigation. While in the U.S., I investigated electrically powered machinery. This will be part of future research also.

The obstacles preventing the continuation of the research now are the selection of a suitable candidate and the financing of the project.

There are several reasons why this work should now be continued at Silsoe.

(1) Silsoe College, through Professor Godwin, has shown interest in the concept of a new field harvester/combine which would incorporate the stripper header front developed at Silsoe Research Institute, a straw extractor, a resilient tapered thresher, an aspirator and a sieving mechanism. This has happened due largely to the commercial application of the stripper header now manufactured by Shellbourne Reynolds having wide acceptance in the grain harvesting operation and the projection by Ridgway of the combination already mentioned above. He believes that the basic research data should be obtained in a place which has workers in the field and also has the best facilities in the Commonwealth for agricultural machinery fabrication.

(2) Silsoe College were prepared to support the initial evaluation.

(3) The machinery shipped to Silsoe is still there, pending the result of the discussions now being held with Luminis Pty. Ltd., University of Adelaide and the S.A. Department of Agriculture on the future program.

(4) A bilateral research program has an objective advantage.

The assessment done at Silsoe, the discussion with professor Buchele and the letter from Professor Godwin has been most positive in the direction the work should proceed. To ensure the commercial interests of South Australia are protected, Mr. Peter Hart, Managing Director of Luminis Pty. Ltd. the venture development and technology transfer company of The University of Adelaide, will undertake discussions with Professor Godwin during October, 1991 in the United Kingdom.

Encl.: Letter dated 27 August, 1991 to Professor Woolhouse.

DITAC Ref.: 91/978

Dated 30 September, 1991

Appendix 23: Finnish Tapered Thresher Abstract

(Literature Review)

Invention filed 22.7.86 in Finland, serial number 893315 (1986).

An extract from the summary "to realise an improved harvesting machine where the cutting, sorting and cleaning of the grains as well as the transportation of the straw mass, is combined to be carried out in devices rotating around one and the same axis".

Figures 1 and 2 from the filing document are reproduced indicating some of the complexity of the machine.

The abstract from the document is quoted verbatim.

> "A harvesting machine comprising means for feeding seed plants such as grain into the machine, a threshing unit and a sieve set for threshing the said seed plant and for separating the seeds from the rest of the vegetable material, means for recovering the seeds from the machine and means for removing the residual vegetable material from the apparatus. The threshing unit is formed of a drum and of beaters or flails, which drum is conical and is fitted in the apparatus in a vertical position so that it widens from the bottom towards the top, and the flails are installed on the outer surface of the said drum. The sieve set is formed of at least two sieves which are at least partly conical and are nested coaxially around each other and the threshing unit, so that the threshing space is located in between the drum and the said sieve set. The shroud is conical, and the threshing unit and the sieve set are fitted inside the shroud, and in between the sieve set and the shroud there is provided a collecting bin, whereby the seeds are gathered to the bottom part of the collecting bin, where an opening is provided for removing them".

The complexity of this invention is compared with the simplicity of the Resilient Tapered Thresher, Figures 2K & L and 2J page 37.

Appendix 24: "The Development and Evaluation of a Prototype Harvester" by I.G. Ridgway, 1994

THE DEVELOPMENT AND EVALUATION OF A PROTOTYPE HARVESTER

I.G. RIDGWAY, Roseworthy Agronomy and Farming Systems

SUMMARY

Revolution, not evolution, is now required in harvester design.

This project looks at combining three simple components: a 'Silsoe' header; a pneumatic conveyer; and a 'Resilient Tapered Thresher', into a new light- weight, easy-cleaning, easy-to-maintain harvester, which enhances the operator's environment with low and controlled dust emissions.

What has evolved over recent years is expensive, complex harvesting machinery, with components that are both intricate and difficult to access. Maintenance time and costs have escalated while total cleaning between crop varieties, cultivars, paddocks and farms is practically impossible. Without easy cleaning, we are seeing wide-spread weed distribution and difficulties in obtaining pure grain for seed. Cabins have been added to give the operator respite from the dust and noise of these heavy machines, up to 20 tonnes loaded, lumbering along consuming from 1 litre of fuel per tonne of grain harvested.

This paper discusses the work-to-date and progress achieved in the pneumatic conveying of the harvested material.

INTRODUCTION

Williams (1983) defines pneumatic conveying as the 'movement of dry material through an enclosed pipeline by the motion of air' and that 'each new conveying system is an entity in itself and must be engineered as such.' The experiences in this project of first designing, then constructing, testing and lastly re-designing the conveying system fully emphasises Williams' last point.

CONVEYING DETAILS

Both negative pressure (vacuum) and positive pressure conveying systems are used in the harvester. The header consists of 5 steel blades (with plastic fingers) rotating upwards at 500-700 r.p.m. and is designed to generate enough air and impart enough speed to the harvested heads to blow and throw the material up the conveying chute. It acts as a fan providing a positive pressure to force the material up the chute, while at the other end is the thresher (and fan) effectively drawing the material along the chute.

The thresher is in two parts (on the one shaft), and together with the fan attached to its top, is designed to assist the air movement generated by the header. The top of the thresher (above the material entry point) typically removes the straw from the grain leaving the grain, still in the chaff, to fall by gravity into the 'Resilient Tapered Thresher' (RTT) at the bottom which does the final threshing. On leaving the RTT, the chaff and dust is drawn off by the extractor allowing the threshed clean grain to fall into the grain bin.

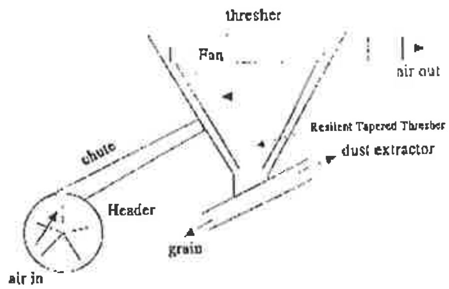


Fig. 1. The pneumatic conveying system.

Interactions between the various air moving components are complex, particularly since the rotational speed of each may be varied independently. Measurements taken using the SOLOMAT MPM2000 air speed indicator have assisted in understanding these interactions.

CHUTE DESIGN

To determine the air flow requirements, the speeds to move and lift grain and straw were needed. The air speed needed to lift a grain of wheat vertically was measured and found to be approximately 6 m/sec. Measurements taken later on the original Plot harvester (Ridgway, 1979) featuring a similar cleaning system, indicated air speeds of 4.5 m/s were required to separate chaff from wheat.

Since there were no means of readily predicting the air velocities to be induced by either the header or thresher, estimates were required for the sizing of the conveyor chute. With the r.p.m. of the header and thresher variable it was expected that the r.p.m. could be varied to obtain the necessary velocities. Of course the conflict between header speed for air velocity generation and reaping had also to be considered.

The design was for a header of 0.6 m diameter, rotating at 500 r.p.m. discharging into a constant area (though reducing width) chute of 0.12 m^2 into a thresher at 450 r.p.m. Tests have been carried out to ascertain the air velocities present and modifications undertaken as necessary.

RESULTS

The preliminary results showed that hand-fed Fiord faba beans went into the chute and almost immediately the beans were expelled forward at high speed, and the straw tended to lodge in the chute. Measurements and observation of the generated air flow showed that the velocity in the chute was typically < 2m/s and very non-uniform with recirculation causing the straw to drop out on the chute floor.

Modifications were undertaken to increase the air speed, including: widening the steel blades (wooden strips); reducing the thresher inlet; various holes in the header to increase inlet air; and finally the addition of a 'Harvestaire' blower to blow additional air in at the bottom of the chute. These measures all failed to produce the throwing and blowing needed to carry the harvested material into the thresher. In addition, measurements showed that the header modifications did not improve performance over the steel blades with plastic fingers.

After consultation with Dr Behrendorff, a detailed study of the component performances was undertaken. This found that, even without considering the recirculation problem, the header at best could supply 2 m/s, the thresher 1.2 m/s, and combined they achieved <3 m/s up the chute.

The investigation clearly showed that with the header and thresher combined, the necessary velocities could not be obtained. Thus the decision was made to reduce both the vertical and horizontal dimensions of the chute. The header end cross-section was reduced by 50% and the thresher end by 75%. It was also expected that these modifications would reduce/eliminate the irregular air flow experienced previously in the chute. Now the header alone produced in the chute 10 m/s, the thresher 7 m/s and combined nearly 8 m/s. The flow recirculation was also reduced and the harvested material now flows along the chute successfully.

Field tests of the harvester indicate that the header stripper can gather the crops tested (lucerne, wheat, barley). The initial settling of the material in the chute was due to lack of air speed and swirling. This problem seems to have been resolved. The mesh in the thresher then became choked with straw, resulting in the mesh being removed. A different threshing surface has now been installed and is being tested.

REFERENCES

Ridgway I.G. 1979. The Original 4 row Plot Harvester. personal information.

Williams O.A. 1983. Pneumatic and Hydraulic Conveying of Solids. Chemical Industries, V13.

SUPERVISORS Prof T Reeves (University of Adelaide, Roseworthy), Dr M Behrendorff (University of Adelaide, Engineering) and Prof R Godwin (Cranfield University, Silsoe, UK).

Appendix 25: Ridgway, Harris and Reimers "The Development of the Ridgway Pneuflo Combine 1977-2000"

THE DEVELOPMENT OF THE RIDGWAY PNEU FLO COMBINE 1977 – 2000.

I G Ridgway, H A Reimers and P L Harris
Department of Agronomy and Farming Systems, The University of Adelaide, Roseworthy Campus, South Australia 5371

ABSTRACT

The major objective of the program was to develop a grain harvester which had a minimum number of moving parts and was gentle in its action. The number of moving parts is kept to a minimum using controlled airflow, a stripping header, a conical self-cleaning thresher and an aspirator for separating grain from dust and chaff.

Secondary objectives include simple access to parts requiring cleaning (particularly important when handling pure seed) and the ability to thresh a wide range of grains of different size and texture with minimal adjustment.

A self propelled version was first constructed in 1978 and incorporated a Ridley type comb and beater combination with a resilient tapered thresher. This machine was used to harvest experimental plots of cereals and has been continuously modified in an endeavour to improve its performance and yet still retain simplicity.

The current version has a Silsoe stripping header front which will enable the harvest of a wide range of field crops, provides suitable airflow and a significant degree of primary threshing of the heads as they are reaped.

The Silsoe front has been modified to include a retractable bottom lip and an adjustable nose cone or top lip in order to further reduce field losses, particularly in lower yielding crops in the cereal zone of South Australia. This uncomplicated design has significant advantages over currently available commercial harvesters in that it has low initial capital cost, low maintenance, easy accessibility for clean-out, rapid harvesting speed, the ability to produce an extremely clean sample, easy adjustment for crops of varying height and is self cleaning. The three moving parts are directly driven by hydraulic motors, improving safety by eliminating shafts, chains and belts.
Key Words: stripping header, controlled air flow, resilient tapered thresher, dust extractor, aspiration, excess air outlet, accessibility, self cleaning, safety, separation tube, pneumatic conveying, top lip, bottom lip, harvester.

INTRODUCTION

Mechanising the human hands concept of threshing and blowing away the chaff has been a lifetime ambition. The potential of mechanical soft threshing became feasible with the development of a technique allowing rubber to be vulcanised to steel. To achieve the constant threshing pressure a conical rotor faced with tough sponge rotating inside a matching stator lined with retreading rubber was constructed.

A pressure lever and a supporting spring were added to the rotor so threshing pressure could be adjusted. Threshing does not require high speeds (Lalor & Buchele, 1963) and when tested threshing heads of wheat the concept produced complete threshing at 90 RPM of the rotor in the stator. There was no grain damage (Ridgway, 1977).

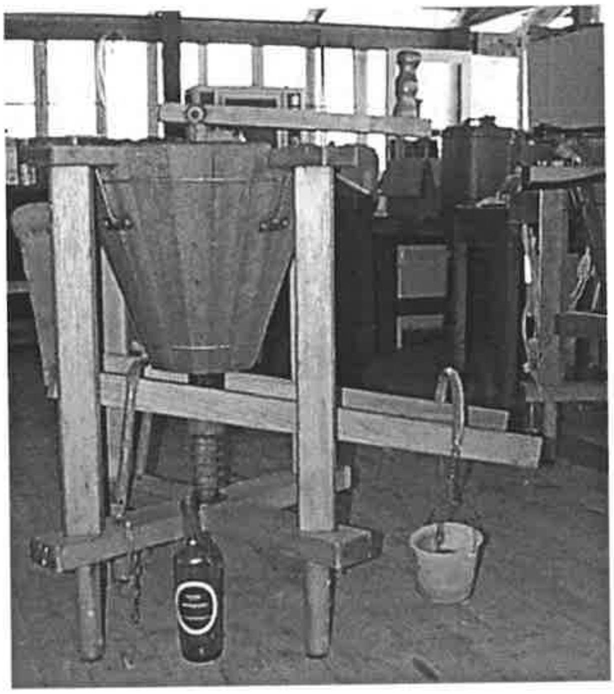


Figure 5: Early model resilient tapered thresher used for a range of cereals, clovers and grasses, shelling peanuts, crushing grapes and removing testas from soaked soy bean.

COMBINE DEVELOPMENT

The next phase in developing a combine was cleaning chaff dust and straw from the grain without loss of grain using a controlled air flow, as Lamp and Buchele (1960) stated that "air alone will be sufficient to clean centrifugaly threshed grain". This was achieved by allowing the threshed mixture to fall through an updraft of air that removed unwanted material and allowed the cleaned grain to fall into a tray. The prototype of this concept threshed and cleaned approximately 50,000 samples of various research materials without replacement of the threshing surfaces.

The first field combine (plot size) harvested a standing crop using comb fingers and a beater that delivered crop to a resilient tapered thresher. The threshed material then fell into an updraft of air for separating with the clean grain falling into a collection bin.

Several concepts of harvesting standing crops were tested.

- A patented belt cutter (Ridgway, 1982) combined with a Ridley stripping front.
- A Ridley stripping front with rubber coated beaters.
- An oscillating knife and a chute with an auger to lift the harvested material.
- An open front cutter and reel and a sloping conveyor belt.
- The Silsoe stripping header with upward rotating plastic fingers.

Finally, the Silsoe stripping header with controlled air flow seemed to have the necessary potential. Hale (1990) puts the power requirement of the stripping header at 1-4.5 kWm^{-1} at a speed of 7.5 kph or up to 9.0 kWm^{-1} in lodged rice.

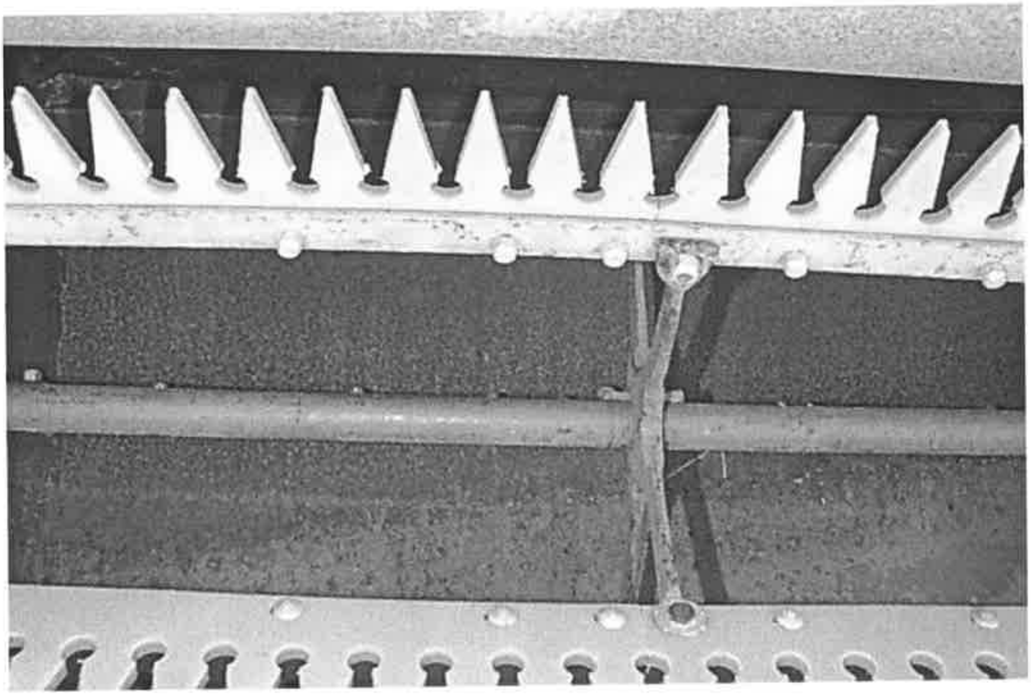


Figure 6: Silsoe stripping header rotor

Figure 7: Plot Pneu Flo combine capable of reaping at ground level.

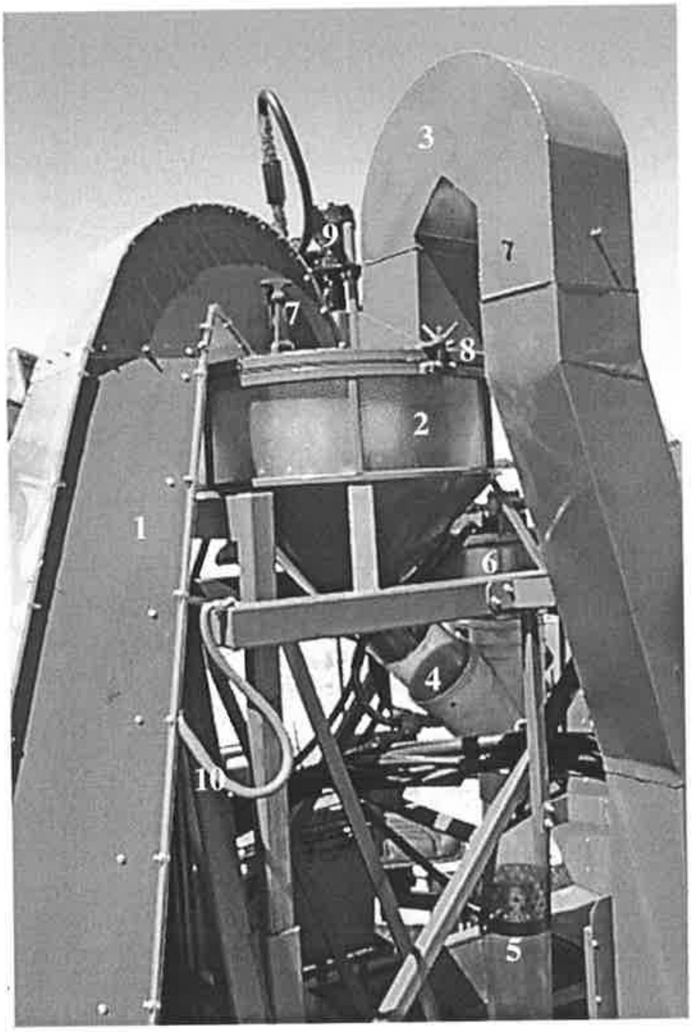
Two Ridgway Pneu Flo Combines are now operating and giving good results. Testing for losses and grain damage meant basic design alterations and many hours of field work to get a near perfect sample and minimal losses.

Critical dimensions have evolved in the design of the lips and the apertures in and out of the chute from the stripping header to the resilient tapered thresher. The volume and shape of the chute are also critical so that air speed takes the harvested material to the thresher. The speed of the stripping header rotor requires monitoring with a rev counter and must be driven at a speed adequate to remove the grain from the standing crops and deliver it to the resilient tapered thresher. The thresher must be driven as slowly as possible while still achieving thorough threshing, too high a thresher speed creates an updraft of air which conflicts with the chute flow and can cause grain to be rejected. Threshing does not require high speeds (Lalor and Buchele, 1963)

The dust and chaff extractor also has a critical speed, over speed causes grain loss and under speed causes chaff to be left in the sample.

The angle of the delivery chute from the resilient tapered thresher to the cleaning chute is also critical, as is the angle of the cleaning chute. Williams (1983) states that less velocity is required to convey material vertically upwards than is required for horizontal movement. The threshed material needs to access the updraft of air in the cleaning chute at a right angle. At least six formats of this component have been built and tested.

The two plot combines now in use are giving good results for harvesting speed, efficiency and sample cleanliness. However, operator acceptance and preconceptions have been the main problems with acceptance of the concept. The Pneu Flo combines are capable of reaping plots in from 2 to 4 seconds, then they need about 5 seconds to clean before proceeding. To achieve the potential harvesting speed needs a team approach and empathy between driver and bagman.



1. Chute from stripping header
2. Resilient tapered thresher
3. Excess air and light straw outlet
4. Conveyer tube - thresher to separator
5. Separator Tube
6. Extractor Fan
7. Quick release - chute to thresher
8. Access to RTT
9. Thresher hydraulic motor (direct drive
10. Safety cable to hold chute.

Figure 4: Close up of the Pneu Flo components

The speed of harvesting, so critical in a large breeding program, is being slowed by the grain handling which currently involves transfer from bucket to paper bag followed by folding and stacking the samples in a transfer sack or crate.

Figure 5: Indication of size of the Pneu Flo plot combine

Figure 6: 1m diameter RTT used for almond shelling, garlic separating and corn cob threshing. Note the pressure lever at the top of the shaft.

Figure 8: Calibrating components

Figure 8: Checking for forward losses

It was found that losses from the front were reduced by increasing the ground speed. Rathjen (1999) reported that in its first full season (the 1999 harvest) the Ridgway Pneu Flo combine proved to be an excellent innovation. Ultimately the combine harvested 17000 plots with almost no down time. Rathjen also states that the plot combine has the potential to harvest

250 plots per hour with two operators, is capable of harvesting in moist conditions and can be shifted from site to site on a trailer towed by a utility.

CONCLUSION

Having got the Ridgway Pneu Flo Plot Combines to a harvesting speed of over 200 plots per hour, producing acceptable grain samples, no time should be lost in producing a prototype farm model.

PATENTS

The Stripping Header patent is GB2176685B and the Thresher is Australian Patent No 512415 (1978)

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Appendix 26: Report on IGR Silsoe visit 1991

REPORT OF VISIT TO SILSOE COLLEGE, UNITED KINGDOM FOR FURTHER EVALUATION OF THE PLOT HARVESTER INCORPORATING A RESILIENT TAPERED THRESHER AND A STRAW EXTRACTION DEVICE.

This report covers my visit to Silsoe College and Silsoe Research Institute, U.K. to undertake further research and development of the Plot Harvester and the United States where discussions were undertaken with interested parties on threshing concepts and associated engineering problems.

En route to the U.K., I visited Dr. D.W. Puckridge of the International Rice Research Institute and discussed rice planting and harvesting machinery, and together we visited the Huntra Research Station.

The machinery was shipped to London by British Airways and was carried from Heathrow to Silsoe College by a College truck one week ahead of my arrival. The reassembly and the testing prior to getting some results took almost 2 weeks; the Buchele type thresher had to be set on a temporary stand which had to be built up from salvage material around the project laboratory including using an electric motor from a disused auger, pulleys, belts, bolts, etc., from the store. During this assembly time, I gathered together samples of barley, wheat, and beans (vicia faba L.) to allow them to dry enough to test the threshing principles. Samples of maize from a post-graduate project were already dry and available. Professor R. Godwin and Dr. M. O'Dogherty arranged for any service I needed and also arranged a demonstration, presentation and discussion for Friday 23 August. The workshop staff gave me excellent support.

I was able to get data of some significance on the time needed to thresh and clean samples of wheat as heads only, heads on 150 mm of straw, heads and straw direct from the Silsoe Research Institute experimental header stripper and the same samples pre-threshed in the Buchele concept. These samples were all fed through an improvised hopper on the top of the Resilient Tapered Thresher (R.T.T.) component of the Plot Harvester. Also threshed were samples of barley as heads, as total crop from the header stripper and pre-threshed in the Buchele concept. The beans were threshed as heads only and maize as sheathed cobs and desheathed cobs. Neither beans nor maize were pre-threshed in the Buchele concept because of lack of time to prepare a mesh liner of adequate opening size. The testing demonstrated:

(1) The threshing was satisfactory in all cases. Samples pre-threshed in the Buchele concept were threshed much faster than those not, but the aspirator was unable to adequately clean them.

(2) Maize samples were adequately threshed in time, but the format of the R.T.T. in the Plot Harvester is too small for large cobs and there is not enough clearance to pass the threshed cobs between the rotor and the stator.

(3) Bean pods presented no problems nor was the upper limit of capacity to thresh and clean them reached.

(4) The limiting factor of the system appears to be the aspirator at this point.

(5) The aspirator ducting is inadequate in size and layout for the higher capacity of the R.T.T. The adjusting valve which regulates the flows of air and hence the flow of chaff, corn sheath and bean shells can readily cause bridging across the opening causing total loss of air flow.

Measurements of oil flow and oil pressure to the R.T.T. motor were obtained and an estimate of power required to turn it under load were made.

Estimates using a watt meter were made of electrical power available and used by the Buchele concept. As it was not possible by hand to present a capacity load to it no measurement of capacity was obtained. The outstanding feature of the Ridgway concept of the Buchele principle was the ability to totally thresh the material presented.

The demonstration on Friday 23 was attended by twelve of the fourteen invited, among them Dr. John Chisholm, Dr. Michael Neal, Dr. Jim Price, and Dr. Norris Hobson from the nearby Silsoe Research Institute, which I believe is an indication of the joint interest the equipment has created between the two Institutions. Dr. Roger Arnold, retired from S.R.I., was present also. Indicative of the interest in this project was the length of presentation and discussion which lasted some three and a half hours and continued support has been indicated in the letter of 27 August from Professor Godwin to Professor Woolhouse.

Due to staff vacations within the typing team the completed results of my testing were not available before departing Silsoe College.

My return to Australia was made via the United States with visits and/or discussions with:

1. Emeritus Professor W. Buchele at Ames, Iowa.
Discussions relating to the threshing concepts of my work at Silsoe resulted in great encouragement to continue the research and testing. Professor Buchele took me to the Nevada factory of Almaco where custom building of harvesters and associated machinery for seed growers and research workers has created a business employing 70 people. A visit was made to a machinery dealer and photographs of harvesting machines along with prices indicated that the big combines are currently selling at US$160,000. New concepts of tillage and crop production were also visited.

2. Professor N. Benevenga, University of Wisconsin, Madison.
Professor Benevenga introduced me to Dr. K. Skinner in Agricultural Engineering who suggested I contact Professor R. Allcock, University of South Dakota Agricultural Engineering Department, who is researching electrically driven tractors and machinery which has great application for future work with the harvester.

3. Miss D. Solum, Montana State University, Department of Plant and Soil Science, showed me the laboratory resilient tapered thresher which has been giving good service for 10 years. Mr. M. Solum wheat farmer near Rudyard, Montana gave me a copy of the magazine 'Farm Journal' which included an article on a new rotary thresher. This concept involves a rotating concave and rotating beaters built by two farmers to improve

the rotary threshers now available. This concept appeared far more complicated than necessary.

Conclusion:

The result of the work done and contact with research workers at Silsoe College and Silsoe Research Institute suggest more research is needed to obtain a basis from which a commercial prototype could be designed and built. The time needed for this will depend on the input mounted to obtain the required data, format, matching and eventual designs needed. Silsoe College interest has been covered in the letter from Professor Godwin to Professor Woolhouse of 27 August, 1991. The indications are that as soon as a suitable applicant and adequate sponsoring are available this work could begin at Silsoe College where the necessary facilities are available.

Acknowledgement:

I am most grateful to Luminis Pty. Ltd. and the Department of Industry Technology and Commerce for assistance and financial support for this project, and Hannaford Seedmaster Pty. Ltd. for their practical assistance in crating and shipping the machinery

I am grateful to Professor Godwin for the invitation to take the machine to the U.K. for further developmental work and I wish also to express my appreciation to everyone at Silsoe for their most willing co-operation and encouragement.

c.c: Professor H. Woolhouse, Waite Agricultural Research Institute
Dr. John Radcliffe, S.A. Department of Agriculture
Professor R.J. Godwin, Silsoe College
Mr. G. Nuske, Hannaford Seedmasters Pty. Ltd.

Encl.: Correspondence dated 27 August, 1991 to Professor Woolhouse

IAN G. RIDGWAY
26/9/91

Appendix 27: Cartoon

KONDININ GROUP
FARMING AHEAD