# THE AGRICULTURAL ENGINEER

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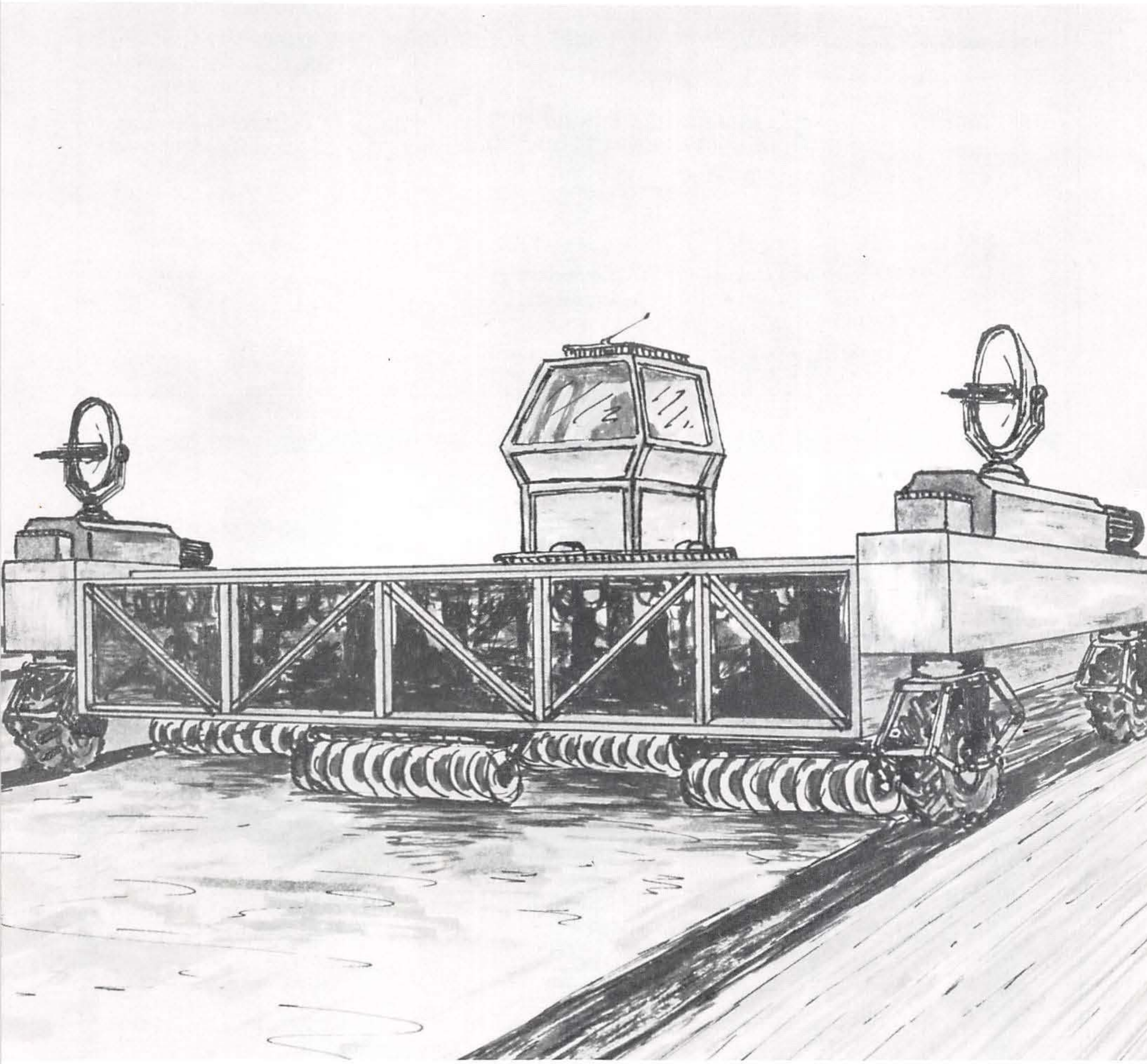

In this issue: AD 2000 — Survival and Success Engineering for Agriculture in the 21st Century

## INSTITUTION NATIONAL CONFERENCES 1980/81

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|---|---|---|
| 1980 Autumn | AGRICULTURAL MACHINERY MANUFACTURE IN DEVELOPING COUNTRIES | Tuesday, 14 October<br>National College of Agricultural Engineering, Silsoe, Bedford.<br>(South East Midlands Branch) |
| 1981 Spring | ENGINEERING IN HORTICULTURE | Tuesday, 17 March<br>Wye College, Ashford.<br>(London/Kent Branch) |
| 1981 Annual | ENGINEERING FOR BEEF PRODUCTION | Tuesday, 12 May<br>National Agricultural Centre, Stoneleigh |
| 1981 Autumn | ENGINEERING FOR INTENSIVE VEGETABLE CROP PRODUCTION | Tuesday, 13 October<br>(North Western Branch) |

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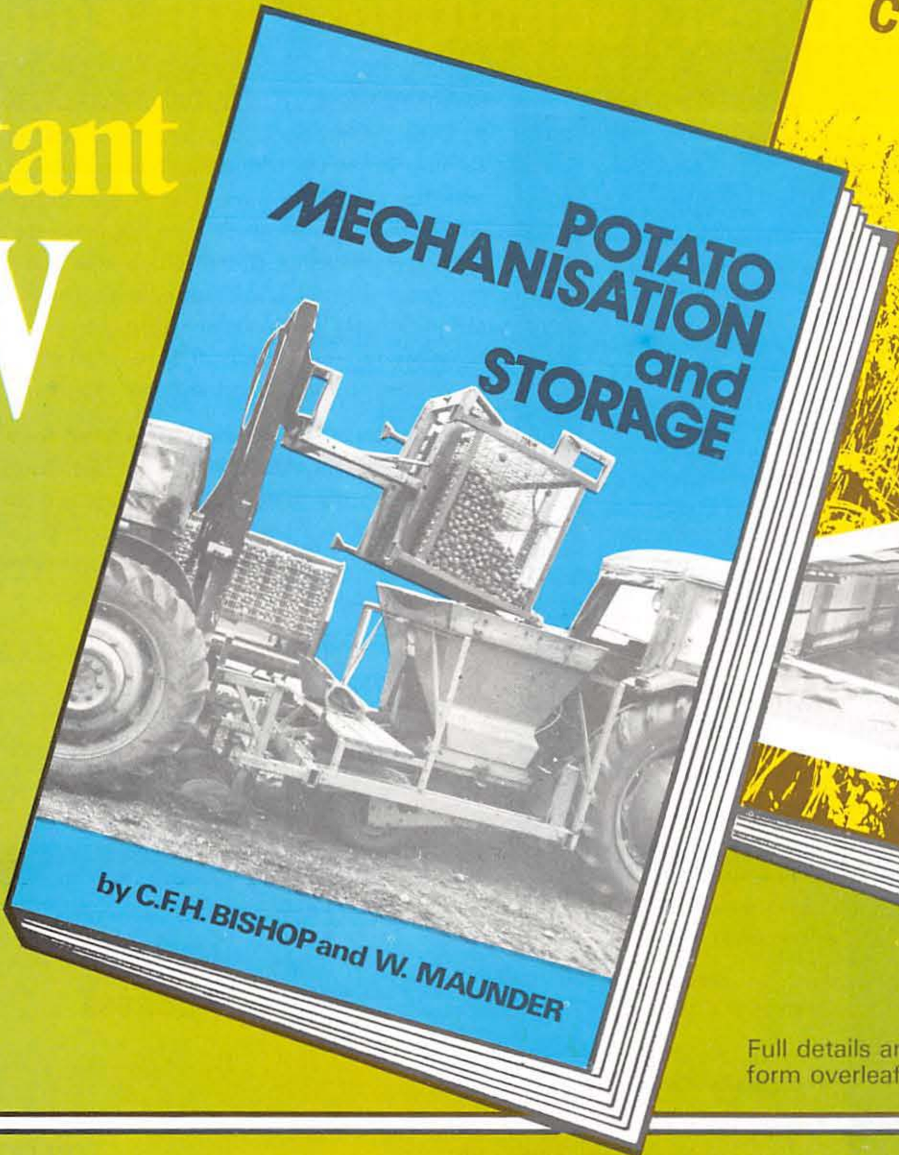


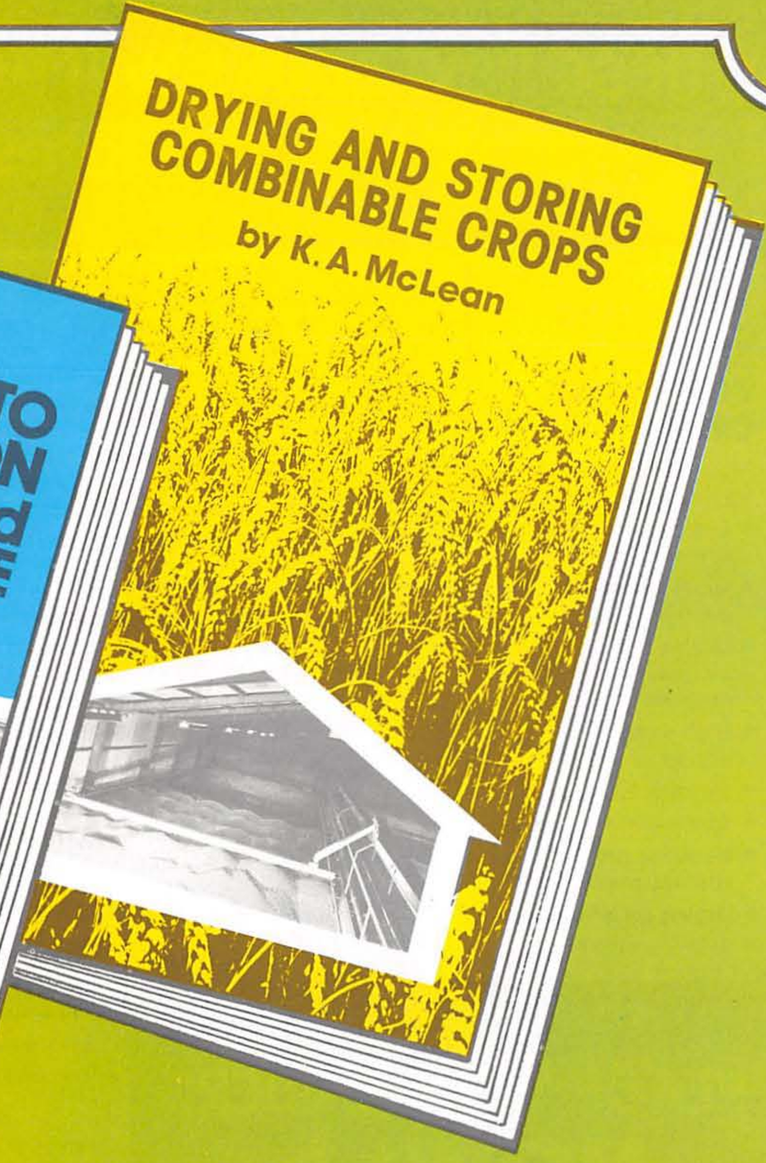


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## Contents



*Cover – Is this the tractor of the future?* *Turn to page 63 where the whole subject is discussed*

# A D 2000 ~ survival and success

## J C Turner

IT is with pride and humility that I have accepted the Presidency of the Institution of Agricultural Engineers. Although it is relatively young among the professional associations, our Institution has made massive advances in acquiring the techniques and stature which are necessary to promote and protect the position of agricultural engineering, with its many ramifications. Whilst not one of the largest industries, agricultural engineering serves the most vital industry of all.

Our previous Presidents have come from all branches of agricultural engineering and each, in his Presidential Address, has drawn from his own expertise to draw attention to some facet of the industry. As an educationist I will do the same. However, today's Conference provides a valued opportunity to comment on wider issues and indeed to discuss the future needs of the Institution and the changes which may have to be considered for our continued survival and success.

In its short life the Institution has had to adapt to survive: we have experienced two moves of headquarters, we have undergone one change of title, we have had numerous changes in the educational routes by which agricultural engineers qualify for the various grades of membership. In the early 1950's there was virtually no pattern of education in agricultural engineering; now there is a comprehensive range of courses, at all levels, covering subjects as diverse as soil and water engineering, design and manufacture and environmental control. As new needs have become evident our industry and the Institution have learnt new skills and processes. Our members have been pioneers in the application of technology and in harnessing nature's powers so that our fellow beings have been better clothed and fed.

In my opinion today's Conference papers show a variety of approaches to the technology of the future. However, the majority of predictions seem to be based on extrapolation. This approach is, of course, valuable but history shows that on some occasions a new graph is initiated rather than an old one continued. Improvements in horse breeding and sail making continued long after the introduction of power on the land and on the sea and, indeed, old fashioned methods were almost always initially superior to the new ones, so that these improvements to the old tided us over the transition period until the new technology became more efficient. Fundamental changes of this type occur at irregular intervals and it is not always possible to recognise readily when one is taking place. Such changes create a need for completely new types of skill, and consequently, education, training and certification must be of a radically different nature.

Today's Conference will be taking a hard look at technical possibilities and probabilities of the future and it is typical of the vision of the Convener that one of the papers is a composite one presented by a group, the members of which have comparatively speaking, only recently become established in the mainstream of their careers. These men will still be working in the year 2000; some of us will be fortunate to see it. I say fortunate because I believe that we carry the seeds of our own success or failure, happiness or unhappiness in ourselves. If we look forward with foreboding we will fail; if we are determined to triumph over our environment and meet its many challenges we will do so; although our paths may well have changed many times during our travels and our destination may be in a rather different direction from the one in which we set out. This fact is inevitable due not only to the accelerating pace of technology but also to the many social changes which sometimes assist and often oppose technological advance. Advance is an emotive word. If it means application of advanced technology, who is to say that mankind will be happier under the 'knife-edge' conditions that appertain in a heavily mechanised society? Whatever our course, there will be massive technological and social changes in the near future although some of the former may lie more in the fields of appropriate rather than advanced technology. How long can we justify a throwaway approach when many raw materials are in such short supply? Indeed the need for better wearing components was the subject of a recent paper to this Institution, presented by a Past President. The social changes may well be profound and necessary for us to live in a world which we can but dimly discern. Mankind has shown that it can cope with anything except excessive comfort and extreme wealth, but perhaps these will be out of reach due to shortages of raw materials and energy.

We, in education, must produce knowledgeable and able personnel at all levels but above all they must be adaptable for job mobility in the present, and for re-training for technologies — as yet unthought of — which are bound to occur in their working lives. We, the Institution, must recognise these needs in our membership requirements and in the support which we give to various education and training courses.

Agricultural education and, in consequence, agricultural engineering education has been in ferment during the last two decades. Whether this ferment will produce fine wines time alone will tell. Massive changes have occurred in the format of courses and the consequent examinations. Syllabuses are being continuously revised and more material added but one wonders sometimes whether the curriculum is not being overloaded by the addition of new material without the exclusion of the old. For instance, the introduction of the electronic calculator makes unnecessary the ability to carry out certain types of mathematical calculation; the complexity of modern materials eg alloys, plastics and spray chemicals means that it is almost impossible in courses of limited length, and for those with finite brains, to absorb more than their names, properties and applications. Fuller information on their manufacture and structure is really only for the specialist. We in education must ensure that subjects are covered in the most appropriate way, rather than in the traditional exhaustive manner, so that current technology can be applied efficiently.

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## AD 2000 survival and success

We need the continued help of industry, research and the advisory services to enable us to provide the type of education which is required. I am conscious that many people, including a substantial number of members of the Institution, give generously of their time in order to serve on various types of liaison and advisory committee; this is an appropriate time to express publicly the thanks of all the education service. However the rapid changes in technology, which are likely in the future, will make increased demands on the time and energy of all concerned. On behalf of my colleagues in education I ask for continued support in the knowledge that it will surely be given with the same goodwill as previously.

While agricultural engineering has in the past been concerned largely with the mechanisation of food production and, to some extent, with the production of raw materials such as cotton, perhaps the emphasis will change and we will be more heavily involved in the mechanised production and even processing of crops for the production of oils and materials for fermentation to gas or alcohol. We must ensure that those who are engaged in this type of work, who are suitably qualified and who wish to join our Institution are eligible to do so. By the same token, it is essential that engineers of proven competence who apply their skills to agricultural engineering are immediately eligible for a suitable grade of Institution recognition.

It is generally assumed that survival in the twenty-first century relies on the greater application of more advanced technology. I was delighted and fascinated by comments of a reverse nature in some of today's Conference papers. References to the re-invention of hand tools and the development of smaller manufacturing units are particularly interesting. Changes such as these may be necessary because of social and living pressures and the cost of transport. The latter is a technical matter but the former point has other connotations. When reading one of the papers — my mind, I confess, running on a parallel rather than a coincidental line — I scribbled the equation "mass production equals efficiency equals boredom equals industrial insanity". As engineers it seems to me that we have social as well as technical roles to play and we should be conscious of the possible results of our technological designs. It is important that the highest possible level of recruit is attracted to engineering, and particularly to agricultural engineering where it is probable that quite staggering changes will occur. For instance, how long can we afford live-stock farming with its very inefficient conversion of energy to meat and milk? Indeed, will farming in the soil survive? Will the concept of nutrient film technique spread to the production of most if not all food? These are changes possible in the long term only, but in the immediate future do we, the Institution, class fish farming as agriculture and the necessary equipment as the purview of the agricultural engineer? These are matters which we must continually bear in mind.

Success in an organisation is usually equated to numbers and size but in a world where fewer people can produce more, does this necessarily apply? The number of Institution members has not varied greatly in the past few years but will it stay the same in the future? It could fall to match the reduced number of people engaged in the industry; it could remain constant or it could even rise because the greater proportion will wish to enjoy the technical and other benefits and status which the Institution provides. The latter may well be important in the future if the pattern from other countries spreads to the UK and a "licence to practice" is required in a wider range of activities. It does not seem unreasonable that one should be assured of the proven competence of those entrusted, for instance, with a valuable machine for repair of the installation of a complex system.

The future will put pressures on the Institution and inevitably one of these will be finance. We must look closely at our procedures to maintain the cost effectiveness and the good housekeeping which is a feature of our Secretariat. However, we may need to examine our practices which could exclude from Institution service talented members who are unable to bear a substantial financial load, in addition to the gift of time, which our present procedures dictate. In addition, the Institution will be involved in expense if it is to continue to have a say, nationally, in matters affecting our profession.

Technical and social changes will put many pressures on all branches of the education service. Possibly the greatest need will be for a good general technical rather than a specialised education. Techniques and their applications will change, and a broad understanding of engineering science, together with the ability to undertake management duties, at all levels, will be needed to prepare agricultural engineers for the demands of the future. Improved opportunities must also be created for mature persons to acquire new types of knowledge and skill. Present re-training arrangements tend to concentrate on lower level courses which are admirable in their own sphere but may not provide for those of the managerial or innovative type.

The Institution, by selecting the theme for today's Conference "Agricultural Engineering in the year 2000 and onwards", has shown itself aware of the need for continued self-evaluation. The Conference will, I know, provide food for thought and I am confident that whatever the new problems and challenges the Institution meets in the future it will continue to face them, to solve them and to prosper as it does today.

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*Presented at The Allesley Hotel, Allesley, Coventry, Warwicks, on Tuesday 13 May 1980, by John C Turner F I Agr E, following his election as President of the Institution for the 1980/81 session.*

THERE being still 20 years to the year 2000, the 21st century may to many of us still appear a long way off. Twenty years, however, represents only half the length of a professional career, so half of the Institution's members will still be playing an active part in agricultural engineering, at least at the opening of the century. Moreover, machine development can take up to ten years in extreme cases, whilst the life span of marketing a product is generally from ten years upwards. When talking about mechanisation systems rather than individual machines, time scales are much longer. For example direct drilling has developed over a period from the first experimental work to the point where 20 years later it is an increasing, but to many, a somewhat "novel" trend. Again, we are told that the market for chisel ploughs is at long last beginning to show a downward trend although these implements were first introduced in today's form more than 20 years ago. Thus, for application in the 21st century, in many cases experimentation must start now.

This reminder of time scales may seem an adequate justification for the title of the 1980 Annual Conference. It would be wrong to think, however, that it was the only, or, even, the main justification. The idea, in fact, developed from much more imaginative thinking by the Executive Committee who reasoned that it was important that the Institution as a whole and, in particular, its younger members, discuss some of the longer term extrapolations of engineering and the associated sciences and technologies that make up the Institution membership. This should then enable a better course to be plotted in the intermediate years. It would permit shorter term development to be seen as being steps in the most appropriate direction, and longer term research programmes and centres of expertise to be developed to establish the necessary technologies which will be needed in 50 years time.

It must also be said that it was hoped that such a subject would be considered an attractive addition to the education of our engineers still in training, be they at post-graduate or at a more modest level. However, registration for the meeting from student members was disappointing, possibly due to the unfortunate choice of date so near to final examinations, so that in the later stages of planning this aim was largely dropped.

When covering several decades, neither strategies nor timetables are easy to foresee. The development of individual machines will often follow the invention of a new mechanism, the availability of a new material or the growing of a new crop. The best that could be anticipated from the conference therefore was to examine the influences that might affect the design of such future machinery, and to specify with some elaboration the mechanisation systems which might become realities. We attempted to first outline the need of agriculture for engineering and the opportunities provided by engineering developments which might permit new ideas in machine

# Engineering for agriculture in the 21st century

designs. The shape of the manufacturing industry and the techniques which it will use to design, test, or market equipment were reviewed and account taken of the social and economic factors in both developed and developing countries which will influence machinery needs.

After the scene had been set by the Conference Chairman, Professor J R O'Callaghan, the opening speaker J J North predicted the needs of the farmer in the next century. To do this he reviewed the probable external influences on farming and the farmer, featuring national and world markets, increased pressures to preserve the environment, and other social and economic matters. Two particularly severe challenges for engineers were the needs to provide for a predicted fourfold increase in the use of irrigation water, and the development of systems for growing fuel crops bearing in mind that at present the energy needed to grow, harvest and distil the fuel would exceed that produced.

The role of research and development in preparing for the next century was covered by Professor R L Bell who drew a picture of past achievements to extrapolate to the nature of potential improvements likely to be still available.

He emphasised that further advances would come both from the identification and solution of problems or constraints to increasing production, and also from exploiting those fields where an active research programme was likely to throw up new advances in technology. This paper also introduced the emphasis which ran through the engineering papers on the dominant part to be played in the future by data processing equipment. Dr Bell was followed by four younger authors who we hope will still be working in agricultural engineering in the 21st century. They were asked to let their imagination run on mechanisation and engineering systems which technology will permit in the next century, with the agreement that their ideas should not necessarily be confined to the fields within which they work at present. The imaginative ideas put forward were well received and such is the sophistication of audiences today that they could be seen by the majority to be serious possibilities although not necessarily economic at this time.

Ir F Coolman, Director of the Netherlands national agricultural engineering research institute contributed several valuable ideas on issues which will affect the future, not only in relation to views on the continent of Europe, but also from his long experience of work in developing countries. He considered that we must gain much more knowledge of the interactions between our machinery and either plant or soil materials, as a prelude to further improving performance. He also outlined the principles which should govern the design of equipment for satisfactory interaction with the human operator or with other workers. In mechanisation for developing countries he emphasised the need to take adequatee account of social factors particularly where mechanisation could significantly affect population employment or population aspirations. Finally, from his standpoint as Group Managing Director of a large manufacturing company, J C H Richman envisaged the establishment of a large number of smaller production units within a multi-national company as being the norm. This would follow from the rapid development of easy, effective, and economic communication via computers, video-phones and facsimile transmitters. He also raised the intriguing thought of many more materials for the construction of farm and other equipment being obtained from agricultural sources such as straw, this further stimulating demand for agricultural production should we reach food self-sufficiency, and also demanding new design and constructional techniques to employ the new characteristics.

The forum discussion varied between consideration of the principles which would apply in the 21st century, and the much shorter term thoughts on how the agricultural engineering industry is to thrive in the UK within the next few years. In the longer term considerations — although this might equally well apply in the shorter term — the matter of gainful employment of the population both in industrialised and developing countries was considered although it was emphasised that this needed to be coupled to a maintenance of correct economics. A "small is beautiful" policy was put forward by Prof T A Preston from Canada, but another speaker, keen to ensure the maintenance of adequate nutrition for the world's population pointed out that, whereas in China a farmer feeds 1.3 people, in the UK he feeds 48. The conference also dealt at some length with the matter of education of engineers for the future, and the nature of their career, a topic which time had prevented being included in the presented papers. It was emphasised by some speakers that interaction between the various branches of engineering application was very important and that a healthy industry might be one in which a proportion of the engineers come and go from other industries. Finally, the Chairman pointed out that whereas it was the industry's main concern to be successful over the next few years, it was important that we all understood that someone must have the responsibility to look further forward. The evolutionary process as we have experienced it in agricultural engineering is probably a satisfactory way forward, but a sufficient number of bright ideas obviously has to be seeded within the development structure if it is to retain its liveliness and an adequate degree of advance. It was thought that government supported teams had an important responsibility for looking ahead but it was certainly, in the author's view, correctly pointed out that the British farmer plays an important role as an inventor and that adequate attention should be given to the proper exploitation of his ideas.

# Agriculture's demands on the engineer in the next century

J J North

**Summary**

IT is envisaged that the total demand for food in the UK will only change marginally; a limited increase in agricultural production will occur toooon raise the level of self sufficiency and satisfy export markets.

Production units will continue to grow in size but at a relatively slow rate, whilst specialisation will continue. Economic pressures and the application of technology will result in improved yields. Energy availability and cost are likely to have a considerable influence on many aspects of farming, shortage or high prices will result in an increase in the use of legumes. The use of pesticides will be restricted because of environmental pressures demanding a reduction in the total active ingredients applied and increasing the need for precision in application.

Automation will play an increasing role in improving management and in increasing labour productivity.

IN order to predict what British agriculture will be like in the next century it is important to identify the factors which will affect changes and also the rate at which these changes will occur. At first sight this appears to be an impossible task and unlikely to be worthwhile, except that those responsible for investment in research and for major capital works are already making these judgements. The recent ACAH report "Water for Agriculture" Anon (1980) is a contemporary example of essential forward planning.

The future role of British agriculture and associated with this some guidance to changes in production on a medium term was considered in a recent Government White Paper "Farming and the Nation" Anon (1979). It concluded that changes in the demand for food by the consumer would involve a broadly stable protein requirement and a small reduction in carbohydrates. In commodity terms this represents an increased demand for beef, pork and poultry meat, fruit and vegetables and a reduced consumption of sugar and sugar based products, cereal based foods, mutton and lamb. It anticipated little change in the consumption of milk and milk products. Overall recent estimates predict only modest increases in the total volume of food required by the year 2000 in contrast to earlier estimates of about 25% increase, Edwards & Wibberley 1971.

This report also suggested that it makes sense to produce foodstuffs in this country in which we have a competitive edge either for home consumption or for export. Advantages of soil and climate where they exist, should be realised and also the proximity of a large consuming market for fresh produce. Developments throughout the world, both economic and political would also support the concept of selective increased production at consumption points, provided that economic advantage is maintained. In 1979 (Anon 1980) almost 71% of indigenous type foods consumed in the UK was home produced and 56% of all food.

**Self sufficiency 1977**

| | *UK* | *EEC* |
|---|---|---|
| *Cereals* | 67 | 82 |
| *Sugar* | 37 | 104 |
| *Potatoes* | 81 | 96 |
| *Fresh vegetables* | 75 | 92 |
| *Meat* | 82 | 96 |
| *Milk* | 68 | 108 |

*Source: "Farming and the Nation" MAFF (1979)*

These figures suggest scope for increasing the production of cereals to make good current deficiencies and to meet the increased demand for milk and meat; there are also opportunities for increasing sugar production and field vegetables. Membership of the EEC may constrain some of these developments. The challenge is to achieve these higher levels of output economically from a reducing area of farm land brought about by the demands for land outside agriculture. The recorded loss between 1971 and 1978 was about 50,000 ha/year (Carter and Sayce 1980). Farming must therefore be looking for improved crop yields, increased output per animal and, on all but the smallest farms, improved labour productivity.

The cost of capital and its availability will influence developments but in most individual farm situations the limiting resource is land. This precludes the option for most farmers of running lower input/lower output farming systems and maintaining incomes. The identification and uptake of new technology is of paramount importance.

Yields have increased substantially over the last 30 years, generally between 2 and 3%/ annum. About half of this improvement is achieved from the availability and use of improved genotypes in both animals and plants. These improvements are likely to continue well into the next century. The other 50% arises from the adoption of new technology, most of this being fossil energy dependent. The cost and availability of energy will have a significant and maybe an overriding effect on the future pattern of agriculture.

White (1979) identified four main areas of use of primary energy in UK agriculture. Petroleum and fertilisers are roughly equal and together equivalent to 50% whilst machinery and animal feedingstuff processing off the farm made up a further 25%.

As tractors and self-powered machines use almost half the petroleum fuels, economies in soil preparation and harvesting operations would seem desirable. Developments and adoption of reduced or zero-cultivations prior to planting are attractive and an increased uptake of these techniques can be expected.

Soil management has considerable influence on water availability and nutrient uptake and therefore on crop yields and although the movement of large masses of soil during cultivations may be precluded by energy considerations, subsoil cultivations and distribution of nutrients through the soil profile will be required.

Agriculture is largely concerned with making the best use of solar energy. Estimates of yields, based on available solar energy and taking into consideration the constraints of temperature, indicate a potential well above the current average (Gasser and Wilkinson 1978). Wheat grain yields of 12-14 tonnes/hectare, and maincrop

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potato yields exceeding 100 tonnes/hectare have already been achieved on individual fields in a particular year. To achieve these potentials, crops generally require a longer growing season. Extension at the beginning of the season to a limited extent can be achieved by seed treatment, but transplanting provides much larger increases. Crops will also grow for longer at the end of the season, providing a range of challenges to the engineer. Increased yields will result in smaller areas or reduced livestock numbers where demand for home produced products is satisfied. Potatoes, some fruit and some vegetable crops are contemporary examples.

Changes in structure of agriculture as denoted by the numbers and size distribution, the type and size of the farm business and the specialisation on certain enterprises are likely to continue. Change in this area has been and will continue to be slow; although technical and short term economic factors influence this, it is largely brought about by social, economic and political forces operating over much larger time scale.

and ensure more effective management. This increases the capital requirement. At the lower end of the scale businesses of borderline viability will lose ground and present social problems. Between these extremes "family farms" will strive to keep up with the leaders and should maintain productivity by use of appropriate technology.

If fossil fuel inputs as nitrogen fertiliser have to be restricted, this will have dramatic effects on the pattern of farming. Legumes may assume much greater importance, partly as a source of nitrogen and in part to provide more home produced protein for livestock feed. It is envisaged that existing legume crops will be grown rather than new ones.

The current use of pesticides is already under the scrutiny of environmentalists. Reduced inputs will be made possible by more efficient use including application techniques and greater use of integrated control. The concept of the 1960's of a weed, pest, disease free environment have long since passed.

Automation particularly in animal production will become increasingly important, reducing labour and

**Distribution of holdings smd**

| | *1965* | | *1979* |
|---|---|---|---|
| *smd* | 000 | *smd* | 000 |
| *Under 275* | 201.4 | *Under 250* | 131.3 |
| *275 – 599* | 96.4 | *250 – 499* | 50.4 |
| *600 – 1,199* | 66.6 | *500 – 999* | 45.5 |
| *Over 1,200* | 41.9 | *Over 1000* | 30.1 |
| *Total* | 406.3 | *Total* | 257.3 |

*Source: 1965 The Structure of Agriculture MAFF 1966*
*1979 Annual Review of Agriculture MAFF 1980*

The average size of holding will tend to increase, the holdings will become increasingly specialised, to optimise the use of specialist equipment and labour

management inputs. Electronic monitoring of animals would provide a basis for preventive medicines and reduce the inputs of "stockmanship". The efficient recycling of all animal and plant waste will figure prominently in farming systems. A major challenge to the engineer is the provision of facilities to carry out operations at the right time and with reliability. In large scale operations disturbance and failure to achieve this can have serious financial implications.

The ACAH report (1980) on water needs envisaged a possible fourfold increase in the use of water for irrigation of outdoor crops. On farm supply problems exist involving water transfer and storage, whilst application equipment requires considerable development to improve application efficiency and energy saving.

Finally, will farm crops be grown to produce fuel? The climate of the UK is ideal for the production of carbohydrate, a suitable substrate for distilling alcohols. At present in net energy terms the energy used in growing, harvesting and distilling would far exceed the energy available in the fuel. Perhaps an interesting challenge.

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# Research and development for the next century

R L Bell

**Summary**

A BRIEF historical survey of developments in agricultural engineering during the twentieth century is made with a view to deducing the time-scale of future innovation. Opportunities for improvements in existing processes are identified; developments which take advantage of these opportunities will provide the advances in agricultural mechanisation in the first part of the 21st century. For the longer term, research which addresses itself to gaps in basic knowledge is required; some of these gaps are at the boundaries between agricultural engineering and other disciplines, others the prime responsibility of the agricultural engineer.

## Introduction

AT first sight, the task of forecasting the situation which will appertain in agricultural engineering more than 100 years from now looks to be an impossible one. On the one hand, the political equilibrium of the world on which all else depends seems, at the most optimistic level, to be metastable. Hence, it is not possible to predict the economic conditions in which agriculture and agricultural engineering will be operating even in 50 years' time, let alone 100. On the other hand, it appears to many people that the pace of technological advance is ever quickening so that one cannot even guess what innovations will be feasible only 20 to 30 years ahead. Despite these difficulties, if we begin to define a little more carefully the actual problem that faces us as agricultural engineers we shall find that the solution is not quite so hard to obtain. Stimulating as it would be to speculate on those aspects of agricultural engineering that will be born a hundred years from now, the task before us at this time is surely not this. Rather do we need to ask the question: what research and development ought to undertaken now in order that the demands of the 21st century can be met as and when they arise?

### A twentieth century perspective

Before attempting to answer this question it is instructive to examine how agricultural engineering has developed over the past 80 years. During this period the agricultural industries of the developed world have undergone a transformation which is often referred to as the "green revolution". In terms of the magnitude of the changes that have taken place the transformation has indeed been remarkable, but in terms of the time period over which it has been spread the changes have been much more evolutionary than revolutionary. For example, there has been a rise amounting to about a factor of two in the overall crop production per hectare but this has

been spread over a 50 year span (see fig 1). The improvement in yields has been due to the use of better plant varieties, of chemical fertilisers and pesticides, and of better drainage, cultivation and harvesting procedures. Mechanisation has played a very important role but its adoption — like that of the new chemicals — has been a long drawn out process (see fig 2).

Tractors first became commercially available in the UK at the turn of the century; yet it was not until about 1960 that their numbers began to saturate. In a similar way, it took some 50 years for the combine harvester to achieve its full impact. Some other equipments were adopted a little more quickly but overall the general pattern was one whereby once a new piece of machinery had been produced commercially there was a slow build-up of sales over the first ten years until the new technique or practice it involved became firmly established. Numbers then increased more rapidly, but even so there often elapsed a further 20 or more years before the market saturated.

Now these protracted periods of adoption, taking anything from 30 to 60 years, did not include the research, design and development phases. The extent of these initial stages is less easy to specify because so many "new concepts" are found, on close examination to depend on previous knowledge and experience. However, it is easy to set a *lower limit* on the research and development phases of any important innovation at say ten years at the very least, so that the total time period from conception to full exploitation has been typically of order of half a century or more.

### A perspective for the twenty-first century

How far can this analysis of the past be used as a guide to the pace of things to come? Is the rate of technological innovation not increasing? So far as the second question is concerned, it appears that the rate of production of new inventions and devices is certainly increasing but that the capacity of industry and society to digest and use them fully is not increasing at anything like the same rate. This must surely be as true for agriculture as it is for other industries.

So far as developing a policy for research and development is concerned, we may safely conclude therefore that the new machines and techniques required in the early parts of the 21st century will be based on development possibilities that can be identified now. In the following section the opportunity areas for these developments will be explored.

For the longer term, there is only one way to proceed and this is to build up the intellectual capital, the basic knowledge, on which later developments can be founded. So, in the final section of this paper, there is an attempt to identify important gaps in knowledge which will need to be bridged so as to facilitate further developments during the second half of the 21st century.

## Developments for the first part of the twenty-first century

Highly efficient as our agricultural industry is, there is no doubt that competition will force it to become even more efficient in producing good quality produce at the most competitive prices. To meet this challenge the farmer will want to eliminate any waste in his inputs and to maximise the value of his outputs by good storage, distribution and marketing procedures. Superimposed on this requirement for ever increasing efficiency will be the need to respond to pressures from the environmental and welfare lobbies. To meet both types of requirement the farmer of the twenty-first century will have little choice but to make best use of improved materials, equipment and techniques. In providing these the agricultural engineer will have a major part to play.

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**Present limitations mean future opportunities**

In order to identify areas where engineering developments could improve efficiency it is useful to examine critically every kind of farming operation to see whether it could be improved. Let us examine the arable sector first:

On the input side, arable farming involves the following sequence of operations: cultivations, seed and fertiliser placement, spray application. Whichever one of these is examined, considerable scope for improvement is found:

(a) Cultivations, where 25% of the fuel used in agriculture is consumed, can be minimised under certain soil conditions or made more efficient by applying the work through the implement rather than in a straight draught mode via the tractor wheels. (b) Experiments on cereals suggest that seeding rates could be cut by a factor of four without loss of yield, whilst (c) Only 50% of the fertiliser applied is taken up by the plants. (d) The possible saving in spray materials is even more spectacular; in extreme cases the amount of active ingredient needed to control a pest is less than 1% of that considered necessary with present methods of application.

Now in all of the four cases mentioned above, it will prove easier said than done to achieve the maximum savings. However, here are attractive targets at which to aim new machinery developments.

On the output side of arable farming the processes include harvesting, grading, storage and transportation. Whilst there have been improvements made in all of these over the last 50 years, there is considerable scope for further innovation. To take just two examples: (a) Although the modern combine harvester has separator losses of only 1-2%, header losses may be much higher than this and field losses higher still, even running into tens of per cent under extreme conditions. Impressive as the modern combine is these possibilities of loss must remain a challenge, an opportunity for improvement — maybe via some completely new system of harvesting. (b) Post-harvesting losses occur all the way along the line until the produce reaches human or animal mouths. Whether the loss is due to degradation which is such as to render the commodity unfit for consumption or is due to a loss of quality, the outcome is the same, namely a loss of value. A balanced programme of research and development aimed at improving the economic efficiency of agriculture must pay due attention to the need to reduce post-harvesting losses still further.

Turning to livestock farming, it would not be difficult to draw up a whole catalogue of limitations set by current machinery and techniques; again these limitations present opportunities where research and development could lead to increased efficiency. Rather than making the point by listing all the possibilities, let us briefly examine the essential process that lies at the very heart of any livestock operation. This is the conversion of feedstuffs to live-weight gain. The optimisation of this process involves controlling the quality and quantity of the feed, and measuring the live-weight gain produced. In principle, nothing could be simpler but at the present time these two processes cannot be monitored and controlled fully because either the instruments required for measuring quality of feed are not available, or the means of weighing feed or animals are not easy or cheap enough to apply on the farm scale.

**Possible solution via new developments**

In seeking to indicate how the opportunities identified in the previous section might be exploited, it is convenient to deal separately with new ways of solving old problems, and traditional ways of solving new problems.

*On-line computers: Automatic control:* The most dramatic changes in agricultural mechanisation that will come about in the next 20 to 30 years will be those associated with the introduction of computers — "minis" and "micros" — built into the tractor, the combine, the grain drier, the dairy parlour and so on. These will be used to provide a measure of automatic control and/or data recording so as to enable the more efficient management of each operation. This is a case of new technology being harnessed to provide better solutions to old problems.

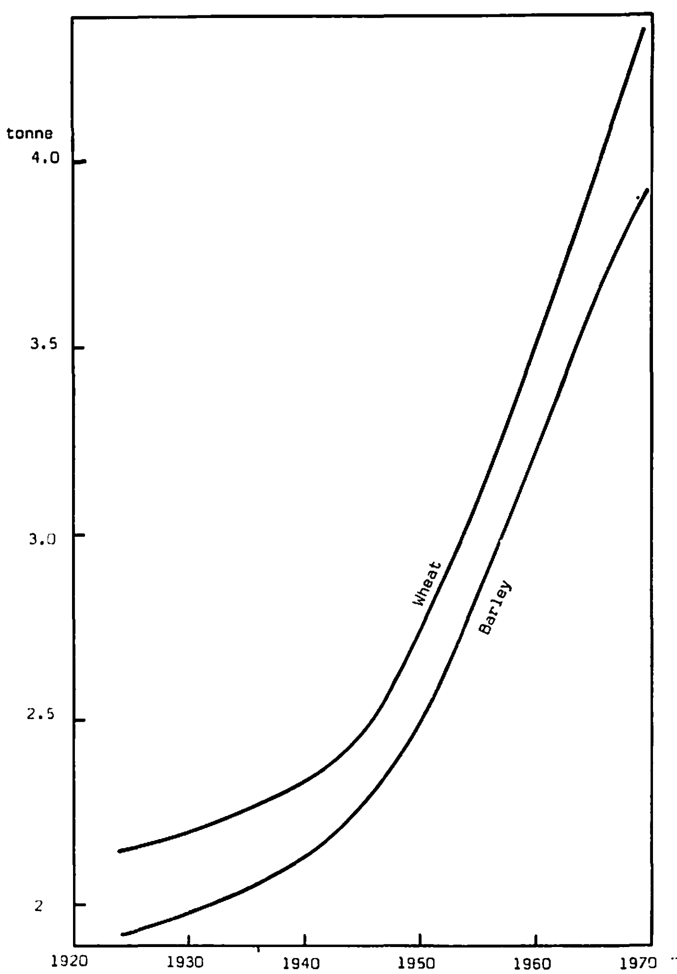
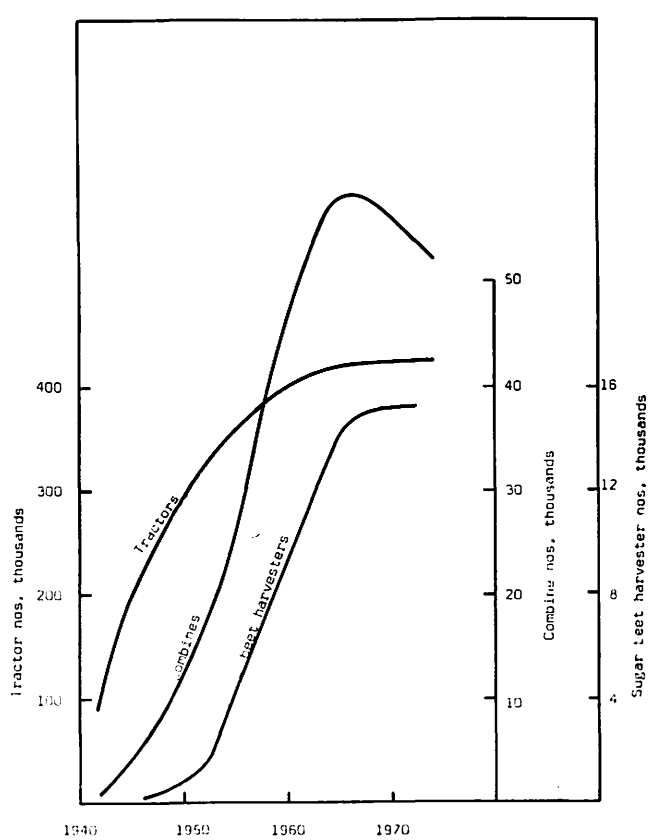



*Fig 1 (left) Crop production per hectare (England and Wales)*
*Fig 2 (below) Tractors, combines and sugar beet harvesters on farms (England and Wales).*



*Off-line use of computers:* The entry of computers into the farm office is already taking place. With the development of radio- and telephone-based information systems their present use for accounting and financial management purposes will be extended to include their use as an aid in making short-term marketing decisions. Or, with computers of somewhat greater capacity, there is the possibility of using them in the strategic planning of farms. For example, if a farmer is considering a re-shaping of his enterprise he will use a computer-based operational research model to help him select that combination of machinery and equipment which is most appropriate to the proposed new distribution of crops.

*Solutions via new or improved mechanical design:* Although the impact of electronics on agricultural engineering is new and therefore the more dramatic, the scope for improved mechanical design and for mechanical design solutions to newly identified problems remains exciting and just as rewarding. Even here the computer cannot be wholly excluded, however, because the techniques of "computer-aided design" present extra strings to the agricultural engineer's bow. Let us investigate the possibilities by looking at a few examples:

Many arable farming operations are limited by the vibrations to which men and machines are subjected when they travel at speed over bumpy ground. Drivers become fatigued; seed, fertiliser and spray distribution become imprecise. This is a well-known type of engineering problem for which some solutions are already available. A difficulty is to find solutions which meet the agricultural requirement at an appropriate price level. Typical of the exogenous developments which throw up new problems for the agricultural engineer is the whole area of zero-, and limited-cultivations. The introduction of the "direct drill" seems certain to spark off a whole series of new implements for seeding and light cultivations and the logical succession to the present range is a development of the tramline concept (via something like the Dowler gantry) or of a new range of lightweight vehicles and associated minimal-draught equipment.

In the area of livestock husbandry it is only within the last ten or 20 years that the agricultural engineer has begun to play a full part. There are still many repetitive and/or heavy and dirty operations from which the stockman could be relieved by ingenious mechanisation. These range from the delivery of the feed to the disposal of the waste and the harvesting, transport and slaughter of the animals.

## Research for the second part of the 21st century

Following the exploration of any new general concept it is necessary to focus on to a clearly defined set of conditions if realistic and rapid progress is to be made in devising a workable solution to a particular problem. At this stage one is concerned with design/development work which by its very nature is limited in the extent of its usefulness (viz. it provides, at best, a solution to a specific problem); development work is expensive too because the trial solution has to be perfected by rigorous testing under typical farm conditions. Another limitation is that the particular problem and the most appropriate means of solution may change over a period of years. In other words, both the specific problem and the chosen solution have to be considered in a particular time domain.

It follows from these arguments that development work — the perfecting of a solution to a highly specific problem — must be carried out relatively quickly if it is to be useful and cost-effective.

By contrast background research — the accumulation of useful knowledge — has a much longer "shelf-life" because it sets out to solve more general questions. Unfortunately, this kind of research has been criticised of late because some small part of it is not well-directed. However, such research must not be neglected because it is out of these basic studies that the most exciting innovations are likely to arise in the longer term. The question is how to identify those areas where the accumulation of basic knowledge now is likely to lead to the most important developments in the future?

At this point it is important to recognise that several of the most important innovations in agricultural engineering have stemmed from advances made in the sciences applied to agriculture. For example, the very requirement for the direct drill followed from the formulation of herbicides. The lesson to be learned from this is that agricultural engineers must ever be on the lookout for advances of this kind and be prepared to contribute their expertise at an early stage. The burgeoning field of biotechnology looks to be one that will yield many exciting opportunities for collaborative work.

In a similar way, it is important for agricultural engineers to keep abreast of new ideas and techniques becoming available in the physical sciences and in electronic, mechanical and civil engineering. Certain of the developments in these disciplines may require the investment of long-term effort on the part of agricultural engineers, in order to adapt the general principles to agricultural requirements. Two such areas that come to mind are ergonomics and solid state instrumentation.

But what are the "knowledge gaps" in agricultural engineering *per se?* Although agricultural engineering is essentially an amalgam of agriculture with the traditional branches of engineering, it has in recent years championed one or two disciplines of its own. Foremost among these is the study of the interaction of soils with cultivation implements. The ultimate objective of such studies is to enable the design of cultivation equipment to produce a specified result in any chosen soil. Unfortunately, the agronomist is not able to specify in quantitative terms the conditions required for optimum plant establishment and growth, so the engineer is working towards an ill-defined objective. The problem is also complicated by the extremely wide variations in soil-type and by the inhomogeneity of soils which can occur on a very localised scale. However, progress is being made and unless methods are found for by-passing the problem it will remain a major stumbling block to the design and operation of equipment and to the identification of factors limiting crop yield.

In an earlier section one of the most important of the "opportunity pull" areas identified was the application of spray chemicals. Here is a problem crying out for solution and some amelioration is already in hand. However, the problems and opportunities that remain are such that there is need for further basic studies of the physics, aerodynamics and biology of the different processes from drop formation, transfer and impact to translocation and physiological effects. Only when these fundamental physical and biological processes are better understood is the most effective and efficient use of spray chemicals likely to be achieved.

The selection of just two areas where there is a requirement for knowledge-oriented strategic work in agricultural engineering *per se* was not intended to give the impression that there are no others. However, the examples were deliberately limited in a number so as to give emphasis to the following two concluding remarks:

Firstly, since agricultural engineering is able to draw on so many other disciplines it is appropriate that the bulk of available research and development effort should be devoted to medium term problems/opportunities such as those listed previously. Secondly, that in allocating resources available for longer term strategic work serious consideration should be given to new opportunities arising through collaboration with biological scientists.

# Mechanisation opportunities likely to be provided by engineering in the 21st century

**W T C Chamen, T S Collins, R P Hoxey, A C Kight**

**Summary**

CONSIDERATION is given to the different areas and technologies from which advances could emerge, and pinpoints specific mechanisation opportunities.

Harvesting both of food and energy crops is discussed with the aim of simplifying procedures to improve efficiency. Electronic controls will be to the forefront of all systems together with improved reliability and new methods of energy transmission. An alternative method of field crop drying is proposed and the practice of double cropping suggested to provide winter fodder. Growing of energy crops on marginal land and the use of crop residue and animal waste could provide for all farm energy needs.

Crop production is envisaged with wide span gantries replacing the present design of tractor. The gantry it is suggested could be the medium through which many of the electronic and computer aided controls reach the field. As a system for carrying out all field operations it has great potential for the introduction of operational control, efficient cultural practices and reduced implement costs.

Further improvements in livestock production in the short term are likely to come about from a common efficiency level equal to the highest present levels. Computer technology will aid management systems while on farm milk analysers, automatic milking machines, heat detection/prediction methods and central milk collection points will improve overall efficiency. In the longer term alternative methods of milk production are considered with a national control matching supply and demand.

Farm management is considered in the light of growing computerised systems with microprocessors on most farm machinery monitoring and to some extent controlling operations via a farm computer. Connection of all farm computers to a national network will allow the individual farmer to manage his cropping for maximum profit. Weather as the only uncontrolled factor in the system will require continuous modifications to the management model.

Mechanisation opportunities however will be constrained by the future social and political climate and present interpretation of man's requirements may be far from his 21st century needs.

## Introduction

THIS paper speculates on a few possible mechanisation opportunities which might be applicable to agriculture in the 21st century. Its joint authors are not necessarily experts in the disciplines of agriculture and technology about which they write. Their objective is to stimulate thought and conversation by trying to project the state of present day technological development into the future.

How often have we said "if only it were possible to do things:— quicker, cheaper and with greater proficiency?" These are all requirements for the essential increases in agricultural production and profitability; our quest for solutions will to an increasing extent place demands on engineering. There are however many complex and often contradicting factors which affect optimum efficiency; the availability of capital, energy and manpower are all relevant in the agricultural environment.

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Previous conferences have considered efficient use of resources (Wilton, 1979), and if we are to succeed in the 21st century continuous appraisal and optimisation of mechanisation efficiency must be maintained.

Improvements in efficiency can be achieved either by simplification of existing procedures or by optimisation of performance. Procedural simplification can result from developments of new mechanisation concepts to eliminate inefficient practices. Minimal cultivations, larger machinery, improved buildings and the adoption of practices which are less susceptible to failure are all trends which will be continued. Performance optimisation will be achieved by technological developments, many of which will originate in other industries. Electronic innovations will without doubt contribute very significantly to machine and plant optimisation during imminent decades.

Advances in mechanical engineering such as improved energy transmission and materials technology are other aspects of progress which will play a significant role in future agricultural mechanisation.

Chemical and bacterial advances could well change the whole agricultural scene, and engineering expertise will be required to ensure that the full benefits are attained.

Today agriculture has one of the highest industrial accident rates, and therefore all mechanisation developments should make progress in bringing about improvements in this poor situation.

Some mechanisation opportunities will be provided by revolutionary ideas, but the majority of advances will result from new technology facilitating utilisation of previously impractical ideas.

Present day "accepted inadequacies" of machinery will be highlighted and rectified as technological advances provide alternative solutions. One such inadequacy is crop drying in the field which, by the 21st century, could be of greater importance, since many more field crops could be harvested for human consumption with appropriate processing technology. Mechanical advances have been made in developing machinery to hasten the drying rate of cut crops, but this is mainly effective during initial drying stages. Chemicals could well be developed to modify plant cell structure and thus improve drying rates at the latter stages. This could either be applied at the mowing-conditioning stage or later as the conditioning effects are beginning to reduce. Standing crop, deprived of a source of moisture will without doubt dry more quickly than cut crop. The introduction of machinery to apply treatments (Philipson, 1971) either chemical or physical, which are capable of creating drought conditions in the uncut crop could facilitate the possibility of natural drying of standing crops. Root stocks capable of enduring drought conditions would be required together with the ability of the "drought treatment" to be neutralised after cutting to maintain plant growth for further harvests. Engineering requirements would include pre- and post-harvest treatment application equipment, and harvesting machinery capable of processing dry material without losses. The obvious necessity for safety would be of utmost importance and hazards should be eliminated at the treatment development stage. New technological developments in physical subjects such as thermal, audio or electromagnetic radiation could be applied and thus create completely new concepts of crop de-hydration.

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*T S Collins*

*R P Hoxey*

*A C Knight*

Successful development of machinery capable of maintaining traction over wet land, especially during winter months, could completely change animal fodder harvesting policy. An alternative system for maintaining ruimant feedstuffs throughout the year is to grow crops which are capable of reaching maturity during winter months. With modern practices of housing animals during the winter it would therefore become necessary to harvest fodder crops throughout the year. An immediate advantage would be that double cropping could be practiced, with crops being grown on the same land in both summer and winter. Also the abolition of the present requirement to store winter feed would result in a saving of manpower and machinery in the summer and capital investment in storage facilities. However, suitable machinery would be required to harvest crops in all but severe snow conditions. Requirements for simplicity, to ensure minimal complication in unfavourable working conditions and the difficulty of maintaining traction without causing soil damage would lead to the development of lightweight field machinery, carrying out minimal operations with other crop processing being performed at a subsequent stage. This could either be at a stationary site at the field headland or, if transport conditions permit, at the farm.

## Harvesting

Today, as in the past, agricultural industry in the UK is striving to increase production. Political and economic factors will continue to affect production policies, and adjustments in agricultural objectives will be required to accommodate possible changes. It is therefore essential that policy and systems remain flexible. Crop harvesting has always created one of the peak activity periods in agriculture. Developments in harvesting systems are required to minimise susceptibility to adverse weather conditions and thus optimise harvesting performance and crop quality.

Energy provision could become a partial responsibility of agriculture. Efficiency of land utilisation would therefore become of even more importance to ensure that some energy production could be accommodated and yet food production maintained. The trend of farm specialisation will without doubt continue, and production of the various agricultural commodities will be concentrated in the most favourable areas to a greater extent than is the case today.

### Food harvesting

Increased production and profitability will result from achieving optimal conditions in the soil and crop, together with machinery systems which are capable of handling high yielding crops. Simplification of harvesting systems will contribute towards optimal efficiency; a consequential machinery requirement will be for reductions in the number of operations. Present day trends in forage conservation, such as the replacement of hay with silage and the more recent preliminary development of whole crop harvesting are typical of the continual changes occurring in agricultural systems. The present trend for large, high output machinery will without doubt continue; however the achievement of maximum size for UK conditions must be imminent. Machinery efficiency, both performance and reliability, will be improved with the introduction of electronic equipment. This will facilitate continuous automatic control of operational adjustments and hence optimal functional performance will be continuously maintained. Component malfunction identification and prediction will be possible, thus improving operational reliability and efficiency. One possibility is to fit individual electronic control equipment (today it is called a micro-processor) to each piece of machinery and establish modular simplicity. However, a multi-purpose central control unit incorporated in the implement carrier (futuristic tractor) and programmable for all implements and operations would surely be a favourable alternative. In this way standardisation of electronic components would be more readily achieved and hence maintenance requirements simplified, although interfaces between the control unit and implements would require rigorous standardisation, something which should perhaps be initiated in the near future.

Various operational parameters such as crop yield and condition, loss evaluation and fuel utilisation efficiency will be monitored, with the use of transducers fitted to the harvesting and power source machinery. It is obvious that careful design and operation of this type of sophisticated machinery will be required to ensure that it is completely durable in the arduous agricultural conditions.

Mechanical design will be improved to eliminate unreliable systems and components. Reductions in wear and increased durability will result from the introduction of presently unused materials. Components and mechanism strength will be increased and yet weight reduced to facilitate higher loading at greater speed. Technological advances will allow improved energy transmission; traditionally shafts have been used in machinery, but advances in electrical safety, improvements in hydraulic efficiency and the introduction of alternative energy transmission media will present the designer with far greater scope for innovation in machine layout and performance potential.

### Energy harvesting

Possible alternative energy sources have previously been highlighted (White, 1977); the success of most will depend upon engineering expertise and innovation. Capture of wind and sun energy is already possible to a limited extent; in the future this will become more efficient and combined with an energy storage facility could become a major piece of agricultural equipment. Today it is possible to store energy by pumping water to a higher level reservoir or some other such kinetic/potential energy conversion. However, machinery and plant economics for both pumping and ultimate conversion to useful energy do not permit this on a farm scale.

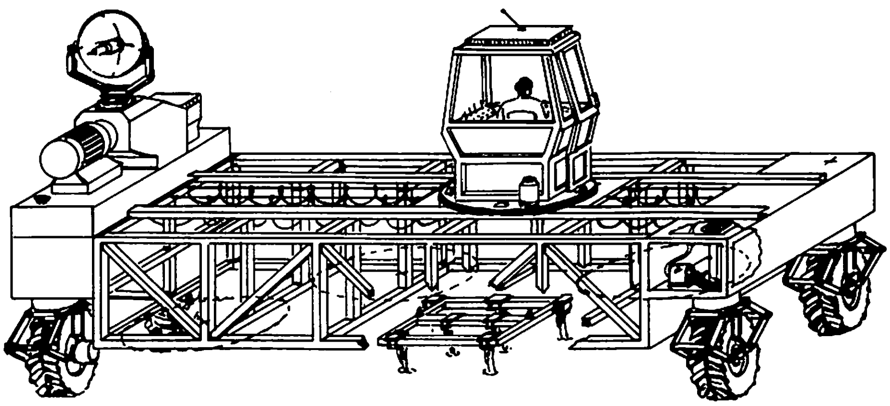


*Fig 1 Is this the tractor of the future?*

Previously it has been mentioned that alternative energy transmission media may be developed. This is not only applicable within machinery for replacement of shafts etc, but transmissions of electrical energy from "collector/generator" to storage and ultimately to machinery may be possible without cables and rails. Utilisation of the laser beam is already a possibility which is illustrated in the next section of this paper, fig 1.

Today, various nations are investigating biomass energy conversion programmes in an attempt to extend transport fuel supply by use of renewable resources (Brown, 1979). Due to under-production of food in the UK and the relatively low dry matter yields compared with tropical countries, it is unlikely to become viable in this country to devote agricultural land to energy crop production. However marginal land, unsuitable for food production, could be utilised for either siting equipment to capture solar and wind energy, or, with the introduction of suitable crops and associated harvesting machinery, production of energy crops may become viable.

Crop residue and animal waste are agricultural by-products which are beginning to be utilised as an energy source; engineering developments to minimise handling and processing costs combined with the increasing costs of other types of fuel will eventually make this energy source completely economically viable.

It is not impossible to envisage agricultural energy requirements being satisfied by farm produced energy; in fact, by the turn of the century, if technology permits, it could be possible that agriculture is at least self sufficient in energy requirements. Technological developments of an economic energy accumulator system will facilitate energy storage, and the introduction of new energy transmission concepts could result in complete changes from present day practices.

## Crop production

It is envisaged that in this area the emphasis will be on both the operators' and the machines' ability to monitor the task in hand and by the necessary responses provide the opportunity for improved crops and more efficient use of limited resources.

It seems unlikely that in 50 years from now the vagaries of the weather a month or so ahead will be significantly more predictable than they are at present (Hardy, 1979). Thus an improvement in efficiency must come about by a better use of the time available rather than a system based on long term weather prediction.

The system of crop production proposed in this section will bring together many ideas which are at the moment isolated, to form a flexible, simple and integrated whole capable of making use of the advantages of each. It could also prepare the way for many of the ideas put forward elsewhere in this paper, for example, all year round harvesting and computerised control.

**Nothing new**

The lessons to be learned from our forebears are many and varied and returning to the 1800's one finds that most "new ideas" have been tried before. These were the heydays of steam power on the land and conjure up the names of Fowler, Howard and Marshall to name but a few. Among these venerable gentlemen was one Lieutenant Peter Alexander Halkett RN who proposed a system very similar to that being put forward today (Halkett, 1855, 1858). Unfortunately it was at a time when such a far sighted idea could only flounder in the absence of sufficient technology to support it. Today, and in the future, this missing link will be available and when matched with present day terms such as "controlled traffic", "reduced compaction", "whole crop harvesting" and the "chip", the whole begins to gel into a mechanisation opportunity which we cannot afford to miss.

The basis of the crop production system proposed for the 21st century will be a variable height gantry spanning some 12 metres, with traction provided through four medium sized wheels capable of travel in any direction, but restricted to certain pathways in the field, fig 1.

**Detailed design and operation**

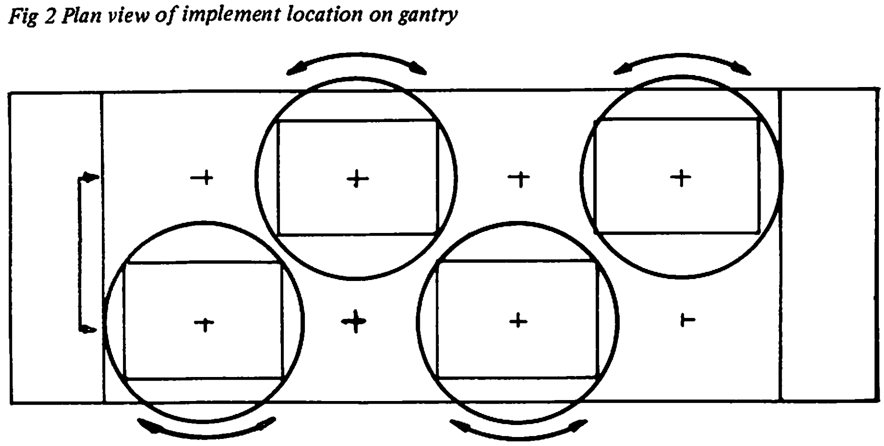
The gantry, which will be used as a means of carrying out all field operations on the farm, will be equipped with a power unit of 100-150 kW output plus associated hydraulics and electrics. Implements will be matched to the gantry in modular form and will be handled much in the same way as containers are today at container ports.

Four pick up points, fig 1 and 2, capable of 360° rotation as well as fore and aft movement, would incorporate the sort of latching features shown in fig 3. Scissor type lift on each wheel of the gantry will give overall depth control and provide an underframe clearance of two metres. Each wheel will have individual steering which will be linked through an on-board micro-computer so that different modes of steering can be selected with the computer acting as the track rod for any particular mode. Driving to and from fields will be achieved in the manner shown in fig 4 giving road widths of only about three metres.

To obtain the advantages of a controlled traffic regime, the gantry will only travel along pre-determined pathways in the field. This will be achieved using a guidance system rather than relying on the skill of the operator, whose main task will be to monitor and regulate the performance of the implement. This guidance will need to be sophisticated because with high draught operations it must not only keep the gantry going in the right direction but compensate for differential slip between the two sets of wheels.

As an example, if a shallow cultivation were the required operation, then the gantry would pick up the correct implement at the farmstead with the power and traction available this could probaby match the width of the gantry. The unit would then be driven to the field and "locked in" to the guidance system. At the end of a bout two options would be open, either to index sideways if the

*Fig 2 Plan view of implement location on gantry*



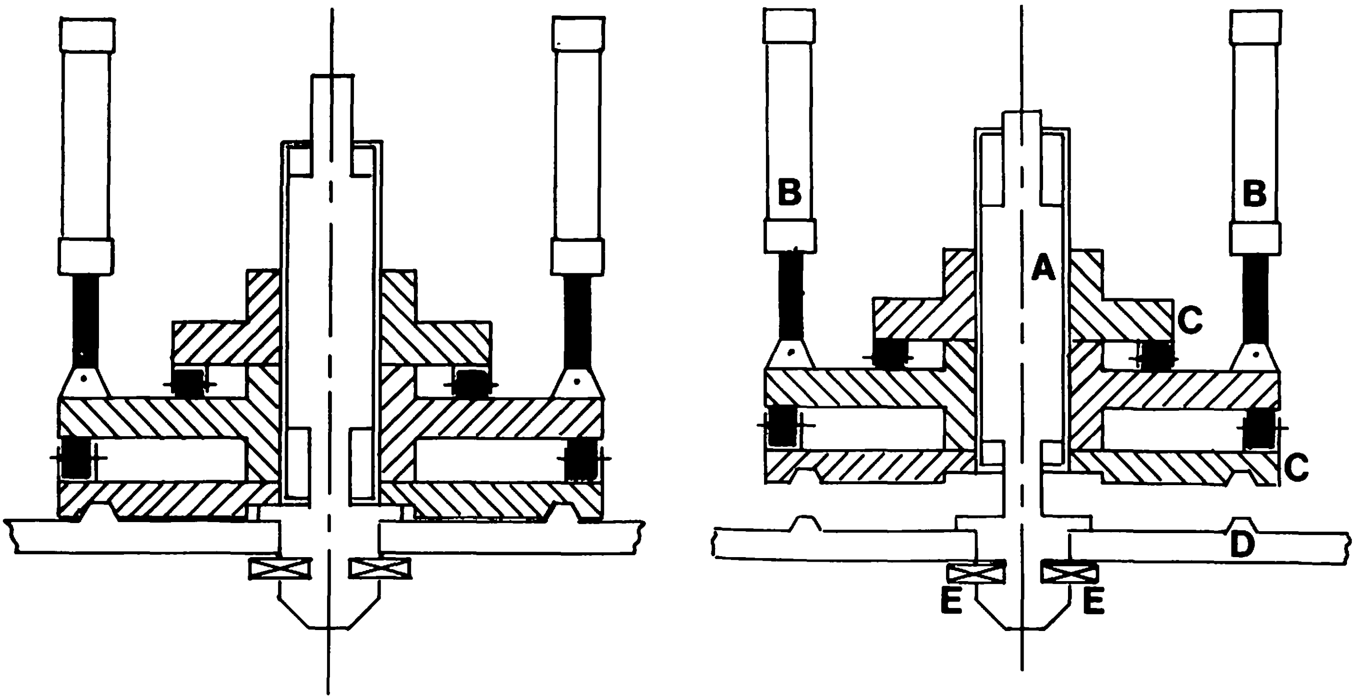


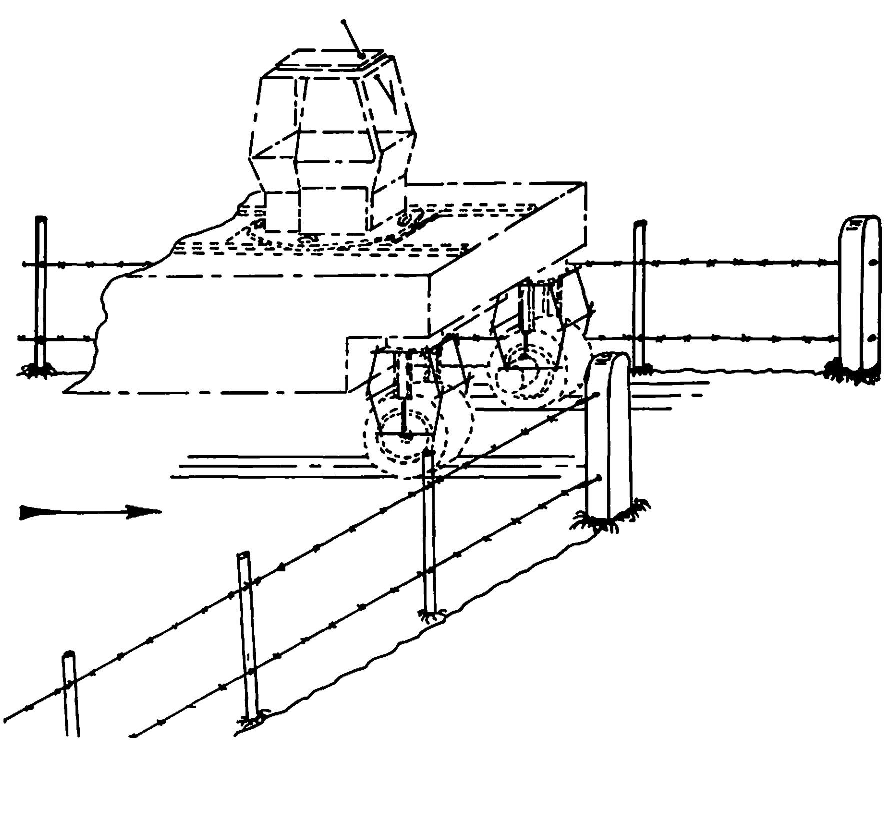

*Fig 3 Possible system for latching implements. A – latching ram; B – height control rams; C – rotating section; D – implement frame; E – solenoids*

implement is reversible, or to swing around one pair of wheels to the next position.

Irregularity of field shape would provide fewer problems than at present, since modular design would allow raising or shutting off of individual implements while reversibility would cut down on headland manoeuvring.

The problem of high draught operations (if they still exist in a controlled traffic regime!) such as subsoiling and ploughing could make use of an onboard winch system together with mobile anchors on the headland.

*Fig 4 Gantry in raised position travelling longitudinally*



**Potential for the system**

The ability to monitor and control operations will be considerably improved because the gantry acts more or less as a fixed datum. Thus the possibility exists for detector probes ahead of the gantry to monitor soil conditions, eg soil density, and for individual units on the gantry to respond to these changes by either loosening deeper or perhaps recompacting to a different degree. Similarly detectors could follow the soil profile and enable seed to be placed at a very precise depth. Operations such as fertilising and spraying could be completely automated and enable the operator to keep well away from toxic chemicals. Accurate matching of bouts with no boom bounce would reduce costs and, most important, work could proceed in a wider range of conditions. Mowing, tedding, turning and baling could be carried out with multiples of units to follow ground contours making full use of all the available power. Outputs could therefore be higher than at present while "big bales" could be transported by the gantry to the most convenient headland to await collection.

Gathering of cereal crops could also be achieved more efficiently and with less specialised equipment. The basic crop processing components of whatever width of combine is required could be latched in beneath the gantry in its high level position with plug-in hydraulics to provide the necessary drive. Temporary grain storage above the gantry would provide rapid off-loading at the headland by gravity. Forward speeds could be improved because, firstly, no steering would be necessary, secondly, the ground surface would be generally more level with no ruts and thirdly, the wide span of the wheels would practically eliminate rolling movements. Alternatively a cutterbar or forage harvester, matched with a container and a high speed transport vehicle at the headland, could be the basis of the system with fixed equipment at the farm supplying the necessary processing. The high speed transport vehicle would be an integral part of the farming system and unlike today would not be called upon to be a "Jack of all Trades".

The concept of self-propelled cultivators could become a far more viable proposition. At present this idea is faced with the problem of wheelmarks, or in the absence of wheels in obtaining a controlled forward motion. These two limitations would not be a problem with the gantry and one could arrange for powered rotors to match the draught from non-dynamic implements. These need not necessarily be one behind the other but side by side with the balancing forces transmitted through the gantry framework.

Harvesting of root crops could also be based on a unit system which could be picked up by the gantry with the necessary drives being coupled in. Damage to the soil in this situation would be minimal with the crop being brought to the headland for transport to the farm. In the other direction so to speak, slurry and farmyard manure could be dealt with in the same manner, the gantry picking up the spreading unit and container at the headland.

### Feasibility and cost

At present, gantries spanning some six metres are already in use in greenhouses (Sharp, 1979) while larger units for spraying and fertilising are about to become available commercially for use in the field (Dowler, 1979). Advances in control systems and structural engineering techniques all contribute to the feasibility of such a system and provide scale as the main problem. A possibility for detecting differential movement between each end of the gantry due to wheel slip could be an inertial system based on the laser gyro. For steering control, the gantry provides a more suitable environment for the operation of off-wire guidance. Detectors 12 metres apart could sense differences in field strength from a single wire at the edge of the field far more readily than those at the 2½ metre spacing of present tractors.

Rutting by the wheels could be a problem, but with spans of 12 metres or more the cost of prepared tracks over main drains, as proposed by Reece (1968), would not be completely out of the question. Where many stones are present in the soil these could be windrowed into specially prepared trenches at the required spacing across the field.

The total cost of the system is difficult to calculate because every implement and operation on the farm is affected and certain assumptions would have to be made. For example, the cost of individual implements could be reduced because no depth control system would be needed, frameworks could be modular and therefore lighter and the existing need to fold up wide implements would be eliminated because of the gantry's ability to move lengthways. Draught forces on cultivators would be reduced (evidence suggests by at least ten per cent (Perdok, 1979)) while the present highly expensive and specialised self-propelled combine harvester may no longer be a necessary evil.

Results from Dutch experiments (Perdok, 1979) with controlled traffic indicate that yield increases of up to ten per cent are possible even when 16.7% of the cropped land is lost to traffic lanes. With a gantry clear-spanning 12 metres on 0.5 metre wide tyres, the loss of land would only be four per cent. The potential advantages from such a system would seem considerable and backed up by the necessary engineering input, also a practical proposition.

## Livestock

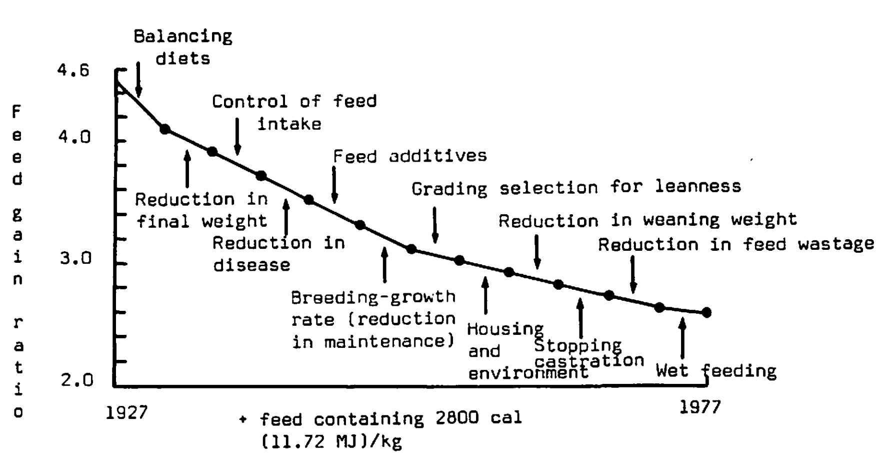
### Introduction

The last 40 years have seen remarkable changes in the efficiency of energy conversion in animals such as cows and pigs for the production of meat and/or milk. In the case of pigs, the efficiency of meat production (measured in terms of liveweight gain per unit of food consumed) has been improved by almost 100%. Similar trends have been shown in milk production from cows. The average yield per cow has increased by almost 50% during the period 1950-1975.

Most of the obvious factors restricting meat and milk production have been identified and methods developed to minimise their effect. Figure 5, for example, shows how some of the factors affecting the feed to liveweight gain ratio in pigs over the period 1927-1977 have been reduced (NIRD, 1978).

Such trends, however, have limits. Future improvements are likely to be less dramatic and will require more and more research to obtain. Even though such improvements are going to be harder to achieve, much can be done to improve national efficiency by improved herd management. Figure 6, for example, shows that only a small percentage (2.5%) of herds in the UK are achieving the highest milk yield possible (ADAS, 1977). Much can therefore be done to bring milk producers up to a common level of efficiency.

*Fig 5 Factors affecting the feed to liveweight gain ratio in pigs during 1927-1977*




When all possible steps have been taken to ensure efficient use of resources by each farmer, improvements can only be made by seeking alternative means of milk and meat production. This section of the paper will deal with the engineering opportunities in milk production.

### Improving efficiency of milk production

As stated earlier, the widespread use of improved husbandry techniques will ensure that the milk production from cows is kept at an optimum level. Advances in microprocessor technology will help to ensure that each herd is kept at peak milk producing efficiency by constantly monitoring the milk output of each cow and relating this to the food concentrate intake, with automatic feeding of concentrates based on the expected yield of individual cows. Work towards this end is already well advanced.

Access to economic computer programs through terminals on the farm will make it possible for a farmer to plan his herd management more logically by allowing him to examine the effect of varying his herd size or altering his management technique. In addition he can assess the effects on him of changing demands for milk and beef and look at the economics of, for example, varying the frequency of milking for any given set of circumstances.

An on-farm milk analysis system will ensure that minimal delay is caused if any cow is producing sub-standard milk. In this case the analyser can automatically alert the cowman and divert the reject milk to waste before it is mixed with that from the rest of the herd. The results from the on-farm analysis can be fed to a central computer for a region of the country to show that the milk has been accepted/rejected and allow collection to be suspended if necessary, thus avoiding waste of time and contamination of milk from other farms.

If this system were to become widely adopted, then central milk collection points could be set up, with several farms in an area feeding, by pipeline, a central bulk tank, from which regular collections would be made, thus eliminating the need for collections from remote farms.

Advances in automatic milking would allow milking machines to be automatically put on and taken off, the control perhaps being achieved by sensors on the cow's udder. With a milk analysis system the milk from each cow could be tested and the milking cycle automatically altered if necessary.

The use of computer aided diagnosis techniques could be usee by the farmer to draw conclusions from the milk analyser to enable him to pinpoint the cause of the milk failure and indicate a possible course of action. He could then decide on the economics of various treatments and hence the advisability of keeping the cow in his herd.

Improved heat detection/prediction methods can be used to make better use of the AI services. Also, the use of egg transplants as an addition to the AI

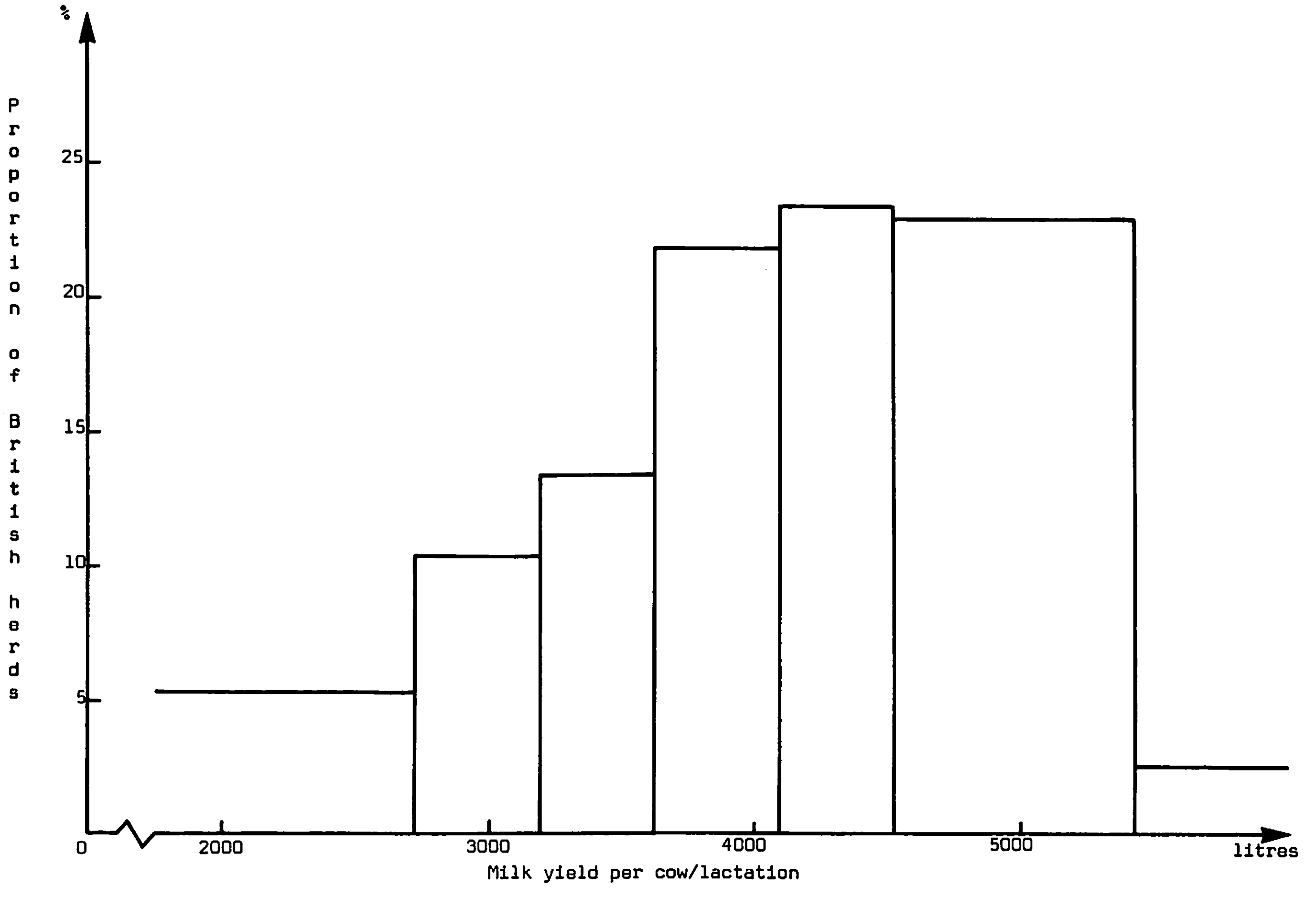



*Fig 6 A breakdown of milk yield per cow in UK herds*

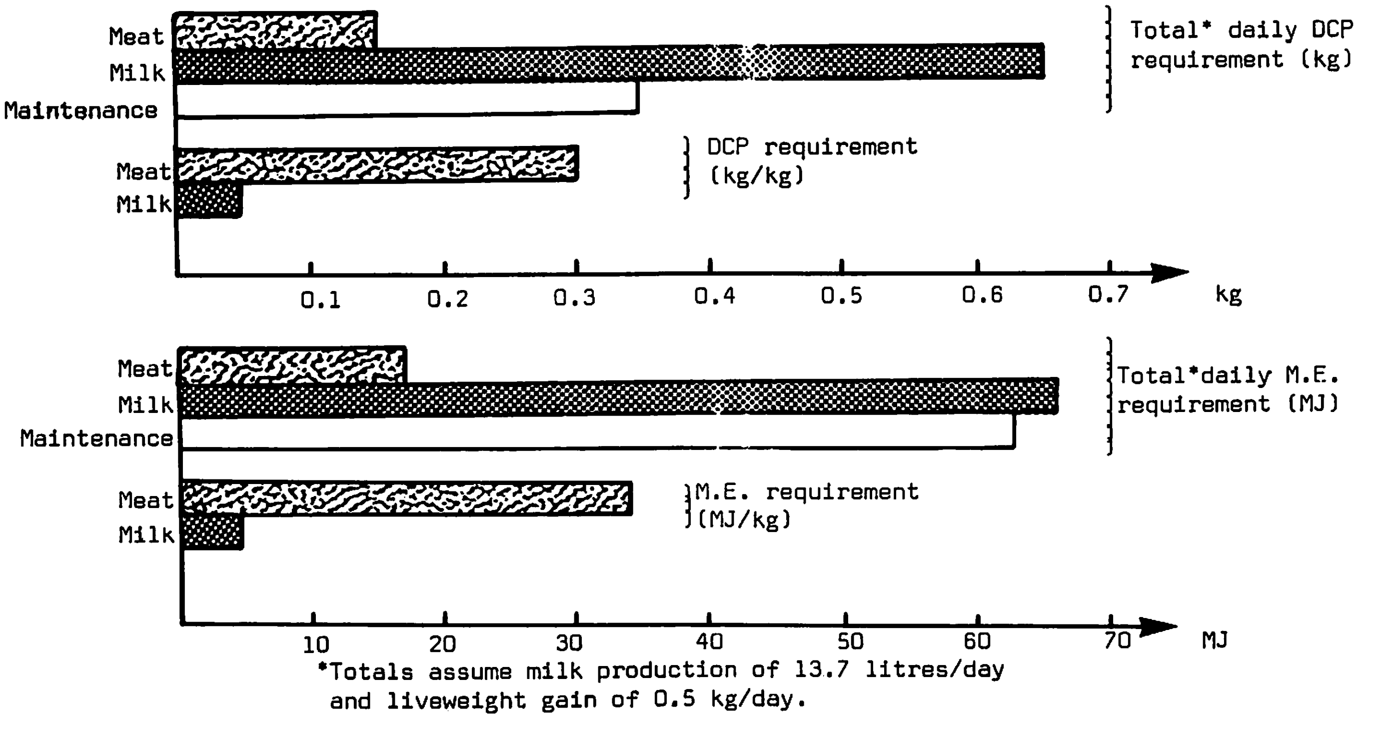
service can help in improving milk yield and meat production since some greater measure of control can be exercised over the oestrus cycle and the type of offspring produced.

Use of methods of artificially inducing heat can ensure that calving takes place at the most convenient times from the point of view of herd management, and the cow's milk production, thus allowing a steady level of milk and beef production to be achieved throughout the year.

**Alternative methods of milk production**

It has to be remembered that it is only as a result of scientific breeding and feeding techniques that cows can produce large quantities of milk. In addition, the biological necessity for a cow to bear calves, repair udder tissue and build up body reserves for the next lactation means that its milk production is halted for some 13% of the year (seven weeks on a 365 day calving index). This suggests

*Fig 7 Metabolisable energy (ME) and digestible crude protein (DCP) requirements for an Friesian cow of 600 kg liveweight*



that a more efficient method could be found.

Figure 7 shows the Metabolisable Energy (ME) and Digestible Crude Protein (DCP) requirements of an average Friesian cow (ADAS, 1977). It can be seen that the ME required to produce milk at 13.7 litres/day (the current national average yield) is far in excess of that needed to produce meat.

This prompts the question, could the cow be a better meat producing animal if it were not required to produce milk as well? Cows could then be devoted to the task of rearing calves for beef, making full use of egg transplants and "test tube" techniques for controlling the quality of the offspring produced.

The advantages of being able to make better use of the energy value of fodder and the reduction in total energy needed to build, equip and run milking parlours may mean that artificial milk could be produced more efficiently. In addition, it offers the opportunity of producing a milk substitute of the correct constituency to cater for infant and adult consumption based on requirements of nutritional quality and palatability.

With the introduction of artificial milk-producing plants comes the possibility of matching supply and demand more readily. Milk deliverers for example could order milk direct from the milk producing depots, thus avoiding over-production or shortages.

With milk production controlled nationally, a distribution system similar to that at present used by the Water Board would ensure that, if not each household, then a local distributor would be 'on tap' to a nearby milk factory.

Improvements in the storage techniques for milk will make it possible for a back-up supply of milk to be kept for times of emergency and also for export, and maintain quality of milk in pipelines.

The most likely opportunities for the engineer will (in the short term) be in the area of improving the efficiency of milk production from cows. The advantages of using artificial milk will, we think, only be realised in the absence of opposition to the traditional methods which are now firmly established and for which, we admit, we have considerable affection.

## Farm management

Over the last decade interest has been growing in computerised farm management systems and models. These computerised farm models have been used to optimise financial return, for example, in the case of an arable farmer, by comparing profitability of the various crops and husbandry methods. With the cost of computer hardware falling it will make possible and financially justifiable the provision of on-farm computers, not only as an accounting aid, but also as a planning and management aid. These aspects are likely to be exploited by the end of this centry and will form the components of an integrated computer system which will become a way of life in the next century.

Before exploring this concept in further detail, it is necessary to review the development of other digital computer systems that will be appearing on the farm, particularly the microprocessor dedicated systems which are already being developed for monitoring and control. By the end of the century most farm machinery will incorporate a microprocessor to monitor the performance of the machine and to carry out some, or possibly all, of the operator functions. It is unlikely that the operator will be replaced however because the development of sensors which could provide a micro-processor with all the information that human sensors can detect are unlikely to have been developed. Even if such sensors become available their cost is going to restrict their wide spread application before the middle or possibly the end of the next century. Furthermore, the human operator can also detect malfunctions and in many cases diagnose and find the fault and make the necessary repair without calling for assistance — even if the computer detects a fault in a machine it will be many decades before it can repair the fault without human assistance. A machine that stops when it detects the fault and requests human assistance can hardly be called automated.

The dedicated microprocessor will initially be developed as a controller and is likely to monitor parameters that are directly involved in the control process. The processor has far greater potential, especially when it can communicate with a central farm processor which has capacity to store information collected by the microprocessor. Information can then be collected over a season on the operation of a machine and be used in the management model to up-date the projected performance with the measured performance. This regular up-dating will improve the model which will result in more realistic prediction. The communication link would also make it possible for the central processor to alert the farmer when remote machinery requires attention. The communication channel is envisaged as a two way link and instructions from the central processor will modify the operation of a machine. Instructions can also be sent to the operator requesting changes to be made.

The flow of data between farm machines and farm computer is only one aspect of information collection required for a fully deterministic modelling approach. Information is also required on factors external to the farm, such as fertiliser costs and market prices of produce. It is envisaged that such information will be provided by national computer systems to which the farm computer will be connected. The farm computer will then be able to interrogate the national system for the information required and in return all farm computes will provide the national system with updated predictions of output.

Such a system is illustrated by examining the management of an arable farm in the year 2030. A national computer system will have been established and nearly every household in the country will have a video/audio link. The system will be used for communication — replacing the telephone, for information from data banks, for reading material — books and newspapers may be replaced, for carrying out financial transactions and ordering goods; the list is endless. The system will have become an accepted and welcomed way of life.

On the farm the new technology will have been developed to remove some of the uncertainties of farming. The farm computer connected to the national network determines before sowing the type and variety of crop to grow on each part of the farm. This information together with that for other farms will be processed and predictions madee of the likely production of each crop; the market price for each crop can then be eetimated and the information sent to the farm. An iteration of the process now takes place by the farm computer modifying the cropping programme to optimise profit and again this information is sent to the national computer network. The cycle is repeated until the projectted national demand meets projected supply and profit has been optimised in so doing. By this method all the control a farmer has on crop production can be taken into account leaving the only uncontrolled factor as the weather. It is unlikely that man will have resolved this problem within the next 50 years.

The weather must be considered as the most important influence on crop production that man does not have the ability to control and makes the model proposed not a fully deterministic one. Only a partial solution to this problem can be offered.

Throughout the growing season the crop performance will be monitored by sensors in the field measuring crop growth, soil conditions and climatic conditions. This information will be processed by the farm computer and the crop performance compared with the model used in the optimisation process. Climatic conditions are likely to perturbate the measured performance from the modelled forecast and variation can be included in the management model to update production forecasts. This information will be used to update the national forecasts and thereby adjust the expected production and financial return. The farm computer will be able to use this information to maximise profit by changing crop husbandry methods by such ways as irrigation or additional fertiliser. This procedure will continue and all operations in crop production will be determined by theeupdated model approach which takes into account the uncontrollable factors and determines future action based on crop response that is measured and not necessarily predicted.

Such a system of farming lends itself to full exploitation of the automated machinery which, as we have discussed, is also in communication with the farm computer. The ultimate automation will be a farm management system where the farm computer determines the action required and instructs machinery to carry out the work without the farmer being involved.

## Concluding remarks

In this paper only a limited number of ideas has been developed; the reality of the developments in the 21st century will be far more varied than it is possible to conceive at this time. Financial, social and political factors will influence the way that is chosen to develop agriculture and the engineer will be constrained by what is acceptable to the industry and the community in which we live. The demands on the farmer will also change; perhaps the next generation of farm worker will need to be skilled in electronics or computer programming.

This paper is entitled "Mechanisation Opportunities likely to be provided by Engineering in the 21st Century" and most engineers will interpret this as opportunities to relieve man of the burden of work. The choice of society may be to reject this approach; in that event the engineer may have to re-design or re-invent hand tools, but nowhere in the origins of man has work been proved to be necessary for his survival, except that which is in man's own indoctrination. In the next century this doctrine will have to be re-examined — the engineer, given resources, might change the way of life.

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## Summary

ENGINEERING has continued to play a vital part in the development of agriculture, particularly through the contribution of improving engineering materials, improved design, better power units and, more recently, electronic elements. Agricultural engineers need to study the potential offered by increased knowledge of the relationship between machines and the soil, plants or animals, while at the same time considering the machine operator's efficiency and welfare.

The bigger problems in the future may come from developing countries where energy will be particularly scarce and where the nations' economies will need to be improved by agricultural production for export. Assistance for these countries needs to integrate agricultural development, engineering development and adequate education.


TECHNICAL inventions play a very important role in agricultural developments. It started with better materials, new construction, and better engines. Hydraulic systems opened new possibilities. Electronics followed with automatic devices and, during the last decade, with aids for management. The agricultural engineer now has to cope with a new discipline, mainly concerned with software. Looking into the future, further applications may be found in the field of distance-control, wire-guidance and laser-beams.

A special example has just been shown at the Dutch machinery exhibition in Amsterdam. One of the Dutch manufacturers exhibited a completely new big baler, where the hydraulic compaction unit is controlled by the amount of material brought into the chamber and the density of the bale being formed. This is balancing out an irregular intake by automatic control of the compacting force.

Some other facts to be mentioned here are the more general relationship between machines, the soil, the product and the plant or the animal to be handled. The variation in physical properties creates the need for constant adaptation or regulation. Modern electronic aids are able to react in a very short time. This means that each apple, pear, or tomato can be handled individually. For dairy cows we are already well on the way; for sugar beet topping the same is true. What is quite often missing is a knowledge of the right parameter to be measured, the basis for the electronic equipment to react. Research and development is needed in this area.

Another aspect of technical development is the strong relationship between the work to be done and the man who is doing it. It started with the need to save labour. This caused new work organisation problems and went on to data collection and modelling. New software offers new possibilities. Cow-identification is a clear example of a technical advance leading to new management possibilities, not only automation in feeding concentrates, but also more information on production and variations in milk (body) temperature to support good decision making. Other aspects such as mastitis and body-weight control for dairy cows are under development, as well as the control of the total feed according to quality and quantity.

A special aspect in the field of labour is the human side of engineering. Better work positions started with better seats for grading, tractor and machine driving. It led on to safety-cabs with climate-control, and better positions for levers and indicators. From the physical facilities, technical innovations and developments contributed to mental aids. The worker's brain is released from some monotonous tasks in order to give opportunity for better attention to those points which still need it. Further developments may be expected: remote-control, monitors, indicators and perhaps view-data.

When mechanisation started, labour-saving was the main basis for improved economy. Still one can find this in labour intensive production areas such as greenhouses, preparation and packaging. Much of the agricultural production went over to larger scale operations. In this case a new aspect comes into the picture; enterprise-management including, of course, the total work organisation aspects. In many developed countries the fast rise of wages did pay for the investments needed for getting the lowest cost-price possible. Present comparisons show that if we grew potatoes in the way we did in the Netherlands around 1960, the cost-price would be about 150% of what it is today. The same is true for milk, wheat and sugar beet. Of course the situation varies in different countries. The big family farms in the United States of America have a much lower input of labour and machine costs per unit of produce than in the Federal Republic of Germany and the Netherlands. This is due to farm sizes and also to the value of the land and the cost-price of other input

# Agricultural engineering in the 21st century – an overseas view

**F Coolman**

factors. But in nearly all the developed countries we can see a clear move to less labour and more investment in technical aids per unit of production. The rise in yield per hectare or per cow has also played a very important role in keeping the cost-price as low as possible.

Development of new techniques in horticulture show a spectacular picture. Already quite a number of crops can be and are grown on sub-strates in greenhouses. This offers the possibility of controlling not only the climate inside the greenhouse, but also the temperature in the root-zone. Plant nutrition is completely under control. New varieties have been bred in order to raise the production per unit of input and per unit of energy. These techniques show that there are still many possibilities to work on. We can dismiss the traditional assumption of high production levels only being possible on good soils close to concentrated population areas.

These pictures of improved economy must also be looked at in future in relation to the scarcity of energy. All over the world one is looking for savings and alternatives: methane gas from manure is already close to the economic break-even point or has in some cases even passed it. Experiments with solar heat recovery are widely done and are showing, in such-rich countries, promising prospects. Wind-energy seems somewhat further away, even in the windmill country, Holland. But the higher the cost of fossil energy, the closer the break-even points are coming. One is thinking also of simple power plants, based on water level differences in flat countries. Finally, thermal heat from Mother Earth is a subject of research and development. For the future we may expect quite a number of new applications which will change farming patterns and methods.

A discussion of energy would not be complete if there were no mention of the use of waste material and biomass production. Biogas from manure has already been mentioned but there are more possibilities. The first inventions are with us to use straw, stems, leaves and cobs of maize and sawmill by-products. In developing countries power plants based on wood waste are being studied. Overviewing the total amount of waste in agriculture, we can state that quite a lot of energy is wasted or brought back into the soil where it has its useful function in improving soil fertility. It is mainly a question of economics to apply those waste products in another way.

Biomass production is advancing. Fast growing wood varieties are developed, but we still need 15-20 years to produce a reasonable amount of organic matter under good growing conditions. Moreover fresh material is not always suitable for direct use, but it will be worthwhile to pay attention to these future possibilities. The fact is that we will never succeed in replacing in 15 or 20 years the conversion of organic matter to oil or coal which took perhaps millions of years somewhere down in our earth. New technologies however can fill these gaps in part.

Up to now we have mainly considered agriculture in developed countries, but we must remember that the biggest problem of agricultural production is in developing countries with a very low or a medium level of technology. The developed world is producing enough agricultural produce to meet demands for food, clothing and domestic products. In those countries we are thinking of biomass production for delivering energy to the non-agricultural part of the population. In the developing countries, however, we have to take care not only of better supply of agricultural products for the population, but also to start production with export possibilities. This is necessary in order to reach the position where these countries can buy products on the world-market, mostly coming from countries with hard currency. Improving agriculture can and will contribute a lot to the national balance, but every production level goes hand in hand with the mental capacity of those who are carrying out the production. This is the main reason why developments have to go step by step. Every technological step introduced when the educational level is not able to handle it, will have little success. Many examples in the past have shown this. One of the tasks of agricultural engineering in future will be to educate and train skilled practical people who are able to handle new technologies. In particular, they must be able to uphold and continue any progress which has been initiated by consultants and specialist advisers. Unfortunately, at present the consultants concerned often do more than the workers can cope with. When the consultants leave after their mission they sometimes leave an educational vacuum. One of the remedies is of course training and education in developing countries, but again we have to remember that they will need a considerable time to catch up.

Special attention should be given to activities from industries, commercial contracts and other private enterprises, which are introducing new technologies in those countries. They are the most direct contacts quite often under Western direction. This type of co-operation can be a very favourable one, but has to be handled carefully. Firstly in an independent country with political difficulties, and which therefore may not be as stable as western countries, it will be very difficult to create the stability necessary for a continuous production on a reasonable technical level. Secondly one has to keep in mind that the human being over there has a right to his own way of life, which is the basis of motivation.

Thirdly, our responsibility towards people has also a mental aspect. If for one reason or another the commercial contract is broken, the inhabitants of the developing countries concerned should be able to continue all the lines brought by the common activity. If we leave them poor we did not do our task in the right way. This is not only in the interest of developing countries, but also in the interest of the developed countries when they want to sell their products to the countries which are at this moment not able to pay for them. We have to prevent the gap between these two types of countries becoming bigger and bigger. Simple ways of developing agriculture are the most important way to reach this goal.

Agricultural engineering has a great responsibility in attaining this worldwide and peaceful objective.

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# The challenge of the next century–an industry view


## J C H Richman



**Summary**

A personal view is given of the opportunities likely to be open to the world in the 21st century. The pressures of population, raw material availability and technology are investigated to propose a world approach to industry with small production units scattered throughout the world, controlled by multinational organisations using new communication techniques.

It is suggested that raw materials to replace traditional resources are likely to come from agricultural products, stimulating demand for agricultural machinery and introducing new techniques in the use of synthetic materials.

The motivation of the successor to the Consumer Age might be to provide the maximum number of people throughout the world with a newly recognised minimum standard of living and time to enjoy recreational activity.


THE title of the paper is something of a misnomer as industry does not have a view of the next century. It is far too busy trying to cope with the challenges of this century to feel the need to look at those of the next. Industry will always argue that its function is to be pragmatic and respond to current pressures; to make profit and not to waste resources trying to see where there is no light.

Let us remember that looking forward from 1980 to the middle of the 21st century is the same in years as looking back to 1910. Consider the great changes which have taken place since then and contemplate the increasing rate of change which we have experienced during the 20th century. It is an impossible task to forecast so far ahead with any hope of being right.

This paper must, therefore, be my personal view, involved as I am in industry. Because it is a personal view, I feel no responsibility to my colleagues and I have allowed myself to view the future with my own cheerful optimism. I feel that this is justified by the proven ability of people to solve problems which face them and eventually to make improvements. In the past we have progressively improved our lot although progress has often been lost for short periods. I see no reason why this long term trend should not continue although, in the short term, some of the facts might encourage a contrary view.

It is necessary to consider life in general in the 21st century before arriving at economic and technical theories. Industry is the result of the pressures of life and their economics; it cannot operate in a vacuum.

For this reason I take a broad look at the life and times of the 21st century in order to conjecture how industry might develop within that context.

First, consider some of the major factors which will affect our lives in the 21st century. These can be summarised as follows:—

1. World population and its government.
2. Raw material and power availability.
3. Technological development.

World population is changing and will change at an increasing rate during the 21st century. The World Bank population growth analysis shows a slowing down of population growth throughout the world, but with the developed countries being the first to show population decline. This brings a change in population profile in developed countries with an increasing proportion of old and retired people and a reducing proportion of young and working people.

The undeveloped countries of the world are likely to continue population growth right through the 21st century with a consequent increase in the proportion of young people wanting to work. Their population growths will add to the already enormous pressure on the resources available to feed, house and employ them.

As these trends continue the currently unacceptable world levels of absolute poverty will only slowly improve. Absolute poverty by World Bank definition means those people who are starving. Not just that they are poor, but that they suffer from malnutrition diseases, infant mortality and reduced life expectancy. The numbers are so large that they are difficult to comprehend but they will become an increasingly important factor in world affairs, particularly as the world's population profile changes and world communication improves. At the beginning of the 21st century there will be 600 million starving people in the world, and we will all be well informed about each other.

This trend towards a reducing and

**World population growth rate levels**

| *Growth Rates 1970 – 1977* | *Number of countries* | *Population mid-1977 millions* | *GNP 1977 US $000m* | *1977 av GNP per capita US $* |
|---|---|---|---|---|
| *Less than 1.0%* | 37 | 920 | 5095 | 5540 |
| *1.0% to less than 2.0%* | 41 | 1362 | 1728 | 1270 |
| *2.0% to less than 2.5%* | 27 | 928 | 195 | 210 |
| *2.5% to less than 3.0%* | 39 | 565 | 454 | 800 |
| *3.0% and over* | 34 | 271 | 308 | 1140 |

**Projected levels of absolute poverty 1975 – 2000**

| | *Number in millions* | | | *% of total population* | | |
|---|---|---|---|---|---|---|
| | *1975* | *1985* | *2000* | *1975* | *1985* | *2000* |
| *Low income countries* | 630 | 575 | 540 | 52% | 39% | 27% |
| *Middle income countries* | 140 | 140 | 60 | 16% | 12% | 4% |
| *All developing countries* | 770 | 715 | 600 | 37% | 27% | 17% |


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ageing populion in the developed countries and an increasing population of young, poor people in the developing countries of the world will have a major affect on the politics of the world. I hope that by the early years of the 21st century we will have been forced to look at world problems as a whole. The competition of different political systems will become less important than the competition between the "haves" and the "have nots". If we can reach the 21st century without national crises having destroyed us, then there is a good chance that the people of the world will work together to solve the world's problems.

We are constantly reminded that the fuel we need to power our industry is fast running out. Fossil fuels have a finite life and will become more expensive as they reach the end of that life. This situation is well known to us all and we appreciate that at present usage levels our total fossil fuel resources might not last another 150 years. Fuel price will relate to its availability, our need for it and to the pressures created in the developing countries who largely supply it.

There is also a less well known problem, with the world supply of raw materials at present used by industry. J V Fox in his paper to the last Annual Conference of this Institution reminded us that whilst known reserves of iron ore are equivalent to over 200 years usage at present rates, other metals used to produce alloys, are likely to run out much earlier. It is probable that before the end of the 21st century all the raw materials used by industry for its products and power will become increasingly scarce and more expensive.

However, think of the technological changes which have occurred since 1910 and consider what technology might do for us by 2050. Surely we can solve the raw material problems with some of the techniques we see about us now? Atomic energy and hydrogen fuels seem near and plastics materials could replace metals if we could produce them from base materials other than oil. In my optimistic mood I am sure that technology will solve the problems and give us the replacement fuel and raw materials we need; but in the time scale we are contemplating they are still likely to become disproportionately expensive.

Technology will also have its effect on other parts of the industrial world. Mass manufacturing processes and administration and control functions will become more automated. Unit production costs are likely to increase because of increased material costs and large capital investment producing reduced quantities. In developed economies, there will be fewer people available to work and automation will be necessary to replace them. The problem of automation creating unemployment is likely to disappear as the population profile changes.

What effects are all these pressures likely to have on industry and the way we will work in it during the 21st century? The dangers in meeting the pressures will occur during the early years and I happily assume we will overcome them to reach the "World Age" of the 21st century. The 22nd century will truly be the "Space Age" but perhaps that is a subject for a meeting of this Institution in the year 2080.

The 20th century saw the "Consumer Age". It started mid 19th century and will soon be over. The motivation of this period was to create a need for material things which could be produced at a profit. The more things which could be supplied the better, even though their supply and use was wasteful in resource and perhaps in the quality of life. Things were only produced for those who wanted them and could afford them. People were motivated to consume more than they needed to prove their success.

We are already unable to continue wastefully using our expensive resources and we will have to find a way of supplying people with the essentials they need but possibly cannot afford. Transport of people and goods may become very expensive during the period we are considering but communication will improve so that a world view will develop on what is essential and how it may be obtained. The results of this might be far reaching as we may discover quite different essentials when the pressures of the Consumer Age are removed.

A major requirement which the world must meet will be an increase in agricultural production both to remove starvation and to provide raw materials. During the 21st century I do not see factory operated artificial chlorophyl doing the work of plants; that is even further into the future. But during our period I do see existing crops, and new ones, grown to provide fuel and the base materials for the chemicals we will use to synthesise the materials we need.

Equipment to help produce these increased agricultural products will be high on our world requirement list. And their technical scope will be wide as we will have to utilise intensively a large area of the world's surface to produce what we need. Our industry may well prove to be one of the more important activities of the 21st century.

Because of improved world communication the world's problems will tend to be viewed on a world wide scale. Increased transport costs and political pressures will cause things to be manufactured near to where they are required and in smaller production units than at present. The developed countries of the world will become relatively less important areas of demand and will produce less goods but will provide more services on a world wide basis. Production units will tend to be concentrated in the, at present, undeveloped countries who will have higher demand due to their increasing and younger populations at a lower economic starting point.

These smaller factories operating all over the world are likely to be controlled by multinational companies who will be required to provide the know-how and capital to start and control the operations. Developing countries will first finance their own demands with the rapidly escalating price of the traditional raw materials they have. This will gradually be replaced by their own production of goods and also by the new agricultural production which must find its way to the open spaces of the less developed countries of the world.

On the time scale we are considering the development of crops to produce alcohol, starch and protein must be important. We are already seeing maize, sugar and manioc used for these purposes. In principle all that is required is a suitable plant, light, air and water. Will the sea be used to produce sea weeds which can give us the raw materials we need? Whatever it is, the present developing countries could benefit enormously from this role of raw material production.

We obviously have a special interest in what will happen in our own developed Europe. Its population will be ageing, its export markets for manufactured products will be declining and its own demand for expensive consmumer goods will be reduced. The use of new machines and materials will reduce much of the routine and labour of work.

Our agricultural engineer in the European industry of the 21st century is likely to be a member of a multinational organisation. A large part of his daily task will be in the designing of systems. These may be farming, production engineering or business systems, which he will develop for use in units throughout the world.

The electronic developments we see today are likely to have a big effect on all areas of our business in the period we are considering. I see production units being smaller and producing smaller quantities of more varied products. The easily programmable robot or machine tool will be a valuable part of this development. A small number of men assisted by a large number of easily programmed machines will work together in small cells producing a wide range of things. Such production units will be easy to reproduce all over the world, given the capital and technology to create the plant in the first place.

Electronics in the factory may have an even more important part to play in the organisation of that operation. Communications will obviously be affected and will be the change which encourages business on a world scale. But within the factory the ability to transmit complex instructions to machines which can subsequently carry them out unattended will allow great change. Production control will be a matter of computer talking to computer. Stores will control themselves with material moving in and out automatically with automatic control of the quantities. Conventional production lines will be replaced by production stations which take themselves about the factory to have the various operations carried out.

The types of material available will effect the production processes we use but throughout the 21st century I still see us largely using natural materials. A much wider use of synthetic materials will probably occur later but could give rise to manufacturing plant which takes in the base chemicals and forms them in one process into complex machines. Then we will not need any people in the manufacturing process.

Another aspect of our industry which will be affected by electronics is design. Both design and testing will become computer aided. The computer will never be able to provide creative thought but it can provide facility to store information and retrieve that information in many different ways. A large part of design and testing consist of these functions.

Farm machinery particularly requires considerable data on conditions as they vary with geography and weather. Data of this type, probably expressed in stress calculations, will be available in the designer's computer. Man will design something and have the computer vary it to meet the conditions likely to be met in different parts of the world and at different times of the year. The computer will also be able to provide information on production techniques to select a design of minimum cost to meet the required parameters of strength and function.

Testing will consist of two components. One involved in keeping the computers up to date with information for the designers and for the test rigs which will do much of the strength testing of machinery. The other will be function testing to see if the machine will actually do the job it was intended for; this I see still being the work of teams of real people using their minds and experience creatively.

Indeed, the advent of these sophisticated data processing machines will give people much more scope to use imagination and inventiveness in all sorts of ways. I see there being a much greater need for people with imagination in all these new walks of life.

Offices, factories and laboratories will become increasingly more expensive and require maximum throughput to support their capital cost. This will be achieved by multishifting all these resources with people who want to work perhaps as little as 20 hours week.

They will be doing somewhat different jobs to those at present. They will be designing, planning, repairing and operating sophisticated equipment. They will spend long periods being trained to do their work and will be retiring earlier. There will be a population consisting of a large number of fit and active retired people, a small working population with short hours of work and a larger population of students and trainees.

I wonder where the motivation will come from to make all this work? The need for money to buy consumer goods to keep up with the Jones' will be much less important in the Europe of the 21st century. The goods will be expensive but more durable and more universally available. The propensity of demand will be different as there will be relatively fewer new consumer goods that people will want.

I think that motivation is likely to spring from release to enjoy different activities. The thing which the World Age is most likely to give people all over the world is more time. Time in longer life spans and away from work, time to do what they really want to do. Together with this increased time there is likely to be a changing attitude towards what is worthwhile. We may see a considerable widening of the scope of so called leisure activities perhaps to include things like the carrying out of craft labour as a release from regular employment in a much more sophisticated technical role.

My successor in 2050 is likely to be involved in leading a network of agricultural machinery operations throughout the world. Production units will be small, perhaps not more than 500 people in each, and will be located relative to agricultural systems rather than national boundaries. Material research and factory design will be carried out in Europe; product design and user systems research in North America. Financing will be shared between Tokyo and London.

My successor will travel extensively, speedily and at enormous cost, but most of his communication will take place by video links which will allow meetings to take place with the participants scattered all over the world. Business and technical information will similarly be transferred through satellites to be freely available to the many units in the world.

Although his staff will be working 20 hours/week in a four shift system with four men to every job, I'm afraid the chief executive is still likely to be only double shifted because he won't be able to find three other people he can trust not to change his decisions when he is off duty! In his off duty time he might make wooden fishing boats to be used by an elderly group of fishing enthusiasts who prefer wild fish to the cultivated sort found in the shops.

Throughout this paper I have tried to draw conclusions on the future from the trends which we can see in operation today. I think that this will apply equally to the distribution methods of the 21st century.

Distribution of farm machinery requires:—

1. Contact with the customer.
2. Pre sales technical advice to select the right equipment.
3. Supply of the product.
4. After sales service.

With agricultural products, which by their very nature involve customers spread thinly over a wide geographical area, I see this function continuing through dealer networks. However, I see these dealer networks changing somewhat.

As agricultural operations become more complex and themselves use automated management techniques the dealer will have to specialise. This may well take different forms. We might perhaps have people in the countryside, and I hesitate to call them dealers, who sell farmers "software" for their management systems. These people will have to become involved to some extent with machinery as the equipment and the system will be inter related.

The equipment itself will be supplied and serviced by dealers who will become much more specialised in single ranges of equipment. I do not see a continued long line system where the manufacturer and dealer offer a full range of farm machinery from the same franchise. I see much more the dealer becoming a specialist in a farming system and carrying all the equipment and expertise for that system, be it cereal growing, livestock or some specialist crop.

It sounds an interesting world and I rather wish I could be there to live in it. The difficult part will be reaching the 21st century. We are at considerable risk as the developed nations squabble over the fast disappearing raw materials and declining export markets. We have 700 million starving people who know how the other 3300 million in the world eat, and resent it.

We should now be preparing for the future and making more efforts to ensure that it is there for our children to enjoy. But that is perhaps straying even further into the dark of politics and away from my brief of industry where I find just a little light.

# Engineering for agriculture in the 21st century

## Edited summary of discussion

**Dr D P Blight** (Director SIAE) opened the discussion, suggesting that the Conference turn its attention to ways in which agricultural engineering could best contribute to world development — in particular the third world. How could the production of more food, energy crops and raw materials such as cotton and starch be reconciled with the fixed land area available? Perhaps multiple cropping should be the aim but what then would be the implications of water supply limitation? Perhaps the automatic monitoring of crop and animal performance coupled with automatic control of environment and growing conditions should be anticipated. Dr. Blight pointed out that machinery costs tend to rise faster than returns on food products. The reaction to this by farmers was often to attempt to cut costs. Should we, instead, turn our attention more to the maximizing of returns?

**Mr F Moore** (Howard Rotovator Company) felt that we should beware of making dangerous assumptions about the social habits of our descendants who perhaps may prefer vegetable to meat products. We might also imagine changes in consumption of milk and possibly the disappearance of tobacco. Mr North replied that grass is one of our most important resources. It was difficult to visualise that in the next century ways would be found of converting this into acceptable food by factory methods rather than by means of animals. However, with our large production of cereals it was possible that consumption of these might increase significantly.

**Professor T A Preston** (University of Alberta) vigorously drew the attention of the Conference to the importance of people in agriculture. What was so magical about denuding the countryside of people and concentrating our efforts on factories for the production of processed food? He emphasised that "small is beautiful" and that properly designed hand tools, for example, were an essential aspect in the development of third world agriculture. Successful plant breeding was another requirement — an example being the need for cotton varieties which would allow flexible planting dates to fit in with the priorities of sowing of food crops. Ir F Coolman agreed that, in developing countries where there were few mineral resources, the agricultural population was the basis of economic health and stability. It was important therefore that nutrition and the social implications of changes in agricultural planning were realised. Mr North was also in agreement quoting the example of the Chinese farmer who feeds 1.3 people whereas in the UK the farmer feeds 48. It was necessary to identify the essential factors or the limiting resources in agricultural production — maybe one of these was to provide gainful employment for the population. But was it always economic?

**Professor Preston** suggested that more attention should be paid to the return of sewage to the land in order to avoid breaking the cycle of nutrients. Mr. North observed that this had been tried over many years but that a broad programme of co-operation would be necessary for this to be successful since sewage contained many products from manufacturing industries which were harmful to the growth of plants.

**Mr P Hebblethwaite** (Rolls-Royce Motors) felt that agricultural engineering in the future would find it necessary to "borrow" from many technologies. Did we expect, in the future, that agricultural engineers would be "lifetime committed" or come and go from the industry over short periods of time?

**Professor Bell** observed that it was healthy to import people into agricultural engineering. To educate a man for a lifetime would imply educating him to anticipate change, but this would not necessarily always be successful. Young people like to have an immediate objective — but they should bear in mind that it may need change in ten years or perhaps less. A need for the revision of outlook and even for retraining could well arise.

**Mr Richman** was proud of the breadth of agricultural engineering as a profession but we should not be complacent and should be conscious of the need to make it even wider in the provision, within formal education, of language and business studies.

**Professor O'Callaghan** (Chairman) expressed the opinion that education towards an end is a myth. There are plenty of facilities for re-education after formal training has been completed — particularly when employers are prepared to provide resources and are aware of the necessity for motivation.

**Mr E Barnes** (BP nutrition UK Ltd) felt that education was necessary to provide a sound fundamental basis for later specialization. A man needs to know how to understand a problem — and how to tackle it. There was a need for fundamental approach to problem solving. Returning to Professor Preston's observations, Mr Barnes felt that elementary technology was not the entire answer. The difference in standard of living among countries depended on differences in their level of technological achievement.

**Mr C Great** (Alpha Laval) was concerned about the means of financing the research that was necessary for 21st century developments. Could a small company be expected to plough back five per cent of its profits or would the Government finance such ventures? An alternative was to rely on advances made by multinational companies.

**Mr Richman** agreed that there was a great problem particularly in view of inflation and current interest rates. Industry must show a 25% return merely to "stand still". Small companies may not be able to afford the investment necessary in development which explains why more of them do not appear to be looking forward. For large scale projects demanding many resources, multinationals might be viewed as a source of progress. Government agencies might be expected to help in providing data but not in the production of finished designs of equipment.

**Professor Bell** commented that in the immediate future it was the intention of NIAE to help both small and large industry. There was a gulf between the acquisition of data and the production of a design. NIAE had a role, working with AEA and DoE in helping both small and large companies with the objective of increasing the added value of their products.

**Ir Coolman** explained that the implement manufacturing industry in Holland comprised mainly small units, the largest having 1000 employees. It was the task of IMAG to support this industry and to invent equipment and techniques. He cited examples of cooperation with industry on a non-paid basis where his Institute had experimented with the planting of chitted potatoes. In another example, this time of a rotary mower development, three years work had been done, in secret, paid for by a manufacturing company before the results were publicised. He saw the role of the Government sponsored research institute as being the development of equipment and provision of guidance in its use.

**Professor O'Callaghan** observed that industry was concerned with what happened within the next two or three years. Whose responsibility was it to look forward? The evolutionary process was perhaps satisfactory but it was necessary to encourage bright ideas. If the industry is taxed on its production the resulting funds should be re-cycled and made

→ *page 76*

available to the industry through its research establishments.

**Lord Kearton** agreed that this was a major role for Government institutes and that there were many examples of successful developments. The industry no longer had the funds to fulfill all of the tasks which it should be tackling. The pressure, even in large companies, was for immediate results. The best solution for this was to have close liaison between Government laboratories and industry. If financial backing was not available from the Government we would be looking back in 1990 on a decade where manufacturing potential would not have been fulfilled.

**Mr P A M Murray** (farmer) was horrified by the capital cost of high technological machinery. Emphasis should be placed on simple engineering. The farmer should not be relied upon to develop his own machinery. Agricultural engineers were needed who could build machines which were successful from the outset.

**Mr G F Shattock** (Consultant Design Engineer) wholeheartedly supported Mr Murray. The farmer was inventive by nature but there existed an abyss between prototype construction and production line manufacture. Was the panel satisfied with the training of production engineers in UK? Leading manufacturers are currently bringing in proven machines from overseas — was this because our production engineers were insufficiently trained?

**Mr Chamen** observed that, as far as NIAE was concerned, there would become closer ties with manufacturers. Development was a long and painful process.

**Mr R F Norman** (Ciba-Geigy) observed that everyone was concerned to reduce overheads in order to have funds to invest in research for the future. Present day financial pressures made this difficult. The institutions were very good at fundamental research and should not, therefore, spend too much time on development. The important thing was to convey the results to industry at the appropriate time.

**Mr T S Collins** observed that there were three main areas in the evolution of a machine, as far as NIAE was concerned. These were invention, development, and a vital link between the institution and industry. Mr Manby pointed out that the NIAE would be very pleased to help in bridging the gap between the institute and industry by receiving seconded personnel from industry during the development phase — or other relevant phases of evolution.

**Mr F D Swift** (AEA) wanted to know what had happened to British marketing. Many originally British inventions were now widely used around the world — he cited examples of television tubes, motor cycles, binoculars and the ubiquitious i/c engine. We were now importing many of these products and the fault must lay in our marketing.

**Mr Richmond** did not entirely agree. The whole of Europe currently has the "English disease" of self denigration. It is a form of "industrial revolution" and we must be the first to emerge from it. Commercial success arises from a suitable mental attitude. Side issues such as taxation must be overcome. It was an attitude of mind.

**Mr Barnes** observed that British companies had a reputation for failure to deliver on time. He believed that this arose because accountants were reluctant to allow companies to keep adequate stock.

**Mr J C Turner** (President) pointed out that efforts were being made to increase the awareness of students to practical necessities in development and marketing. It should be realised, however, that in the training of students it is always necessary to begin from the beginning. Another problem was that engineering still had a rather poor image in the public eye, particularly, in the public school sector. The image must be improved if the lustre of our engineering is to be retained through the next century.

**Mr C J Bevan** (Laurence Gould Consultants) pointed out that many UK manufacturers do not understand the importance of marketing or take opportunities which are offered. A recent market survey of opportunities in Ireland proved to be of o interest to small companies — multinationals and two large British companies were the only interested parties.

**Mr D J Bottoms** (NIAE) was concerned that little attention had been given to the relationship between the human operator and the machine — this would be as important in the 21st century as in the 20th. Even automatic systems needed human supervision! There would be an increasing need to take into account the limitations and the abilities of the human operator if optimum performance was to be obtained from equipment. Operator motivation was an important factor in these considerations.

**Professor O'Callaghan** (Chairman) — closing the conference — hoped that the meeting had made a positive contribution towards the lightening of the general depression which had become recently apparent in the British agricultural machinery industry. There was, happily, an awareness of the need for the industry to be able to view ideas as parts of a system in agricultural production. There was a reassuring resurgence of mutual concern and interest between the manufacturing industry and the research institutes. Such interaction must be fostered and the Institution of Agricultural Engineers had a significant part to play in the promotion of this. The research institutes must keep their eyes firmly on a far horizon; industry in many cases was too concerned about the present and the immediate future. How would the research institutes help to foster evolution? Finally the input of management into the industry must be well considered and forward looking. An awareness of the implications of national and international trade was necessary for success to be anticipated in the time ahead.

"A DIAGRAM can save many words" is a maxim well known to scientific report writers. As a means of communication, however, practical demonstrations of inventions and developments, and the opportunity to discuss equipment and ideas with those who are responsible for them, must surely be the most effective means open to man.

The success of the recently reformed British Society for Research in Agricultural Engineering depends upon the support it gains from the agricultural industry. Membership is increasing steadily and there is no doubt that members are finding "value for money", not least from the carefully organised Members Days.

On Wednesday 4 June, members were able to see that part of the work of NIAE which is related to the production of field vegetables. Demonstrations included harvesting and market preparation, cooling and storage, irrigation and glasshouse mechanisation. Each is of major importance to the industry — but, as Mr Frank Brown pointed out, the one process which every grower must understand and control is that of initial crop establishment. Accurate and reliable seeding, labour saving in the transplanting operation, and even so mundane a job as the effective repair of damaged irrigation pipes have important commercial implications. And all were well featured at Wrest Park on 4 June.

The objective of BSRAE is to enable its members to have close contact with the work of NIAE and SIAE. The record to date is a good one. Very successful Members Days have featured the subjects of tractor research and testing, and of livestock buildings and equipment. The field vegetable day was the third in a series which will continue with:

Agricultural Drying
21 October 1980 at SIAE

Computers in farm mechanisation
Spring 1981 at NIAE

Greenhouse engineering
17 June 1981 at NIAE

Potatoes/root crops
Autumn 1981 at SIAE and NIAE

Details of the Association may be obtained from: The Secretary, BSRAE, NIAE, Wrest Park, Silsoe, Bedford MK45 4HS.

*Hand operated tool for floretting cauliflowers for quick freezing.*

# BSRAE members days

Crop – spanning gantry for glasshouse or outdoor use, obviates uneven soil compaction and need for pathways

NIAE Experimental seed drill allowing accurate placement of seed and manipulation of soil environment to achieve good emergence.

NIAE Experimental transplanter, each unit handling 5000 plants per hour. Three or four such units mounted on a tractor can be managed

*Left: Self-steering tractor for transplanting, can be controlled by transplanter operator.*

## Errata

**WE regret the following printing errors which occurred in the previous issue of The Agricultural Engineer (Vol 35 No 2).**

**page 52, col 1, line 34, should read "6% scuffing"**

**page 52, col 3, line 1, should read Houston**

**inside back cover, col 1, line 10, should read 1.5-2 rev/300 mm.**

# Guidelines for designing operator access systems for tractors and mobile equipment

**D J Bottoms**


## Summary

EASY access is important for safety, comfort and productivity. The paper provides guidelines for the design of agricultural machinery where there is insufficient space for such optimum arrangements as are possible in buildings.

The recommendations are based on extensive laboratory experiments of tractor access and on published information. The need to consider the whole access system is emphasised because of the interactions between the size and location of steps, handholds, doors and workplace arrangement. Some experimental assessment of access systems for new designs is recommended.


## Introduction

THE design of an operator's workplace on any type of mobile equipment often involves compromise because of the limited amount of space available. Over the past decade considerable improvements have been made in workplace design on agricultural equipment, particularly in the design of cabs for tractors and self propelled machines. However one aspect which can still be improved is the provision of good access to and from the cab or working platform.

Drivers and operators find good access particularly important when they need to dismount frequently to adjust or clear machines. Table 1 suggests that the chance of an accident occurring while mounting or dismounting from a tractor is high. The fact that most of the accidents occur when the driver is dismounting implies that this movement is usually more difficult than mounting.

Published data on workplace design are often more applicable to buildings and fixed equipment where space is less of a restriction and optimum arrangements more easily provided than to mobile equipment. Some data are also available on minimum access requirements, eg for maintenance purposes. There is however, very little guidance on designs which are less than optimum but may still be generally acceptable. To obtain this type of data, an extensive series of laboratory experiments was conducted at the National Institute of Agricultural Engineering with particular emphasis on the tractor cab. (Bottoms *et al* 1979).

The entry-exit system for a particular design needs to be considered as a whole because there are interactions between individual components. The specification of a single system that is applicable to all machine designs is therefore not practical. For convenience the following subjects will be discussed in separate sections together with some interactive effects:

(1) (a) doorways and passageways — location, size and shape.
 (b) doors — hinging (front and rear).
(2) steps — size, height and arrangement.
(3) handholds — type, size and arrangement.
(4) operators workspace — size and arrangement.

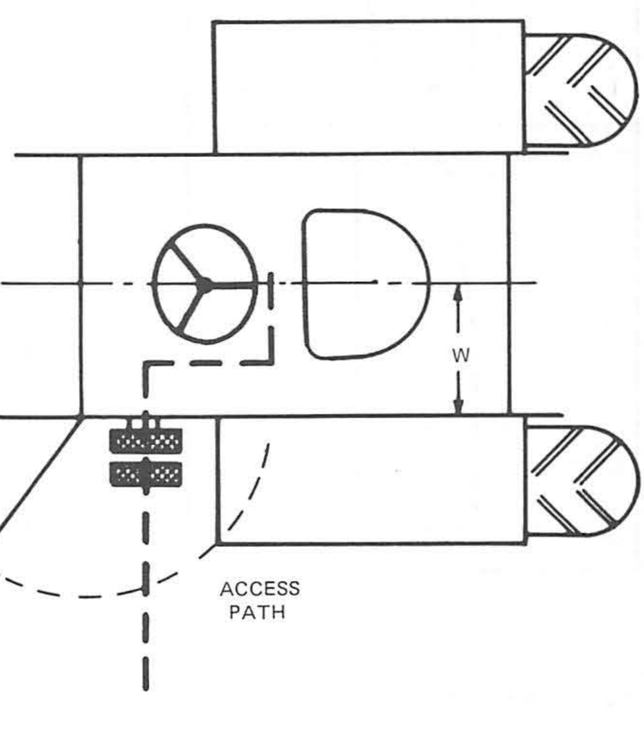
A final section describes some experimental methods for evaluating a design or the effects of changes.

## Doorways, passageways and doors

### Location relative to the operator's seat

The one factor that is likely to determine

*Fig 1 Schematic diagram showing relationship of seat to doorway position on a typical tractor W = Effective platform width*

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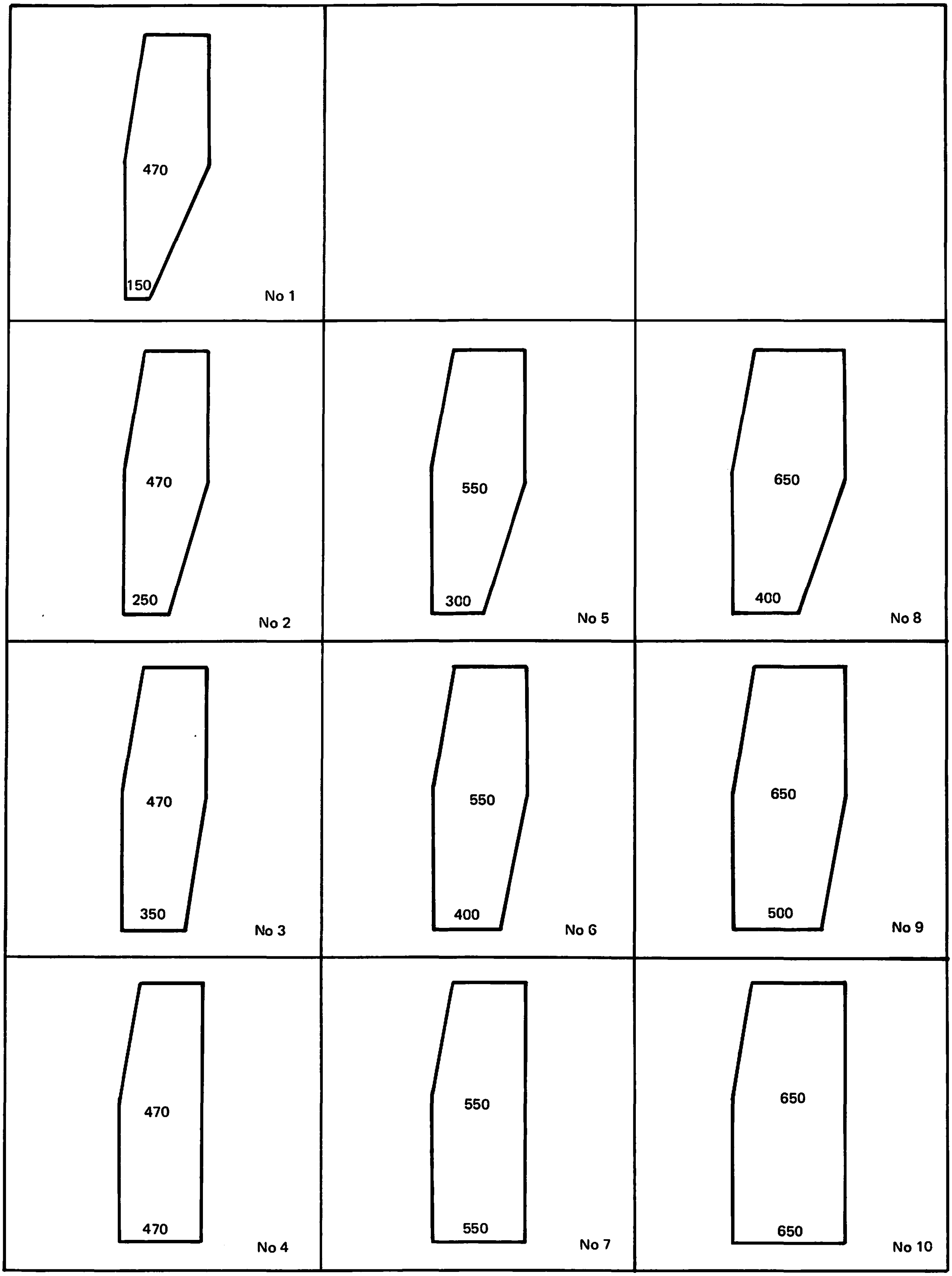



*Fig 2 Door sizes and shapes used in NIAE tractor cab studies; All doors 1.5 m high; dimensions in mm*

whether good or indifferent access can be provided is the relationship of the operators seat in the workplace to his point of entry to it.

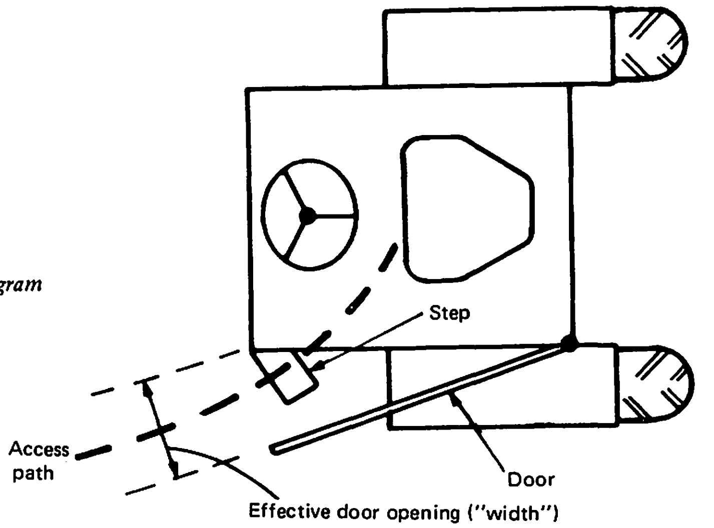
On many two wheel drive tractors the driver climbs into the cab just in front of the driving wheels and the seat is positioned approximately over the rear axle. This results in a Z-bend in the access path which makes entry and exit difficult (fig 1). For good access to a tractor the gap between the seat and steering wheel should be opposite the doorway. (Bottoms 1973). The same principles apply to other machines and right angle turns in a confined space are undesirable. When a Z-bend cannot be avoided access can be improved by minimising other restrictions, particularly by using wide doors and making the effective platform width, W (fig 1) as large as possible. (See discussion on operators' workplace).

**Size and shape**

The ease of access depends on the height and width of doorways and passages. It is unlikely that a doorway 2 m high and 750 mm wide (the size used in many buildings) could be provided. For large military aircraft the minimum size of a passage way, which is trapezoidal in cross section, is 560 mm wide at the top 300 mm wide at the bottom (Woodson *et al* 1964).

In the NIAE experiments a range of door sizes and shapes was evaluated subjectively (fig 2). The results (fig 3) showed a marked improvement in access as the area of the doorway is increased, and suggested that a width greater than 650 mm might be desirable. However the difference between the access scores of doors 8, 9 and 10 is small, so a 650 mm width at waist level and 400 to 650 mm at foot level may be adequate for most doors and passageways. The minimum size recommended is that of door number 5. The minimum dimensions given for doorways should also apply to the whole length of the pathway to the operator's seat. For example, when the entire side of a cab is used as a door the critical dimension from an access point of view may be the distance from the cab frame to the inside of the door (fig 4).

*Fig 4 Schematic diagram of access path when the whole cab side is used as a door*



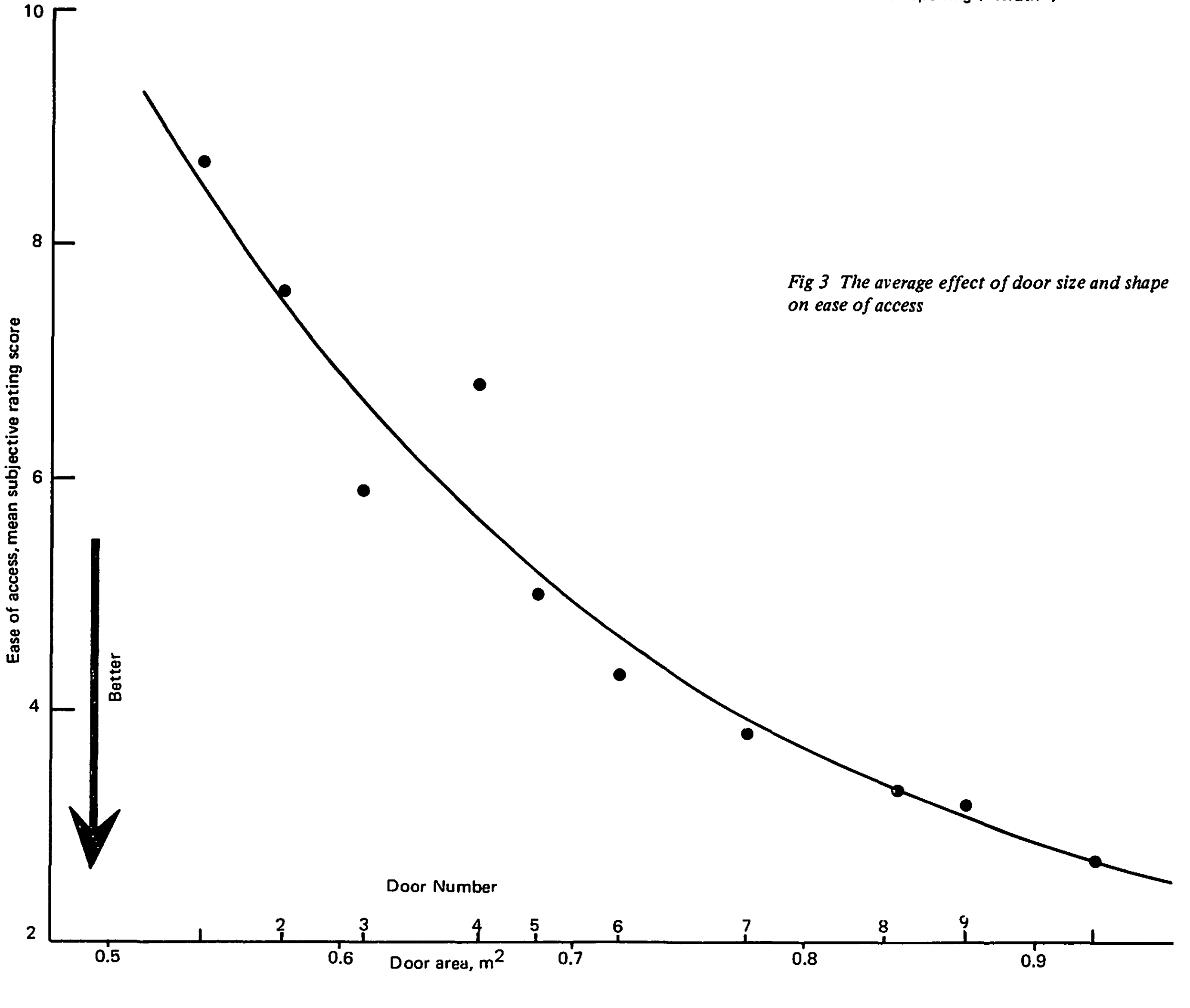




*Fig 3 The average effect of door size and shape on ease of access*

**Door hinging**

There is no evidence to indicate whether a conventional door, such as those in fig 2 should be hinged on the left or right side. The complex interaction of many factors such as door position and step arrangement tends to observe a clear solution. It is therefore strongly recommended that practical evaluations are made for particular designs.

If hinges are fitted to door posts that are not vertical, gravitational forces will tend either to close the door or open it wider depending on the angles involved. In both cases the person entering or leaving may have to hold the door. This creates additional difficulties for him, particularly if a large force is needed. Doors should therefore be hinged on vertical posts unless a *small* amount of gravitational assistance is beneficial, or a compensating device is fitted.

## Steps

Ergonomics text books differentiate between ladders, which have a rise angle relative to the horizontal of 50 to 90° and stairs where the rise angle is less than 50° (Morgan *et al* 1963). Stairs are not practical on mobile equipment, and the optimum size and arrangements of a ladder (fig 5A) is seldom practical either.

Steps should be arranged so that they form a continuous natural pathway rather than a series of "stepping stones". This means that they will not always be directly aligned to the side of the machine (fig 4).

In the NIAE study on tractor access, rise angles of 60° — 70° were preferred to a vertical arrangement of steps (Bottoms *et al* 1979). Vertical ladders may be unavoidable, for example on some large self propelled harvesters, but steps should be provided rather than rungs if at all possible.

The smaller the step, the more difficult access will be because of the greater accuracy required in placing the foot.

The available evidence suggests that the tread widths could be as little as 450 mm while still retaining reasonable access. This width allows operators to place either the left or right foot on any step. Smaller (300 mm wide) steps can be used but should be staggered (fig 6) so that their combined width is 400 to 450 mm (Bottoms *et al* 1979).

Tread depth is dependent on rise angle and should not be less than the values given in fig 5A. For a vertical ladder rungs may be used but they should be made from circular tube rather than angle iron since they may be used as handholds as well as steps.

Irrespective of the rise angle it is important that an adequate clearance space is provided beyond the step for the operators toes.

Ideally, the height of the bottom step above the ground should be the same as the vertical height between successive steps. On mobile equipment however, this is often impractical and UK legislation limits the maximum height to 550 mm (anon 1962). An acceptable bottom step height for tractor access is 400 mm.

The distance from the bottom step to the cab or platform will dictate the number of steps needed. The interstep height should be kept constant, as on a stairway, the last "step" being the platform at the top. It is preferrable to use interstep heights of less than 300 mm. In fact the greatest physiological efficiency in climbing ladders is achieved with a rise angle of 70° and an interstep height of 260 mm (Grandjean 1971). In the NIAE tractor access studies,, a bottom step height of 400 mm and interstep height of 270 mm were preferred to 350 mm and 295mm respectively.

**Step location relative to cab doorway or platform**

The transition from the steps to the platform or cab can be a critical part of the access system, particularly when the design is below optimum standards. Usually the best compromise can only be evaluated experimentally. For example, the position of the 300 mm wide steps shown in fig 6 in relation to the doorway was determined experimentally for the particular configuration of the NIAE rig with a door hinged at the front. With a rear hinged door the steps needed to be moved towards the front of the tractor (table 2). In both cases the subjects preferred to put the left foot into the doorway.

## Handholds

During access it should be possible for a person to maintain a 3-point contact at all times (Hemmings 1974). The design of handholds is therefore as important as steps.

Handrails, which allow movement along the handhold, are to be preferred to handgrabs because the number of restricting dimensions is effectively

*Fig 5a Optimum step size and arrangement for ladders (Adapted from Morgan et al, 1963; Woodson et al, 1964)*
*(a) Sloping ladder – one handrail omitted for clarity*
*(b) Vertical ladder*

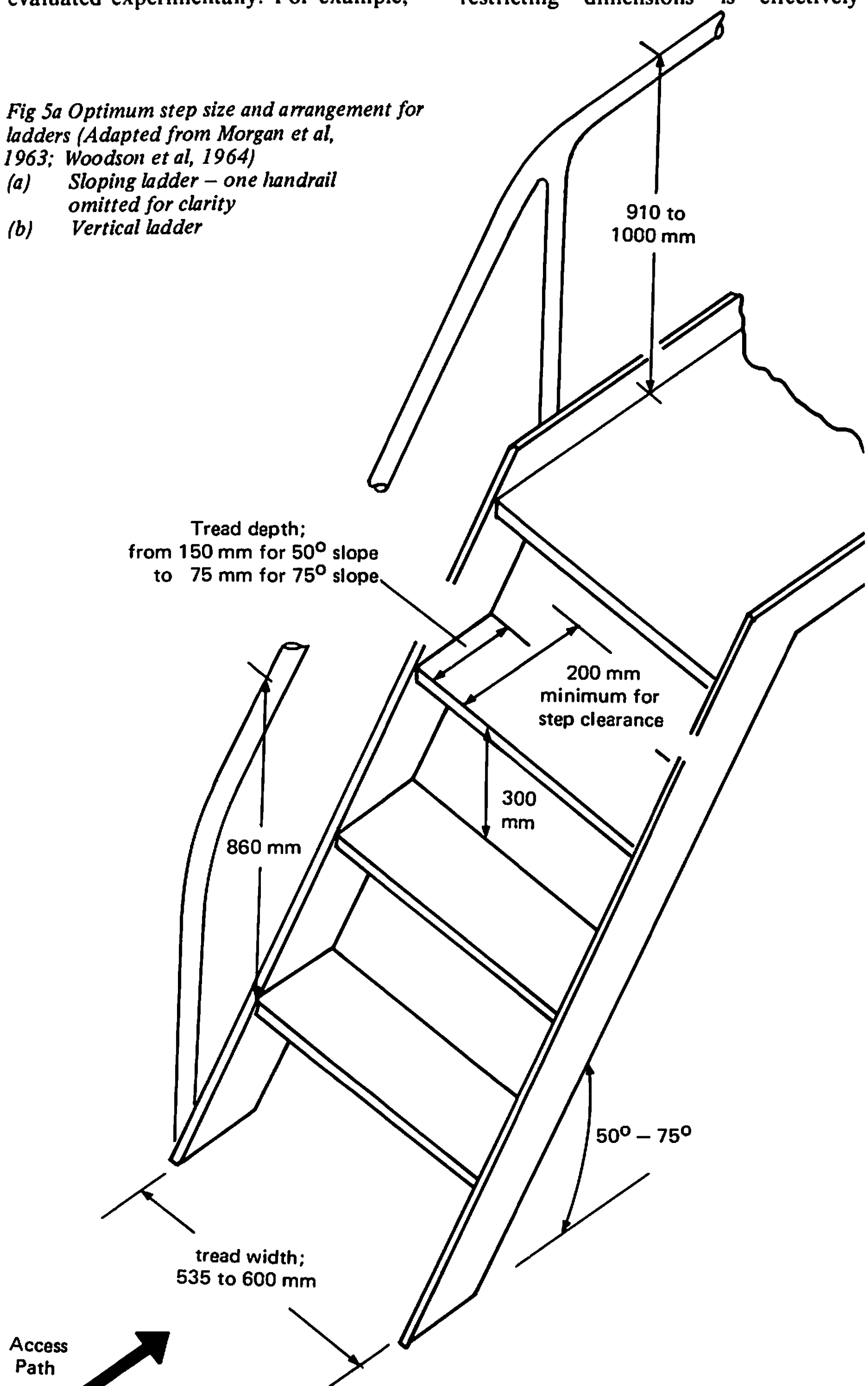


**Table 1 Non fatal accidents involving tractors other than those overturning**

| *Country* | *Great Britain* | *W Germany* |
|---|---|---|
| *Period* | 1976 | average for 1974 to 1978 |
| *Source of data* | HSE Statistics (anon, 1977) | An Insurance company's claims (anon, 1979) |
| *Average number of accidents per year* | 309 | 74 |
| *Percentage occurring when entering or leaving the cab* | 30% | 44% |
| *Approximate proportion of access accidents occurring while dismounting* | 80% | 70% |

**Table 2 Footsteps arrangement required with rear hinged and front hinged doors** *(assuming step size of 300 x 100 mm).*

| | | *Rear hinged door* | *Front hinged door* |
|---|---|---|---|
| *Centre of step from front door post for a 650 mm wide door with a 400 mm wide threshold* | *Top step (right foot)* | 290 | 370 |
| | *Bottom step (left foot)* | 110 | 250 |

**Table 3 Recommended handrail lengths for a 940 mm cab floor level (See fig 7)**

| | *On inside of door and hinged side of doorway* | *On latch side of doorway (opposite hinges)* |
|---|---|---|
| **Angled handrails** | | |
| *Vertical height of lower end above cab floor, mm* | 100 | 200 |
| *Vertical height of higher end above cab floor, mm* | 850 | 950 |
| **Vertical extensions to angled rails** | | |
| *Vertical height of higher end above cab floor, mm* | 1150 | 1200 |

reduced to two, the actual position of the hand on the rail not being constrained.

The preferred diameter for handholds is well documented as 32 to 35 mm (Morgan *et al* 1963), with a maximum diameter of 44 mm (Woodson *et al* 1964) and a minimum of 19 mm diameter if the force exerted is small (Morgan *et al* 1963). The distance from the handhold surface to all other surfaces should be at least 50 mm, but double the distance is desirable if adequate allowance is to be made for an operator wearing gloves.

**Handrails for steps and platforms**
Ideally, handrails should be positioned on both sides of the steps, inclined at the same angle as the step rise angle. The optimum vertical distance from the nose of the tread to the top of the rail is 860 mm. Transferring from the steps to the platform or cab can create difficulties except, in the simplest cases. For horizontal platforms or catwalks the handrail height should be 910 to 1000 mm.

On many self propelled machines, including tractors, the driver opens a cab door before ascending or descending the steps. The NIAE study showed that in this situation vertical extensions to the angled handrails are desirable (fig 7). For a cab platform height of 940 mm above ground level the recommended lengths of handrail are given in table 3 (Bottoms *et al* 1979) and these are longer than those on most existing tractors. These dimensions need to be used as a practical guideline because:

(a) drivers often need to hold a handrail more than once, particularly during entry.
(b) the distribution of the hand position on a rail during entry is about 200-300 mm lower than that for exit but the ranges are about the same.
(c) taller drivers reach higher up the handrail on the latch side than shorter drivers.

A surprising feature of the NIAE results was that the steering wheel was frequently used as a handhold, particularly when getting out, even when good alternative handholds were provided inside the cab (Bottoms *et al,* 1979). The implication of this is that handholds which aid climbing in and out are more important than ones in the workplace. Whether handholds need to be available for an operator at the workplace of a particular machine can only be evaluated for the individual design.

## Operator's workplace

From the cab entrance to the work area there should be a clear pathway into which controls must not impinge since their presence makes access difficult and creates trip hazards.

Obstructions are often encountered in the gap between the seat and steering wheel. Table 4 shows that removing gear levers and/or a "hump" in the floor from this space improves the ease of access (Bottoms *et al* 1979). The data also show that access is improved with larger steering wheel to seat gaps. However the relative positions of seat and steering wheel affect comfort when driving and the driving position deteriorates exponentially as the gap increases. This emphasizes the value of having a flat, uncluttered floor.

Where the access path includes a Z-bend, the effective platform width should be as large as possible. With narrow platforms the effect of alternative parameters needs evaluation. For example for the particular configuration used in the experiments on cab width, fig 8 shows that a rear hinged door is preferable to a front hinged door.

When the door is approximately opposite the space immediately in front of the seat, a wide platform may not be so necessary and may even be a disadvantage because the operator has to take an extra pace (Bottoms 1973).

## Experimental assessment

The preceding discussion has sometimes recommended that the effect of a parameter on ease of access should be evaluated experimentally. Three assessment measures suitable for

Table 4 The effects of obstructions in the gap between the seat and steering wheel on ease of access

*(Low scores best)*

| *Horizontal distance from centre of steering wheel to seat reference point, mm* | *Ease of access, average subjective assessment score* | | |
|---|---|---|---|
| | *Flat floor with no obstructions* | *Flat floor with gear levers in seat – steering wheel gap* | *Transmission hump and gear levers in seat – steering wheel gap* |
| 500 | 6.3 | 8.6 | 8.3 |
| 540 | 4.1 | 5.8 | 7.3 |
| 600 | 2.3 | 3.0 | 5.0 |
| 645 | 2.4 | 3.7 | 4.8 |
| 710 | 2.3 | 3.0 | 4.0 |

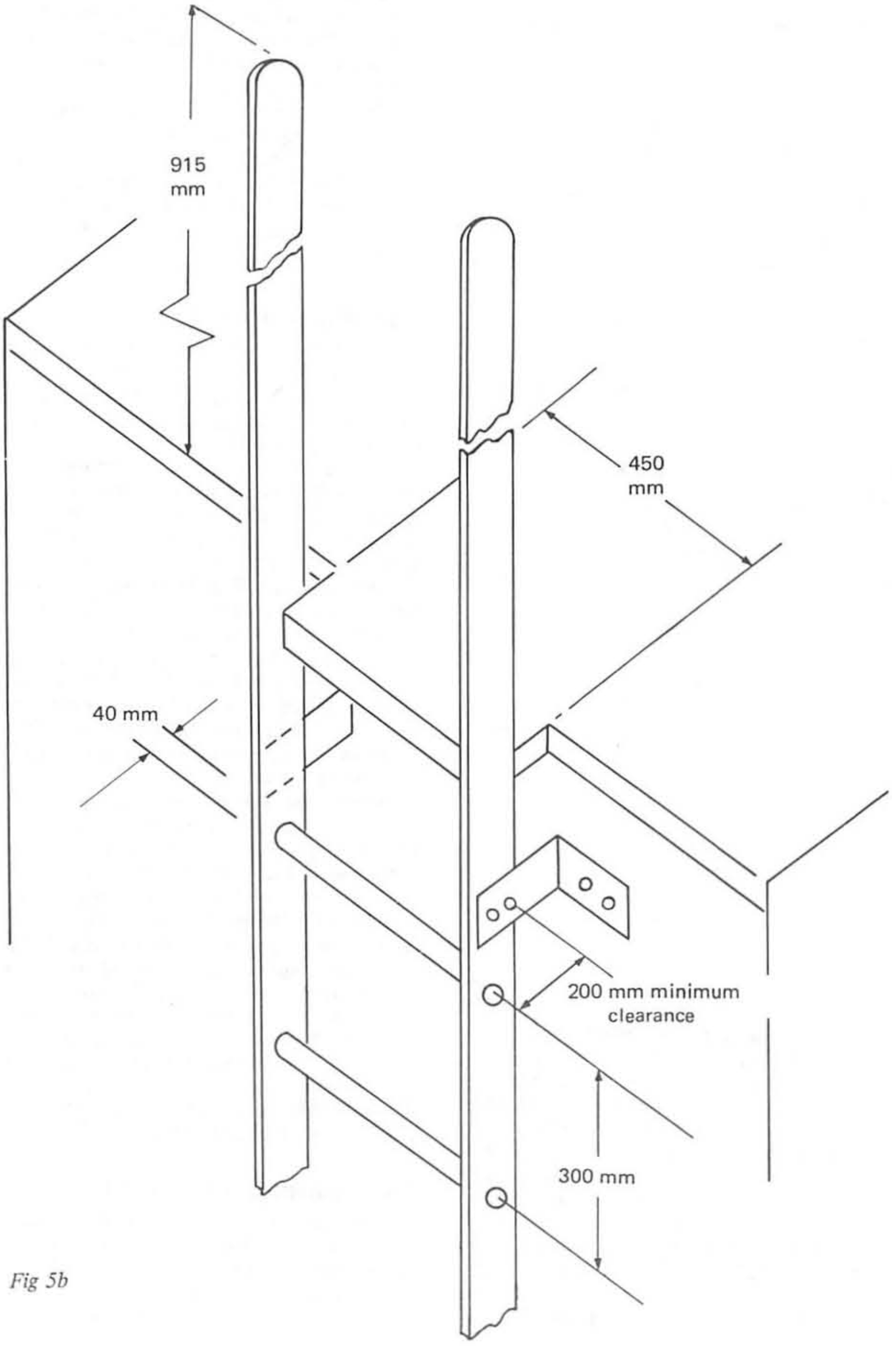



*Fig 5b*

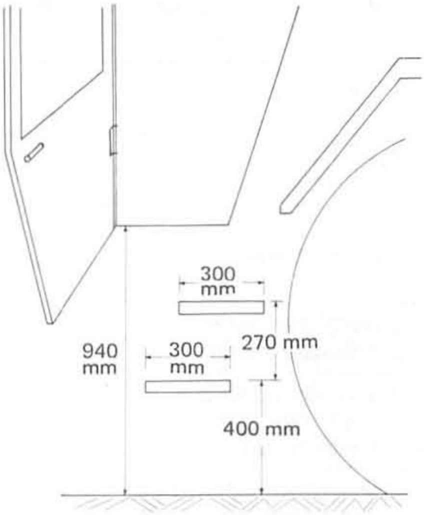



*Fig 6 A step arrangement which constrains the operator to put his left foot on the bottom step*

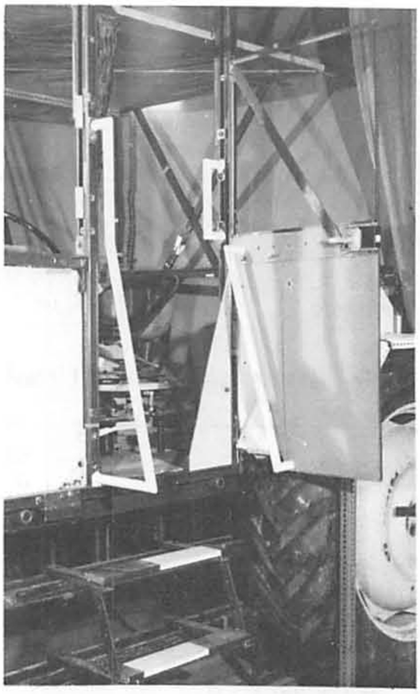


*Fig 7 Vertical extensions to angled handrails on the NIAE laboratory rig*

*Notes: (a) Handrail diameter = 32 mm*
*(b) Minimum hand clearance = 60 mm*
*(c) White portion of steps correspond to those given for a rear hinged door in table 2*

laboratory experiments and one for field evaluations are now briefly described. An alternative to these is a specialist computer aided ergonomics design technique which is beyond the scope of this paper but has been used to evaluate a tractor cab (anon 1980).

**Laboratory assessment**
Building a mock-up in the laboratory will often enable designers to see problems which were not apparent on drawings. Rigs need to have some similarity with the machine being simulated without necessarily being exact replicas. People chosen as subjects for experiments should be representative of the user population;

those in the NIAE study were selected on the basis of tractor driver stature. (Fishwick 1975). The results will be more reliable with a larger number of subjects but 9 or 10 should be enough. Experiments should be conducted with one subject at a time, preferably in private.

Each subject should get on and off the rig a prescribed number of times (five to ten) and should sit in the operators seat for a few seconds before dismounting. He should be allowed to relax while the parameter under investigation is altered, but he should not be able to witness the change being made.

The *subjective assessment* is the simplest measure of ease of access and can be made by the subject while rig parameters are being adjusted. One method is by placing a mark on a line, say 150 mm long, labelled "great difficulty" at one end and "little difficulty" at the other. Ratings given to any previous arrangement should not be visible.

The two other measures are obtained from cine films or video recordings. The *frequency of use* of features such as hand grabs can be counted or the *useful portion* of steps and handrails determined from a frame by frame analysis. Details of behaviour can also be checked, for example to see which foot was placed on the bottom step.

**Field experiments**

The problem with laboratory experiments is that subjects may behave in an untypical manner simply because they know they are acting as "guinea pigs". The use of a simple unobtrusive measure under field conditions can confirm or invalidate some laboratory results.

Those parts of the access path which are frequently used may show over a long period, signs of wear either because they are dirty or because the paint has been worn off.

Examples are:

(a) steps which have insufficient clearance behind them will have paint worn from the nose of the tread but not from the tread itself because the operator cannot put his foot on the tread;

(b) handrails which are mainly gripped near the top may need extending or moving upwards;

(c) paint worn off a machine part where there is no handhold could indicate an area where one is needed.

## Discussion

It is almost impossible to estimate quantitatively the financial benefits of good ergonomics design. In particular, access sytems can only affect nett work rate indirectly because speed of operation is not influenced by the ease of getting in or out. However, an operator is less likely to stop a machine and dismount, to clear a blockage or make an adjustment, if access is difficult. Improving access is therefore likely to increase net work rates because the probability of more serious delays due to breakdowns is reduced In addition it should reduce the chances of an accident occurring at a time when the farmer can least afford to have an operator off work

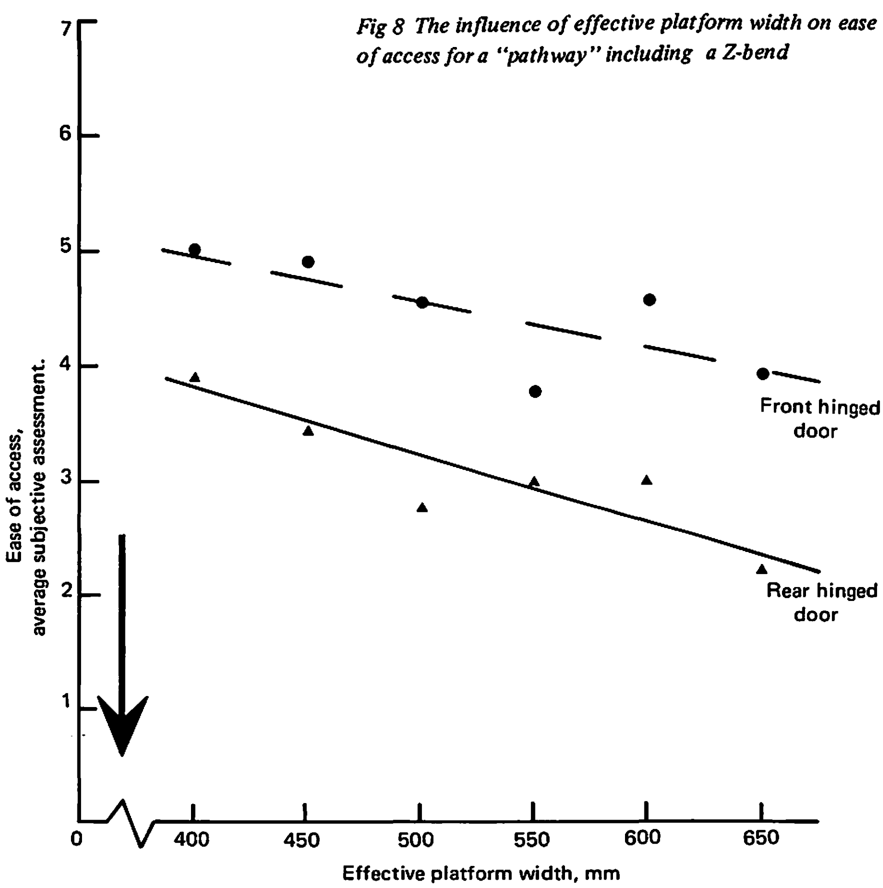



*Fig 8 The influence of effective platform width on ease of access for a "pathway" including a Z-bend*

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