I AGR E

Volume 26

Number 4

Winter 1971

The Effect of Machines on Dairy Building Layouts

Engineering Problems in Forage Conservation

Air Distribution in Ventilated Structures

JOURNAL

and Proceedings of

THE INSTITUTION of AGRICULTURAL ENGINEERS

WINTER 1971 Volume 26 Number 4

The front cover illustration shows members of East Midlands Branch at Marshall-Fowler Ltd.

President: C. Culpin, OBE, MA, Dip Agric, FI Agr E
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Published Quarterly by the Institution of Agricultural Engineers, Penn Place, Rickmansworth, Herts., WD3 1RE. Telephone: Rickmansworth 76328

Price: 75p per copy. Annual subscription: £3·00 (post free in U.K.)

THE INSTITUTION OF AGRICULTURAL ENGINEERS

AUTUMN NATIONAL MEETING 1972

COMBINED WITH A C.I.G.R. Section III meeting

SUGAR BEET & POTATO PRODUCTION IN EUROPE

to be held at the NATIONAL COLLEGE OF AGRICULTURAL ENGINEERING Silsoe, Bedford.

on 2–3 and 4th October, 1972.

Programme Convenor Professor P. C. J. Payne N.C.A.E.

Part I **2nd October PAPERS DAY**

Aspects of Sugar Beet Production
Survey of European Production
Trends in Plant Establishment
Harvester design and system
Performance assessment

Part II **3rd October PAPERS DAY**

Aspects of Potato Production
Survey of European Production
Soil Preparation and Planting
Harvesting and Handling
Performance assessment

or

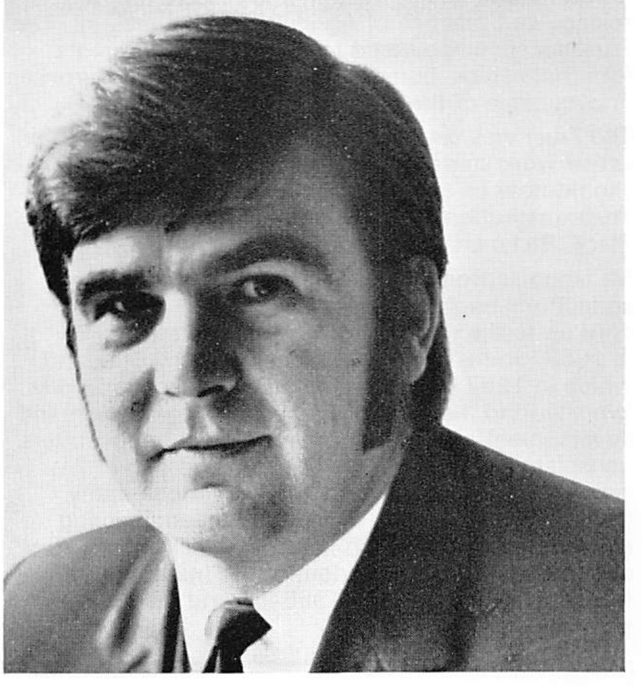
Visit to Sugar Beet growers and factories (mainly for continental visitors).

Part III **3rd or 4th October**

Visit to Potato Marketing Board
Harvesting Demonstration, Driffield, Yorks, (mainly for continental visitors).

It is hoped to produce full programme details and conference fees by April 1972.

GUEST EDITORIAL



Brian May

A NEW HONORARY EDITOR

As the Institution's Honorary Editor since 1961, it is with great pleasure that I have the privilege of introducing my successor, Mr Brian May, whose photograph appears on this page. At a recent meeting of Council it was agreed that Mr May should be appointed Honorary Editor as from the beginning of the new Institution year on 9 May 1972, and that he will also be the Chairman, ex-officio, of the Editorial panel. His term of office will be expected to be for three to five years.

In point of fact, Mr May requires no introduction to the largest Branch of the Institution, the South East Midlands Branch, on whose Committee he has served for several years. He is a lecturer in the Engineering Design Department of the National College of Agricultural Engineering at Silsoe, and is also Senior Warden at the College.

Brian May has been a member of Council for the last two years, becoming Chairman of the Papers Committee in June 1971. He has also been a member of the Editorial Panel since its inception in 1970. In the latter capacity he has made a major contribution in planning and co-ordinating the production of the Agricultural Engineer's Data Manual which will replace the data section of the former Institution Yearbook. Notes on the form of the Data Manual and the ways in which the Editorial Panel expect it to be of service to members appeared under the heading 'Institution Notes' in the last issue of the Journal (Autumn 1971). Mr May will be very pleased to receive suggestions from members regarding new material.

My one regret, in handing over to Brian at this stage, is in connection with the serious delay in the publication of the last two numbers of the Journal, Volume 26—Autumn 1971 and this number. The delay was mainly due to the disruption of the work on the Journal which is carried out by the Secretariat, due to the resignation of Mr Bennett. Mr Bennett's contribution to the production of the Journal was very considerable, both in terms of writing some of the material, assembling the contents of each issue and undertaking all negotiations with the printers. It has taken some time for the Editorial Panel to make alternative arrangments, but I am confident that these matters are now in good hands. I hope and expect that the Journal will be published on schedule from the next issue onwards—that is, on 15 July, to be followed by further issues on 15 October, 31 December and 15 April.

It is appropriate that the change in title already agreed by Council will coincide with the first issue to appear under Brian May's editorship. The title page heading will become THE AGRICULTURAL ENGINEER instead of I AGR E. I believe that the new ideas and energy that he, and the Editorial Panel under his Chairmanship, will bring to bear on the Journal and other Institution publications will raise them to a new high standard. In saying this, I should like to pay tribute to our former Secretary, Mr Jon Bennett, for the very great amount of thought and work that he put into the Journal, in particular, during his period of office. The improvements in presentation and format which have been made during the last few years have sprung almost entirely from his experience and imaginative thinking.

I have been extremely fortunate in having such outstanding support from the Secretariat during my term as Honorary Editor, together with the backing of successive Councils and, over the last year or so, the unstinted and most helpful support of the Editorial Panel. In expressing my warmest good wishes to Brian May as he succeeds to the Honorary Editorship I cannot do more than hope that he will receive support of a similar kind.

J. A. C. GIBB

NEWSDESK

The Douglas Bomford Trust

Through the generosity of Mrs Betty Bomford the memory of her late husband, Mr Douglas R. Bomford, is to be perpetuated by the establishment of the Douglas Bomford Trust. The objects of the Trust are to further education, training and research in the science and practice of Agricultural Engineering. The Trustees are empowered to make monetary grants for scholarships, bursaries, prizes and similar purposes in pursuance of these objects.

The Trust was established on 1 January 1972 and its active work started on 1 February, 1972. Enquiries should now be addressed to The Douglas Bomford Trust, Institution of Agricultural Engineers, Penn Place, Rickmansworth, Herts. WD3 1RE.

Mr Douglas Bomford had a distinguished career in agricultural engineering in which he was active right up to the time of his death at the age of 75, in 1969. In his family business, Bomford Bros. Ltd, which in 1967 was merged and became Bomford & Evershed Ltd, he was concerned with the design and development of cultivation implements, hedgecutters, transplanters, harvesting machines, and other agricultural equipment. He also undertook many responsibilities within the agricultural engineering educational and research fields to which the Trust is dedicated. He was President of the Institution of Agricultural Engineers in 1955–57 and made an Honorary Fellow in 1964.

New Director for Farm Buildings Centre

A new full time Director of the Farm Buildings Centre (FBC) has been appointed. He is David Long *BSc* (*Agric*) *NDA AIAgrE*, who took over from Rev. Peter Buckler *BSc* (*Agric*) *NDA FRAgS*, who held office in a caretaker capacity for the last three years.

The new Director was previously on the staff of Agricultural Press Ltd where in addition to writing for *Farmers Weekly* he was concerned with design and construction of buildings on the company's own farms. Previously he had been Editor of *Farm Buildings*, and before that was on the features staff of *Farmers Weekly* with special responsibilities for farms development and trials. David Long was educated at Solihull School and Reading University.

It's Business Sense to Guard Your Health

Efficiency is all important in today's business and professional world and to be 100 per cent efficient a man needs to be 100 per cent fit. The 'undramatic' illnesses, such as a slipped disc, ulcer or hernia, which seems to drag on and on, keeping a man below par, can cause a disproportionate amount of worry and strain and affect a man's work.

Yet in many cases a prompt operation would clear up the trouble in a short time. The snag is that, for such non-critical operations, the waiting list is a long one—500,000 people are currently waiting for their operations, and a delay of months or even years is not uncommon.

The alternative is to be treated privately. The private patient can have his treatment at a time to fit in with business and domestic arrangements; he chooses his own specialist in consultation with his G.P., and he can opt for a private room, with the 'home comforts' of telephone, television if required, and informal visiting hours.

The only problem is footing the bill. A private room at a hospital or nursing home plus fees for surgeon, anaesthetist and often specialists could mean a bill for many hundreds of pounds.

The answer for most people is to join BUPA, a non-profit making provident association, which enables them to pay a regular subscription to protect themselves against the cost of private treatment.

The Institution of Agricultural Engineers has its own BUPA Group which is open to all members. By joining our Group you can obtain a 10 per cent rebate on standard BUPA subscription rates and you will be eligible for benefit immediately, whereas the individual subscriber has to wait three months before he can claim benefit.

Many members of the Institution may be interested in forming a BUPA Group for their own companies. You need only five employees to start a Group. Of the one and a half million people covered by BUPA, over half are members of the 10,000 companies and professional organisations in the country.

For further details you can contact Group Management Limited, 14 Park End Street, Oxford OX1 1ED.

NEWS FROM BRANCHES

East Midlands Branch

Mr H. F. W. Flatters, *UK* sales manager of Marshall-Fowler Limited, chose as his subject 'Crawler Tractors in Agriculture', when members of the East Midlands Branch of the Institution paid a visit to the Marshall-Fowler works on the 30th September.

A minor revolution has occurred in crawler tractor utilisation during the past three years, which has been attributable to a number of factors, said Mr Flatters.

1. Radical engineering developments.
2. Greater machine utilisation.
3. Improved farming techniques and operations.

Fundamentally these three items cannot be divorced from each other as, combined, they all give the farmer what he is demanding:-

higher outputs
greater efficiency
lower labour costs
higher yields
greater operator comfort

1. *Radical Engineering Developments*

These embrace a number of developments, and the first to be introduced was increased track life as a result of greater expertise and 'know-how' in track running gear production.

Essentially base materials have improved but far more important, are the improvements in gas carburisation and induction hardening. These are the two operations which give the 'guts' to the tracks—the hard core centres and base strength—and the final hard skin which gives the main life to all track running gear components.

It was then necessary to introduce long life sealed track rollers and idlers. Only a few years ago it was necessary to lubricate track rollers and idlers every day, and in particularly bad conditions twice a day. The fact that a crawler tractor works in conditions where it is impossible for either large two wheeled or four wheeled tractors to operate, mud and filth become predominant, particularly in the areas of the track rollers. Under these conditions it was only exceptional operators who would take the trouble to lubricate these units and, consequently, track running gear life deteriorated. This is now obviated and it is only necessary to periodically check that the correct amount of lubricant is present.

Hydraulic track adjustment then followed, which in essence, made a previously difficult job very easy to perform. It should be remembered that probably the most significant factor relating to track life is to ensure correct track tension is always maintained. A particularly tight track chain can accelerate pin, bush and sprocket wear far more than the most abrasive soil conditions. Additionally, over-loading can be imposed on final drive units with subsequent damage.

2. *Greater Machine Utilisation*

The three fundamental items covered by this paper cannot be divorced from each other, and much of this section relates to the availability of the hydraulic three point linkage.

The crawler tractor was, essentially, a ploughing tractor and still is for much of its life, but now with linkage availability all central draft equipment may be fitted for seed bed preparation (with all the advantages of low ground pressure work). Also planters, cultivators, chisel plough, subsoilers, and mole drainers can be operated, and a very important factor is they can now be pulled more effectively as mounted or semi-mounted equipment, thus giving far greater outputs from the base machine.

The linkage has given the crawler tractor at least 20 per cent greater utilisation, and in this context it is interesting to record some figures recently published by *ADAS*.

Medium powered wheel tractors — Approximately 80 per cent utilisation
Crawler tractors — Approximately 80 per cent plus utilisation
Large two wheeled and four wheeled drive tractors — Between 50/60 per cent utilisation

It should also be remembered that linkage availability will, possibly with certain minor modifications, allow users of large two wheeled and four wheeled drive tractors to adapt their existing larger equipment to be operated with the crawler. Obviously, when changing to a crawler tractor this is a most important economic factor. Naturally with the considerable advances which have been achieved in a relatively short time, much more has yet to be done.

3. *Improved Farming Techniques and Operations*

During the mid-sixties we had a number of wet years, and certain eyebrows were being raised, as water was standing on land which was extremely fertile and which had been well drained. Crop yields were becoming lower but blind eyes were being turned. Then in 1968 the crunch came with possibly the wettest year in history in many areas of the country. Strong land farmers were hit very hard, the *NFU* were advocating special government grants should be given, the Government formed a special Commission to investigate soil structures and tens of thousands of acres were put to fallow and became unproductive. Soil compaction became the biggest talking point in the farming community.

From this many improved farming techniques and operations have evolved, and for that matter many radical solutions have been offered, all of which combined, revolve around two basic factors:-

(i) Large heavy tractors should not work in the bottom of the furrow.
(ii) Heavy equipment should only be on the land for the least possible time.

To combat this problem many farmers realised they either had to go back to crawler tractors or introduce them for the first time. This trend is now increasing.

It should also be pointed out the crawler tractor with three point linkage can now also be operated more efficiently. Manufacturers of cultivating equipment are beginning to appreciate the fast growing market which is emerging and big reversible ploughs, cultivators, discs, harrows and straight ploughs are being introduced which have been specifically designed for crawler operation.

This trend will, obviously, continue, but much more has yet to be done before the full potential is realised.

West Midlands Branch

Mr C. T. Riley of the Ministry of Agriculture, Guilford, was the speaker at the West Midlands Branch of the Institution at the Electro-Agricultural Centre, Stoneleigh, on the 7th February, when he took as his subject 'Basic Principles of Waste Treatment'. There were 35 people present to hear Mr Riley introduce the subject, which referred to different types of farm wastes. A major problem, he said, lay with farm manures and these had become prominent because of the increase in size of animal units and the recent legislation on the pollution of rivers which had emphasised the difficulties in disposing, particularly of liquid manures, on land.

Wash down waters from dairy units, for example, and miscellaneous rainfall from concrete areas also presented problems. The waste from slaughterhouses was already being satisfactorily used and on an economic basis.

With the introduction of pre-packed vegetables there would probably be problems arising in the near future with the large quantities of liquid involved in the washing, peeling and preparation of these vegetables.

A considerable amount of experimental and development work was already in hand and there was every hope that it would be possible to treat any liquids arising from these operations in such a manner that they did not cause any river pollution. Broadly speaking it was likely that 90 per cent of farm waste solids would have to go back to land, and with proper husbandry could be disposed of satisfactorily. Nevertheless the liquid effluents arising from these sources would need storage and treatment in order to reduce nuisance from smell and any pollution aspects. The remaining 10 per cent of farms might well be those with a very high livestock number on a large acreage. It would be possible to dispose of such wastes by treatment but the cost would be very high.

Why, therefore did not agriculture adopt normal sewage treatment for its wastes? The answer was that agriculture differed from sewage wastes in two specific ways. Firstly they were very much stronger in terms of pollution load and secondly the liquid flow was normally very much smaller. This brought in cost and design factors which would make standard sewage works treatment completely uneconomic. Nevertheless attempts were being made to use some sewage treatment ideas in agriculture.

What were the future trends? We should undoubtedly see longer storage of manure whether it was handled on the farm as a liquid or as a solid. This storage would probably run for a year with the material being spread onto farmland at the autumn or some other time when the land was crop free. The speaker felt that properly designed stores whether solid or liquid would retain the gross organic pollution within them, and that this could be spread onto land, but that the liquid part of the effluent would require storage and treatment before it was spread onto land and certainly it would require treatment and a thorough clean-up before it was permitted to enter a river. Most of the experimental work on hand in developed countries at the moment was concerned with this aspect of cleaning up the liquid fraction of the wastes and there was every hope that there would be satisfactory answers in the next year or two.

The meeting concluded with a number of slides which illustrated new treatment methods that were being investigated.

Northern Branch

Lively discussion followed an address to the Northern Branch of the Institution by Mr Ian Rutherford of the *NIAE* Liaison Unit, Silsoe, on the 11th January at the Royal Hotel, Hexham.

The main points from his talk entitled 'A Systems Approach to Farm Machinery Selection', were that farmers were too conservative in choosing speeds at which to combine, and that driers could as well be run early in the season to assist natural drying, as later on when rewetting in the field was common.

In a recent combine survey, over 50 per cent of farmers were found to be operating at less than 2·5 mile/h whereas this value could be taken as a minimum for economic operation with present day machines. The key factor concerns threshing losses through the combine, which could be economically allowed to run to 2 per cent of the crop, or around 80 lb/ac; and cutter bar and shedding losses, which can easily increase to 5–6 per cent at the end of even a good season.

Few farmers operated combine loss monitors and many of these could not put numerical values on their actual losses. The ADAS was being encouraged to help farmers by showing them jars containing the numbers of grains equivalent to a given loss rate, for instance 500 grains/yd was equivalent to a 70 lb/ac loss from a 12 ft combine.

The audience of about thirty people, including representatives from AMTDA, seemed unwilling to accept that one could successfully start combining at around 30 per cent/m.c. While granting that the local growing season was relatively compressed, Mr Rutherford maintained that dry matter in the ear reached a maximum at around 40 per cent moisture content, and hence one should start combining as soon as the separation mechanism could handle the crop. There seemed little point in letting the long sunny summer days slip by, while a drier was standing idle and could be used in removing dew from the crop. Starting ten days earlier could save high shedding and cutter bar losses later on, and also facilitate early cultivation, to enable a greater acreage of winter cereals to be sown. This was the essential concept, to see machine cost, timeliness and harvested yield all interacting in the cereal crop system, while this itself was likely to affect the economics of the crop to follow.

Mr P. R. Philips of Newcastle University, whose own investigations of economic combine operation made him a keen contributor to the discussion, moved the vote of thanks to the speaker at the close of a successful meeting.

OBITUARY

The Council announces with deep regret the death of the following members of the Institution:

Dearn, A. F.	*Member*
Robinson, H...	*Associate*

THE EFFECT OF MACHINES ON DAIRY BUILDING LAYOUTS

by C. Dobson*

Presented at the Autumn National Meeting of the Institution of Agricultural Engineers at the Theatre of the Faculty of Letters Building, University of Reading, Whiteknights Park, Reading, on 30 September 1971

The increasing use of machines designed to move fodder, dung, milk etc. in and around dairy buildings has had a significant effect on the design of the various buildings making up dairy units. This paper does not attempt to discuss the machinery details but does set out some of the more important considerations that arise when the installation or use of machines are being contemplated.

In the main this paper discusses the effect of choice of silage storage system, silage conveying systems and muck disposal systems on building design and gives some information on the effect on winter labour requirements.

Some interim results of a National (England & Wales) Farm Buildings Survey are given showing the frequency of various types of new buildings now being erected.

Tower Silos

Before planning tower silos there are a number of basic questions that first must be answered. These are:—

(a) Is more than one tower required?
(b) Is more than one type of crop to be stored?
(c) Is mixing of silage with concentrates or other additives required?
(d) How are the silo contents to be transported to the cows?
(e) What is the overall effect on labour and building costs?

Siting of Towers

If the answer to the first three questions above are positive then optimum plans will need to be based on a group of towers sited near to the housing block but in a low priority area. Priority areas being reserved for milking and muck disposal activities and space for future extensions.

At least 5 metres should be provided at the sides of towers for filling operations and 10 metres at the ends of groups of towers for circulation of vehicles.

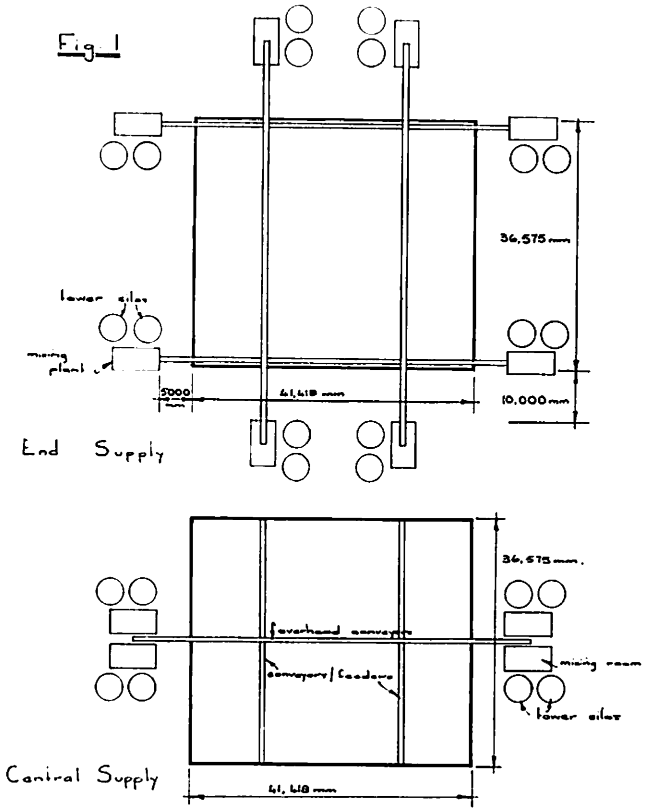
Conveyor lengths to fixed feeders requiring either end feed or centre feed will be found to be the same whichever side of the housing block is selected (Fig. 1).

For groups of towers the relationship of underloader at its lowest point and the adjacent conveyor need careful consideration. Where the unloader has no lifting facilities then in most cases the conveyor should be in a trench, at least 1—1·3 metres below the bottom of the silo (Fig. 2). This in turn can effect the design of the silo foundations.

Choice of Feeding Machine

These can be fixed (augers, belts or chain and flight etc.) or mobile (self unloading trailers etc.).

With towers a combination of the two is economically more attractive than a system depending on fixed conveyors. Automating a tower loader and a short length of conveyor/elevator to fill a trailer is a relatively simple job when

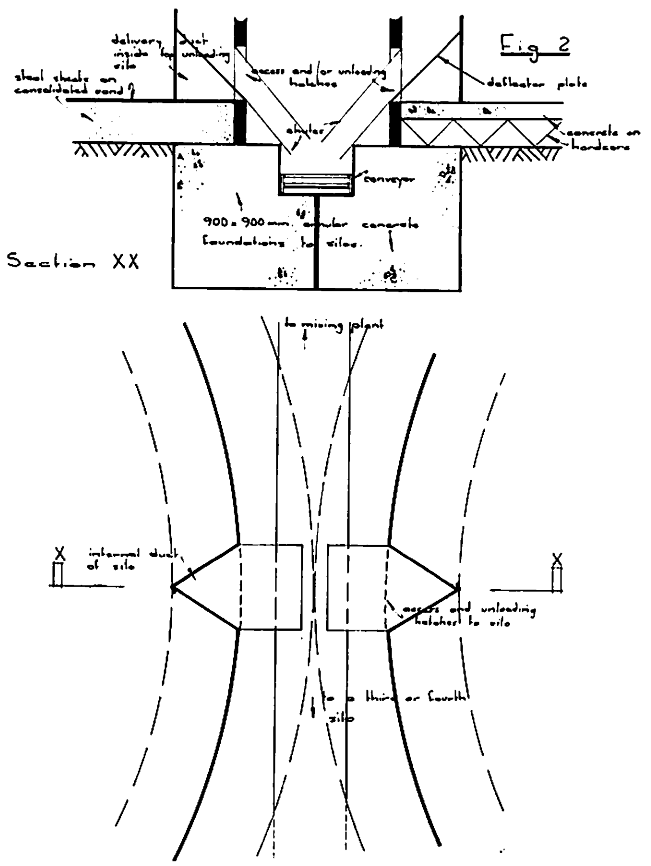


compared with the problems of having a fully automated fixed conveyor system.

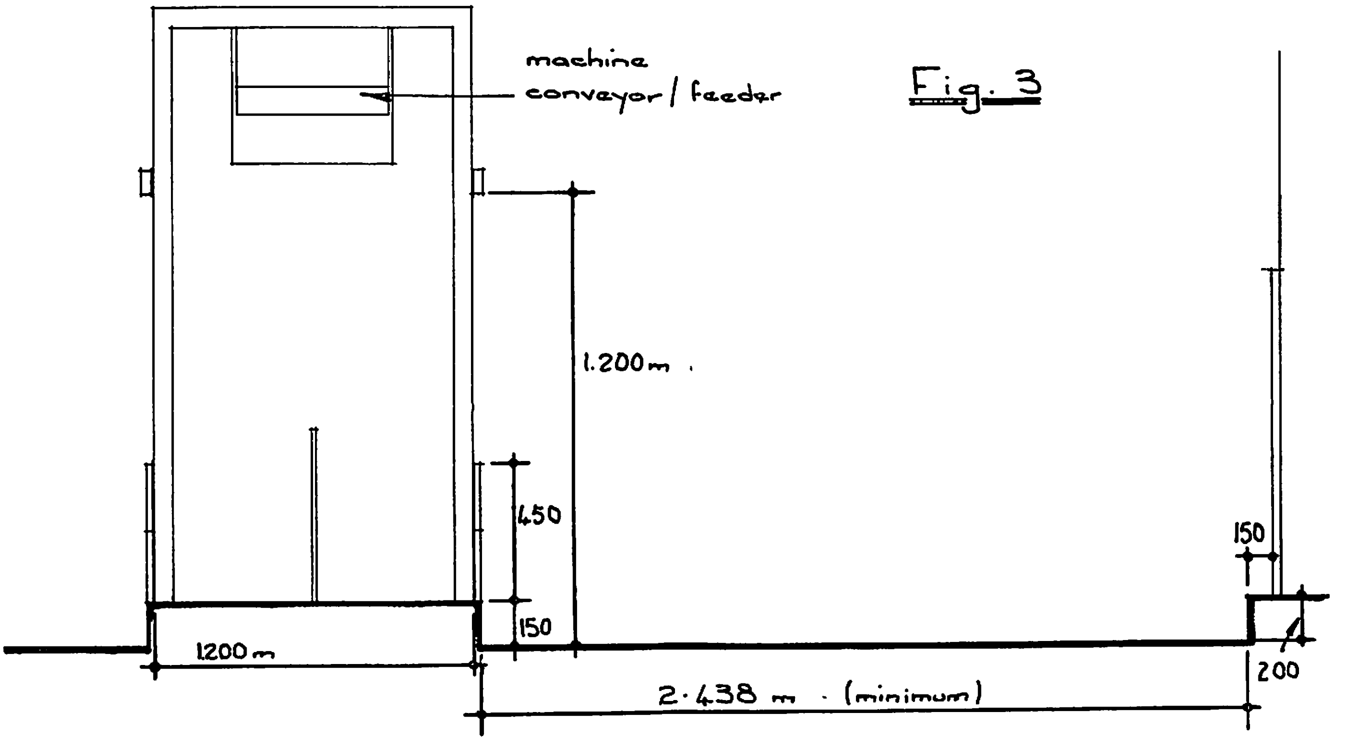
Effect on Building Dimensions

Fixed Conveyors/Feeders

There is no need for a feeding passage. Single sided mangers would require twice the length of feeder that would be



* Agricultural Development and Advisory Service, Reading.



needed for a double sided manger consequently mangers are almost invariably double sided : i.e. cows fed head to head.

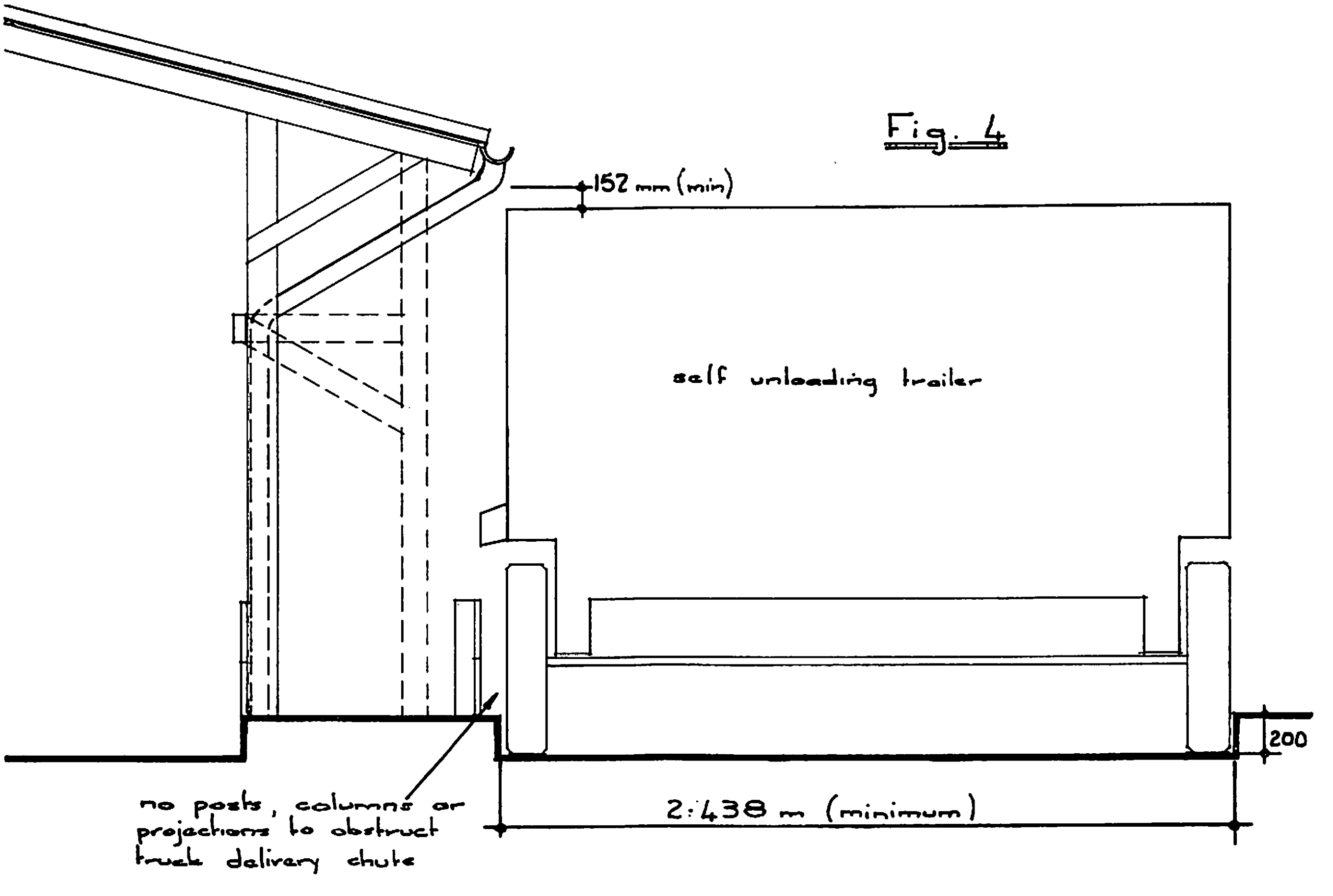
The feeder needs to be capable of feeding different amounts to each side and the manger requires dividing to allow for separate different rations. The minimum manger feeding area dimensions are shown in Fig. 3.

Without automation the labour requirements (Hunter) are probably y (mins/day)$=7\cdot0+0\cdot31x$ where x=number of cows : i.e. for 100 cows=38 mins per day.

Mobile Feeders (Self Unloading Trailers)

These are normally hitched to a tractor. At least 7·3 metres turning space is required at openings into tractor passages. Mangers and buildings should be designed with any necessary posts or rain water pipes positioned to allow the trailer outlet chute to run above the front edge of the manger (See Fig. 4). The passage may include kerbs or channels to guide the wheels of the vehicles.

For once a day feeding of 70 lbs of silage per day per cow (usually less would be required) with barley added, Hunter



found that this type of equipment could fill 30 metres per minute of manger. Based on a tower unloader working at 6 tons per hour he gives the total time required in minutes per day (y) as $y=7 \cdot 77+0 \cdot 39x$ where x is the number of cows : i.e. 46·77 mins for 100 cows

Mechanized Feeding from Clamps and Bunkers

Self unloading trailers and hydraulic loaders are commonly used for loading and transporting silage from clamps to feeding areas. Concentrates being added on top of the silage and are adequately mixed by the unloading mechanism. This method is in use at Sonning Farm and was timed by Hunter. He gives the labour requirements for feeding 70 lbs per cow per day as $y=4 \cdot 54+0 \cdot 12x$: i.e. 16·54 mins for 100 cows.

Three independent timings were carried out with different men doing the same job. To feed 60 cows took each man approximately 12 mins.
Broken down the times were:—

	Constant (min)	Variable (min)
1. Mount tractor, bring to trailer, hitch up and move trailer to silage barn front	1·255	
2. Dismount trailer, mount grab, move to silage face (for each trip from tractor to grab).		0·555
3. Load grab, reverse, unload into trailer, move forward and repeat with desired quantity achieved—(for each 8 cwt load).		0·854
4. Dismount grab, mount trailer, move to food loft, climb loft and load barley through first floor door, move to tractor passage, return to repeat or park (average travel excluding manger filling 300 m) (for each trip).		4·44
5. Unload forage into manger 133 ft. long.		1·33

The cost of manually switched fixed conveyors, machine feeders and tower unloaders for a 250 cow unit is at todays prices likely to be at least £8,000 (ALS Tech. Report No. 18). Adding automation would cost at least £2,000. On a similar sized unit the cost of self unloading trailers and power loaders for use in clamps is unlikely to exceed £3,000 (excluding tractors). If the main purpose of machinery is to save labour then for every £1,000 invested in cow feeding machines there should be a saving of 125 man minutes per day calculated as follows:—
£1,000 at 10% over 5 years=£264 per annum.

$$\text{Cost per day over housing period} = \frac{264}{180} = £1 \cdot 465$$

$$\text{Equivalent time at } 0 \cdot 70 \text{ per hour} = \frac{1 \cdot 465 \times 60}{0 \cdot 70} = 125 \text{ mins}$$

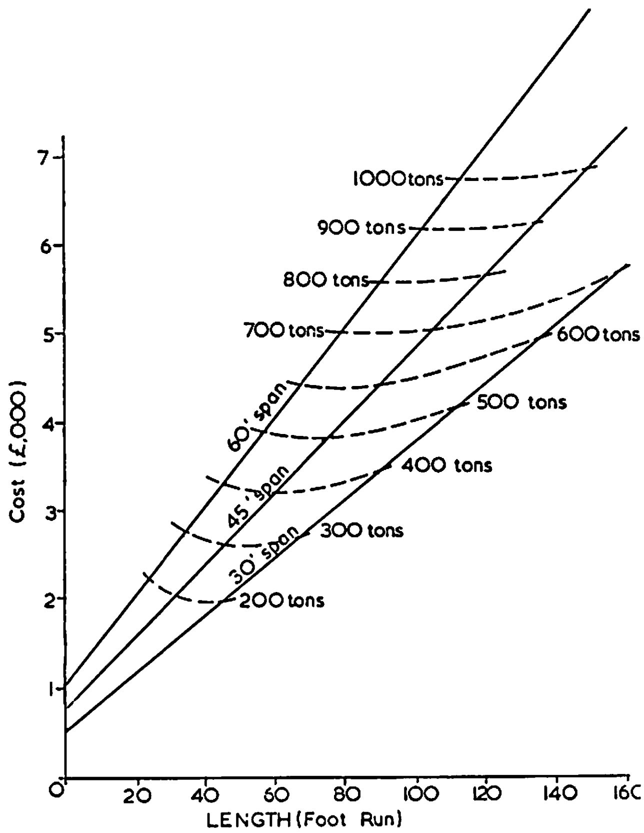
Using Hunters figures the labour requirements for 250 cows fed twice a day would be 83 man minutes per day. If this labour could be reduced to nil it would only justify an investment of about £660. Since the actual cost of a fully automated tower fixed conveyor system is likely to cost at least £7,000 more than the comparable clamp and SU trailer system then the tower system cannot be justified on winter labour savings alone.

Silage Clamps and Bunkers

These are the most common methods of storing silage (See Appendices A and B).
(Pages 135 and 136).

The shape of 2 metre deep unroofed clamps is usually determined by self feeding face dimensions. Where self feeding is not practised and particularly where clamps are roofed then the shape should be determined by building costs. Typical cost equations for steel framed barns covering 2·5 metres deep stores, walled and clad on three sides and with a 7·3 metres wide concrete apron at the open end are:—

(a) 60 ft span Total cost=£1,030+£5·680x
(b) 45 ft span Total cost= £746 £6·18x
(c) 30 ft span Total cost= £520+£7·38x
where x = number of tons.



Where self feeding is not to be adopted then new clamps, like towers should be sited in a low priority area, preferably on the high side of buildings.

Housing

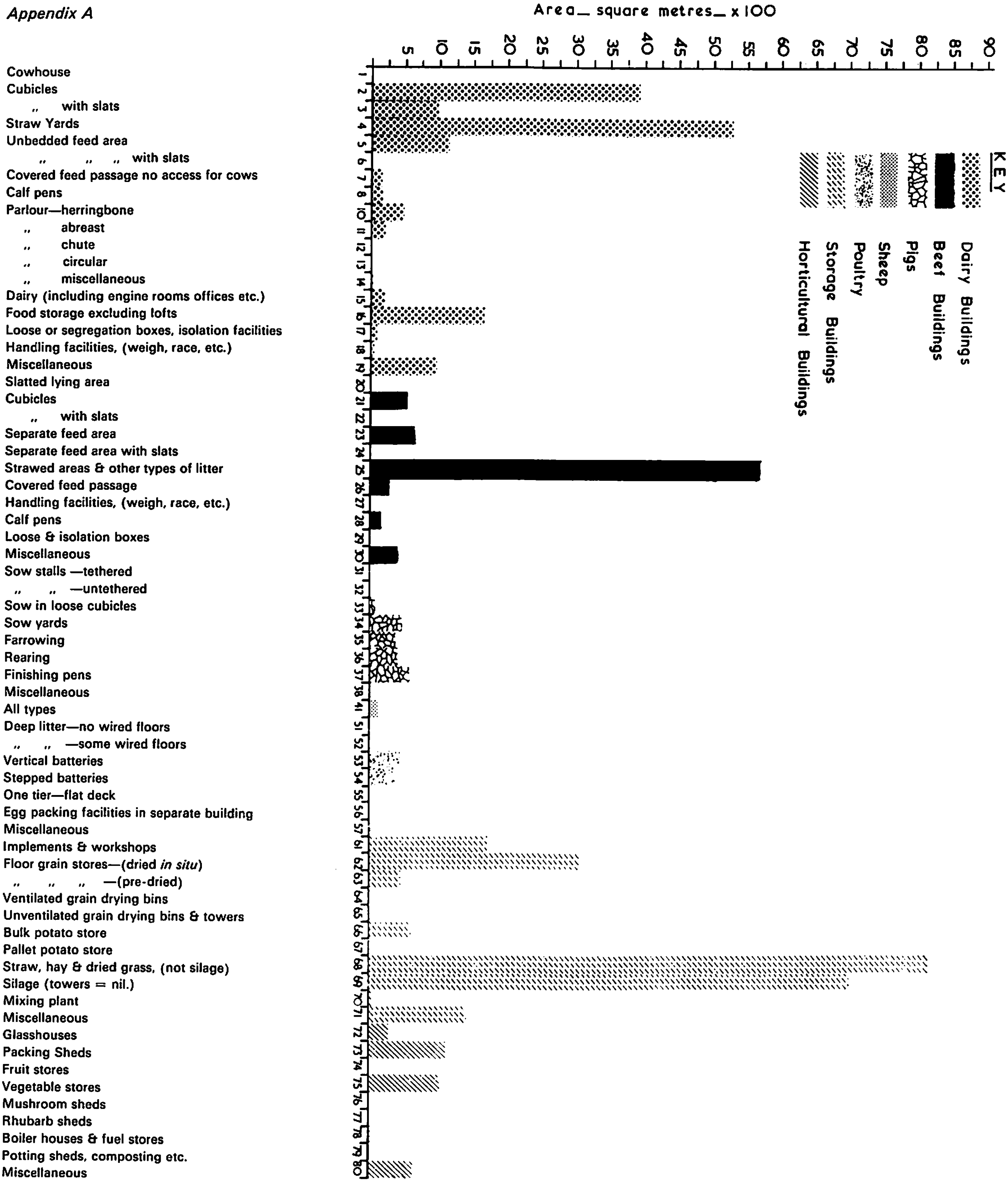
Although dairy replacements are often housed in straw yards the great majority of new cow housing is in some form of cubicle housing. Dimensions of this type of house do not vary much except where influenced by the slurry cleaning methods. Housing with slatted passages between cows or in feeding areas accounts for a negligible proportion of the total new housing being erected (See Appendices A and B). This small proportion is largely due to the fact that annual charges for labour and extra capital are higher than for non slatted systems. Most farmers adopt solid concrete passages with tractor scraping of slurry to some collection point.

Where light-weight prefabricated housing is used then careful thought must be given to prevent damage by the tractor or scraper. One of the simplest methods is to provide kerbs projecting 75 to 1·50 millimetres from the face of the cladding (Fig. 3).

Levels of Floors, Roads and Aprons

With solid floors there is a wide latitude in the acceptable falls. For various reasons level floors in animals housing

Appendix A

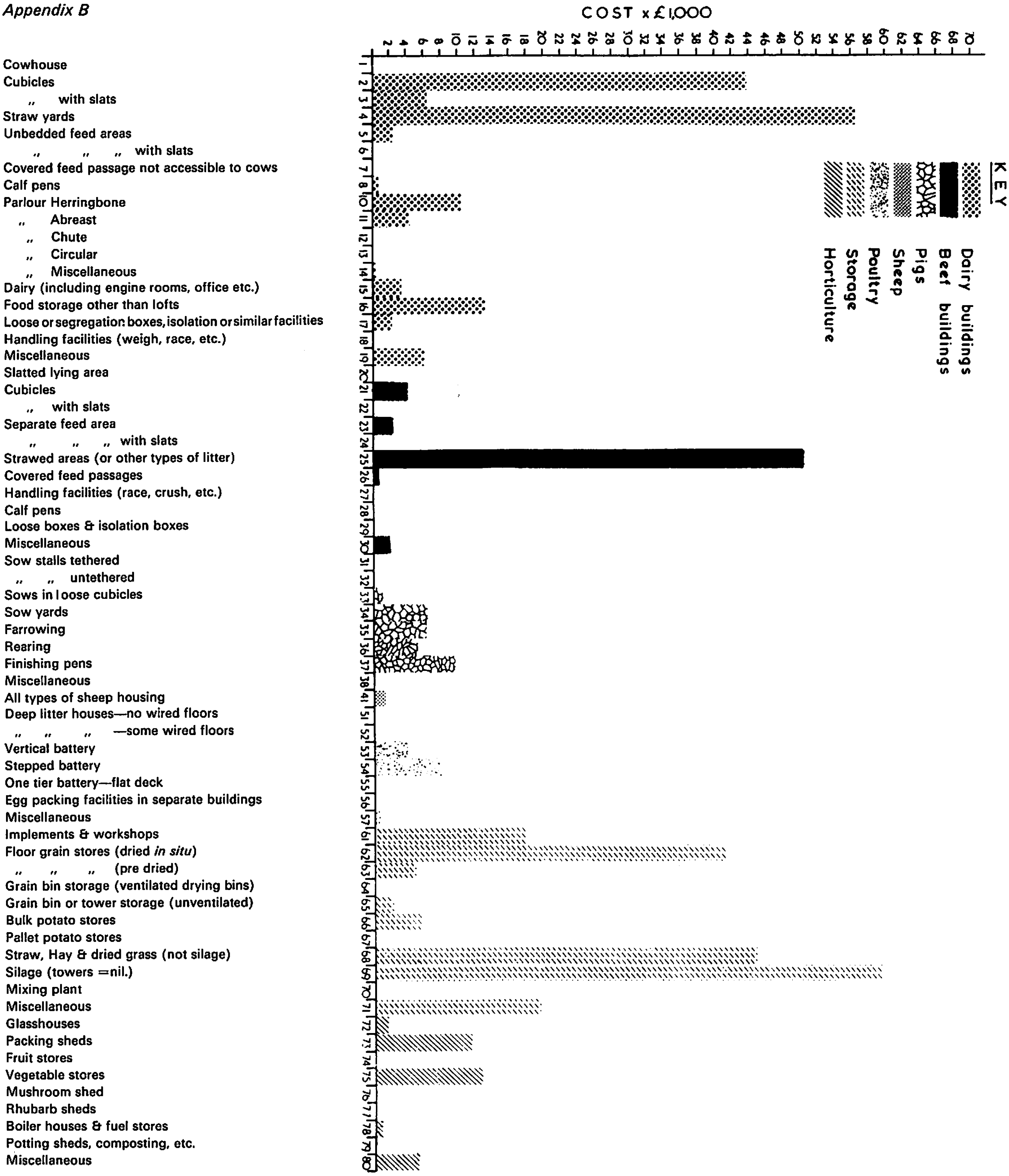


should be avoided, mainly because pools of liquid are then unavoidable particularly in unroofed areas.

Falls can range between 1 in 30 to 1 in 90. Where the Bridgets type horizontal roof is used then under farm conditions 1 in 70 is probably the minimum to ensure good roof drainage. The eveness of the roof fall is a reflection of the accuracy of the gradient on the floor. Since farm concreting is not always as accurately set out as it might be then this can be a limitation on the roof falls. Where formwork and workmanship are both of good quality then 1 in 90 should be suitable for the roof and floor.

Usually two passages per house plus any tractor feeding passages are necessary. On this basis for a 150 cow herd in two houses there would be 4 or 5 passages.

Where cubicles and walls etc. are prefabricated then it is vital that passages should be exactly parallel both in line and gradient, otherwise building erection could be difficult and expensive. Roads are usually provided at each end of the houses and this demand for parallel passages affects the levels of the concrete roads also. If tractor and vehicles are to be able to turn smoothly from roads into passages the relationship between passage and road level needs to be



carefully worked out. The roads at the ends of the houses should again be parallel in line and gradient. This ensures that any steps or ramps to the entrances to each passage are all the same. (Fig. 6).

Ramps in the road itself should be avoided otherwise they will interfere with slurry scraping along the roads. Any entrance ramps (usually 75 to 150 mm high) should be in the passage themselves (Fig. 6).

The milking block is often situated alongside one of the roads across the ends of the housing blocks. Any doors into the building from the road should again be 150-200 mm above the road level to prevent slurry flowing through the door during slurry scraping. Similarly any cattle races placed alongside the road should have the floor of the race 150-200 mm above the level of the road.

Slurry Collection Points

There are a number of ways of collecting slurry from the various areas. Much will depend on its consistency and the method of cleaning. In most cases the cleaning method is by tractor scraper but in and around the milking block the practise of using high pressure hoses is increasing particularly in association with liquid slurry systems.

In solid muck handling systems then, of course, the amount

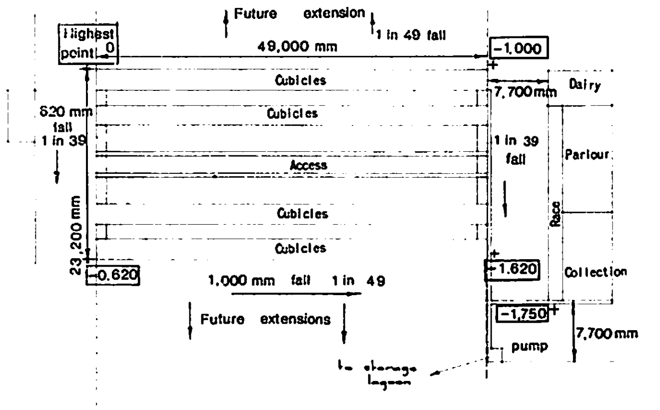


Fig 6

of surface water should be kept to a minimum and should drain to separate outlets (i.e. not into the midden). Solid manure can be scraped either up or down hill and to some extent the same applies to semi liquid slurry.

A convenient point for the collection of slurry is usually about 10 metres away from the entrance to the assembly area. Where because of some site restriction it is necessary to provide the slurry storage facilities perhaps 100 metres or more away from the buildings, then it is often sensible to collect the slurry in a small pumping chamber near to the assembly area and use a sludge pump to pump the slurry from the collecting point to the store. The capacity of the pumping chamber can be quite small.

The period of storage being determined by the incidence of pump break downs and the time taken to effect repairs. In most cases a 2-3 days capacity would be quite adequate. Where the slurry is to be handled in liquid or semi liquid form then the provision of collecting ducts across the ends of doorways is often worth considering. These ducts can obviate the need for a considerable amount of tractor scraping.
Where such ducts are provided then the design of the grid or openings into the duct needs careful attention. Dimensions that are normally suitable for cattle grids have been found to provide too small a gap area. It would seem that the duct should have an opening area of at least 1·5 square metres. This can be in the form of a number of holes or one large hole that can be covered by a removeable plate when not required. Unlike normal cow slurry storage ducts, these ducts are not for storage and need not be laid level. They can be laid parallel with the adjacent road, i.e. at a fall of about 1 in 30 to 1 in 70. The cross sectional area of the entries to the ducts is dictated by the volume of slurry that will be discharged from one scraping. It would seem that this should be at least 0·6 square metres for the full width of the entry (usually a gateway). If required, the connections between entry points can be much smaller, i.e. 200-300 mm diameter pipes.

Shape of Cow Assembly Areas

In some areas it has become popular to adopt semi circular type collecting yards as an aid to smoothing the flow of cows into the parlour. When considering such a plan it is always worthwhile detailing the proposed method of cleaning. It may be that the time saved on cow collection can be more than offset by the extra labour in cleaning a circular type area. This will always be true if the area has to be cleaned by use of hand scrapers etc. In these cases the adoption of a rectangular area is to be preferred and again thought should be given to the method of cleaning particularly if tractor scrapers can be adopted.

Conclusions

Before selecting a machine, the overall effects on labour costs, machine capital costs and any added building costs need to be studied.
Where tractors with scrapers or trailers are to be used the width for turning, the concrete levels and the positions of ramps all require careful consideration.
The overall building plan requires zoning into priority areas and the housing, feeding, storage and milking elements sorted out in order of priority. The need for further extensions should never be overlooked since the size of individual herds has been increasing steadily since 1945.

ENGINEERING PROBLEMS IN FORAGE CONSERVATION

W. F. RAYMOND, The Grassland Research Institute, Hurley

1. Introduction

At Hurley we are concerned with growing forages and feeding animals. Your problem, as agricultural engineers, is to harvest this forage and to devise means of transferring it, either directly or through storage, to the animals we feed. It is vital that we understand each other, and that we get our priorities right. For just as it would be foolish for us at Hurley to grow forages for conservation which you cannot mechanize, so it would be unwise for you to develop mechanization systems which bear no relation either to the kind of forages we may be growing or the sort of animals we may be feeding in 1980. We accept, of course, that in many areas grazing rather than conservation will continue as the main method of utilizing grass and other forage crops.

It is essential now, more than at any time in British agriculture, that people from different disciplines should work together to get an integrated picture of overall requirements, rather than that each should study in great depth aspects of their own speciality which may be quite irrelevant to what is happening in other spheres.

Therefore I want to talk not so much about the exact details of machines as about what we are trying to do as agronomists and nutritionists in forage conservation and feeding. We can then see the gaps in our knowledge, and by working together we can perhaps fill these gaps.

Why do we need forage conservation at all? The basic problem of grassland management is the pattern of forage production throughout the year; a very low level of production through the winter is followed by a tremendous boost of growth in the spring, a mid-summer trough, perhaps a slight autumn flush and a falling off again into the winter. In contrast we are faced with an urban population which wants food evenly throughout the year; yet because of the way grass grows we tend to produce more milk in the summer than in the winter, and to fatten cattle in the late summer. Our joint problem as agronomists and engineers is how to smooth out the variable pattern of forage production so as to even out the supply of animal products to the market. Up to now, as a nation, we have balanced this by importing a lot of meat and other products for sale in the winter; the challenge to British agriculture in the 1970's is how far we shall be able successfully to even out this variable production pattern. To do this we must find methods of transferring the variable pattern of forage production into a fairly uniform pattern of animal output and marketing.

A paper presented to the South-East Midlands Branch, I.Agr.E., on 27 January 1969.

This problem is in fact exactly the same for the grasses and forages as for the cereals, potatoes and other crops grown on the farm, for none of them grows on every day of the year. Virtually all the crops that you are concerned with mechanizing have a peak of production. But I want to suggest that the trouble with forage conservation is that we have approached it quite differently from the way that we have tackled the harvesting, storage and distribution of direct sale crops such as cereals and potatoes. This attitude is reflected in all the discussions one has about forage conservation, which is one of the most inefficient jobs the farmer does; yet the same farmer will make a first-class job of growing and of storing cereals and then feeding them throughout the year to the animals or humans that need them.

A reflection of this was the tremendous interest that followed immediately after Preston, in 1960, developed the barley beef feeding system as an alternative to feeding cattle on grass. Feeding barley throughout the year created great enthusiasm because for the first time the farmer was using a crop which he knew how to store efficiently, and which he could feed to his beef animals at the same level every day of the year. Hence it became possible to market beef every day of the year (that 'barley beef' now accounts for only 6 per cent of our beef production is, one may add, largely due to the farmers' readiness to adopt alternative grassland systems developed by 'integrated' research in the 1960's).

To put it into focus, there is a fundamental difference between the way we regard cereals and the way we regard hay or silage. As a friend of mine once said, "When I grow barley I buy a £3,000 combine, trucks to transport the grain to my buildings, a grain drier, a ventilated grain store, and cleaning machinery to do the job properly. For silage I use a buckrake and a few railway sleepers." This summarises the whole difference in approach. The operative word with forages is 'Cheap', and cheapness has conditioned our whole thinking about forage conservation in this country. In the 1950's we talked about grass as the cheapest food for livestock; unfortunately this led to the idea that not only should we *grow* it as cheaply as possible, but that we should also *use* it as cheaply as possible. And as a direct result we get the high losses, which many have accepted as an inevitable part of forage conservation. NAAS figures for these losses are greater than 30 per cent; in other words we accept that when we make hay or silage we are going to lose at least 30 per cent of what we cut—and every now and again we are successful in losing the lot. If you told a good barley grower that he would lose 30 per cent of his crop he would start asking one or two questions.

And obviously if conservation losses are going to be high the farmer might just as well start with the biggest, bulkiest crop possible—and such crops are generally mature and of low nutritive values—so that he ends up with a product of low nutritive value. These two aspects, high losses and low feed value, are inextricably linked in the primitive systems that we now use in forage conservation systems which contrast with any other form of crop conservation on our farm. The low value arises partly because the farmer, knowing he is going to lose much of the crop, starts off by cutting a low value crop, but also because the losses that do occur are generally of the most nutritious parts of the crop, i.e. the leaf and soluble materials. And this low value of hay and silage is accepted in our farm rationing systems; with hay or silage maintenance feeding is all that can be expected and obviously if we are producing something of low nutritive value it must be made cheaply. I believe that if we accept this concept of cheapness we must also accept the vicious circle of high losses and low nutritive value in the product.

When we first became interested in forage conservation at Hurley, about 1960, we discussed the fallacy of this approach with our colleagues at NIAE (Silsoe), and asked why work with forage should be restricted to buckrakes and railway sleepers, when the cereals farmers were prepared to invest in combines, grain stores and so on. Starting from this point we decided that we had first to study the *biological* features of conservation systems which would convert high loss into low loss, and how to produce feeds of high nutritive value, without worrying *in the first place* about expense. Until we had examined these aspects we could not possibly question whether the systems required would be practical or economical, and whether or not they would present problems to the engineer.

Thus we first emphasized the overall problems of reducing losses and improving nutritive values. We must not begin with the idea that forage conservation systems *must* be cheap (although this does not mean that systems we develop will necessarily be expensive). But clearly if in future we can produce better products with lower losses then we can obviously use rather more expensive systems than we have envisaged in the past.

What are the biological possibilities of forage conservation, and what are the key features we must build into our future forage systems? First of all there must be lower losses; although we cannot realistically demand 100 per cent conservation (just as few people get 100 per cent conservation of barley) we cannot continue to accept the present losses of from 30–100 per cent. Secondly we want higher nutritive value, and also the possibility of producing different qualities of hay and silage for different classes of stock. Thirdly we want the system to be mechanized, and it is here that the engineer needs to know the characteristics of the systems developed by the agronomist and nutritionist. Finally the key feature emerges that, if each crop is to be cut at the stage of optimum nutritive value, we must have systems which are independent of the weather. Independence of weather is especially important in the U.K., where we have a grass-growing climate, which by definition makes it a difficult climate for traditional conservation methods.

Entirely new systems may be developed in the future, but at present six systems appear worth considering, and I think it is worthwhile looking at these in relation to the points which I have mentioned, i.e. degree of losses, level of nutritive value, possibility of mechanization and independence of the weather.

2. Methods of Conservation

2.1 Haymaking

We make 9 million tonnes of hay in the U.K. each year. But haymaking is essentially a method in which we cut grass, leave it in the field until it is fit to bale, store it, and then feed the bales that have not moulded. I do not think that we can base an intensive agriculture in this country on such a system—although I am sure thousands of farmers will go on making hay until the end of the century! I do not think, in the terms of our discussion, that barn drying of hay is the complete answer, not because one cannot make a superb feed in the barn hay drier, but because it does not satisfy my last point of total weather independence. The feature of barn-dried hay as we at present know it is that the crop must be wilted in the field to 50 per cent dry matter or higher before being brought into the barn. There is therefore a tendency to leave the time of cutting the crop until the weather forecast is favourable, rather than basing it on whether the crop is nutritionally ready for cutting.

2.2 Tower and High Dry-Matter Silage

There will, I know, be much less agreement if I put tower silage into the same problem category as hay. There are parts of the country where the farmers are very successful at both barn-hay drying and tower silage production; but I do not believe that these can be the ultimate systems, because even with tower silage, with all the advantages of mechanization it gives us, the crop has to be wilted in the field to 35–40 per cent dry matter. And as we go further west the system becomes more hazardous and satisfies less and less the requirement of independence of the weather.

2.3 Chillage

At Hurley we have been deep freezing grass for the last 20 years, to use in our nutritional experiments. It is a wonderful way of preserving grass, which when thawed out is just like the fresh product. But I am not sure if the enthusiasts for this system have visualised the problems of scale. We store about 50 tonnes a year at G.R.I.; it is quite an effort putting this tonnage into store, and a large amount of refrigeration is required. An even bigger problem is that if the frozen grass is stored in a heap it forms a green 'iceberg' and has to be hacked out before it can be fed. To get over this the grass could be put into individual polythene bags, but this would increase the cost and the problems of getting the grass into cold store. A further problem would arise in feeding the frozen grass—10 tonnes of frozen grass introduced into a cow shed would have a severe effect on environmental conditions. I don't think that this system has a place in the future.

2.4 Low Dry Matter Silage

By low dry matter silage I do not mean necessarily unwilted silage, but rather grass which has been cut at the right stage of growth, in terms of nutritive value, and which has then been loaded into the silo as rapidly as possible and with the minimum of losses in the field process. If it has been cut in the morning, loaded at 4 o'clock in the afternoon, and has wilted in the process then this is fine; but the system must be such that if it is raining when the crop is ready it can still be cut and put into the silo, without the losses caused by over-maturity or weathering in the field. In other words, if we can get the advantage of some wilting—and there are certainly advantages in terms of silage fermentation—then we will take it; but the primary demand of the system must be that the crop is cut when it is at the right stage of feed value, and not when the weather forecast is favourable, even if this means putting the crop into the silo without wilting.

2.5 Dried Grass

The only other large scale system that meets these requirements at the moment is high temperature dehydration. Like low dry-matter silage this is relatively independent of weather conditions in the field, although I must admit that both output and cost of production are adversely affected by exceptionally wet weather.

I would thus like to concentrate on these two systems, and to look at some of their implications for mechanization; finally I hope to bring them together, because in my view they are not alternative systems but complementary systems of forage conservation.

3. Digestibility and intake

I have suggested that conserved forages must have a reasonably high feed value, and so I would like to consider the two main components of nutritive value which concern the agronomist and nutritionist. They will not concern you *directly*, as engineers, but I believe that your task will be to develop systems which will translate the digestibility and intake characteristics of the crop into a product which has high digestibility and which will be eaten in large quantity by the animals. These are the two key features in animal production, Digestibility and Intake, and they must be the basis of all conservation systems. If together we can produce feeds with these characteristics, and with relatively low 'system' losses, then we are well on the way to having a viable system of conservation.

3.1 Digestibility

First I want to look at forage digestibility, because this is the factor which is particularly affected by date of cutting. I will not describe how we measure digestibility, but suffice it to say that crops such as forage, straw and hay vary widely in the extent to which ruminants—cattle and sheep—digest them. In young forages as much as 75 per cent of the forage can be digested, or, put the other way round, only 25 per cent comes out in the dung, but with mature forages only half is digested and half comes out in the dung; the higher the digestibility the better the utilization of the feed, and so we must aim to our immature forages for conservation.

As the grass crop develops the stems elongate, the ears emerge and it steadily decreases in digestibility; hay made from young grass is a good feed, while very old mature hay is a poor feed. Even more important, if we grow bred varieties of grasses these change in digestibility in a predictable way; with S.24 ryegrass for instance we can predict fairly closely the dates in April, May and June at which it will reach a given level of digestibility. But at the same time as digestibility is falling, yield is increasing, and the advisor must then discuss with the farmer the best compromise between yield and digestibility for his particular feeding system. Once this is decided the date of cutting is virtually set. For instance if for the next winter we want dried grass, silage or hay of, say, 65 per cent digestibility, to obtain this we must cut S.24 ryegrass on May 21st, or within a very few days of that date; implementation of this decision is difficult or impossible with most present conservation systems. In short the conservation system of the future must allow us to decide that, if the D value will be 65 per cent on May 21st, then the crop must be cut between May 16th and 24th—an acceptable range, as no farming system will allow us to conserve all our crop on one particular day, but it will prevent a serious fall in D value, such as might happen if harvesting were delayed until it had stopped raining.

The agronomists and the engineer must accept a reasonable compromise; the engineer may offer a method which is completely independent of the weather but cannot harvest 10 million acres of grass within a week; the agronomist, recognizing this, has available other grasses whose changes in maturity are not the same as S.24. For instance there is S.23 ryegrass, which because it is later flowering and later maturing than S.24 has its digestibility pattern delayed, so that it does not reach its 65 per cent D value until early June. The sort of agriculture we are thinking of will not put all the fields down to one seeds mixture, but will split into fields sown to different grasses (and other forage species) chosen because they will give a succession of cuts—in just the same way as the farmer grows some winter barley and some spring barley to give a spread at harvest. By sowing fields to 3 different ryegrass varieties the farmer can already harvest forage, all within a few units of 65 per cent digestibility, but over a period of 2 to 3 weeks instead of the single week available for S.24. This is just the beginning, and with the varieties that are already in commercial use. But we can now discuss with the plant breeder the possibility of breeding late-maturing grasses, which will maintain high digestibility even later in the the season. For example, there is a ryegrass bred in Holland which can be harvested up to June 15th, and still have a high digestibility value. This indicates the scope for producing new forage varieties which will make more sense of engineering developments by allowing a better spread of the season of harvesting.

In the past we have made nonsense of the work of the grass breeder. Each variety of ryegrass is grown in isolation from other crops of ryegrass, the crop is rogued, the seed harvested, dried and packed in sealed bags, and each variety carefully stored separately. Then, before the seed is sown the merchant takes bags of several different varieties and mixes them together. Imagine doing that with seed potatoes! Until we talk about using grass as a crop, with each field sown to a single variety with a predictable performance to give a sequence of crops for harvesting, I do not think we shall make sense of sophisticated conservation systems.

This is the picture of digestibility; we are learning how it changes for many different grasses and legumes as they mature, and also how digestibility patterns change in regrowths later in the season. The information is now becoming available to the farmer, and already many of our farming friends have a digestibility-date graph on the office wall. For example a farmer in Dorset predicts that his Italian ryegrass should be made into silage between the 20th and 25th May, and because he is genuinely working to a digestibility value, he makes his silage between 20th and 25th May, and to do this, incidentally, he has developed a silage method which is largely independent of the weather (the Dorset wedge system, described below).

3.2 Intake

As I mentioned, besides the feed being high in digestibility, it is also important that animals are able to eat a lot of it. We are therefore very interested in knowing what factors determine how much an animal eats; and most important we find that animals are able to eat more of feeds which are highly digestible. Any good stockman knows that a beef animal readily eats a bale of young, leafy, highly digestible hay but eats very little of a bale of straw. This is because the highly digestible feed passes quickly through the digestive tract, whereas straw just fills up the system. In short, with a highly-digestible feed animals eat a lot and they digest a lot and therefore they give a high level of production; with straw they eat little and do not digest it very well and so are unproductive. This emphasises again the importance of having high digestibility feeds, for by cutting the crop at the right stage of growth we also get a high intake characteristic.

This is particularly true with hay, but problems of intake do arise with silage. If we take a good crop and make good hay, or good silage, they will both have a high digestibility similar to the crop as cut. But when we offer both feeds *ad limitum*, cattle or sheep tend to eat more dry matter as hay than as silage. Thus despite the problem with weather-dependance of hay-making, this result, which has emerged from many experiments in the last ten years, appeared to indicate a real feeding disadvantage of silage compared with hay.

So how can we possibly consider silage as a main conservation method for the future? The reason, I think, is that these experiments on forage intake have been obtained at research stations, and that the results have then been translated to commercial farms without considering farm systems of feeding. This is a very dangerous extrapolation. The research results have simply shown that if half of a field is made into silage and half into hay, and each is then fed separately to similar animals, the animals are likely to eat more hay than silage, and are likely to produce more. It is then concluded that hay is a better feed than silage. But in practice the farmer does *not* feed his animals just on hay or silage alone, but includes other components to make a complete ration. *The important question is not whether hay or silage alone is best, but how hay and silage compare when they are included as part of a mixed ration.* Ref. 1/2.

Let us then consider the response of hay and silage intake to the feeding of increasing quantities of barley—for barley feeding will continue as long as the arable farmer in U.K. is prepared to subsidize the livestock farmer! As we feed increasing quantities of barley the animal eats less hay; this decrease is quite rapid, at 0·68, so that for every kilogramme of barley the animal eats it reduces its hay intake by just under 0·75 kg. It will grow more rapidly, because 1 kg of barley has a much higher feed value than the 0·75 kg it replaces, but this may not represent value for money, in the sense that it is a partial replacement rather than positive supplementation. But if we feed similar quantities of barley with the silage we find that it replaces the silage much less completely, the replacement being something like 0·28, and so we have better supplementation, in which silage intake is reduced by only about 0·25 kg for each 1 kg of barley fed. Thus as the proportion of barley fed increases the difference between hay and silage decreases; in an experiment with lambs, by the time we were feeding 40 per cent of barley and 60 per cent of hay or silage in the total ration there was no difference between the amounts of hay and silage dry matter eaten.

I have placed some stress on this aspect because the argument of the 1960's, that hay was a better feed than silage, was based on feeding hay or silage as sole feed. This perfectly legitimate experimental result was then applied to the farm situation where it was not necessarily applicable, because the feeding of barley or other concentrates is a quite reasonable and economic thing to do at present. Under these circumstances the difference between hay and silage, in terms of the amount animals will eat, may virtually disappear.

It is of course possible to make silage which is so poor that no animal will eat it and which therefore can make no contribution to any ration. But there has been a problem even with well-made silage, which has an intake lower than that of hay—except when both are fed in a mixed ration. Wilted silage is intermediate, with an intake better than unwilted silage but not so good as hay, when each is fed as sole feed; but when fed in compounds ration these differences appear of much less significance. This could be a most important conclusion; unwilted silage may be weather independent, but has been regarded as poor feed, so that most emphasis to date has been put on hay and wilted silage. In future we may be able to put more emphasis on unwilted, or slightly wilted, silage to be used in a mixed ration.

The second problem which then arises is that we are told that 'the losses with unwilted silage are at least 30 per cent'. But if the intake problem can be solved it is then legitimate to question whether it is necessary to have such high losses in unwilted silage. Clearly loss is related to the way silage is made, and recent thinking about this may bring silage right back into the fore-front of conservation methods.

4. Reduction of Losses from Silage

The development I want to talk about did not take place at a research institute. Research workers have, with a few notable exceptions, been inhibited by this idea of cheapness in conservation in their research programmes. They have not seriously tackled the real problems of conservation, i.e. how to reduce losses and how to produce better feeds, because they have considered that farmers generally could not afford to use better methods. So it was farmers who introduced tower silos into this country, it was farmers who began the present re-look at dehydration, and it was certainly farmers who developed and then demonstrated the potential of conservation by low-wilt silage making. A lot can be learned by travelling around the country to attend farmers' discussion groups, and certainly the three most important systems of conservation, tower silage, dehydration and sealed wedge silage, all developed in this country by farmers, first came to my notice in this way.

The principle of silage is simple. All silages are made from a heap of cut crop which ferments to form lactic acid and reduce the pH to give stable preservation—if you are lucky. Many people are not very lucky, or not very skilled, and it is touch and go whether they produce a heap of silage or a heap of compost.

There have been three phases of silage making since the war; the first was pretty messy; in the second, the hot silage phase, the grass had to heat up to 50°C before the next layer could be loaded. In the third phase the silo was filled very rapidly, and if the thermometer went over 30°C you were told to expect trouble. To my mind none of these made any rational sense, in that little attempt was made to explain to the farmer why a particular system should work. In a book published in 1868 silage was described as 'green crop kept in the complete absense of air', and this we have conveniently forgotten. In 1868 they knew the principles of how to make silage, but they did not have polythene—and plastic sheets are halfway to the solution for silage. A heap of grass heats up even if we consolidate it; as the warm air rises out of the mass it draws in fresh cold air, and the convection current set up prevents the establishment in the silo of the vital anaerobic condition. By the time the grass has packed densely enough to prevent this movement of air the temperature within the mass may be well over 38°C, most of the sugars in the grass will have been burnt up and we are well on the way to making poor silage. Consolidating the grass to stop it heating up is a laborious and sometimes a rather dangerous job; it is also sometimes most ineffective because with a dry spongy crop the whole mass breathes as the tractor goes to and fro, which is a very good way of aerating it.

What a number of farmers found was that the most effective way to prevent heating was to stop the warm air escaping by covering the surface of the silo whenever crop was not being loaded. This prevention of convection is the basis of the development in sealed silo systems which has become known as the Dorset wedge or sealed-wedge system. The basic idea is now being adapted to different methods of filling silos, whether these are bunkers or field clamps, that whenever grass is not being loaded the surface of the silage must be covered. We now do this at Hurley, and are making much better silage than ever before and with greatly reduced losses. High Mowthorpe E.H.F. have shown, over two winters, that the system loss from cutting the crop to feeding the animals was only 15 per cent. Surprisingly this was about the same as the loss in the tower silo system on the same farm, when field and harvesting losses were added to in-silo losses. Hence direct-cut or low-wilt silage, which reduces field losses, begins to satisfy the requirement that the system must have a low total loss. The other major development in silage making is the introduction of formic acid as an effective silage additive. In fact formic acid has been known for a long time but has had little impact because it was never uniformly mixed with the cut crop. Now this can be conveniently ensured by a simple device, fitted to the forage harvester, which introduces the acid directly into the cutting chamber—and for the first time allows the results of laboratory silage experiments to be translated into a practical silage method.

5. Grass Drying and Feeding

Obviously I think there is a future in silage. But we shall have to feed something with it because of its low intake characteristic; one of the feeds we are likely to use will be dehydrated grass. I want to develop this idea, because dehydration has a big engineering component and so must be of interest to you. It has been under a shadow for the last 15 years since it failed in the 1950's. I think we know now some of the reasons why it failed—the scale was wrong, the machines were wrong, and the crops were wrong. But I believe we have now learned enough about all these aspects to justify a reappraisal.

First of all dehydration, unlike ensilage, can actually increase the nutritive value of grass. If we dehydrate and package properly we can convert the crop grown in the field into a much higher quality feed—and this is quite a change for a conservation system! Results of an experiment at Hurley illustrate this point and show the real benefit that can be obtained from packaging the dried crop and I believe we must package if we are thinking in terms of a mechanized feeding system. When the chopped feed from the drier was milled and pelleted the cattle ate 38 units of dry matter, compared with only 26 units of the chopped feed. Hence by milling and pelleting the dry feed we increased the amount of feed the cattle would eat—and you will remember that the intake of a feed is one of its more important nutritional features.

In a number of experiments this increase in intake following milling and pelleting has been accompanied by a considerable increase in level of animal production. For example, a daily rate of carcass gain of 0·79 kg by cattle fed on chopped dried grass was increased to 0·89 kg when the same feed was milled and pelleted.

This illustrates the importance of packaging which we are now studying jointly with our colleagues at Silsoe. We already know that, whether the crop is early cut and has a high digestibility, or is a mature crop with low digestibility, processing has a dominant effect. Milling and pelleting cannot bring the productive value of a late cut feed up to the level of a young leafy crop, but, whatever the digestibility of the feed, milling and pelleting are likely to increase its nutritive value.

However, the situation is not quite as simple as this, for what exactly do we mean in mechanized terms by milling and packaging? Different methods of milling may reduce the particle size of a given feed to widely differing degrees (different moduli of fineness) and also to different moduli of uniformity. Different machines may package dried grass in different shapes and size, in packages of differing hardness etc. And animal production may depend on any or all of these. To study this we have set up a joint programme in which our colleagues at NIAE are studying the mechanical aspects of these processes, and we at G.R.I. are studying the nutritional responses of the animals being fed. This programme has been helped greatly by the modification, at Silsoe, of a Glomera piston press to produce packages (of very similar physical dimensions) but varying widely in modulus of fineness of the particles.

We believe that this *must* be a joint programme. Without this the engineer could well develop a packaging system which produces an unacceptable feed, or the nutritionist could demand a package which makes nonsense in engineering terms—as happened a couple of years ago with the development of a piston-press which produced dried grass wafers the size of small dinner plates!

But, just as was the case with silage, this programme must be completely integrated with an examination of the systems of feeding in which dried grass is likely to be used. And just as with silage, the conclusion appears *that dried grass is most unlikely to be used in a sole feed.* This means that the nutritional/engineering study must be extended to examine the optimum particle size, package size etc., for dried grass when fed in combination with other farm feeds—and this could well modify conclusions derived from the (essential) more basic studies in which dried grass is examined as a sole feed.

At different research centres work is already in progress to examine dried grass in feed combinations with barley, hay, straw, silage, etc. Our own particular interest is with silage, for as I noted earlier, we believe this could be the most effective way of storing grass on the livestock farm, and we wish to examine the possibility of supplementing this silage with dried grass, possibly bought in from a nearby arable farm.

5.1 Feeding Complementary Rations of Silage and Dried Forages

From the work we have so far carried out a most exciting nutritional interaction is emerging. In one experiment one half of a field was cut and made into unwilted silage at 18 per cent dry matter, whilst the other half of the crop went through the grass drier and was milled and pelleted. Both feeds were then fed *ad lib* to sheep, which ate twice as much dry matter as dried grass than as silage. Clearly, as sole feed the dried grass was superior to the silage. But the really interesting thing was not what happened when just silage or just dried grass was fed, but what happened when the two were fed together. For this study we used a series of intermediate feeding levels, in which we fed increasing controlled amounts of dried grass but allowed *ad lib* intake of silage. As noted earlier, when we fed barley with silage, the intake of silage decreased (although not as rapidly as the intake of hay). But as we increased the amount of dried grass there was an initial tendency for the intake of the silage to increase, and even when about 40 per cent of the total intake was dried grass the intake of silage was still very similar to when it was fed alone. At this intermediate region as would be expected the animals were eating more dry matter of the mixture of unwilted silage and dried grass than when silage only was fed; but more important, the intake was also higher than when only dried grass was fed. And current experiments are showing a similar response in terms of animal production, with higher rates of gain by cattle fed the 50:50 silage/dried grass combination than by cattle fed only on dried grass: in several experiments daily gains have been well over 1 kg—a level generally expected only when much barley is fed. There are several implications to this. The first is that, unless there is something seriously wrong with our techniques or our economics, it must be cheaper to store a unit of dry matter as unwilted silage than as dried grass. The reason we do not feed just silage is that this does not give an adequate level of animal production. But a combination of dried grass and silage appears to give good animal production and at a cost considerably cheaper than dried grass alone. We are only at the beginning of a series of experiments to examine this interaction in production terms, and with different classes of stock, in which we will pay most attention to the region in which animals are offered *ad lib* access to silage plus a controlled amount of dried grass or other supplement. And in these situations we may have to re-examine some previous conclusions on the optimum modulus of fineness in dried grass packages, for we are concerned not with the package fed by itself, but with the form of package which is best when fed say 50–50 with silage. There are many implications in this for agronomists, for engineers and for economists, to achieve the optimum combination of silage and dried grass in lowest-cost animal production systems. Feeding on dried grass, alone, although it is a super feed, is expensive; silage can be a very low unit cost feed, but by itself is rather unproductive. There are interesting nutritional problems in the interaction of these two feeds, which we must understand before 'grass drying' can be closely defined in mechanical terms.

6. Forage Crops for the Future

We have talked mainly in terms of intake; but silage making is also an unnecessarily difficult process because we have insisted on a high crude protein content in silage on the assumption that grass protein is cheap. This makes fermentation difficult and may give unsatisfactory silage—whereas there is no problem at all in dehydrating high protein crops. So there is a possibility of reducing emphasis on high protein content in silage, because in the combined ration dried grass could provide the supplementary protein. We could then aim for high digestibility and high yield but relatively low protein content in crops for silage, and for higher protein crops such as lucerne and red clover for dehydration. The trend of forage breeding in the future could then be towards high yielding but low protein crops for silage, and a crop which falls into this category is forage maize, already sown on some scale in the south east of U.K., and an ideal crop for mechanical harvesting.
We have already obtained excellent cattle gains with maize silage supplemented with dried lucerne or dried whole-crop beans. So we now have the prospect of maize silage, unwilted low dry matter grass silage, and dehydrated crops as nutritionally complementary feeds.

7. Farming Systems and Transport Problems

Although these may be nutritionally complementary feeds the immediate reaction is that it would be very expensive to haul dried grass from Lincolnshire to feed dairy cows in Pembrokeshire, however good a feed it may be. I suggest that if one looks at the distribution of farms in Britain, we do not find arable areas suitable for grass drying only in the East, and grazing areas only in the West, but arable areas dispersed right throughout the country. Dried grass from Lincolnshire would surely go to livestock farms in the Midlands, dried grass from Shropshire would go to Wales, dried grass from South Devon would go to North Devon, and so on. Thus the possibilities we are now discussing are of linking up dried grass production on the arable farm with livestock feeding in neighbouring areas.

Silage and dried grass would then be complementary not only in terms of nutrition, but in terms of farm systems. In my view they cannot be *alternatives* in terms of farm systems because dehydration just cannot cope with the spring flush of grass. A dehydrator has only a limited evaporative capacity, and this means that either a very large grass drier must be installed which will work at full capacity for only a few weeks in Spring, which is pretty uneconomical, or a small grass drier is used, so that at peak periods only part of the grass is dried and the remainder has to be made into silage.

Dehydration can only sensibly cope with the spring peak of grass if the drier is also supplied with other crops to be cut when grass growth slows down in July and August, crops such as barley, whole-crop beans etc. Very few livestock farmers are likely to adopt such a cropping policy to keep an enterprise like grass drying going. But farmers in the arable areas, whether in Lincolnshire, Yorkshire or Dorset now consider that such cropping programmes are basic to the efficient dehydration enterprize. They want to know what crops other than grass and lucerne will help them to keep the drier operating for as long a period as possible at fairly high capacity. Much of the economics of dehydration appears to depend on a long and uniform drying season so as to spread overheads, labour charges and so on. There are of course developments with small grass driers which may allow them to fit onto a certain number of livestock farms. In my own view the main future of dried grass appears to be in its integration with other forms of conserved forage, and particularly with silage which is largely independent of the weather and which fits in remarkably well as a method of conserving surplus grass on the intensively-managed livestock farm. This silage will serve as the basis of the winter feed and will be supplemented with dehydrated forages and barley. But these will not be produced as an offshoot on the livestock farm, but produced instead as a cash crop on an arable farm, where the farmer thinks in terms of crop sequences, production per man and level of management, all of which are vital to the economic success of the dehydration enterprize.

There are two main features to consider. Firstly the nutritional combination I have suggested of silage and dried grass, with the probability also of barley included in the ration for some years to come. Secondly these are not alternative methods of conservation, for they represent quite different ways of thinking about forage. Silage is an essential ancillary to a mainly grazing livestock enterprise, whereas dehydration must be thought of very much as a cash crop in its own rights. And the answers to both these questions are likely to come mainly from research, rather than from farming, for farming cannot solve the problems of packaging, let alone the problems of the optimum combinations of silage, dried grass and barley in different rations for different classes of livestock.

This is why we at Hurley and our colleagues at Silsoe are putting so much emphasis on examining these basic aspects of conservation systems. Developing new grass driers is not the answer at the moment. The real answers will relate to crop production sequences to the packaging of dried feeds, and to the ways in which these are fed in combination with other feeds. We do not yet know whether in this new context dehydration and forage conservation will prove more profitable than was the case in the past. But we are pretty sure that success is more likely than from the buckrake/railway sleeper philosophy, to which the research worker and the farmer have become conditioned.

This paper was edited by G. Shepperson, N.I.A.E. Silsoe, Bedford, who wishes to acknowledge the considerable assistance given by the author, W. F. Raymond.

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AIR DISTRIBUTION IN VENTILATED STRUCTURES

by J. N. WALKER, G. M. WHITE and B. F. PARKER

The engineer planning a ventilation system for agricultural structures must consider both the quantity and the distribution of the ventilating air. The distribution system should provide the same temperatures for all animal or plant locations within the structure without creating draughts. The engineer can utilize a wide variety of ducts, diffusers, outlets, inlets, exhaust or pressure fans, and deflectors to achieve the desired control.

By proper selection of the size and configuration of ventilation components the designer can modify the throw, entrainment and rate of spread of the ventilating air. To be able to predict system performance, he must know quantitively how each of the ventilation system characteristics changes with changes in the ventilation rate and other physical parameters. For many of the common commercial ventilation devices the throw, entrainment and rate of spread are known[1,5,10,14]; however, devices and ventilation configurations commonly used in agricultural structures have not been as extensively studied. In many instances research on agricultural ventilation systems has been conducted in production facilities and the performance of the plants or animals was used to judge the adequacy of the ventilation system. Such studies do not provide the essential design information which leads to predictability when such systems are installed in other types of structures or when system parameters are varied. Many of the conventional ventilation devices also need to be re-evaluated to determine their suitability in agricultural structures owing to the difference in design criteria for animal and plant structures when compared to structures for human occupancy. For example, higher noise levels and higher air velocities are generally acceptable in animal and plant structures.

Paper presented at the South East Midlands Branch of Institution of Agricultural Engineers, 5 October 1970.
The authors are J. N. Walker, Professor in Agricultural Engineering, University of Kentucky, and Visiting Scientist, Glasshouse Department, National Institute of Agricultural Engineering, June-Dec. 1970; G. M. White, Associate Professor in Agricultural Engineering, University of Kentucky, and B. F. Parker, Professor and Chairman, Department of Agricultural Engineering, University of Kentucky, U.S.A.

Characteristics of Air Jets

Free jets: With most ventilation systems air enters the ventilated space through a contracted area as a high velocity jet of air. The behaviour of ventilating air jets can be characterized by defining:

- The decay of the peak velocity.
- The entrainment of room air by the jet.
- The rate of spread of the jet.
- The trajectory of the jet.

It has been suggested[1,11,16] that a jet can be defined in terms of four zones. The zones for an air jet issuing from a ceiling fan baffle arrangement are shown in Fig. 1.

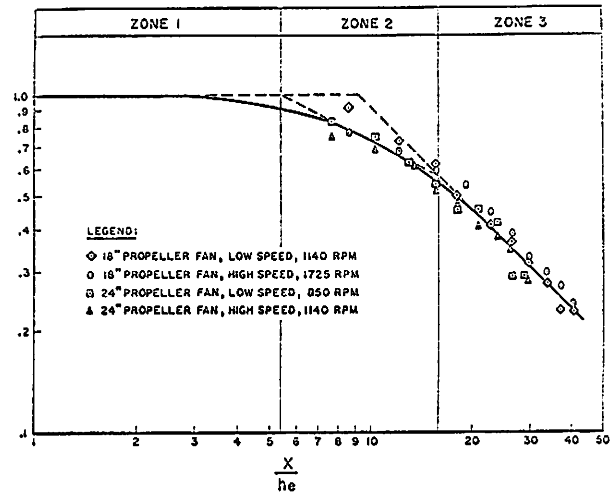

Fig. 1. Plot of Vx/Vo versus x/he along the axis of maximum velocity for an air jet issuing from a ceiling fan baffle arrangement.

Zone 1 is the core region of the jet in which the peak velocity is constant and is essentially the same as the initial velocity at the point of jet origin. No entrainment or spread of the jet occurs in this zone. The zone is relatively short, extending only 2 to 6 outlet diameters away from the outlet, i.e. the opening through which air issues into the room being ventilated.

Zone 2 is a transition zone where the peak velocity can be assumed to decay inversely as the square root of the distance from the outlet. The zone usually extends out to 8 to 10 outlet diameters from the outlet. For a rectangular outlet this zone is longer than it would be for a circular outlet. For rectangular outlets the distance from the outlet in diameters is the diameter of an equivalent round nozzle which has the same gross area as the rectangular outlet. Entrainment occurs in this zone.

Zone 3 is the longest zone and is the zone where the peak velocity can be assumed to decay inversely with the distance from the outlet. The zone extends out to 25 to 100 diameters from the outlet depending upon the configuration of the outlet and the initial velocity. This is sometimes referred to the zone of fully established turbulence. Entrainment also occurs in this zone.

Zone 4 is the terminal zone where the velocity rapidly decays into large-scale turbulence. The zone is quite short and velocities within it are not defined.

The zones of maximum interest would be zones 2 and 3 which include most of the distance of the jet penetration into the ventilated space. If consideration is restricted to a free jet, i.e. a jet issuing into a room of still air away from any boundary surfaces, the peak velocity decay can be defined in zone 2 by[16]:

$$\frac{V_x}{V_o} = K\sqrt{\frac{A_e}{x}} \qquad \ldots\ldots(1)$$

and in zone 3 by:

$$\frac{V_x}{V_o} = K'\frac{\sqrt{A_e}}{x} \qquad \ldots\ldots(2)$$

where V_x is the peak velocity at some downstream distance, x, K and K′ are constants, and A_e is the effective outlet area. The constants depend upon the outlet configuration, outlet turbulence and the manner in which A_e is defined. In some studies the outlet diameter D is used in lieu of the square root of A_e. The relationships are normally considered valid until V_x drops to 200 to 100 fpm (1 to 0·5 m/s)[16].

For outlets which are circular the most commonly reported value for K′ is 7·0[10]. For rectangular outlets zone 2 is elongated and theoretically for an infinitely long slot would extend out to the point at which the jet dissipates. For slots where the ratio of length to height is 20 or less, there is a definite zone 3 which is larger than zone 2. Common values of K′ for rectangular slots vary between 6·0 to 6·5. For jets issuing from slots having other than very large aspect ratios there is a coalescing of flow into a core region, i.e. the flow develops into an elliptical or circular flow region[2]. It is after the development of such a pattern of flow that zone 3 flow can be assumed.

As the jets move away from the discharge outlet, entrainment of room air occurs. The amount of entrainment for a circular jet has been found to vary approximately linearly with the distance from the outlet face in accordance with the following relationship[5].

$$\frac{Q_x}{Q_o} = \frac{2}{K'}\frac{x}{\sqrt{A_e}} = 2\frac{V_o}{V_x} \qquad \ldots\ldots(3)$$

where Q_x is the total quantity of air flowing at distance X from the outlet face, Q_o is the quantity of air discharged into the room, and the other terms are as previously defined. For a long slot the relationship would be:

$$\frac{Q_x}{Q_o} = \frac{\sqrt{2}}{K}\sqrt{\frac{x}{A_e}} = \sqrt{2}\,\frac{V_o}{V_x} \qquad \ldots\ldots(4)$$

The above relationship indicates that for a given outlet the entrainment ratio is a function of the distance from the outlet face. If a larger number of entrained volumes of room air per unit volume of ventilation air is desired, the distance the air jet moves before dissipating should be increased, i.e. the initial velocity should be increased.

As the jet slows down and entrains room air, it spreads out. This divergence of the outer boundaries of the jet has been found to be relatively uniform[16]. The boundary of the jet is normally defined as the point at which the velocity has decreased to 50 fpm (0·25 m/s). For jets issuing from circular outlets the angle of divergence between the upper and lower boundaries has been defined as being 20 to 24 degrees[2,16]. For rectangular outlets similar angles of divergence have been observed once fully turbulent flow occurred. For aspect ratios up to 100, angles of divergence of the core section within the above range were reported.

The velocity profile of free jets in zone 3 has been defined as following the Gauss error-function curve. An approximation of the velocity profile has been suggested in the literature as[16]:

$$\left(\frac{r}{r_{0 \cdot 5}}\right)^2 = 3 \cdot 3 \log\frac{V_c}{V} \qquad \ldots\ldots(5)$$

where r is the radial distance from the jet centreline to the point under consideration, $r_{0 \cdot 5}$ is the radial distance from the jet centreline to a point where the velocity is one-half the velocity at the jet centreline, V_c is the centreline velocity, and V is the velocity of the jet at the point under consideration.

Wall jets: As jets enter into bounded spaces, they are influenced by the boundaries. In particular, it has been found that when a jet is discharged adjacent to a smooth boundary such as a ceiling, the apparent length of throw has been increased, i.e. the rate of velocity decay decreased. A wall jet can be visualized as one-half of a free jet with a thin wall placed along the free jet centre. Since the drag on smooth walls would be very small, the throw and entrainment of the original jet would not be expected to be altered; however, to account for the reduction of A_e, the square root of which appears in the velocity decay equations 1 and 2, K would have to be increased by the factor $\sqrt{2}$. This has been shown to be a valid conclusion by a number of investigators[5,16].

As a wall jet moves along a ceiling, it tends to flatten with the angle of divergence of the jet in a plane parallel to the ceiling being increased and the angle of divergence away from the ceiling being decreased. Specific values of decrease have not generally been reported; however, values of less than 10° are suggested as being appropriate[16].

The entrainment of wall jets has not been as extensively investigated as free jets; however, the relationships 3 and 4 are generally considered to remain valid with K or K′ being adjusted by multiplying by $\sqrt{2}$.

The velocity profile from the point of peak velocity outward away from the wall velocity tends to hold closely to the wall. The depth from the wall to the maximum velocity and the profile of the inner boundary layer have been defined mathematically[15]. The depth of the inner boundary layer increases as the jet moves away from the outlet and slows down, but seldom is it greater than 2 inches (50 mm).

Non-isothermal jets: Due to buoyancy forces chilled jets tend to fail and heated jets tend to rise. A number of different relationships have been proposed for the trajectory of hot and cold free jets. One of which is[7]:

$$\frac{y}{\sqrt{A_e}} = 0{\cdot}238a \left(\frac{x}{\sqrt{A_e}}\right)^{2{\cdot}50} \qquad \ldots\ldots(6)$$

$$a = \frac{\sqrt{A_e}}{V_o^2}\, g\, \frac{\Delta t}{T_l} \qquad \ldots\ldots\ldots(7)$$

where y is the upward or downward deflection of the jet, g is the acceleration due to gravity, Δt is the temperature difference of the jet and the ambient room temperature and T_l is the absolute temperature of the room air.

The equations for throw, entrainment, and angle of divergence for isothermal jets are generally considered to be applicable to non-isothermal jets. The profiles of temperature difference also follow an error function type curve; however, temperature differences tend to even out more rapidly than velocity. This is due to a more rapid diffusing of heat than momentum within the jet.

Experimental Studies

Utilizing the procedures and theory presented above, a number of studies were conducted at the University of Kentucky on systems or air distribution problems of interest in agricultural structures.

Ceiling baffle[14]: A winter ventilation system which was considered to have merit in agricultural structures was studied. It consisted of a ceiling mounted fan which pulled air from an attic space and discharged it against a flat baffle located in front of the fan. A cross-section of the system is shown in Fig. 2. Though the system had been installed in a number of buildings and had operated successfully, no adequate theory or analysis of its effectiveness in mixing and distributing ventilating air was available.

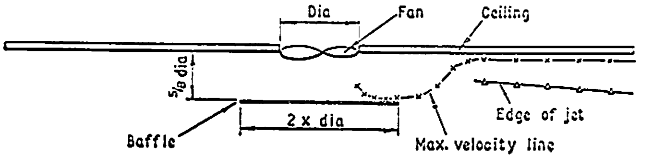

Fig. 2. Cross section of a Kentucky ceiling fan baffle arrangement.

To evaluate the performance of such a ventilation system, a false ceiling section was set-up approximately 8 ft (2·4 m) above a laboratory floor. Different sizes of fans were then mounted in the ceiling. A square baffle was placed ⅝ of the fan diameter in front of the fans. This baffle position was selected after tests which were conducted with various baffle positions ranging from ¼ to 1 fan diameter from the ceiling, showed that the ⅝ fan diameter position created very little pressure resistance and reduced fan efficiency by only 1 to 6·2 per cent. A cone deflector placed in the centre of the baffle did not appear to improve performance.

Velocity profiles were measured at intervals away from the baffle edge along rays extending out from the centre of the baffle. The data for all the fans tested along a ray 75° from the ray perpendicular to the baffle edge were plotted on log-log paper and zones 1, 2 and 3 of the jet were defined as shown in Fig. 1. Air flow in this direction was analyzed since the flow along this ray at a distance of 7 feet (2·1 m) from the fan was approximately equal to the mean of the directional air flow supplied by the fan-baffle arrangement. The velocity decay equation for zone 3 flow was found to be:

$$\frac{V_x}{V_o} = 9{\cdot}3\,\frac{h_e}{x} \qquad \ldots\ldots(8)$$

where h_e is the effective distance between the baffle and the ceiling. On the basis of the observed air flow pattern at the baffle edge, this was assumed to be 0·3 of the actual distance between the baffle and the ceiling. The outward flow from the baffle was concentrated in the lower one-third of the space between the ceiling and the baffle. Eddy flow was observed in the remaining distance between the baffle and the ceiling.

The square baffle resulted in a reduced flow at the corners and a maximum flow perpendicular to the sides. This is shown in Fig. 3. In accordance with theory, flow was coalescing and forming core regions of flow in the directions of maximum flow; however, significant quantities of air were discharged in the other directions as well. For optimum flow in rectangular spaces the corners of the baffle should be orientated towards the sidewalls and the flat sides orientated towards the corners. When a circular baffle was used a variation of flow around the baffle of less than 4 per cent was observed.

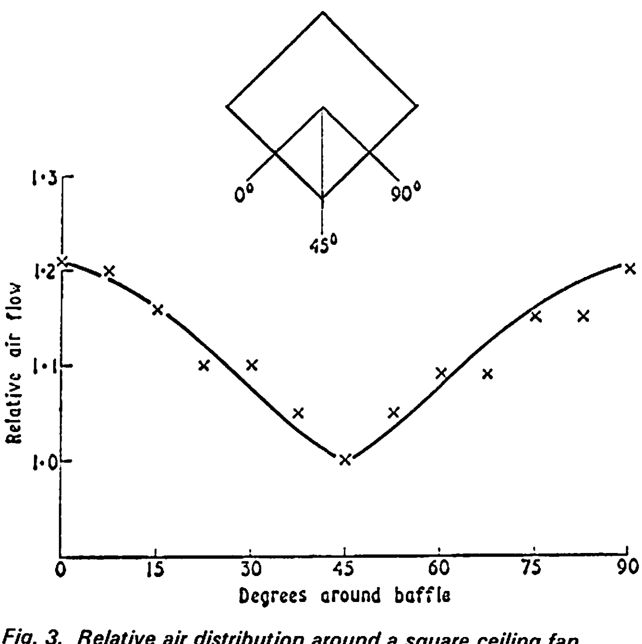

Fig. 3. Relative air distribution around a square ceiling fan baffle arrangement.

The spread of the jet was only evaluated along the ray located 75° from the perpendicular ray. Along this ray the angle of divergence from the ceiling was only 5° which was considerably less than the 10 to 12° suggested in the literature. These larger angles of spread would, however, only be expected for the core region. It was observed along all rays that the maximum velocity remained very close to the ceiling.

The entrainment along the ray at an angle of 75° to the perpendicular ray was found to vary linearly with x/h_e.

A regression analysis yielded:

$$\frac{Q_x}{Q_o} = 0{\cdot}1\,\frac{x}{h_e} + 0{\cdot}91 \qquad \ldots\ldots(9)$$

This equation does not agree fully with the proposed relationships in the literature; however, the theoretical equations in the literature were developed for the core region of flow. Entrainment for the core region was not determined in this particular investigation.

Winter ventilation systems based upon this concept have been designed for many livestock buildings and systems have proved highly successful in uniformly distributing and mixing air. A positive low velocity flow of tempered air is achieved across the floor without the conditions of 'a draught' occurring. Structures up to 40 feet (12 m) wide and 300 feet (90 m) long have been ventilated with 7 fans located along the centreline. The heat picked up from the attic due to solar heating of the roof has proved very helpful in maintaining a moisture balance within the structure. This heat is a disadvantage, however, in the summer. Under these conditions intake ducts to ridge intake ventilators are necessary.

Horizontal ceiling slot in vertical triangular duct[17]: In the design of pressure ventilation systems it is often desirable to discharge the air at points along the sidewalls, i.e. from fans located in the walls at spaced intervals. Ideally each fan should discharge the same amount of air to each segment of the space it is ventilating. This means that higher flows are needed diagonally away from the fan. The distances over which high velocity flow would need to be maintained would also be greater in the diagonal direction. The authors theorized that a horizontal slot in a triangular duct orientated vertically on the wall would meet these requirements. By placing the slot at the ceiling, the air would be discharged along the ceiling so that maximum distance of jet penetration could be achieved and maximum entrainment of room air into the jet could occur before the ventilation air entered the space occupied by animals or plants.

The experimental tests evaluating the performance of such a ventilation concept were conducted in a space where a 20 × 40 ft (6 × 12 m) false ceiling was placed 6 ft (1·8 m) above the floor. One of the 40 ft (12 m) sides had a false wall built along it. All surfaces were plywood. A triangular duct was positioned in the centre of this wall. A fan placed at the bottom of the duct was used to create the desired slot exit velocity. Three apex angles of the triangular duct were evaluated 60°, 90° and 120°. In each case the slot distance between the ceiling and duct was 6 in (152 mm).

Complete velocity profiles were measured along rays 15° apart. Readings were taken of the slot face outward until the peak velocity decayed to 75 fpm (0·38 m/s). It was found that there was a definite core region into which flow was coalescing. This was approximately along a line perpendicular to the sides of the duct with the exception of the 120° apex duct. In this case the flow was along a ray about 50° from the wall as opposed to the 60° ray which was the perpendicular ray. A plot of measured maximum velocities for each duct is shown in Fig. 4. Approximately twice as much air per unit horizontal angle was directed along the axis of maximum velocity as was directed out through the apex of the triangular duct. Both for the core region and for the regions where flow was less intense, the maximum velocity remained close to the ceiling.

The decay of maximum velocity was determined by plotting the data on log-log paper as shown in Fig. 5. The decay relationship for the ducts studied was:

$$\frac{V_x}{V_o} = 6{\cdot}2\,\frac{h_e}{x} \qquad \ldots\ldots(10)$$

where h_e was the width of the slot between the ceiling and

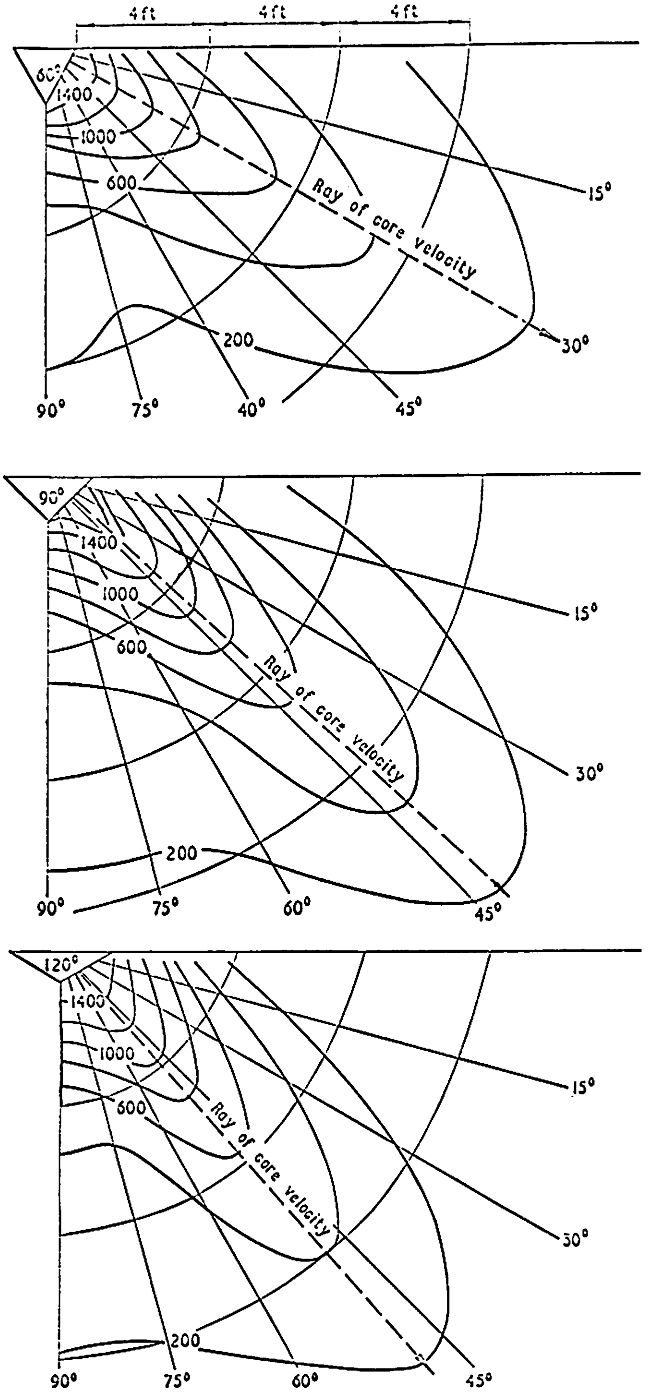

Fig. 4. Plan view of the air velocities and axes of maximum velocity for 60°, 90° and 120° apex angle triangular wall ducts.

the duct edge. As shown in Fig. 5, Zone 1 extends out a distance of 3 times the slot height; Zone 2, which is the transitional zone, extended from 3 to 12 slot heights; and Zone 3, which is the principal zone extended out to 35 slot heights.

Due to the diverging nature of total flow, entrainment was very difficult to define. Not only was the flow coalescing into the core region, the jet was expanding outward from the outlet into the total space of the room. The entrainment into the core region occurred not only from the room, but also from the other parts of the jet. Entrainment in the core region was estimated by considering the flow in unit solid angles as the jet moved outward from the duct. At a distance of 6 to 8 ft (1·8 to 2·4 m) from the slot the air flowing in a given solid angle had increased by three to four times.

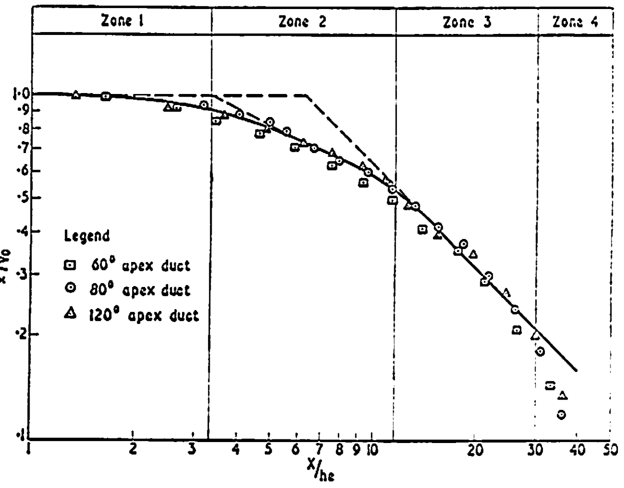

Fig. 5. Plot of Vx/Vo versus x/he along the axis of maximum velocity for an air jet issuing from a horizontal ceiling slot in a triangular wall duct.

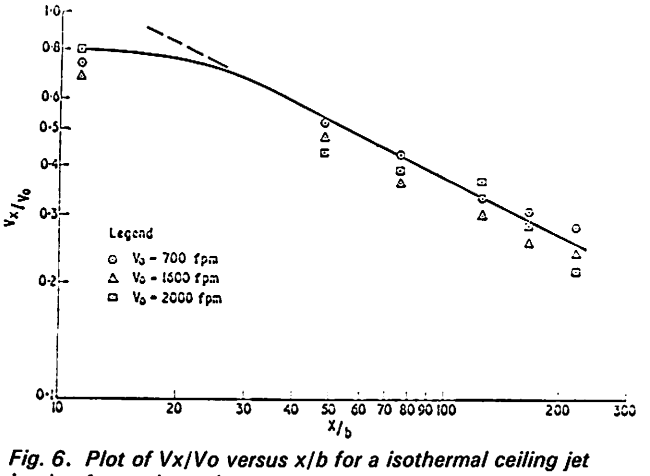

Fig. 6. Plot of Vx/Vo versus x/b for a isothermal ceiling jet issuing from a long shot.

The discharge of air from a ceiling slot in a triangular duct was shown to produce a directional distribution of air which was compatible with the ventilation requirement of rectangular spaces ventilated from point sources along a side-wall. The jet promoted entrainment and the peak velocity remained near the ceiling until it dissipated. The triangular wall duct has been utilized in a greenhouse pressure ventilation system and has proved very satisfactory.

Non-isothermal discharge along a smooth ceiling[3]: When ventilating air is discharged into a space, it is generally either warmer or cooler than the air in the space being ventilated. If the air is cooler, it can be expected to fall towards the floor. However, if the air is discharged into the space along a smooth boundary, such as a ceiling, there is also a force tending to hold the jet to that surface. It was not known whether this force was sufficiently strong to overcome the buoyancy forces due to the temperature differences. The data in the literature also did not clearly define whether differences between the jet and space temperatures would affect the velocity decay or entrainment of air. The rate of temperature difference decay for air discharged along the ceiling from long slots was also not known.

Experimental tests were carried out in a 20 ft × 20 ft × 8 ft (6 m × 6 m × 2·4 m) room which was built within a laboratory. Air after heating or cooling was discharged into this room from a 1 in × 60 in (25 mm × 152 mm) slot. Air could leave the room through a large screened opening in the wall opposite the slot. The ceiling was heavily insulated to minimize heat loss or gain through the ceiling. Both temperature and velocity profiles were determined along a perpendicular centreline which bisected the air discharge slot. Tests were carried out for various levels of heating and cooling and selected levels of outlet velocity.

It was found, in accordance with previous investigations, that momentum was essentially conserved for all jets tested between 4 ft and 18 ft (1·2 m and 5·4 m) from the jet outlet. Within this region a core of flow did not appear to be developing. The decay of velocity for such conditions should occur inversely according to the square root of the distance from the slot. The decay for the isothermal condition is shown in Fig. 6. For this condition maximum velocity decay was found to occur in accordance with the following relationship:

$$\frac{V_x}{V_o} = K\sqrt{\frac{b}{x}} = 3{\cdot}68\sqrt{\frac{b}{x}} \qquad \ldots\ldots(11)$$

where b was the slot width.

When the influence of temperature was considered, it was found that temperature had approximately a linear influence. By pooling all data the decay constant, K, was statistically determined to be:

$$K = 3{\cdot}58 + 0{\cdot}58\Delta t_o \qquad \ldots\ldots(12)$$

where Δt_o is the difference between the temperature of the ventilating air at the slot face and the temperature within the room in °F.

Due to the variations in K with temperature difference, entrainment could not be simply defined. It was found that the basic relationship given in the literature predicted entrainment too low for warm jets and too high for cold jets. A regression expression was determined for the experimental data and was found to be:

$$E_x = \frac{Q_x - Q_o}{Q_o} = -5{\cdot}38 + 0{\cdot}0961\,(\Delta t_o + 30°) + 3{\cdot}1908\sqrt{x} \qquad \ldots\ldots(13)$$

The observed higher entrainment of the warm jets was consistent with the results of other investigators. It is felt that this is due to a difference in the rate of mixing of warm and cold jets. With a cold jet the buoyancy of the entrained hot air is promoting mixing with the jet and hence a more rapid decay of velocity with a subsequent reduction in entrainment. The opposite would be true for warm jets.

It was found that the centreline of maximum velocity did not drop significantly from the ceiling for any of the jets investigated. Initial temperature differences of approximately ±32°F (±18°C) were included in the study.

The decay of temperature difference did not occur at the same rate as the decay of velocity. An attempt was made to derive a prediction relationship by using an energy balance approach. The relationship involved a number of terms and was dependent upon having valid relationships for velocity decay and entrainment. Though the mean temperature could be estimated by use of this relationship and by using the previously determined relationships for velocity decay and entrainment, the dependence upon these relationships made the prediction relationship of little use. The lack of good mixing of hot jets also appeared to adversely affect the accuracy of prediction. In general the derived relationship predicted temperatures too high for the cold jets and slightly too low for the warm jets.

The profiles of both temperature and velocity followed an error function type distribution.

Effect of surface obstructions on air wall jets[9]: When air is discharged into a space along a smooth boundary such as a ceiling, maximum jet penetration occurs and the maximum opportunity exists for entrainment of space air prior to the movement of the ventilating air into the space occupied by plants or animals. In many practical situations the boundaries are not completely smooth. Beams, rafters, duct work, piping and other obstructions frequently extend downward from the ceiling into the space being ventilated. If the obstructions are small, air will move past them and continue along the ceiling. If they are large, the air will be deflected from the ceiling and part of the structure will not be properly ventilated.

When studying air jets, it is generally assumed that momentum is conserved. If this holds true for jets striking an obstruction, the initial deflection of the jet due to an obstruction can be defined by:

$$\cos \alpha = \frac{M_{ij} - F_j}{M_{f\alpha}} \qquad \ldots\ldots(14)$$

where M_{ij} is the initial momentum rate of the jet in the j direction before it strikes the obstruction, $M_{f\alpha}$, the final momentum rate of the jet in the direction α, and F_j, the force upon the obstruction due to the air jet impingement on it. In each case the momentum of the jet could be represented by integration of the velocity squared multiplied by an appropriate unit interval.

The force exerted upon the obstruction having a unit depth by the fluid impingement can be determined by use of the following relationship:

$$F_j = \frac{C_d}{2_g}\rho \sum_{i=1}^{n} (A_i \overline{V}_i^2) \qquad \ldots\ldots(15)$$

where C_d is the coefficient of drag, ρ is the air density, g is the acceleration due to gravity, A_i is an appropriate finite area, and $\overline{V_i}$ is the mean velocity acting on the unit area. In preliminary studies it was observed that when the obstruction was twice the distance from the wall to the point where the velocity is one-half the maximum jet velocity; the jet was deflected at an angle of approximately 90° away from the ceiling. This corresponds to a C_d of 2·0. For small obstructions the force upon the front face of the obstruction corresponds to a C_d of 0·8. It was assumed that this applied to obstructions completely immersed in the inner boundary layer, i.e. between the ceiling and the point in the jet of maximum velocity. The depth of the inner boundary layer, the jet profile, and the location of the point at which one-half the maximum velocity occurs are all defined by appropriate relationships in the literature. It was assumed that C_d varied linearly with obstruction depth when obstruction depths were between the two extremes indicated above.

The force tending to pull the jet back to the ceiling and preventing jet detachment was assumed to be that called the Coanda force and which is described by others[4]. Based on this work the re-attachment distance was theoretically defined by:

$$\frac{X_r}{r_{0\cdot5}} = \frac{\sigma\,(1/t^2 - 1)\sin\alpha}{3\alpha} - \frac{\tanh^{-1}t}{3t^2 \sin\alpha} \qquad \ldots\ldots(16)$$

where X_r is the reattachment distance, $r_{0\cdot5}$ the distance from the ceiling to the point in the jet where the velocity is one-half the peak velocity, σ is a parameter, which for a free turbulent jet is 7·7, α is the angle at which the jet passes the obstruction, and t is defined by:

$$\cos\alpha = \frac{3}{2}t - \frac{1}{2}t^3 \qquad \ldots\ldots(17)$$

Re-attachment would occur when the predicted re-attachment distance was less than 0·7 the length of the obstruction. When it was greater than 0·7, re-attachment was unlikely. The applicability of the theoretically derived relationships was experimentally evaluated. The studies were conducted in a 20 ft × 20 ft × 8 ft (6 m × 6 m × 2·4 m) room within a laboratory. Air was discharged from a 1 in × 60 in (25mm × 152 mm) and a 2 in × 60 in (51 mm × 152 mm) horizontal slot along the ceiling. Obstructions having a face of varying depth and a length of 8 ft (2·4 m) were placed 8 ft (2·4 m) from the slot. Velocity profiles were measured both upstream and downstream from the obstruction. The test arrangement is shown in Fig. 7.

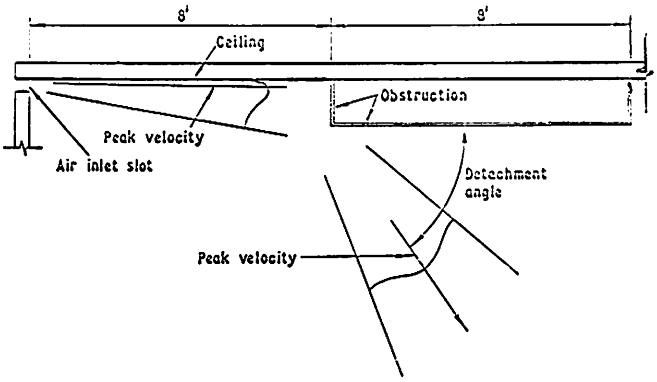

Fig. 7. Experimental arrangement for investigating the effect of ceiling obstructions on jet deflection.

It was found that the unobstructed jet behaved similarly to jets studied by other investigators, and that the proposed velocity decay, velocity profile, and jet spreading relationships given in the literature were applicable.

A comparison of predicted re-attachment or detachment to observed jet performance for the various test conditions showed that the proposed relationships gave acceptable results. Re-attachment and detachment was correctly predicted in all but one case. In this case the air tended to move parallel to the ceiling at a larger distance from the ceiling than normal. The velocity profile of this jet downstream from the obstruction more nearly resembled a free jet than a wall jet. For other jets impinging upon obstructions of the same depth, it was observed that they were also pulled back to the ceiling to an almost parallel direction; however, re-attachment occurred in only the one case.

When re-attachment occurred, the re-attachment distance was less in each case than that predicted. This would suggest the need to modify the proposed relationship. In particular, the depth of the air jet at the obstruction was chosen as the distance from the ceiling to the point where the velocity was one-half the maximum velocity. This portion of the jet contained over three-fourths the momentum of the jet; however, by the selection of some other depth, a closer fit between predicted and observed re-attachment distances could have been obtained. In the literature the Coanda effect was studied by issuing air from carefully shaped nozzles of known dimensions at selected angles. It was not felt that sufficient experimental evidence was available from this study on which to recommend alteration of the proposed procedure.

For the detached jets the angles predicted by the initial deflection relationship were not the final angles at which the jets left the ceiling. In each case the ceiling tended to pull the jets back towards the ceiling, and the actual angle of departure was less than the predicted initial deflection angle. The effect of the ceiling in deflecting the jet back towards the ceiling was the least for the jets initially deflected the greatest amount. For the jets theoretically deflected 90° there was little, if any, effect of the ceiling.

The rate of velocity decay downstream from the obstructions increased; and as obstruction depth increased, the difference between the decay of an unobstructed and obstructed jet was greater. This may have been due to increased turbulence and hence increased entrainment, or it may have been due to energy losses in eddy flows that occurred between the main jet and the ceiling downstream from the obstruction to the point where re-attachment occurred. This region of eddy flow is referred to as a separation bubble and was particularly observed when jets re-attached after impinging upon moderate sized obstructions. These obstructions also resulted in increased angles of spread downstream from the obstruction.

For wall jets the velocity profiles downstream from the obstruction and past the point of re-attachment resembled the velocity profiles for regular wall jets except the centreline of maximum velocity was generally located at a greater distance from the ceiling. For detached jets the profiles quickly developed into the typical shape for free jets. This occurred within 8 to 24 inches (200 to 600 mm) of the obstruction.

Though the proposed procedure predicted re-attachment distances twice those observed, the procedure correctly predicted detachment or re-attachment for every test condition except one. The study did not consider obstructions with short lengths which would be more frequently encountered in actual practice. The proposed method should, however, permit the determination of the depth of obstruction regardless of length which should result in a complete deflection of the jet away from the ceiling.

Summary and Conclusions

The theory of air jets is sufficiently well developed to permit the description of the velocity decay, entrainment, and rate of spreading of the jet for many types of outlets and ventilation configurations. Somewhat less information is available on the temperature decay and temperature related deflection of non-isothermal jets, but even here much basic data are available. The use of these procedures and data permit the complete analysis of ventilation systems and the prediction of air distribution and mixing within the ventilated space. Though the data were developed for commercial or human occupancy conditions, much of the data are directly applicable to agricultural structures.

Less data are available on ventilation concepts developed specifically for agricultural structures. Many of the studies which have been conducted on such concepts have evaluated the overall conditions achieved within the structure, and based upon uniformity of conditions, have judged the system as being adequate or inadequate. Such studies have not permitted the design or prediction of performance of such systems for other situations. For these systems, research is still needed to define the basic design parameters.

Four different ventilation problems, which have been studied at the University of Kentucky, are discussed in this paper. In each case efforts were directed towards the determination of the basic relationships and towards the development of data for prediction of design performance.

For the ceiling-mounted fan with a flat baffle, the velocity decay along a mean vector was determined and was found to be consistent with the type of decay found for other types of air discharge devices. When the baffle was square it was found that less air was directed out along rays passing through the corners of the baffle and the largest quantity of air flowed along rays perpendicular to the sides of the baffle. Flow tended to coalesce along the perpendicular rays. Both entrainment and the rate of jet spreading along a ray between the perpendicular and corner bisecting ray was less than that observed by other investigators for the core region.

For a vertically orientated triangular wall duct with an air discharge slot at the ceiling, maximum flow was also observed along a ray approximately perpendicular to the sides of the duct. Twice as much flow occurred along the perpendicular ray as along a ray bisecting the apex angle of the duct. Apex angles of 60, 90 and 120° were studied. The velocity decay for the direction of maximum flow was characterized and the decay coefficient was determined. The entrainment along the core region was estimated to be three to four times the initial volume of air at a distance of 6 to 8 feet (1·8 to 2·4 m) from the duct.

The velocity decay coefficient for a non-isothermal ceiling jet which issued from a long rectangular slot was shown to be temperature dependent. The entrainment ratio was also affected by temperature and a regression type entrainment expression was developed which included the temperature parameter. It was found that for jets issuing from 1 inch (25 mm) slots which were up to 32°F (18°C) cooler than the room air the buoyancy forces were not sufficiently large to overcome the forces holding the jet adjacent to the ceiling. Such jets remained close to the ceiling for distances of 18 feet (5·4 m) from the slot. The decay of temperature did not occur at the same rate as the decay of velocity. An energy-balance approach to defining the temperature decay proved somewhat satisfactory but was dependent upon having accurate velocity decay and entrainment relationships.

The effect of ceiling obstructions with long obstruction lengths was studied and a procedure for describing whether re-attachment did or did not occur was derived. The re-attachment distances predicted by the proposed method were greater than the distances observed, but the procedure predicted the occurrence of re-attachment for all conditions but one. Obstructions along the ceiling caused a more rapid velocity decay and a more rapid spreading of the jet than occurs with unobstructed jets. For most obstruction depths the detached jet left the ceiling at some angle smaller than the predicted angle of deflection. This apparently was due to the Coanda effect which tended to pull the jet back towards the ceiling.

Though these studies have improved the predictability of selected ventilation systems, considerably more work needs to be done in this area. As new ventilation concepts are conceived, they need to be analyzed in a similar manner so that the essential design information is available to the engineer. The procedures and theories outlined in this paper should be the basis of such studies.

List of Symbols

- A_e effective outlet area, ft^2 or m^2.
- A_i appropriate finite area having a unit width in the horizontal direction and a finite distance in the vertical direction, ft^2 or m^2.
- b outlet slot width, inches or mm.
- C_d coefficient of drag, dimensionless.
- E_x entrainment ratio at distance x, dimensionless.
- F_j force upon an obstruction in an air stream, lb. or kg.
- g gravitational constant, 32·174 pounds mass per pound force feet per sec^2 or 9·81 m/sec^2.
- h_e effective distance of air discharge between baffle and ceiling, ft or m.
- K velocity decay constant for zone 2 flow, dimensionless.
- K' velocity decay constant for zone 3 flow, dimensionless.
- M_{ij} initial momentum of the jet in the j direction.
- $M_{f\alpha}$ final momentum of the jet in the α direction.
- Q quantity of air flowing in an air jet, cubic ft per minute, m^3/sec.
- r distance from the peak velocity to another point within the jet, ft or m.
- $r_{0\cdot5}$ distance from the peak velocity to where the velocity is one-half the peak velocity, ft or m.
- Δt temperature difference between the jet and the ambient air, °F.

T_i absolute temperature of the room air, °R.
V velocity of the jet, fpm or m/sec.
$\overline{V}_i$ average velocity acting through the finite area A_i, fpm, or m/sec.
X downstream distance from the jet outlet, ft or m.
y upward or downward deflection of the jet, ft or m.
α the angle at which a jet passes the edge of an obstruction, degrees.
ρ the density of air, lb/ft³ or kg/m³.
σ a constant which for a free turbulent jet is 7·7.

Subscripts

o a point at the face of the jet outlet.
x a point at a downstream distance x from the jet outlet.
c a point on the jet centreline or along the line of peak velocity.

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Farm Building Programmes, January 1972, published by the Scottish Farm Buildings Investigation Unit, has articles on a 370 cow dairy unit; slatted farrowing pens; tower and clamp silos; and two on choice of site.

Farm Building R & D Studies, January 1972, published by the Scottish Farm Buildings Investigation Unit, carries articles on some environmental aspects of calf housing; and building costs and indices.

Farm Buildings Digest, Winter 1971/72, published by the Farm Buildings Centre, contains an article on ventilation entitled Holes in the Roof—On Purpose; Cow Cubicles—A Progress Report; and the building report is on a Scottish dairy unit.

Thinking Irrigation, published by the Ministry of Agriculture, Fisheries and Food, is Farm Water Supply leaflet number 2, and follows leaflet number 1 entitled *Protecting Your Water Supply*. It deals with a guide to sources, storage and distribution; planning; water requirements; sources; licences; storage; distribution system; distribution pipe work; hydrant chambers; pumping equipment; spraying and other equipment; advice, design and construction; grant aid; and other publications concerning irrigation.

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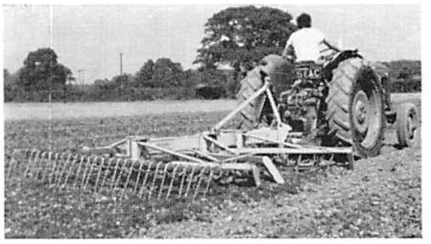

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Printed by The White Rose Press, Mexborough and London.