JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 20 No. 1 - FEBRUARY 1964

JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF AGRICULTURAL ENGINEERS

VOLUME 19 - NUMBER 3 - OCTOBER, 1963

CONTENTS

	Page
Announcement: ANNUAL CONFERENCE, A.G.M. AND DINNER	2
INSTITUTION NOTES	3
ELECTIONS AND TRANSFERS	5
Announcement: 1964 EXAMINATIONS	8
EXAMINATION BOARD IN AGRICULTURAL ENGINEERING, 1963–64	9
THE INSTITUTION'S EXAMINATIONS AND ELIGIBILITY FOR CORPORATE MEMBERSHIP OF THE INSTITUTION by J. A. C. GIBB, M.A., M.Sc., M.I.Agr.E., M.A.S.A.E.	10
PRESIDENTIAL ADDRESS—ACHIEVEMENT AND ANTICIPATION by W. J. PRIEST, M.I.Agr.E.	12
POWER-DRIVEN TRAILERS by D. P. BLIGHT, B.Sc., M.Sc., Ph.D., A.M.I.Mech.E.	16
SOME ASPECTS OF AGRICULTURAL ENGINEERING IN CALIFORNIA, U.S.A. by P. FINN-KELCEY, D.F.H., A.M.I.E.E., M.I.Agr.E., M.A.S.A.E.	24
OBITUARY: MR. ALEXANDER SENKOWSKI	35
IMPROVEMENT OF WORKING CONDITIONS FOR FARM MACHINERY OPERATIVES:	
(I) Noise Measurement and Analysis by S. W. R. COX, B.Sc., A.Inst.P.	36
(II) Better Tractor Ride Improves Driver Safety, Health and Productivity by A. K. SIMONS	47
(III) Safety Aspects of Cabs and their Testing by T. C. D. MANBY, B.Sc., M.Sc., A.M.I.Mech.E., M.I.Agr.E.	53
INDEX TO ADVERTISERS	62
INSTITUTION REPRESENTATIVES ABROAD	*iii of Cover*

Published by the Institution of Agricultural Engineers, 6, Queen Square, London W.C.1
Telephone: Terminus 0140

Price: Ten Shillings and Sixpence — Published Quarterly

THE INSTITUTION OF AGRICULTURAL ENGINEERS

6 QUEEN SQUARE, LONDON, W.C.1

ANNUAL CONFERENCE
ANNUAL GENERAL MEETING
AND DINNER

TUESDAY, 28th APRIL, 1964

PROGRAMME

CONFERENCE AND ANNUAL GENERAL MEETING
at the Institution of Mechanical Engineers,
1, Birdcage Walk, London, S.W. I.

10.30 a.m. PAPER AND DISCUSSION : **" Theory and Practice in Off-the-Road Locomotion,"** by A. R. Reece, B.Sc., M.Sc., A.M.I.Mech.E., A.M.I.Agr.E., Lecturer in Agricultural Engineering, University of Newcastle-upon-Tyne.

11.40 a.m. COFFEE.

12.00 noon ANNUAL GENERAL MEETING.

12.30 p.m. LUNCHEON RECESS.

2.00 p.m. PAPER ND DISCUSSION : **" Control of Environment for the Growth of Plants in Glass-houses,"** by G. P. Shipway, B.Sc., M.Sc. (Agr.Eng.), A.M.I.Agr.E., N.A.A.S. Liaison Unit, National Institute of Agricultureal Enginering, Silsoe.

3.30 p.m. PAPER AND DISCUSSION : **" The Agricultural Tractor—Some Unorthodox Concepts,"** by K. E. Morgan, B.Sc., N.D.Agr.E., A.M.I.Agr.E., Lecturer in Agricultural Engineering, University of Reading.

4.40 p.m. TEA.

ANNUAL DINNER
at the St. Ermin's Hotel,
Caxton Street, London, S.W. 1.

6.15 p.m. Reception prior to Dinner (at 7 p.m. approx.).

The Chair will be taken throughout the day's proceedings and at the Dinner by
W. J. PRIEST, M.I.Agr.E.,
President of the Institution.

Admission to the Annual Conference and/or the Dinner is by ticket, charges being as follows :

Conference Papers, Morning Coffee, Tea and Dinner (inclusive of table wines)	60/-
Dinner only (inclusive of table wines)	50/-
Conference Papers, Morning Coffee and Tea only ..	10/-

(Charges for Student Members, half the above rates.)

Literature and Ticket Order Forms may be obtained from the Institution Secretary.

INSTITUTION NOTES

The views and opinions expressed in Papers and individual contributions are not necessarily those of the Institution. All Papers in this Journal are the copyright of the Institution

Journal Publication Dates

ONE result of the difficulties to which the death of the Institution Secretary in 1963 gave rise was that the *Journal* was published in three parts only —*i.e.*, in February, July and October of that year. The step has been taken of enlarging this February issue so as to include a number of Papers and other material that would in the ordinary course have been published in the fourth issue in 1963. This covers such major features as the Presidential Address by W. J. Priest, M.I.Agr.E., together with the texts and discussions of two Papers presented at the Open Meeting of the Institution in London on 17th October, 1963. For the remainder of 1964, the normal publication dates of May, August and November will obtain.

Open Meetings in London, 1964

An attendance of over 80 members and guests marked the success of the all-day Open Meeting of the Institution which took place in the Lecture Theatre of The Royal Society of Arts, London, on 30th January, 1964. The theme of the three Papers and the ensuing Forum was " Improvement of Working Conditions for Farm Machinery Operatives." Fully illustrated versions of these lectures and discussions appear in this issue of the *Journal.*

Particular attention is directed to the details of the final Open Meeting of the Institution's 1963–64 Session in London ; the programme appears on the opposite page. This will be the first occasion on which an activity of the Institution will have been staged in the Lecture Hall of The Institution of Mechanical Engineers —a fact which affords evidence of the cordial relationship that exists between the two Institutions.

Branch Programmes

Since publication of Branch Programmes in the previous *Journal* in October, 1963, further Branch activities have been organised, as follows :

East Midlands Branch

18th March, 1964.

PAPER AND FILM, " Power Transmission by Precision Chain Drive," by S. Foden, Reynolds Chains Ltd., at 7.30 p.m. at Nottingham University School of Agriculture, Sutton Bonnington.

15th April, 1964.

ANNUAL DINNER (further details to be announced), Grantham.

Scottish Branch

4th March, 1964.

ONE-DAY CONFERENCE on " Modern Techniques for the Handling and Storage of Potatoes," at 10 a.m., at Dunblane Hotel Hydro, Dunblane. Admission 30/- (including lunch), 20/- (excluding lunch).

4th March, 1964.

ANNUAL DINNER, 7 p.m., at the Dunblane Hotel Hydro, Dunblane. Tickets 25/-.

Royal Show

The Royal Agricultural Society of England announces that the 1964 Royal Show will take place at Stoneleigh Abbey, Kenilworth, Warwicks., from 7th July to 10th July inclusive. Further information of this event may be obtained from the Secretary and Technical Director of the Society at 35, Belgrave Square, London, S.W. 1.

International Conferences and Exhibitions

35e Salon International de la Machine Agricole (SIMA)

This Exhibition will be held in the Parc des Expositions, Porte de Versailles, Paris from 9th to 15th March, 1964. It is claimed that some 1,850 makes of machinery are displayed on 750 stands at this famous Paris exhibition, where more than 50 nations are represented. Further particulars are obtainable from SIMA, 95 rue Saint Lazare, Paris, 9e.

British Agricultural Exhibition, Moscow

The purpose of this Exhibition, to be held in the Park of Economic Achievement of the U.S.S.R., Moscow, from 18th to 31st May, 1964, is to demonstrate the present status, world position and achievements of British Agriculture and to develop trade relations between Great Britain and the U.S.S.R. in the field of agriculture. Information can be obtained from Brook-Hart, Ruder & Finn International, 48, Dover Street, London, W. 1.

48th DLG Agricultural Show, Hanover

Many countries are focussing attention on this Show, planned to take place in the famous Hanover Industrial Fair Grounds from 31st May to 7th June, 1964. Exhibits will cover a wide range of engineering plant and equipment, and special shows and demonstrations are to be organised. Further details are obtainable from Deutsche Landwirtschafts-Gesellschaft, 6 Frankfurt/Main, Zimmerweg 16.

ELMIA 64, Jonkoping, Sweden

Farm construction problems, farmyard mechanisation, forestry mechanisation and transport problems are among the themes of the European Agricultural and Industrial Fair, ELMIA, to be held in Jonkoping, Sweden, from 21st to 31st May, 1964. Full details, of this Exhibition can be obtained from ELMIA, Jonkoping, Sweden.

(*Continued on page 15*)

ELECTIONS AND TRANSFERS

Approved by Council at its Meeting on 26th September, 1963

ASSOCIATE MEMBER		Campbell, S.	N.Ireland
		Chrystie, A. H.	Scotland
		Cross, F.	Dorset
		Dilke, N. W.	Devon
		Lockyer, R. W. H.	Devon
		Richardson, M. R.	Norfolk
ASSOCIATE		Cargill, W. M.	Derbys.
		Chivers, F. J.	Warwicks.
		Duck, P. R.	Wilts.
		Kirk, A. R.	Northants.
		Lloyd-Williams, G.	Bristol
	Overseas	Bless, P.	Australia
		Falconer, I. R.	New Zealand
		Munro, R. McL.	Tanganyika
GRADUATE		Jewett, D. W.	Cambs.
		Roberts, P. D.	Worcs.
	Overseas	Akinyede, P. A.	Nigeria
		Morgan, B. E.	South Africa
		Nasir, F. A.	Pakistan
		Sarker, K.	India
FROM ASSOCIATE TO ASSOCIATE MEMBER		Beadle, E. F.	Lincs.
		Gibbs, C. W. R.	Wilts.
		Hadley, M. J.	Hants.
		Mott, J. B.	Norfolk
FROM GRADUATE TO ASSOCIATE MEMBER		Evans, L. P.	Warwicks.
		Pollard, R. G.	Somerset
FROM STUDENT TO GRADUATE		Willcocks, T. J.	Kent

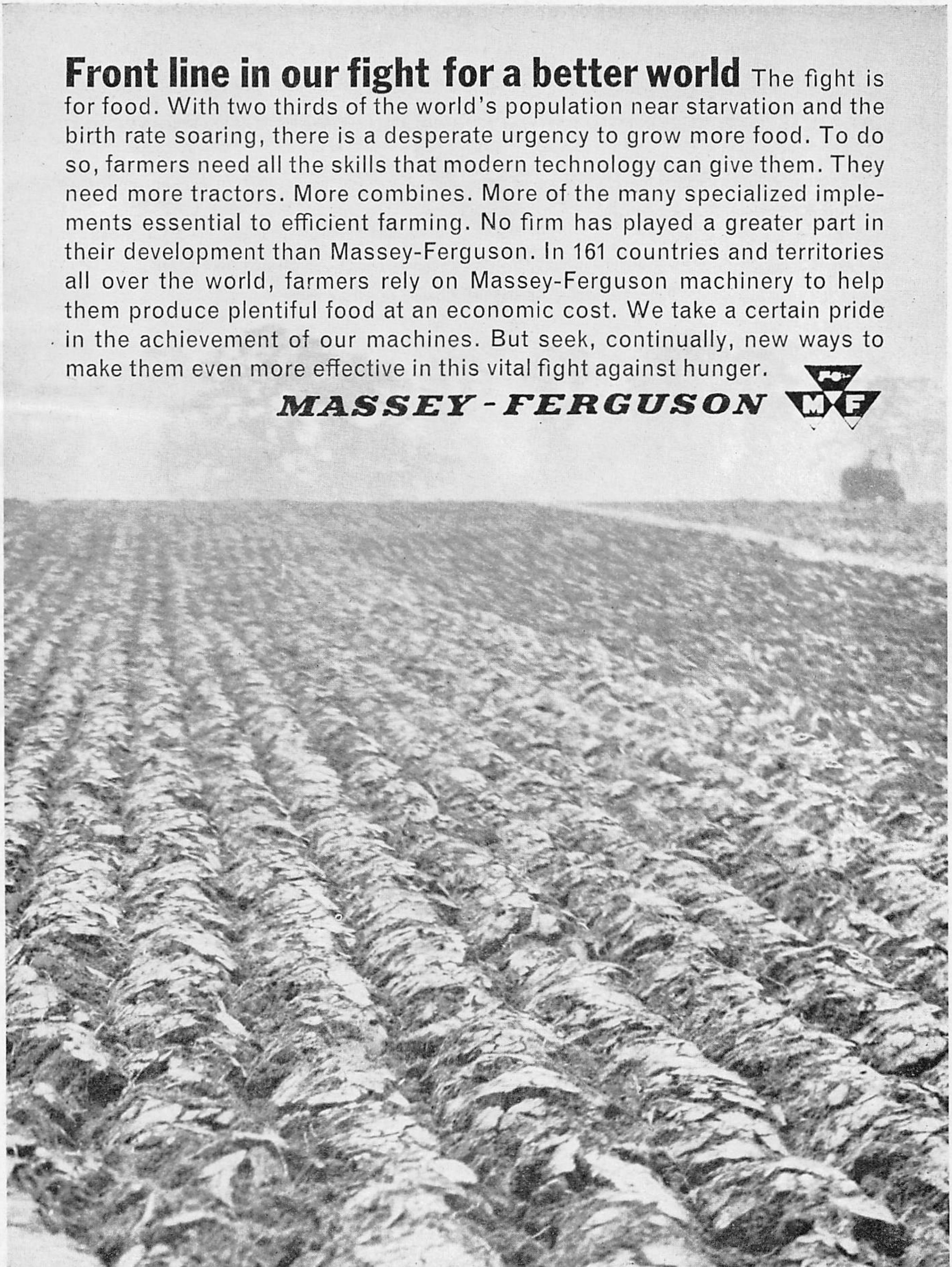
ELECTIONS AND TRANSFERS

Approved by Council at its Meeting on 9th January, 1964

MEMBER		Granger, H. W.	Devon
ASSOCIATE MEMBER		Farrow, B. T.	Cornwall
		Hampshire, J. M.	Devon
		Smith, W. G.	Warwicks.
		Stevens, G. N.	Beds.
ASSOCIATE		Brassington, C. B.	Staffs.
		Clements, H. A. B.	Leics.
		Weaving, T. F.	Warwicks.
	Overseas	Henson, J.	Nigeria
		Norman, S. R.	British Guiana
		Thomson, A. C.	Gambia
GRADUATE		Ainsworth, N.	Derbys.
		Bacchus, N. N.	Yorks.
		Bailey, A. L.	Worcs.
		Brook, R. H. F.	Essex
		Brunner, S. G.	Lancs.
		Burns, R.	Notts.
		Edmunds, J. R.	Surrey

(Continued overleaf)

GRADUATE	Goodfellow, R. E.	Mon.
	Hutton, G. J.	Hants.
	Lake, J. R.	Beds.
	Lamin, W. H.	Cumberland
	Leaf, R. J.	Dorset
	McLean, K. A.	Hants.
	Mitchell, D. G.	Birmingham
	Moon, A. G.	Somerset
	Oliphant, A. J.	Fife
	Pardoe, N. R.	Worcs.
	Rodger-Brown, D.	Warwicks.
	Smith, F. S.	Warwicks.
	Webb, B.	Glos.
	Wheeler, J. A.	Beds.
	Wilford, C. D.	Kent
	Wingate-Hill, R.	Durham
Overseas	De Zoysa, D. J. W. G.	Ceylon
	Mensah, J. A.	Ghana
	Ntim-Addae, Y.	Ghana
	Okai-Koi, N. K.	Ghana
	Punia, H. S.	India
	Quansah, E. K.	Ghana
	Townsend, A. C. C.	S.Rhodesia
STUDENT	Cavill, R. A.	Essex
	Corrie, W. J.	Essex
	Garland, P. J.	Essex
	Gordon, D. J.	Essex
	Harding, J. S.	Essex
	Landsberg, T. M.	Essex
	Mill, J. S.	Worcs.
	Moffatt, D. I.	Essex
	Ormiston, L. W.	Surrey
	Osmond, C. R.	Hants.
	Pearson, M. J. C.	Lancs.
	Peters, I. C.	Essex
	Powdrill, C. L.	Essex
	Provan, I. H.	Glasgow
	Rowling, M. S.	Essex
	Statham, O. J. H.	Beds.
	Tucker, N. G.	Somerset
FROM ASSOCIATE MEMBER TO MEMBER	Payne, P. C. J.	Beds.
Overseas	Jayasinghe, A. C.	Ceylon
FROM ASSOCIATE TO ASSOCIATE MEMBER	Shippen, J. M.	Lincs.
FROM GRADUATE TO ASSOCIATE MEMBER	Boydell, J. M.	Staffs.
	Carpenter, J. L.	Essex
	Grundey, J. K.	Beds.
	Holt, J. B.	Beds.
Overseas	Baxter, K. C.	Nigeria
	Debattista, J.	Malta
	Johnson, I. M.	Kenya
FROM GRADUATE TO ASSOCIATE	O'Hara, T. P.	Worcs.
FROM ASSOCIATE TO GRADUATE		
Overseas	Ankrah, B. O.	Ghana
FROM STUDENT TO GRADUATE	Mead, D. A. C.	Sussex
	Warren, J. D.	Dorset


Front line in our fight for a better world
The fight is for food. With two thirds of the world's population near starvation and the birth rate soaring, there is a desperate urgency to grow more food. To do so, farmers need all the skills that modern technology can give them. They need more tractors. More combines. More of the many specialized implements essential to efficient farming. No firm has played a greater part in their development than Massey-Ferguson. In 161 countries and territories all over the world, farmers rely on Massey-Ferguson machinery to help them produce plentiful food at an economic cost. We take a certain pride in the achievement of our machines. But seek, continually, new ways to make them even more effective in this vital fight against hunger.
MASSEY-FERGUSON
MF

Examination Board in Agricultural Engineering

(1963-64)

Appointed by the Council of the Institution of Agricultural Engineers

Chairman

D. I. McLaren, B.Sc.(Agric.), N.D.A., M.I.Agr.E.

Deputy Chairman

J. A. C. Gibb, M.A.(Agric.), M.Sc. (Agric.Eng.), M.A.S.A.E., M.I.Agr.E.

Ex Officio

President of the Institution of Agricultural Engineers
Chairman of the Membership Committee of the Institution of Agricultural Engineers

Members

D. R. Bomford, M.I.Agr.E.
W. H. Cashmore, C.B.E., B.A., N.D.A., C.I.Mech.E., M.I.Agr.E.
R. M. Chambers, B.Sc., B.Agr., M.I.Agr.E.
C. A. Goodger, C.I.Agr.E.
B. H. Harvey, B.Sc., N.D.A., N.D.D.
Alexander Hay, O.B.E., N.D.A., N.D.D., Hon.M.I.Agr.E.
J. Metcalfe, M.B.E., B.Sc., A.M.I.E.E., Assoc.I.Mech.E.
J. E. Nicholson, O.B.E., T.D., A.C.G.I., M.I.Agr.E.
P. C. J. Payne, B.Sc.(Agric.), M.Sc.(Agric.Eng.), Ph.D., A.M.I.Agr.E.
C. J. Swan, B.Sc.(Agric.), N.D.A., N.D.D., N.D.Agr.E., A.M.I.Agr.E.
J. O. Thomas, M.Sc., N.D.A., N.D.D.
J. A. C. Williams, M.Sc., M.I.Mech.E., F.R.Ae.S., A.M.I.Prod.E.

A Representative appointed by the Agricultural Engineers Association

A Representative appointed by the Royal Agricultural Society of England

Assessor representing the Ministry of Agriculture, Fisheries and Food

C. Culpin, O.B.E., M.A., Dip.Agr.(Cantab.), M.I.Agr.E.

Assessor representing the Ministry of Education

G. Sutton, H.M.I.

Assessor representing the Department of Agriculture for Scotland

W. J. L. Dobson

Assessor representing the Scottish Education Department

J. A. Ferguson, H.M.I.

The Institution's Examinations and Eligibility for Corporate Membership of the Institution

by J. A. C. Gibb,* M.A., M.Sc., M.A.A.E., M.I.Agr.E., M.A.S.A.E.

In his Address (see page 12) the President has referred to the rising standards the Institution is striving to attain in order to play the fullest possible part in an increasingly technological world. In seeking to raise standards, the Institution has recently given special attention to defining the level of knowledge to be required of future applicants for the professional grades of membership (Graduate, Associate Member, Member), and to the function of the Institution's examinations in this connection.

The Effect of the New Measures

It must be made clear at the outset that the new provisions do *not* affect existing members in any grades, or future candidates for membership in the Student, Associate, Companion or Honorary Member grades. The effect of the changes, for the professional grades, is progressively to stiffen the entry requirements, beginning at the earliest practicable date to apply to young candidates for Graduate Membership. The most important *change* is that the Institution Examination will no longer be available to candidates under 30 years of age, and that it will be modified in form to make it more suitable for private-study candidates. New facilities, which will shortly become available, will enable the best of the young candidates who would otherwise have sat the Institution Examination to attend a course leading to the National Diploma in Agricultural Engineering (N.D.Agr.E.). The N.D.Agr.E. will then be the basic minimum qualification for young entrants to Graduate Membership.

The most important *innovation* is a new test of technical performance and ability, to be called the Part III Examination. This will eventually form a hurdle to be surmounted by all Graduate Members or others who wish to become Corporate Members (*i.e.*, Associate Member or Member).

The Guiding Principle

In devising a new pattern of qualifications for membership, the guiding principle has been to establish a high minimum level of attainment for the class of entrant most easily able to obtain effective training in Agricultural Engineering—*i.e.*, the candidate in his early 20s who has followed courses of mainly full-time education almost continuously up to the moment of taking his examination in Agricultural Engineering. Such candidates should be able to achieve a high standard, and the National Diploma in Agricultural Engineering has therefore been taken as the standard to be reached.

Older candidates, who for one reason or another have not followed the same pattern in their earlier years, will nevertheless be acceptable at a slightly lower standard of achievement in the broad field of Agricultural Engineering—provided that their additional relevant experience and detailed knowledge of some aspects of Agricultural Engineering can be regarded as reaching, in total, at least the same high level of attainment.

In this way, provision will be made for candidates of all ages to enter the Institution's professional ranks, a balance being reached, for each candidate, between high paper qualifications and length and quality of professional experience.

Implementation of these provisions cannot reasonably take place all at once. It is necessary for the Institution to give adequate notice of its intentions, and because a number of potential members have already embarked on professional careers of different patterns, there can be only a gradual tightening of the entry requirements. In the first stage, from 1966–1974, certain concessions will be made, especially to older candidates.

In the second and final stage, however, the increased provision of suitable training facilities and the length of notice make it practicable and fair for the more stringent requirements to be brought into effect for candidates, regardless of age. This will be done from 1st January, 1975, and from that date Corporate Membership of the Institution will clearly be seen to be a mark of Professional Agricultural Engineer status.

The New Pattern

The new pattern of examination and other qualifications for the professional grades of membership is unavoidably complex. It must not only provide reasonable avenues of approach for candidates of widely differing ages from various branches of agricultural engineering ; it has also to provide over the next ten years for the gradual increase in standards referred to above.

The Institution is concerned with examinations at three levels—Parts I, II and III—and also with the stipulation of Preliminary requirements in terms of general or elementary technical education. Specified examinations administered by bodies other than the Institution are accepted as equivalent to the Institution's examinations, and many candidates for membership may claim exemption from Part II, while the vast majority of candidates will be exempt from Part I.

In the most general terms, these requirements can be summarised as follows. A more detailed statement is given in the Appendix.

Summary of Qualifications

PRELIMINARY : Five Ordinary Level Passes in the General Certificate of Education (to include English, Mathematics and an approved Science) OR equivalent.

PART I : (*a*) National Diploma in Agriculture OR equivalent (for agricultural entry) ;

or (*b*) Intermediate Qualification of the National Diploma in Agricultural Engineering OR equivalent (for engineering entry).

* Chairman, Education Committee, Institution of Agr. Engineers.

PART II : National Diploma in Agricultural Engineering OR equivalent.[1]

PART III : New provision already referred to (see also Appendix).

Note.—While the examinations quoted are indicative of the minimum levels required, their equivalents are of very great importance to potential applicants. For further information refer to the Appendix.

Membership Requirements

The pattern of requirements *after* 1st January, 1966, is shown in the Tables below.

(*Note.*—This does NOT apply to candidates for membership in the grades of Student, Associate, Companion or Honorary Member, nor does it affect *existing* members of any grade.)

TABLE I
Age and General Qualifications

	Graduate	*Associate Member*	*Member*
Minimum Age	21	27	40
General Qualifications.		Must have had at least 7 years of technical training and relevant experience, and have held a responsible position in Agricultural Engineering for at least 2 years.	Must have had training and experience as for Associate Member, and have held a position of superior responsibility for at least 5 years.

TABLE II (A)
Technical Qualifications Required During Phase I, from 1st January, 1966, to 31st December, 1974

Age at Time of Application for Admission or Transfer	*Technical Qualifications Required (in addition to Preliminary Qualifications and Part I)*		
	Graduate	*Associate Member*	*Member*
Under 30	Part II (EXCL. Inst'n Exam.)[2]	Part II (EXCL. Inst'n Exam.)[2] PLUS Part III[3]	—
30–37	Part II	Part II	—
Over 37	Part II OR Part III	Part II OR Part III,[4]	—
Over 40	Not normally applicable	Part II OR Part III,[4]	Part II OR Part III,[4]

TABLE II (B)
Technical Qualifications Required During Phase II from 31st December, 1974

Age at Time of Application for Admission or Transfer	*Technical Qualifications Required (in addition to Preliminary Qualifications and Part I)*		
	Graduate	*Associate Member*	*Member*
Under 30	Part II (EXCL. Inst'n Exam.)[2]	Part II (EXCL. Inst'n Exam.)[2] PLUS Part III[3]	—
Over 30	Part II	Part II PLUS Part III	—
Over 40	Not normally applicable	UNTIL 31st Dec. 1982 : Part II OR Part III,[4] FROM 1st Jan., 1983 : Part II PLUS Part III	As for Associate Member

APPENDIX

PROVISIONAL LIST OF GENERAL REQUIREMENTS AND TYPICAL EXEMPTING QUALIFICATIONS RELATING TO THE INSTITUTION'S EXAMINATIONS

Preliminary (General Standard of Education)

Five passes at " O " Level in the General Certificate of Education, including Mathematics, an approved Science and English.

Exemption. Engineering-approach candidates may claim partial exemption, on a subject-for-subject basis, in respect of successes in comparable examinations.[5]

Part I (Intermediate)

A 2-year full-time or sandwich course, including (1) Mathematics, (2) Engineering Science, (3) Engineering Drawing, (4) Introductory and Comparative Agriculture.

Exemption. Engineering-approach candidates may claim exemption from subjects 1–3, on the basis of success in examinations such as the Ordinary National Diploma in Engineering.[5]

Agricultural-approach candidates holding the National Diploma in Agriculture or a degree in Agriculture will be exempt from all subjects.

Part II

A 1-year full-time course leading to the National Diploma in Agricultural Engineering (OR, for candidates over 30 years of age, a suitable period of study leading to the Institution Examination).

Exemption. Holders of the Associateship of the National College of Agricultural Engineering (A.N.C.A.E.) or of a degree in Agriculture or Engineering *plus* a higher degree or diploma in Agricultural Engineering may claim exemption.

Part III

An examination, OR presentation of a thesis, OR a professional interview, OR a combination of these requirements, as may be prescribed for each candidate by the Institution. Subjects will be selected in the light of the type of professional experience of individual candidates.

No Exemption is allowed except for older candidates as shown in the Table of Qualifications above during the interim period up to 31st December, 1974, *only* (for candidates over 40, up to 31st December, 1982).

[1] And, for candidates over 30 years of age, the Institution Examination.

[2] After 1965 the Institution Examination will be restricted to candidates over 30 years of age, except :
(*a*) Re-sits in 1966 by candidates failing in 1965.
(*b*) In 1966 and 1967 for candidates already (*i.e.*, on 1st January, 1964) engaged on courses expected to lead to the Institution Examination in those years.

[3] Graduate members under 30 when applying for transfer to Associate Membership, who have passed the N.D.Agr.E. or Institution Examination or other exempting examination before 1st January, 1966 (including re-sits in 1966 of 1965 failures), will not be required to take Part III if such applications are made before 1st January, 1975.

[4] Exemption from Part I may be given in special cases.

[5] *Note.* A list of comparable examinations will be compiled and published in due course.

ACHIEVEMENT AND ANTICIPATION

PRESIDENTIAL ADDRESS

By W. J. Priest, M.I.Agr.E.

Presented at an Open Meeting of the Institution on October 17th 1963.

When, a few months ago, this Institution did me the great honour of electing me its President, there was certainly no thought that this address would begin with a tribute to the memory of Ronald Slade, a distinguished and devoted Secretary.

His sudden death on May 17th was a grievous loss; his lasting memorial is the great work that he did for this Institution and, as a consequence, for the agricultural engineering profession.

I shall always be proud to remember, however, that during the last conversation I had with Ronald Slade, we discussed the form which this address might take. That conversation led to the title "Achievement and Anticipation"; *achievement*, because the Institution has successfully weathered the first 25 years of its existence; *anticipation*, because, on the occasion of this Silver Jubilee, the Institution looks forward, in eager determination, to the accomplishment of work even more successful than that which has so far been done. For more and more it is coming to be realised that agricultural engineering today is among the world's leading technologies.

It would be a pleasant task for the President of this Institution to recall in detail the labours of the past 25 years. In some degree, it might also be a profitable task, for, even in this age which is frequently charged with being unduly cynical, there is much to be learned from the doggedness of pioneers, and from the frustrations and setbacks which they had to endure.

The men who pioneered this Institution, and all who by prodigious effort have steered it successfully to this Silver Jubilee occasion, fit in very well, in my opinion, with a sentiment expressed a long time ago by the Younger Pliny in his letter to Tacitus—a reasonable translation of which is:—

> "Happy those who can do things worth recording or write things worth reading: most happy those to whom it is given to do both."

The Institution has undoubtedly managed to do many things worth recording. By its works to date, it has encouraged all kinds of people to realise that agricultural engineering deserves a status that for long years it was denied. Those who, in the last century and in the earlier years of the present one, successfully applied steam power to farming tasks were properly considered to be engineers. But that recognition was for the most part denied the many who designed and produced the implements and machines which constituted the farmer's tools.

Unrecognised

These latter seemed to be of little account in the steadily extending realm of engineering. For nearly a century, I would say, in the minds of the majority, they were bracketed with the somewhat acid comment passed on the implements exhibited at the first Royal Show, which were described as "crude, cumbrous and ill-executed machines, the work of village ploughwrights and hedge-side carpenters." (1)

I deem it to be an honourable thing that agricultural engineering as a leading technology has evolved from the work of "village ploughwrights and hedge-side carpenters" who, let us not forget, were knowledgeable about the farming problems of their individual localities, and were ready to apply their ingenuity and craftsmanship to the fashioning of equipment which would enable farmers to do their job more effectively.

Other engineering technologies have developed in much the same way. Their status has been acknowledged, perhaps, in a shorter period of time than has been in the case with agricultural engineering. Thomas Newcomen, for example, whose contributions to mechanical engineering science were in no way unimportant, was an ironmonger regarded, no doubt, by many in his day as something of a tinker. In the same context, it is not inappropriate for us to recall that so distinguished a body as the Institution of Mechanical Engineers owes its formation in 1847 to the stark fact that the Institution of Civil Engineers (founded 29 years earlier, in 1818) refused to admit George Stephenson to membership unless he would submit "a probationary essay as proof of his capacity as an engineer." (2)

Fulfilling a Need

I mention this circumstance in support of my conviction that not only was the need for an Institution of Agricultural Engineers becoming more and more obvious 25 years ago, but that there was also at least one good precedent for founding such an Institution.

But in that period which industrial historians will no doubt describe as an interesting one, that period generally known as the inter-war years, British agriculture and the British engineering industries were sorely tried. Industrial unemployment was high, and there was plenty of inexperienced labour available for work on the land. For many of those years, however, the economics of farming were such that it was well-nigh impossible to stimulate investment in equipment for mechanising farming operations.

The majority of those engaged in farming took the view that it was better to " puggle along " with traditional, back-breaking methods than to clutter themselves up with the new-fangled machines which they could not afford to buy, and which were far more difficult to work than animal-powered implements. To say that, in the lean years of the 1920s and 1930s, farmers distrusted the intentions of engineers is putting it mildly!

Yet I never fail to be amazed when I recall the number of long-established engineering concerns which, in the earlier of those inter-war years, designed and produced tractors. Could but a few of them have stayed the course, the story of the development of the farm tractor in this country would have been even more impressive than it now is.

The " Seers "

Nevertheless, it is important to bear in mind, as this Institution celebrates its Silver Jubilee, that throughout the years of farming depression, frustration and scepticism, there were always some engineers who were convinced that the day would come when they would be required to apply their talent increasingly to the promotion of more effective farming methods.

The proceedings of such distinguished bodies as the Institution of Mechanical Engineers emphasise that fact. As a single example, when the " Mechanicals " held a summer meeting in Ipswich in 1926, the late Mr. Frank Ayton, who was then on the staff of Ransomes, Sims & Jefferies, Ltd., presented a paper in which he was bold enough to declare that " agriculture, the oldest of the world's industries, was among the first to enlist the aid of the engineer," and he went on to affirm that the stage had been reached when it could be said that " engineering is the handmaid of agriculture." [3]

Misguided Outlook

Not many farmers, I fancy, and not a tremendous number of engineers at that time supported Mr. Ayton's views. Power stations, aircraft, machine tools, shipbuilding, railways and road transport all then offered great scope for engineering talent—but agriculture, surely, in this country, at any rate, it was felt, was not likely to call for the close attention of qualified engineers. That, I suggest, may have been the likely reaction of the day to statements such as those made by Mr. Ayton. It is interesting to note, therefore, that in the discussion on his paper, there was at least one speaker who remarked that " there was not even a good book on agricultural engineering, nor, in this country, was there an agricultural engineering society such as there was in the U.S.A."

Twelve years later, when this Institution was founded, the climate of opinion had not changed a great deal. The tractor was still not much more than a substitute for the draught horse; the few combines to be found in various places were often rated as useless because they shook too much grain on to the ground and left the straw standing anyway; while most of the other mechanisation developments of the last couple of decades were deemed to be impossible of achievement.

No one, of course, who gives serious thought to the spectacular agricultural engineering developments of comparatively recent times would suggest that they are wholly the result of this Institution's energies during the years of its childhood, adolescence and advance towards full maturity. But it is by no means unreasonable to claim that the Institution's contribution to those developments has been a very valuable one, even though it has not always been obvious. The Institution's main objectives have not changed. The general advancement of agricultural engineering, the provision of professional status for its members, and initiating, in London and in the eight Branches throughout the country, discussion on all agricultural engineering subjects, constitute the task to which we are pledged, remembering that scientific knowledge which can benefit mankind should never be frustrated by international barriers.

Birth of N.D.Agr.E.

An important part of that task is the promotion of high educational standards in agricultural engineering. In this respect, the Institution has certainly not been idle. Initially, the path was by no means easy, but twelve years ago the Ministry of Education agreed to recognise a National Diploma in Agr cultural Engineering as a qualifying mark. The Institution is responsible for organising the necessary examinations, and there are now 269 holders of the Diploma who, with the benefits of disciplined study and practical training, are contributing actively, not only in this country but in many places abroad, to the advancement of agricultural engineering in its broadest and best sense. In more recent years, the Institution has established its own membership examination as a test of the technical ability of those seeking to join, and who are ready to understand that something more than the payment of an annual subscription (important though that is !) is involved.

An Important Milestone

Finally, under the heading of achievement, the Institution can remember, with no little satisfaction, that, in 1955, it fired the opening salvos in a somewhat protracted operation to secure the establishment of the National College of Agricultural Engineering. Seven years elapsed before the College was able to start work, with a distinguished member of the Institution as its Principal. I could not possibly compute the man-hours extended in discussions about this project, many of them in convincing people in high places that a first-class system of agricultural engineering education is imperative to the well-being of this nation and the world in general.

Thus, in its first 25 years of travelling along a road on which the going has sometimes been undeniably hard, the Institution has been able to set up some milestones. But milestones must not be monuments or resting places—they must rather be incentives to push on.

Let there be no doubt that we have an important part to play in shaping the future not only of what the National Farmers' Union aptly calls "Britain's Biggest Industry " [4], but also the future of world agriculture.

We have reached a stage at which it is readily acknowledged that the high productivity of British agriculture is largely due to the intensive use of modern machinery. It is reliably estimated that British farmers expend over £220 million a year on machinery, fuel and lubricants. Moreover, exports of British farm machinery are now running at an annual rate of over £140 million. These are impressive figures, with which many of us have become so familiar that they may not be given the attention they merit.

Further Heights

They do not fully represent the pinnacle of engineering endeavour. There are further heights to be scaled. But such figures could not be achieved, let alone maintained, were it not for the highest quality work at all stages of design, development and production on the part of agricultural engineers.

At this point, I feel it appropriate to put in a word about the description " agricultural engineer." Recently, in my hearing, a distinguished Past-President of this Institution said that, to the uninitiated, " an agricultural engineer was a somewhat peculiar animal." Perhaps he is ! In this day, however, there is understandably a desire for definition, although many will declare that it is far more important to get on with the job than it is to worry about definitions.

Nevertheless, it is of interest to note that the American Society of Agricultural Engineers, now 66 years old, has had a special committee at work for a year endeavouring to draft a suitable definition.[5] I gather that the committee has not yet reached a settled conclusion, though it has got as far as describing agricultural engineering as " a field of engineering and science in which both physical and biological sciences are specifically utilised. It involves power, machines, structures, electronics, land development and soil and water management in connection with the production, processing, handling and storage of food, feed and natural fibre."

Despite its wordiness, I do not think anybody would dispute the thoroughness of that definition. But, with the greatest respect for the diligence of our American friends, I suggest that, in this country, we have crystallised the matter very satisfactorily if we accept a definition, admirably expounded earlier this year by Mr. J. A. C. Gibb.[6] Briefly put, it is that " agricultural engineers are those concerned with the application of engineering to agriculture."

All such, I would emphasise, are the engineers who come within the orbit of this Institution. The education of those who accept the challenge of the future in this particular concept of engineering must be liberal ; but all who are in any way concerned with the fuller application of engineering principles to the agriculture of to-day and tomorrow must realise that " rule of thumb " methods are as out-dated as reaping with a sickle.

Rising Standards

Thus, we face the future with the deep conviction that agricultural engineering is a live and progressive technology. The adequate promotion of that technology is this Institution's responsibility, and in the past few months the most careful thought has been given to our hopes and anticipations. As a result, the council is quite sure about three main needs. They are (i) to raise the standard required for entry of younger candidates as soon as possible; (ii) to allow those who have recently qualified or who are now preparing to qualify for corporate membership under the existing minimum technical requirements to be granted that corporate membership, within an appropriate period, on the existing basis; and (iii) to allow older candidates with lower paper qualifications to continue to be granted corporate membership of the Institution for a period of up to 20 years ahead provided they have had adequate experience and responsibility.

Plans are now being formulated for revision of the Institution's examinations to fit those needs. What is of great importance is that those plans shall make a worthy contribution to the future pattern of agricultural engineering education. Let no one think that these endeavours can be reached and these anticipations realised in the twinkling of an eye. The changes which are demanded by this progress to steadily rising standards of qualification for corporate membership are to be phased over the next 20 years. Long before then, we confidently hope, this Institution will be deemed worthy of a place in the Engineering Institutions' Joint Council ; moreover we feel it our bounden duty to set our sights now on the day when this Institution will have earned the grant of a Royal Charter.

All this, I assure you, is no flight of fancy. Here and there will still be found the sceptic who will say " What is the use of all this—is all this high standard professionalism really necessary to fully-mechanised agriculture? "

Surely, the proof of the pudding is still in the eating. We can—and do—take endless trouble to perfect sales techniques, we can take care, as indeed we should, to see that our commercial efficiency is kept at the highest pitch, but these things are of no lasting avail unless they are preceded and followed by high quality engineering.

Combined Operations

In this context, may I say that this Institution deeply appreciates the encouragement it receives from and the cordial relationship it enjoys with the Agricultural Engineers Association and the Agricultural Machinery and Tractor Dealers Association, long-established bodies which in their respective spheres, make a vital contribution to the commercial efficiency of the agricultural engineering industry. But I feel it realistic to add that, in this era of rapid technological and scientific change, the value of the work accomplished by these and similar commercially-based bodies will be greatly enhanced by even closer attention to high standards of technical skill and efficiency.

For there is one great certainty. It is that agricultural engineering is a technology which cannot stand still. When my father was a youth he was among those who did the thrashing on his father's small farm with flails. He would never have believed then that such a machine as the combined harvester was possible. Even at the end of his long life on the land ten years ago, he would not have credited that fully-mechanised livestock tending or completely automatic systems of materials handling on the farm would be an established fact so soon after his departure.

Recognising the Challenge

Now still more exciting vistas are before us. Much is always being said in many places about the age of full automation; much is always being said about a rising standard of living particularly in the under-nourished and under-developed territories of the world; likewise, much is said about the ever-present need to increase still further the efficiency of this country's agriculture. These are but a few of the things constituting the challenge confronting agricultural engineers of this and succeeding generations. That is the challenge which this Institution recognises, and which it is determined to take up in thoroughly realistic and practical fashion.

Engineers in general, and agricultural engineers in particular, have a reputation for resourcefulness and solid achievement. The maintenance of that reputation, more so than ever in the coming days, depends upon their ability to translate fundamental knowledge into practical application. The Institution of Agricultural Engineers will *not* lose sight of that important factor, no matter what plans it may be required to shape.

Which brings me to my final word. A few weeks ago, my eye was attracted by a banner headline in an evening newspaper which proclaimed that a prominent politician was urging Britain to "Get With It." A slight paraphrase of that is not out of place.

I say, without hesitation, that this Institution is certainly "with it," and it firmly intends to "keep with it." We believe it to be not only an exciting but a tremendously important task.

BIBLIOGRAPHY

1. J. A. Scott Watson : *History of the R.A.S.E.*, p. 30.
2. R. H. Parsons : *History of the Institution of Mechanical Engineers*, p. 10.
3. F. Ayton : *Applications of Engineering to Agriculture.* I.Mech.E., 1926, p. 683.
4. N.F.U. : *Britain's Biggest Industry*, 1963.
5. *Agricultural Engineering*, July, 1963, p. 376.
6. J. A. C. Gibb : *Education and Careers in Agricultural Engineering* National Power Farming Conference, 1963.

Institution Notes—*continued from page* 3

VIth International Congress of Agricultural Engineering Lausanne

Organised by the Commission Internationale du Génie Rural (C.I.G.R.), this important Congress will conduct its proceedings from 21st to 27th September, 1964, as announced in the July, 1963, issue of the *Journal.* It is of special interest to note that this occasion coincides with the Swiss National Exhibition, also in Lausanne, which takes place only every 25 years and includes agricultural exhibits. Listed in the provisional programme of the Congress are such subjects as soil science and its application to agricultural engineering, drainage schemes, economics of irrigation, housing of livestock, pooling of machinery in co-operative farming and agricultural work study. Details of the Congress can be obtained from the Secretary, Institution of Agricultural Engineers.

Year Book

Members are kindly asked to note that the 1964 Year Book will be published in May, in order to follow as closely as possible after the Annual General Meeting of the Institution.

Honorary Membership

It is with much pleasure that Council has conferred Honorary Membership of the Institution upon Mr. D. P. Ransome in acknowledgment of his distinguished services as President, Vice-President and Member of Council in past years, coupled with his early and valuable association with the developments leading to the foundation of The National College of Agricultural Engineering.

Mr. Ransome has been a Full Member of the Institution since 1948 and is a member of both The Institution of Mechanical Engineers and The Institution of Production Engineers.

Agricultural Engineers Association

The news of the retirement of Commander F. D. Bingham, R.N. (Retd.), A.I.Agr.E. (formerly Assistant Secretary (Technical) at the A.E.A.), has been received with regret by both the Institution Council and the Examination Board. The Commander served on the former from 1960 to 1963, and in 1961 was appointed first A.E.A. Representative on the Examination Board, a duty which he undertook and fulfilled with considerable energy and enthusiasm. Both Council and Examination Board extend to the Commander their appreciation of his effective liaison work between industry and the I.Agr.E., together with good wishes for his retirement.

POWER-DRIVEN TRAILERS

by D. P. BLIGHT,* B.Sc. (Agr.), M.Sc. (Agr.Eng.), Ph.D., A.M.I.Mech.E.

A Paper presented at an Open Meeting of the Institution held in London on October 17th, 1963

Summary

A TRAILER axle can be driven from the tractor power take-off in order to improve traction. The drive may be from the normal or from the ground driven p.t.-o. The latter type provides a mechanically simpler arrangement, but if it is to be adopted the peak loads expected should be considered carefully. Use of the engine-driven p.t.-o. may limit the utilisation of the trailer to one particular gear of the tractor. The speeds of the tractor and trailer wheels should not be synchronised ; the trailer wheels should lag in order to maintain the drawbar in tension and to compensate for the smaller turning radius of the trailer compared to that of the tractor. The amount of this lag is not important, particularly on soft ground, and can be as much as 25% without impairing the load-carrying capacity of the unit. The load which can be carried may be as much as two to three times that possible with a conventional trailer under the same conditions. On hill grazing, even under conditions of good wheel adhesion, a given load on a power trailer can be carried up slopes which are steeper than those which can be climbed by a conventional trailer with the same load.

Introduction

Richard Trevithick, in his early experiments with steam propelled vehicles, persuaded one of his friends to assist him to move a carriage uphill by turning its wheels. The success of this experiment showed that it was practicable to set a vehicle in motion by applying power to the wheels, and was a step in the development of his steam carriage. Ever since then, and particularly since the development of the internal combustion engine, means of improving the efficiency of the transmission of power through wheels by means of spuds, chains, cleats, etc., have been sought. One other way in which this greater efficiency may be brought about is to increase the number of driven wheels, leading to a four-wheel-drive tractor or to direct coupling of the trailer wheels to the tractor engine to produce a power-driven trailer. An early attempt at such a trailer was made at the beginning of the present century, the drive to the trailer wheels being through electric motors powered by a generator driven from the tractor engine.

Definition

Thus a power-driven trailer may be defined as a trailer which has one or more wheels driven from the tractor engine by a suitable transmission, usually the power take-off (p.t.-o.).

*National Institute of Agricultural Engineering. (Scottish Station.)

It has been noted above that such a device has been contemplated for some time. Brenner and Gauss(1) claim that a patent for a power-driven trailer was taken out in Germany in 1935. From then until the 1940's the idea seems to have remained undeveloped, and present interest in the subject can be traced to a report by Aniansson(2), together with another by Aniansson and Norén(3) on the use of converted lorry chassis for timber hauling in Sweden. In order to get better traction under winter conditions, the existing rear axle of the chassis was sometimes driven from the tractor p.t.-o. These reports stimulated interest in Germany, whence a large number of Papers on the subject of power-driven trailers have appeared. Little is available in English on the subject, and as power-driven trailers are beginning to appear on the market in this country, it may be of some interest to present a review of the research work which has already been carried out on the subject.

In a report on the mechanisation of hill farms in Wales(4), Slater and Jones mentioned that it might be advantageous for the hill farmer to obtain a power-driven trailer rather than spend the additional capital required for a four-wheel-drive tractor. As the Scottish Station of the N.I.A.E. is interested in matters of farm mechanisation in Scotland and those areas of the United Kingdom where conditions are similar, the Station began a study of the possibilities of the use of power-driven trailers on hill farms, which has in turn led to a study of the published work on the operation of trailers under all conditions.

Advantages of a Power-Driven Trailer

The benefits of a power-driven trailer derive from the use of the trailer load to increase the adhesion of two of the driven wheels, and the greater the load, within limits, the greater is the assistance provided by the drive. In so far as the weight of the trailer and the load together will probably be greater than the additional tractor weight provided by four-wheel-drive components, there are some grounds for supposing that the performance of a loaded power-driven trailer will be rather better than that of a four-wheel-drive tractor with a trailer of the conventional type and with the same load. However, if the trailer is unloaded, the weight on its wheels will be decreased, and under these conditions the four-wheel-drive tractor may surpass it. This may be of importance when the unit is being driven down hill, when engine braking through the driven wheels may be useful. A power-driven trailer seems to be rather cheaper than the additional cost of providing a tractor with four-wheel drive, but against this it must be remembered that with a four-wheel-drive tractor the drive is always available, while with a power-driven trailer the improvement in traction is available only so long as the trailer is coupled to the tractor.

Power Trailers in Practice

Of the power-driven trailers available, it is possible to recognise three main types :

1. Power trailers with only one wheel driven.
2. Power trailers with two wheels driven.
3. Automatic power trailers.

Of those trailers with two driven wheels, two sub-groups may be recognised—those which include a free wheel in the transmission and those which do not.

The advantages of the single wheel over the two driven wheel types have not yet been determined ; both have their protagonists. The advantage of the single driven wheel is that a differential is not required, and because of this and the general simplification of the transmission the cost is kept low. Those who favour the type with two driven wheels point out that to fit only one driven wheel means that only half the potential of the idea can be utilised. This is not strictly true, for unless a differential lock is fitted—and so far as can be ascertained no such trailer has been made—it is still possible for one wheel of the trailer to spin, thus preventing the trailer drive from contributing to the traction of the unit.

The purpose of a free wheel is to enable the trailer to operate as a normal one until the wheels of the tractor begin to slip above a certain predetermined amount. When this point is reached the free wheel drives and the trailer becomes powered. One complication which this brings is that if the trailer is to work in reverse, or to operate as an aid to engine braking, a locking device must be fitted to the free wheel. If a free wheel is fitted it will, however, eliminate any risk of " wind-up " under conditions where slip is generally limited, for the axle is only called upon to drive when the tractor needs assistance to move over a difficult patch.

Automatic working of the power axle was suggested by Coenenberg(5), who considered that such a device would completely remove any possible danger of the tractor getting out of control, since it would arrange for the drive to be disconnected through some form of over-run device. Thus, whenever the trailer was about to push the rear of the tractor the drive would become broken and the trailer revert to a normal non-powered one. A trailer utilising such a device has now been put on the market. German workers' concern for the safety aspect of power trailers appears to spring from the popularity of the light tractor in Germany, coupled with the widespread and dangerous habit there of hitching the trailer high on the drawbar.

Thus, although the concept of a power-driven trailer is a simple one, it requires considerable elaboration to be put into practice. Firstly, the speed of the wheels must be arranged to be, within certain limits, rather slower than the speed of the tractor wheels. This means that it may be necessary to stipulate in advance that a particular trailer is to be used with a particular tractor, and further, that tractor must be used in a stipulated gear when drawing the trailer under power. This can lead to complexities in manufacture, since there is no standard for forward speeds of tractors in their various gears at rated p.t.-o. speed. Secondly, it is important to remember that the sense of rotation of the p.t.-o. remains the same whether the tractor is driven forward or in reverse ; thus if the trailer is to be used for backing under power as well as moving forwards, and this is highly desirable, some form of reverse gearbox must be fitted in the transmission, leading to further complexity. If a free wheel is fitted, it will also be desirable to fit a free wheel locking device.

Theoretical Considerations

The standard technique for determining the characteristic equations for the equilibrium of an articulated tractor-vehicle unit has been described by Steeds(6) and elaborated by Wieneke(7) into the condition where the trailer is powered. The technique is, of course, to resolve forces parallel to, and at right-angles to, the ground, and to take moments about the points of application of the loads on the driven axles. The relevant forces are shown in Fig. 1.

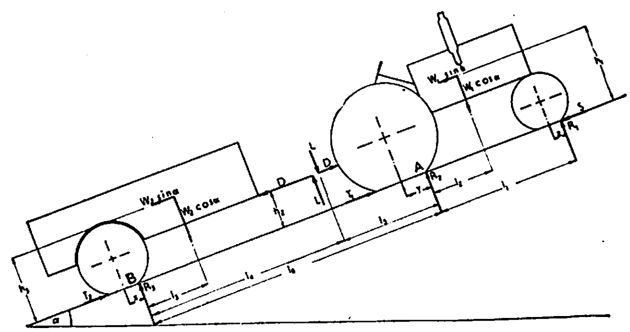


FIG. 1.
Forces acting on a tractor and power trailer (adapted from Wieneke).

Resolving along the plane :

$$T_1 + T_2 = S + (W_1 + W_2)\sin\alpha$$
$$T_2 = D + W_2 \sin\alpha$$
$$T_1 = S + D + W_1 \sin\alpha$$

Resolving at right-angles to the plane :

For the tractor—$R_1 + R_2 = W_1 \cos\alpha + L$.

For the trailer—$R_3 + L = W_2 \cos\alpha$

Taking moments about A :

$$W_1 (l_2 \cos\alpha - h_1 \sin\alpha) - R_1 l_1 - h \,.\, l_5 + D \,.\, h_2 = 0$$

Taking moments about B :

$$W_2 (\cos\alpha \,.\, l_3 - \sin\alpha \,.\, h_3) - D \,.\, h_2 - h \,.\, l_4 = 0$$

These equations have been included for the sake of completeness, but in practice their value is limited by the difficulty of obtaining some of the necessary data, in particular T_1, T_2, S, and the three dimensions x, y, and z, which represent the position of the wheel reactions with respect to the centres of the axles. Wieneke obtained approximate figures for these dimensions, but was forced to make a number of assumptions in deriving the forces T_1, T_2, and S from the pull–slip curve for the tractor he was considering. His conclusions are that the loads imposed upon the tyres of the trailer are greater than those encountered with conventional drawn trailers and recommends that power-driven trailers be fitted with tyres of greater load-carrying capacity than those fitted to normal trailed machines, and that they be operated at greater inflation pressures.

Although no practical comparisons between power trailers and four-wheel-drive tractors appear to have been carried out, a theoretical appreciation has been made by Feldmann(8), who considered the situation from the aspect of the two basic equations :

(*a*) $U = f . W$

where U = the resistance to motion offered by the unit.

f = the coefficient of resistance, composed of the sum of f_r the rolling resistance, and f_c the coefficient of resistance produced by driving up a slope.

W = the total weight of the unit.

(*b*) $P = G_d . k$

where P = the pull that the tyres can transmit.

G_d = the load on the driven axles.

k = the coefficient of traction.

Using these equations, it is possible to derive the value of f, which will characterise the worst conditions of resistance to motion which the unit can overcome with a given tractor equipped with various traction aids, pulling a trailer and load of known weight, knowing the weight distribution and the coefficient of traction. Note that the greater the value of f the greater the resistance offered.

As an example of the way in which Feldmann uses these equations to calculate the critical value of f, let us consider the following situation :

Tractor weight	3,000 lb., of which 1,000 lb. loads the front axle,, and 2,000 lb. loads the rear axle.
Front axle ballast ..	200 lb.
Rear axle ballast	500 lb.
Trailer weight	2,000 lb.
Trailer load	6,000 lb.
Load transfer from trailer to tractor rear axle ..	1,200 lb. (Feldmann quotes Skalweit(9) in support of this figure).

Now, $P = G_d . k$. Suppose that $k = 0{\cdot}5$ for the conditions under investigation. Thus $P = 0{\cdot}5\ (2{,}000 + 500 + 1{,}200) = 1{,}850$ lb. This represents the maximum tyre pull available, and thus if the unit is to move the total resistance offered to motion cannot exceed this. Hence we may write :

$$1{,}850 = U = f.W.$$

Now, $W = (3{,}000 + 200 + 500 + 2{,}000 + 6{,}000) = 11{,}700$ lb.

$$\text{Whence } f = 0{\cdot}16.$$

Feldman carries out similar calculations for various situations, including a conventional tractor, a tractor with four-wheel-drive, and a power trailer. On the basis of these considerations, Feldmann shows that the four-wheel-drive tractor can operate under a coefficient of resistance some 7% worse than can a conventional tractor and trailer, while a tractor and power-driven trailer can operate under conditions which are some 75% worse. The actual values of these figures are of little importance, since they are based on hypothetical circumstances, but the scale of the difference is of interest, and arises because the driven wheels of the unit are able to make use of all the trailer load and not just a part of it, as in the case of a load-transferring trailer coupled to a conventional tractor.

Speed Ratio of Tractor and Trailer Wheels

It is essential that the trailer drawbar be at all times under tension ; *i.e.*, some drawbar pull must always be present when the unit is in motion. If the tractor is inclined at an angle to the trailer—*e.g.*, when travelling round a curve—there is, according to several German workers, danger of the tractor getting out of control or even overturning if the drawbar goes into compression, for the trailer will then be pushing the tractor. Experience at the Scottish Station of the N.I.A.E. would indicate that it is much more likely that one wheel of the trailer will lift and spin, thereby removing the pushing action of the trailer and hence the danger.

When the tractor and trailer are driven round a curve the radii of the paths taken by the trailer wheels will be smaller than those taken by the corresponding tractor wheels by a factor related to the relative lengths of the tractor and trailer drawbars (Fig. 2). In order that the driven trailer should not start to push the tractor, the trailer wheels are usually arranged to rotate at a lower peripheral speed than the tractor wheels—*i.e.*, a lag is introduced. The amount of this lag is usually in the region of 2 – 6%, according to Koenig-Fachsenfeld(10), though Koefoed(11) puts it higher at 10 – 20%. The

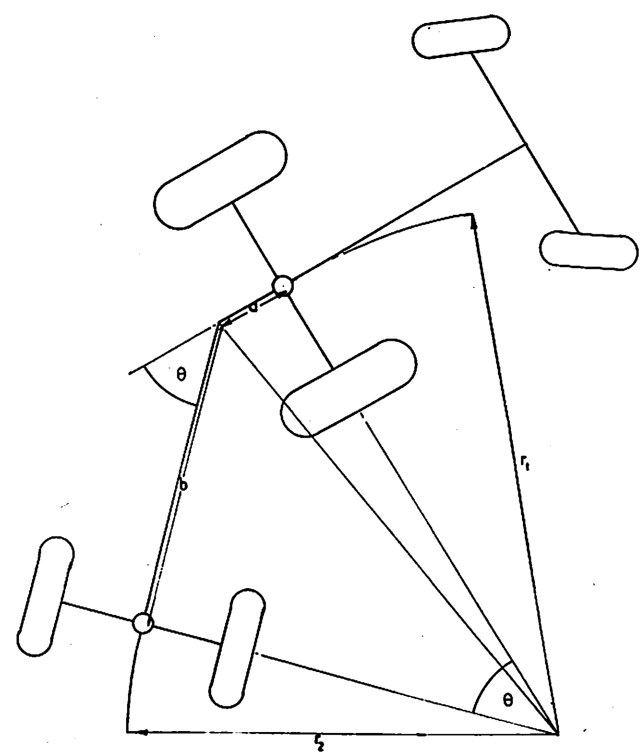


FIG. 2.
Influence of drawbar length on turning radii (after Coenenberg).

mode is probably about 10%.

Koefoed, in an attempt to measure whether there was a value for the ratio of the peripheral speed of the tractor and trailer wheels which would lead to a minimum power requirement of the unit, came to the conclusion that on this consideration alone the optimum value of the lag was 15%. This figure must be considered with some reserve, however, as his results were liable to considerable scatter through variations in soil conditions.

Sass(12) considered that on soft, slippery soil, as opposed to concrete, a lag of up to 25% in the trailer wheels would not diminish the pull which could be obtained on a cable attached to the rear of the trailer, which confirms a finding of Aniansson, that the total weight of the vehicle that can be pulled by the tractor engine is the same in general, whether or not the wheel speeds are synchronised. Thus in terms of the load-carrying ability the amount of lag is not critical. It may be of importance for ensuring the good control of the unit, for Coenenberg shows that for a turn of 60° the trailer may require a lag of 37%. He advocated some means of reducing this figure by adding some form of supplementary steering to the trailer for use by the driver during the relatively infrequent occasions when such sharp turns are unavoidable.

Some other suggestions can be discounted on the grounds of cost and unnecessary complexity, if for no other reason. They include the provision of a longitudinal differential between the drives to the tractor and trailer wheels to prevent "wind up." This is not a problem with power-driven trailers, as under the conditions where such trailers are of most value any difference in wheel speeds can be compensated by wheel-slip.

Performance of Power Trailers Round Curves

That the amount of lag in the transmission does not affect the load-carrying ability of the trailer over a wide range of values has been shown above. Lag is important for maintaining directional control of the unit, and a theoretical analysis of its importance when the trailer is being driven round a curve has been made by Coenenberg. He differentiates between "simple lag" required to maintain the drawbar in tension and "kinematic lag" required for ensuring the correct speed ratio between driven wheels when cornering. The lag required at any instant will be the sum of these two. He points out that the kinematic lag required is always changing and the only way in which it has been catered for is by the introduction of a fixed value of "constructional lag," which by no means reaches the maximum value which may be required. To get over this difficulty, some manufacturers fit a buffer to the trailer draw bar to limit the angle of turn by scrubbing on the tractor tyre when the maximum allowable drawbar angle has been reached. In an example using typical dimensions, Coenenberg has shown this angle to be about 20°.

The ratio of the radii of the paths of the centres of the tractor and trailer driving axles depends on the angle of the turn and the position of the hitch point relative to both axles according to the equation :

$$\frac{r_2}{r_1} = \frac{\cos\theta + \dfrac{a}{b}}{1 + \dfrac{a}{b}\cos\theta}$$

where r_1, r_2 are the radii of the paths of the centres of trailer and tractor axles respectively, and θ the angle made between the projections of the two axles to their instantaneous centre of rotation ; a and b are the distances of the hitch point from the centre of the tractor rear axle and the centre of the trailer axle respectively.

Coenenberg also points out that the characteristics of the ground speed p.t.-o. are more desirable for driving a power trailer than are those of the normal p.t.-o. whose speed of rotation depends on engine speed rather than speed over the ground, necessitating design of the trailer transmission to suit a particular gear of the tractor. It has been pointed out elsewhere (13) that the torque demands on the normal ground speed p.t.-o. may be too high for the shaft, since the speed of rotation is relatively low. In work carried out at the Scottish Station of the N.I.A.E. the maximum p.t.-o. horse-power so far measured is about 18 at 540 r.p.m. while pulling a load of 5,000 lb. up a 1 in 3 slope at about 2 m.p.h. Translated into terms of torque on a ground-driven p.t.-o. shaft, this extreme case will produce a torque loading in excess of the maximum operating loads suggested by the American Society of Agricultural Engineers(14), although some people may consider their recommendation to be a conservative figure, but it is much greater than the maximum continuous torque ratings of the universal joints. When considering the application of a ground-driven p.t.-o. for driving a trailer, it may, however, be important to consider the conditions under which it will be called upon to operate.

Equipment for measuring the magnitude of the side forces exerted on the tractor drawbar when cornering has been made by Koch and Dinse(15), who claim that the point of maximum side thrust is to be found when the train begins to straighten out after negotiating a curve, but this opinion is challenged by Koch and Hünseler(16), who, using the same equipment, decide that the maximum side thrust is reached earlier when the side forces build up steeply as the unit enters the curve. This seems a more satisfactory conclusion.

Power Distribution and Load-Carrying Ability

Some theoretical aspects of the load-carrying ability of power trailers have already been examined. It may be of interest to review some results obtained in the field.

The loads which can be carried by a power trailer have been investigated by Aniansson, who found that over unfavourable terrain a power trailer could carry two to three times the loads which could be carried by a conventional trailer pulled by the same tractor. Sass considered that the load on a power trailer can be up to 290% of that possible with a normal drawn trailer.

Work done at the Scottish Station of the N.I.A.E. has shown that with loads of 2,000 lb. to 6,000 lb. on hill grazing, even under dry conditions, the slope up which the load could be pulled was in every case steeper when the trailer was powered than when it was not. The limiting factor with the unpowered trailer was tractor wheel adhesion, while with the powered trailer the limiting factor was engine power in every case.

The power supplied by the p.t.-o. with the unit operating on level ground was about 2 h.p., rising to 12 on a 1 in 3 slope with a load of 2,000 lb., and as high as 18 on the same slope with a load of 5,000 lb. The steeper the slope the more steeply does p.t.-o. horse-power rise with increasing load.

The distribution of engine power between tractor and trailer was examined by Koefoed, who found that about 40% of the tractor horse-power was used to move the tractor itself, 20% appeared as drawbar pull, and about 40% was transmitted through the p.t.-o. These measurements were made on a wet freshly-harrowed field.

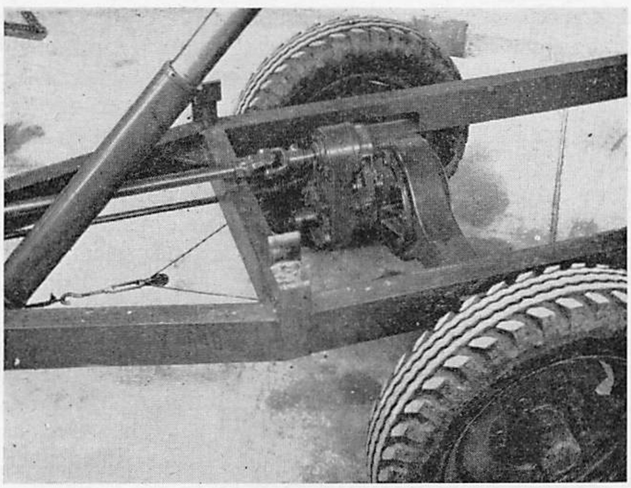


FIG. 3.
Axle of power-driven trailer showing chaincase for primary reduction unit between p.t.-o. shaft and differential (Kessler).

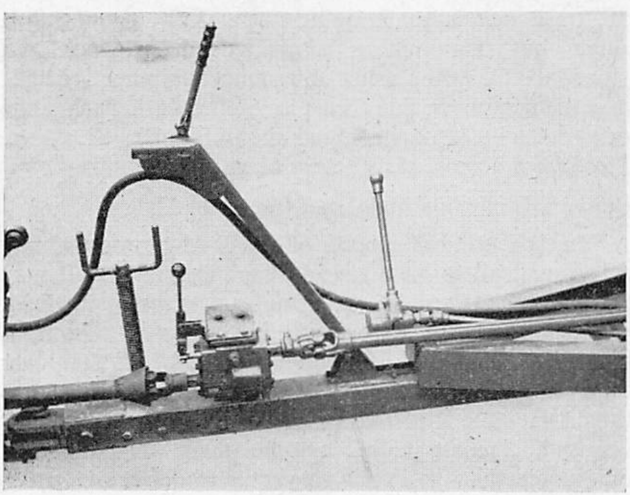


FIG. 4.
Reversing gearbox (centre left) and freewheel lock (centre right) of power-driven trailer (Kessler).

Summary of Recommendations Arising out of Research

The results which have been obtained by the research workers mentioned in the foregoing paragraphs enable the state of knowledge at the present time regarding power trailers to be consolidated as follows.

Because the weight of the load is applied over the driving wheels of the trailer, the power-driven trailer offers some theoretical advantages over the four-wheel-drive tractor for haulage work under difficult conditions. The unit might be produced rather more cheaply than such a tractor, but will not have the same versatility. If the trailer is to be driven at low horse-powers only it will be possible to operate it from the ground-driven p.t.-o., with some advantage in mechanical simplicity and in operating convenience, since the trailer could be used in any tractor gear and could be reversed without the need for any further attention by the driver. There is as yet no widespread agreement between tractor manufacturers as to the relation which should be given to the speed of rotation of the p.t.-o. for unit distance travelled forward, and indeed this may vary slightly with tractors of the same make according to the size of tyre fitted, though this will be unimportant so far as power trailers are concerned. This means that it may be necessary to fit some adjustment to the trailer transmission to correct for differences in the design speeds of the p.t.-o. Where a high power demand may be made on the p.t.-o. it may be necessary to use the engine-driven type, since its higher working speed leads to a lower torque for the same horse-power transmitted. Use of the engine-driven p.t.-o. can bring problems in its train ; when driving the trailer the tractor can be used in one gear only, and if operation in reverse is required it will be necessary to fit a reversing gearbox in the transmission. Some form of compensation for the difference in the peripheral speeds of the tractor wheels between various makes of tractor when the p.t.-o. is turning at rated speed must be included. In practice, this sometimes takes the form of an adjustable pitch vee-belt arrangement, or the use of a roller chain drive somewhere in the transmission so that sprockets giving a suitable change speed ratio can be fitted. A free wheel device has some advantages in preventing " wind up " if the power is engaged when the unit is operating under conditions of good soil adhesion, and can also be of value in eliminating power loss through excessive wheel slip due to the lack of exact matching in the peripheral speeds of the tractor and trailer wheels.

It is important always to keep the tractor drawbar in tension so that there is no danger of the trailer pushing the tractor, since if this occurs when the unit is negotiating a curve, and this is the most likely time, there is some danger of loss of control, particularly with a light tractor. In order to limit the sharpness of the turn which the unit can make, stops can be fitted to the drawbar.

The amount of lag in the speed of the trailer wheels relative to that of the tractor wheels can be quite high without reducing the usefulness of the drive, though if the power is engaged by mistake on a surface offering good adhesion, tyre wear may be heavy if a free wheel is not fitted.

It has been suggested that the tyres fitted should be of a greater load-bearing capacity and operate at greater inflation pressures than those normally fitted to agricultural trailers. The tread pattern should, of course, be of a type appropriate for a traction wheel, and it is possible to get a tread suitable for a wheel which may be driven or drawn according to circumstances.

The load-carrying ability of a power-driven trailer may be as much as three times that which can be carried by a conventional trailer, and the unit finds its most useful application in removing loads from wet land such as beet fields. On hill land it is possible to carry a load up a rather steeper hill by powering the trailer, and if the price can be kept relatively low the power-driven trailer probably has a useful part to play in the mechanisation of agriculture.

REFERENCES

(1) Brenner and Gaus. " Zapfwellengetriebene Ackerwagen," *Landtechnik* 6 (1951), pp. 568–571.

(2) Aniansson, G. " Drivkärror," *Jordbrukstekniska Insituttet Medd.*, 243 : 1952, Ultuna.

(3) Aniansson, G., and Norén, O. " Sockerbets Transporter Med Direktdrivna Kärror," *Lantmannen*, December 2nd, 1950, pp. 927–929.

(4) Slater, J. K. W., and Jones, M. P. " A Survey of Welsh Hill Farm Mechanisation," *J.Agric.Eng.Res.*, 1957, **2** (2), pp. 222–234.

(5) Coenenberg, H. H. " Zur Fahrmechanik Der Triebachse," *Landtechnische Forschung*, 1960, **10** (2), pp. 34–39. N.I.A.E. Translation 119.

(6) Steeds, W. " Mechanics of Road Vehicles," Iliffe, London, 1960.

(7) Wieneke, F. " Rechnerische Ermittlung Des Fahrzustandes Bei Triebanhangern " *Landtechnische Forschung*. 1955 (1), pp. 26–29. Translation in *J.Agric.Eng.Res.*, 1956, **1** (1), pp. 101–105.

(8) Feldman, F. " Möglichkeiten und Einsatzbereiche der Triebachse," *Landtechnische Forschung*, 1960, **10** (2), pp. 29–33. N.I.A.E. Translation 118.

(9) Skalweit, H. " Reifenbelastung Bei Schleppern Durch Heckanbaugeräte Und Sattelwagen," *Landtechnik*, 1959, **14**, pp. 154–157.

(10) Koenig-Fachsenfeld. " Technische Probleme Des Triebachsanhangers," *Landtechnik*, 1957, **12** (11), pp. 334–336.

(11) Koefoed, S. S. " Investigations on the Performance of the P.T.-O.-Driven Tractor Trailer," *Arrskrift Royal Vet. & Agric. Coll.*, Copenhagen, 1958, pp. 1–25.

(12) Sass, H. " Triebachse und Zugkraftgewinn," *Landtechnik*, 1958, **13**, pp. 152–158.

(13) *Power Farming and Better Farming Digest*, 1962, **71** (8), August, pp. 51–52.

(14) " Operating Requirements for Power Take-Off Drives," Agricultural Engineers' Year Book, pp. 192–193, 1963, A.S.A.E., St. Joseph, Michigan.

(15) Koch and Dinse. " Diechselkräfte Am Triebachswagen," *Landtechnische Forschung*, 1961. **11** (3), pp. 61–65.

(16) Koch and Hünseler. " Kräfteeinwirkung Des Triebachsers Auf Den Schlepper," *Landtechnische Forschung*, 1961. **11** (5) pp. 1 7 1 0

DISCUSSION

The Chairman, MR. R. M. CHAMBERS (Massey-Ferguson Ltd.), opened the discussion by saying he was disappointed that Dr. Blight had suggested the use of higher than normal inflation pressures for the tyres on power-driven trailers. For many years he had advocated lower tyre pressures to avoid the " smear " and " puddling " of soil which was experienced with higher pressures. He hoped that it would be possible to work with lower tyre pressures when power-driven trailers became commonplace.

MR. D. R. BOMFORD (Bomford Bros. Ltd.) asked if, in view of the difference in speed, or slip, of the driven trailer wheels relative to the tractor wheels there would be any advantage in designing the trailer hitch so that the trailer wheels followed in the same track as the tractor wheels. If, he asked further, this required the distance between the trailer axle and the hitch point to be reduced, would torque reaction on the tractor wheels then become a serious factor in weight redistribution between the tractor and trailer ?

DR. BLIGHT replied that he thought it would not be possible to design the trailer to track exactly behind the tractor. He considered it was desirable to arrange for the centre of gravity of the load always to be between the tractor and trailer axles, and this might necessitate a very short drawbar on the trailer. There was a German-designed automatic power trailer on which as soon as the drawbar was put in compression the drive was disengaged. This was mechanically complex, but perhaps provided the most elegant of present solutions to the problem of peripheral speed differences between the tractor and trailer wheels. This design also utilized some form of buffer which limited the maximum angle to which the trailer could pivot relative to the tractor. He felt that the situation envisaged by Mr. Bomford would not arise, so that the torque reaction effect would not be important for the reason Mr. Bomford had mentioned.

MR. T. SHERWEN (Consultant, Gloucestershire) referred to a form of ground-speed power take-off on certain German tractors, arranged through a second pinion behind the main driving pinion. This revolved at a constant speed relative to speed over the ground, and was presumably robust enough to transmit as much power as the trailer could absorb. He asked for Dr. Blight's comments on this design, and also asked if the various transmission problems might be overcome in the case of a tractor with hydrostatic transmission driving a similarly equipped power trailer.

In reply, DR. BLIGHT said that the mechanism Mr. Sherwen had mentioned was a normal way of arranging a ground-speed p.t-o. drive, and was, in his view, a very good method. Difficulty arose owing to the fact that the speed of the p.t-o. shaft was low in relation to the tractor's forward speed. As could be seen from the American Society of Agricultural Engineers recommendations (Reference 14), under such low-speed conditions only low powers could be obtained. There was nothing wrong with the design as such, except that it could with advantage be made to rotate faster, and there ought to be some form of international standard.

Coenenberg (Reference 5) had, in fact, suggested a hydrostatic trailer drive, and many problems would be solved if this were adopted. There should be no great difficulty in arranging a suitable oil feed from a hydrostatically-driven tractor.

MR. G. SCOTTORN (Scottorn Ltd.) referred to extensive work his firm had carried out on driven trailers for use with Land Rovers. They had found it was not necessary to avoid compression in the trailer drawbar, and, in fact, that it was an advantage to have the trailer pushing the towing vehicle. It was probable that the Land Rover and its trailer were of roughly similar weight, and that they formed a more stable combination than would an agricultural tractor and a loaded power-trailer, the latter being much heavier. The effect of the driven trailer in pushing the driving vehicle out, in muddy conditions in which it had become bogged, was very noticeable with the equipment he had mentioned.

Mr. Scottorn had not found a differential in the trailer drive to be necessary, but in adding two more driven wheels to a four-wheel-drive vehicle it was very important to use wheels of the same size driven at the same speed. In practice, the performance of the Land Rover with a driven trailer, using rear-wheel drive only on the towing vehicle, was slightly better than using four-wheel drive on the vehicle, with the trailer not driven. He asked Dr. Blight, in conclusion, if he had experienced any difficulty with propeller shafts and standard agricultural or wide-angle universal joints. His Company had not.

DR. BLIGHT said that he had not encountered any such problems with shafts and joints in relation to normal p.t-o. drives. Ground-speed p.t-o. drives, working at much lower speeds, had raised the difficulties he had mentioned earlier. From manufacturers' catalogues he had obtained maximum torque figures for universal joints of 1,030, 1,780 and 2,750 lb./in. For the shafts themselves, the maximum operating load suggested by the American Society of Agricultural Engineers was about 7,500 lb./in., and at least one British tractor manufacturer had told him that his tractor p.t-o. shafts should operate at double that figure. These figures seemed to suggest that the joints rather than the shafts imposed the limiting factor.

MR. J. B. HOLT (National Institute of Agricultural Engineering) asked for information on the manoeuvrability of the combined tractor-power-trailer unit on hill farms. He suggested that with a limited lock on steep gradients limited manoeuvrability might be a serious problem, as sharp turns were often necessary when entering or leaving steep fields through gateways. Dr. Blight had mentioned the use of power-driven trailers for carting crops such as beet in bad conditions, but Mr. Holt suggested that on large arable farms ultimately the best solution might be to have specialised transport machines. These might have some kind of self-emptying device, perhaps in the form of a hopper. Another possibility was a load-carrying machine designed specifically for carrying unit loads or palletised loads. If such devices became feasible, the power-driven trailer might be of only transient importance.

DR. BLIGHT said that he had experienced no difficulty in using the power trailer on hill land, and its manoeuvrability was not unduly limited. If it was necessary to make a really sharp turn, the p.t-o. drive should always be disengaged ; he had not yet encountered a situation in which it was necessary to make a sharp turn with the drive engaged.

Dr. Blight was interested in the N.I.A.E. load-carrying vehicle, and would watch its development with interest. Such a vehicle would undoubtedly have a place on a large farm ; however, there must be intermediate sizes of farm on which it could not be justified on economic grounds, which nevertheless required some kind of effective transport vehicle for muddy conditions. The power-driven trailer was remarkably good in muddy fields, provided the conditions were not so bad that the drawbar bottomed.

MR. W. A. HAYLES (Suffolk) said that Dr. Blight had presented a good deal of information on mechanical methods of driving trailer wheels. Since hydraulic equipment was virtually standard on farm tractors, he would like to know if any work had been done on the use of hydraulic drives which could well make for flexibility in design.

DR. BLIGHT replied that a hydraulic drive system would be excellent but for the fact that on all normal tractors the hydraulic pump was far too small. So far as he could remember, the maximum output of a tractor hydraulic lift pump was about five hydraulic indicated horse-power. Given a bigger pump, he was sure that a practicable system could be designed.

MR. T. C. D. MANBY (National Institute of Agricultural Engineering) referred to Dr. Blight's comments on standardisation of ground-speed power take-off speeds. British Standards Committee N.E.6 had redrafted British Standard 1495, and had agreed on a standard ground-speed p.t.o. ratio in conformity with earlier recommendations. This did not conform with the existing Massey-Ferguson ratio of 19 in. travel per one revolution of the power take-off shaft. Mr. Manby then referred to what he termed " plug-in " hydraulics, utilising a hydraulic motor more or less permanently connected to the tractor and ready to plug in to suitable mechanisms on trailers or other machines. He asked if Dr. Blight thought a differential was a necessary part of the axle of a power-driven trailer. If it was not, it would be relatively cheap to have a solid axle with a reduction gear driven by the " plug-in " hydraulic motor. During braking conditions it would be necessary to disconnect such a drive, but this need not be an insurmountable problem. Consideration was already being given to the use of hydraulic power for braking trailers, as well as for tipping.

DR. BLIGHT said that he was glad to hear that a standard was now in existence, and he hoped it would soon be adopted internationally. In a conversation with some German research workers, he had been told there was considerable variation in this respect between their tractors.

He had not given his opinion as to the desirability of a differential because he had not yet had the opportunity of working on this problem. It was quite probably not necessary, but this was only a statement of opinion and was not based on measurable facts. An alternativ possibility might, perhaps, be a solid axle in combination with a free-wheel device for each wheel. He emphasised that any hydraulic drive system was dependent on more power from the hydraulic pump than was currently available.

MR. P. H. BAILEY (National Institute of Agricultural Engineering) said that he had found when operating a vehicle incorporating a type of power-driven trailer that stability with the drawbar in compression was reasonably good right up to the highest speeds, when a large amount of wheel-slip occurred and the sideways stability of the trailer was lost. With an agricultural tractor of lower weight than the trailer it was conceivable that the sideways stability of the tractor would be lost first.

With regard to factors limiting the maximum torque transmissible by a power shaft, Mr. Bailey asked if any difficulty had been experienced where high torque was transmitted *via* axially-sliding power shaft members. Finally, although Dr. Blight had said in his Paper that a spinning wheel prevented the trailer drive from contributing to the traction of the unit, unless the wheel was raised from the ground so that there was no adhesion at all, some tractive contribution would still be made by the spinning wheel.

In reply, DR. BLIGHT agreed that there might be a contribution, but that it would be almost negligible.

MR. J. H. W. WILDER (John Wilder Ltd.) asked that more publicity should be given to the existence of the British Standard dealing with power take-off drives. It was vital that all concerned should be aware of this important decision.*

MR. D. I. MCLAREN (National Institute of Agricultural Engineering) said that very interesting and informative comparisons had been made in the Paper between the performance of a four-wheel drive farm equipment with an undriven trailer and a conventional power unit with a driven trailer. He asked if similar comparisons could be made with the performance of temporary load-transferring devices tested some time previously by the N.I.A.E. Scottish Station.

DR. BLIGHT said that the instrumentation used in the work mentioned by Mr. McLaren had not been entirely satisfactory, and the project was awaiting new instrument equipment before it could proceed further.

MR. R. J. SIMS (Surrey Farm Institute) asked Dr. Blight for an indication of the range of power-driven trailers already on the market in this country. Dr. Blight said that Messrs. Dyson, Landrive and Scottorn were among the manufacturers of power-trailer equipment which could be described as agricultural ; further designs were likely to appear.

The CHAIRMAN thanked Dr. Blight for his Paper and for his contribution to the discussion.

*"Where ground speed drive is provided for such that the power take-off, the design shall be such that the p.t.-o. speed when so driven is 1 revolution per 7in. $\pm\frac{1}{2}$ in. forward travel of the tractor. This specification applies only to a power take-off having involute splines."

APPOINTMENTS SERVICE

Members are cordially reminded that a monthly list of situations vacant in the agricultural engineering industry, teaching and research, both in Great Britain and overseas, will be supplied on request.

Those wishing to avail themselves of this service should notify the Institution Secretary. It would be appreciated if members would inform the Institution of changes of appointment, in order that office records may be kept up to date and, where applicable, the circulation of lists from the Appointments Service terminated.

INSTITUTION TIE

As announced in previous issues of the *Journal*, Institution ties are available, incorporating the design of the Presidential Badge on either dark-blue, dark-green or dark-red grounds. These attractive emblems may be purchased and worn by members only ; they are available in any quantity at a cost of 15/- for the first tie and 12/6 for each additional tie, which charges include packing and postage.

Order forms may be obtained from the Institution Secretary.

SOME ASPECTS OF AGRICULTURAL ENGINEERING IN CALIFORNIA, U.S.A.

by PETER FINN-KELCEY,* D.F.H., A.M.I.E.E., M.I.Agr.E., M.A.S.A.E.

A Paper presented at an Open Meeting of the Institution held in London, on October 17th, 1963.

Introduction

TO visualise the scope of agriculture in California, it is necessary to have some idea of the farm land in the State and also to look at this area in terms of the United States in general. In round figures, the area of California is 100 million acres, or 5·3% of the national figure ; of this, 10 million acres is in crop land, 24 million in pasture of all types, mainly hill pastures, and 66 million acres is occupied with forest, desert, cities, military areas and the like and is not available for agriculture. Most of the wealth of Californian agriculture is derived from the 10 million acres of crop land, and although this area is only 2·6% of the crop land in the whole of the United States, 9·3% of the gross national farm income is derived in California.

This is due to a number of factors, including the following : (1) High natural fertility of the alluvial valley soils, (2) favourable climatic regions for high-priced crops, (3) long, dry summers, coupled with abundant water, which is used almost exclusively for surface, as distinct from overhead, irrigation, (4) normally mild winters in the valley areas, with low frost hazard, (5) relatively cheap sources of energy available to the farmers in the form of electricity, natural gas, and fuel oils, (6) an efficient farm advisory and "extension" service, coupled with excellent down-to-earth research programmes at the Universities, and (7) boundless enthusiasm and initiative in the top flight of farmers in the State, the majority of whom are university graduates and who maintain a constant and even persistent liaison with current research and experimental work.

This is not to infer that the same thing does not occur in the United Kingdom, but the author's impression is that in California a larger proportion of the farming body is actively following the progress of research relevant to their problems. So keen are they to find solutions to their immediate and predictable difficulties that they will form themselves into small local groups, approach the appropriate departmental chairman at the University and offer a substantial grant for research into their particular problems. This grant will be supplemented by State and Federal research funds, and the investigations can start with the minimum of paper work, committee activity and red tape. Subsequently, the University department will organise an annual conference and open day for the group and others, at which the staff concerned will report and discuss progress of the work.

Complete academic freedom is maintained by the universities in their choice of approach to the problem, and some more basic and longer-term investigations may well be initiated in addition to the applied research, designed to give a quicker answer to part of the immediate problem.

The group frequently makes available some facilities for the research, such as field plots, plant material, a crop for harvesting trials, or a proportion of the produce at their co-operative handling plant.

Financially, much the same arrangement is achieved in the United Kingdom, where the various marketing boards can sponsor research with the funds levied from their producers, but the same intimate liaison between the research and the ultimate users of the findings is not so evident.

It should not be assumed that the Californian farmer is not also beset by a number of familiar problems that do not lend themselves to solution by research. Principal among these are (1) high land values and rents, (2) high labour costs (approximately 8/3d per hour minimum), (3) high initial cost of machinery, (4) a rapidly diminishing labour pool for seasonal work, (5) increasing costs of food processing, distribution and presentation beyond the farm gate, (6) over-production of many commodities.

Despite these and other handicaps, the prices received for some common products are little different from those in the United Kingdom. Two instances of this are to be found in barley and first-quality hay, which may fetch no more than 56 dollars (£20) and 22 dollars (£8) per long ton (2,240 lb.) respectively. In the case of barley, it can be said that no drying costs are involved, but storage is needed and natural moisture content may be only 6–8% wet basis. Similarly in the case of lucerne hay, although five or six cuts can be taken annually with virtually no weather risk, surface irrigation is required after each cutting and land levelling is a necessary pre-requisite. Undoubtedly, it is the high degree of mechanisation in growing, harvesting and handling these crops that allows these specialist operators to remain in business.

Hay Harvesting in Bales

Approximately 6 million tons of hay, mainly lucerne, are produced in California annually, and of this quantity some 5 million tons are sold as a cash crop.. Some hay growers will specialise in this crop alone and they will supply cow-keeping and beef-fattening operations that frequently do not produce any hay or other feeds. On many dairy units, baled lucerne hay is the basis of the ration, and 5 to 6 tons of hay will be fed per annum per beast, with concentrates fed only in the parlour. Such an enterprise may support 200 cows in milk on an area

---

* Electrical Research Association.

The author was invited by Professor C. F. Kelly, then Chairman of the Agricultural Engineering Department, to spend one year as Visiting Associate Research Engineer on the Davis Campus of the University of California. He was privileged to be associated with Prof. Kelly, Dr. H. Heitman, Jnr., and Dr. T. E. Bond in continuing the animal environment studies for which they have established an international reputation.

of 5 – 10 acres—that is no more than an exercise ground. Similarly, beef feeding units may support many thousands of beasts on an area from 100–400 sq. ft. per animal. Again, the principal ingredient of the ration will be lucerne hay, which is milled and incorporated in a ration, with a variety of supplements such as beet pulp, almond hulls, cotton seed, barley and various by-products from crop-processing plants. (See Appendix II.)

With assured harvesting weather, operations in the hay field can be programmed with certainty, and a typical operation might be to cut the lucerne crop with a mower-swather (with or without a conditioner) of up to 16 ft. in width. This leaves the crop in a 4 ft. swath from which it may be baled after three to five days, or two swaths may be taken into one with a finger-wheel side-rake on the day after cutting. These dense swaths will prevent undue drying of the leaf before the stems, but frequently baling will be done at night, when there is some dew to prevent leaf loss. Even in a heavy swath, the moisture content of the crop can drop below 10% in the heat of the day, and 16% is considered a desirable figure for baling. High-density three-wire bales are usual and their weight will be in the range 120 to 150 lb. —a suitable weight for road haulage purposes where a 22½ ton load is aimed at on truck and trailer combined. Bales of such weight obviously preclude any appreciable degree of manhandling, and a variety of pick-up devices are used to load the bales from the field so that they can be stacked on the edge of the highway. A simple crane, or a fork-lift truck, is often used for unloading and stacking the bales and subsequently loading them on to road transport. Nevertheless, there is generally some degree of manhandling required to ensure a sound stack or load. Owing to the uniform moisture content of the crop, the bales will be fairly constant in weight and variations in length will be negligible, and this is of great assistance in building a sound stack or load.

In recent years the handling and stacking of bales has been revolutionised by the introduction of the Haro-bed machine, which is available in self-propelled or trailed form. Not only does this machine pick up bales from the field and load them automatically, but the entire load is neatly stacked at the end of the journey. The larger model normally picks up 56, or at most 63, bales to a load, which represents a weight of somewhat more than 3 tons. The stacks are made to a height of 7 bales on edge, the width being in multiples of two-bale lengths. In practice, a skilled operator can, single-handed, pick up, load and neatly stack 13 to 16 tons of hay per hour, depending upon the length of haul and the density of crop. The Haro-bed is capable of 25 m.p.h. on the road and is well sprung, so that it can pick up bales at speeds of 10–15 m.p.h., depending upon the field surface. Many of these machines have been in use in California for four or five seasons, operating for six months in the year, and it is reliably estimated that more than 50% of the California hay crop is now handled in this manner.

Although a 14 ft. mower-swather is quite generally used in California, and this makes a fairly dense swath, two rows will frequently be turned into one with a side rake. It has been shown that this effects an overall economy in baling time and also in pick-up and loading time. With high-density bales of 125 lb. and a crop weight of 1¼ tons per acre, there will only be 22 bales to the acre ; and if the nett mowing width is taken as 13½ ft., the baler will have to travel almost 1,100 yds. in making 22 bales—that is a spacing between bales of 51 yds. Thus a mounted finger-wheel rake, travelling at a relatively high speed, can halve the travelling distance and time of a high-capacity baler and the Haro-bed machine.

Hay Harvest in Wafers

However well organised the baled-hay trade in California may be, the goal of hay as a free-flowing material that can be mechanically handled from the swath to the cow has been a challenge to agricultural engineers for some time. The potentialities for such a machine, for Californian conditions, are immense and it is not surprising to find that, like the Haro-bed machine, a hay waferer has been invented and developed in California. Although still in restricted supply, waferers, under the trade name Cal-cube, are now in commercial production after a development period of many years. The self-propelled model, selling at approximately £10,000, will wafer 20–40 tons per day ; a five-man team, with three such machines and two tipping lorries, will wafer and transport to storage 100 tons of wafers in a normal working day. A further man with a mower-swather will keep ahead of this gang by a matter of five to six days. As the swath is frequently over-dried and may have a moisture content as low as 6 or 8%, water is added to the material as it is picked up, conditioning it to about 15%. The wafers have a cross-sectional area of 1¼ × 1¼ in., the length varying slightly above and below this same dimension. The wafers are formed in two cylinders with conventional reciprocating pistons, the feed being effected by a vertical tapering auger. The secret of making a tough, resistant wafer appears to lie in two features of design ; firstly, the wafer is made at a pressure of 8 – 10,000 lb. per sq. in., and secondly, by having three extruding tubes per cylinder, the wafers are under compression for a matter of 3 – 4 seconds. The compressed wafers, which occupy only 82 cu. ft. per ton, are elevated into a 1¼ ton capacity hopper that, when full, is hydraulically tipped into the waiting lorry. These wafers are extraordinarily tough and resistant to breaking ; also they have a pleasant smell and retain a great deal of the original green colour. The self-propelled waferer is powered by a 160 h.p. engine, and a 150 gal. tank, mounted on the machine, provides the water for damping the swath before wafering.

Commercial operators of these machines, who previously were selling baled hay, are now selling the wafered product at £2 a ton above the ruling price for baled hay of equivalent analysis. Many of their dairy farming customers are changing over to wafers which are mechanically handled straight into self-feeding bulk storage. It is generally accepted that cows will consume, perhaps, 10% more hay as wafers than long hay, and some users are claiming a general 10% increase in milk yield. Furthermore, they have virtually eliminated any labour in feeding the wafered hay. One such user, with approximately 200 cows in-milk on his 10 acre holding, runs his enterprise with two milkers who work from 6 a.m. till noon and from 3 to 6 p.m. He has now eliminated a third man, previously required for hay feeding and miscellaneous chores, and he claims that he himself is not fully employed. The cows have access to the hay wafers day and night and receive a small ration of concentrates in the milking parlour, more as a bait than a production ration.

Grape Harvesting

So critical was the shortage of labour at harvest time that, as far back as 1953, a programme of research was initiated with the main object of eliminating this peak demand at harvest time by uniformly distributing the season's work-load, even if labour was transferred to an earlier stage of growth of the crop and was utilised in the more time-consuming unmechanised process of pruning and training the vines. Previously, the bearing wood had been trained along each side of the rows of vines, with the bunches occurring at various heights above the ground and on both sides of the row. For mechanical harvesting, it was decided that this wood must be trained horizontally on one side of the row only, so that the fruit would hang vertically downwards, free of the wood and at the same height, in order to be accessible to a harvesting machine. Because an alteration to traditional cultural practice was involved, the department of viticulture was concerned right from the start of the research. Whatever might be the final destination of the grapes—for the fruit market, juice extraction, wine making or raisins—the method of harvesting was likely to be the same, even though the varieties of grapes used would vary, and the physical characteristics of the plants might be different.

The first stage of the research, therefore, was necessarily one of devising a new form of trellis on which to grow the vines in such a manner that the fruit bunches were presented conveniently to a mechanical harvester. The form of trellis chosen (Fig. 1) had the cross-arm 40 in. from the ground and projecting 30 in. from the upright, with five wires, equally spaced and secured to the bottom of the cross-arm. This system of culture required the minimum of alteration to the normal technique of pruning and training, but, prior to harvest, an additional operation was required in which some of the grape clusters that were not hanging down freely were shaken down manually. In some varieties of grapes, the distance is very short between the top grapes of the cluster and the bearing limb from which the cluster has grown—*i.e.*, ¼ to 1½ in.—but fortunately the varieties that furnish many of the grapes for raisins and common wines have a cluster stem of reasonable length, and these varieties only were used in the initial trials.

Four varieties of grapes were grown on this new form of trellis and, at the normal harvest period, a simulated machine harvest was carried out. It was found that 82% of the variety Thompson Seedless was suitably located for machine harvesting. On the strength of

Summary of 1955 harvest.

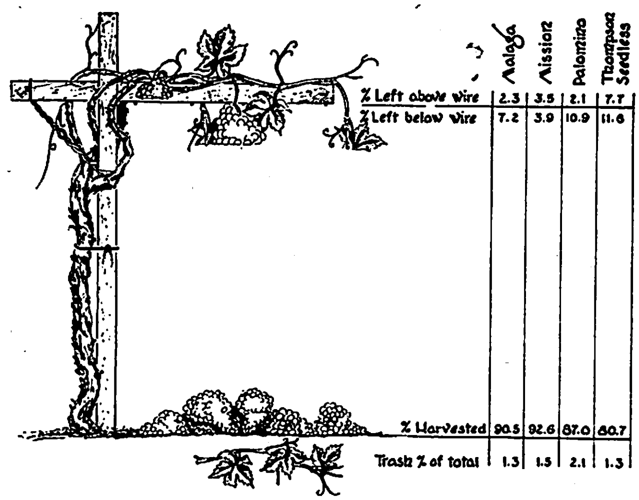


FIG. 1.

these findings, the design and building of a mechanical harvester was started, and it was ready for the 1954 harvest. This machine was tractor-mounted and incorporated the following main features. A saw chain, with knife sections attached, was driven by a hydraulic motor at a speed of about 4,000 ft. per minute. The cutter bar was flexibly mounted and, by means of a counter weight, exerted a nett upward force of about 50 lb. on the underside of the trellis. Provision was made for the cutting head to tilt where the trellis was not horizontal or where the tractor might encounter uneven ground. A deflector was fitted so that any trailing vines were brushed aside from the cutter bar. A spring-loaded device moved along the top of the trellis, exerting a downward force on the canes so that the clusters were depressed to the lowest possible position. A hydraulically-driven cross-conveyor removed the severed clusters, delivered them to an elevator and thence into a bulk tank mounted on a lorry running alongside. Alternatively, they were directed on to a roll of paper paid out from the front end of the tractor. This latter arrangement was used when the grapes were to be sun-dried for raisins. The machine was successfully operated at speeds up to 1·6 m.p.h., but, because the operator had only an obstructed view of the cutter bar, a more satisfactory job of harvesting was done at a speed of 0·5 m.p.h. Results of mechanical harvesting up to 1957 are given in the table below.

TABLE I

Results of Mechanical Harvest

Variety	Location	Percentage of Fruit: Harvested	Left Below Wire	Left Above Wire
Malaga	Davis	91	7	2
Mission	Davis	93	4	3
	Delano	85	7	8
Palomino	Davis	87	11	2
Thompson Seedless	Davis	93	1	6
	Fresno	83	9	8
	Madera	81	8	11

A number of modifications have been made to the earlier model and these include a sensing device that deflects the cutter bar every time it reaches one of the upright stakes, and an air blast that deflects leaves from the cutter bar, thus producing a cleaner sample of grapes. In later models, the grape harvester has been mounted on its own wheels and is towed by the tractor, the operator of the machine having a seat low down beneath the trellis where he can watch the cutter bar and so improve the efficiency of cutting. An economic appraisal of mechanical grape harvesting *versus* hand picking was made in 1960, and the table below gives a comparison of man-hours per annum per acre for the two methods. This comparison was made on the basis of a T-shaped trellis with the harvester passing on either side of the row. To maintain adequate working space, the width between the rows was increased from 12 to 18 ft., but 8 ft. spacing in the rows was maintained.

TABLE II

Man Hours/Acre/Annum

	Conventional			*Machine*		
	Raisin	*Crush-(cane)*	*Crush-(spur)*	*Raisin*	*Crush-(cane)*	*Crush-(spur)*
Trellis (annual *pro rata* basis):						
Stake and set end post	0·57	0·57	0·57	0·74	0·74	0·74
String wire ..	0·17	0·17	0·09	0·79	0·79	0·79
Place cross arm ..	—	—	—	1·04	1·04	1·04
Trellis, maintenance	2·0	2·0	2·0	3·00	3·00	3·00
Pruning	24·0	24·0	20·0	32·0	32·0	25·4
Tying..	4·0	4·0	—	7·0	7·0	—
Freeing clusters ..	—	—	—	24·8	24·8	14·3
Pick	40·0	34·5	34·5	0·7	0·6	0·6
Load into juice tank	—	2·5	2·5	—	—	—
Turn	4·8	—	—	0·46	—	—
Roll	5·1	—	—	—	—	—
Box	8·0	—	—	0·26	—	—
Total	88·64	67·74	59·66	70·79	69·97	45·87

Points of interest from the above table are that more man-hours are required per year with machine harvesting, for trellis establishment and maintenance, for pruning and for tying, but the picking or cutting of the clusters shows a 57 to 1 advantage in favour of the mechanical harvester. The one operation, however, that spoils the whole picture is that of freeing the clusters of grapes prior to mechanical harvesting. If this operation could be eliminated altogether, the annual man-hours required with machine harvesting would then be approaching one-half of those entailed by the conventional method.

However, it should be remembered that, for conventional hand harvesting, the available labour force is shrinking year by year and, for that reason alone, mechanical harvesting may have to be adopted in all vineyards.

The Harvesting of Tree Fruits, including Nuts

For several years the mechanical shaking of trees had been used as a standard method of fruit harvesting, and in particular this method had been employed for prunes and for all types of nuts. Little basic research had been done on the forces required for shaking the trees or the power consumption of the shaker, and the choice of reciprocating, impact or inertia shakers had been an arbitary one. Few studies had been made to find the most suitable frequency or stroke required for efficient removal of the fruit, consistent with minimum damage to the tree ; nor was there much information available on the physical properties of the trees, the effect of the mass of the fruit or the force that must be imparted to it for efficient separation. Research on these matters is proceeding and a considerable amount of information is becoming available as the work proceeds. Fig. 2 illustrates the effect of frequency and stroke upon the completeness of fruit removal.

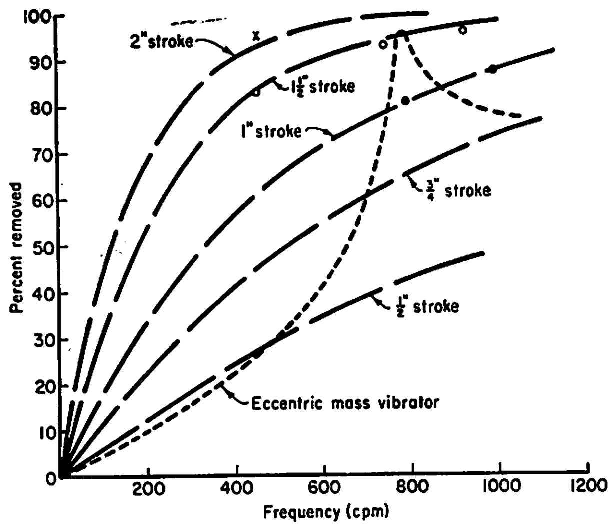


FIG. 2.

Prune removal as affected by frequency and stroke. Note the typical removal *versus* frequency curve of the eccentric mass vibrator for a particular limb. The maximum removal occurs at a natural frequency of the limb.

Almost invariably, the ground beneath nut trees will be a bare fallow and, prior to harvesting time, the ground will be ring rolled and then flat rolled and well compacted. Almonds and walnuts can then be shaken from the tree and recovered from the ground by a device somewhat similar to a street scavenging machine, with a revolving brush. Alternatively, they may be gathered in windows between the trees and from there picked up by a fore-mounted scoop.

Damage to nuts at this stage is not a problem, but obviously it is so in the case of prunes. Of course, with peaches, apricots and similar delicate fruits this technique cannot as yet be applied. It may also be as well to mention that the shaking technique cannot be applied successfully to citrus crops—grapefruit, oranges, lemons, tangerines, mandarins, etc.—because these have a prolonged harvesting period and buds, blossom, unripened and fully-ripened fruit will all be on the tree simultaneously. Thus the development of a citrus harvesting machine is a separate problem that is being tackled currently by a different team of workers, and it is probably one of the most thorny and challenging problems that agricultural engineers have yet had to face.

An alternative method for the collection of fruit or nuts, shaken from the tree, is to collect them by means of portable catching frames, from which the product can be mechanically emptied into pallet boxes or some other suitable container. So far as prune harvesting is concerned, it was found that for some conditions, notably in areas where fruit drops as it matures, a machine for picking up prunes from the ground would be more economical in labour and probably just as cheap as the use of frames, and, in addition, it was found that the fruit falling on to the smooth, well-prepared ground surface suffered surprisingly little damage. Work was therefore started to devise the best method of picking up fruits from the ground, and, in order to study in detail the movement of fruit in contact with various pick-up devices, high-speed photography was employed. From this study, it soon became apparent that pick-up fingers were not necessary, but that fruit could be plucked from the ground successfully between two rubber rollers, the critical point of the design being that the fruit should be in contact with these two rollers and the ground simultaneously. After some experimentation, it was found that the rear roller should be approximately 1 in. diameter and placed close to the ground, and that it should be rotated against the direction of travel. The second roller, approximately 3 in. in diameter, was placed above and in front of the rear roller and revolved in the opposite direction. The smaller roller was covered with fluted rubber hose pipe, whereas the larger was made as soft as possible by wrapping it with foam rubber.

The pick-up assembly was mounted on a framework that was supported by parallel linkage and depth-gauge wheels were mounted on either side so that the rollers were maintained at the correct height above the soil. At the front of the equipment, two rubber augers were mounted horizontally to clear the fruit from the path of the depth wheels and to direct it to the centre of the pick-up mechanism (Fig. 3).

Schematic diagram of experimental prune and nut pickup.

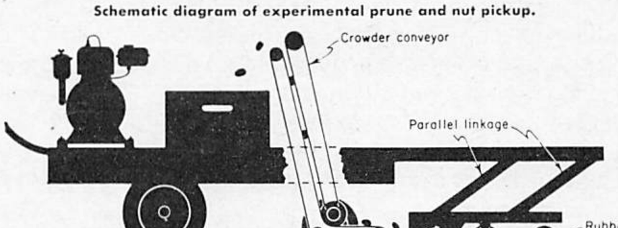


FIG. 3.

Fruit catching frames, briefly referred to earlier, are used successfully for prunes and apricots that have to be dried and for almonds. The assembled frames may be hexagonal, circular or elliptical, some taking the fruit inwards to a central conveyor and others conveying the fruit to the outside, where they can be brushed by hand into boxes. The frames will normally be in two halves, each mounted on pneumatic castor wheels for easy movement from tree to tree. One model, tractor-mounted, is in the form of an inverted umbrella. When manoeuvring into position against a tree, the " umbrella " is retracted radially so that it occupies a segment of 130°. When in position, the canvas-covered framework is opened out radially by hydraulic cylinders until it fully encircles the tree. This model has a conveyor, which brings the fruit from the centre to storage boxes at the rear of the tractor ; it also incorporates its own shaker boom.

Woık is now proceeding to extend the use of catching frames to the more delicate fruits such as peaches, apricots and cherries, etc., which are to be canned. Instead of canvas covering on the frames, expanded polystyrene, sponge rubber and similar materials are being used on a rigid frameowrk. Earlier investigations have shown that a great deal of the damage is caused to windfalls or to shaken fruit when it falls on lower branches or hits the main limbs or crutch of the tree. The pomologists, therefore, have turned their attention to shaping trees, by appropriate pruning, so that the fruiting branches hang down from the main members, which, in turn, form an inverted cone supported on the main trunk. It seems likely that peach and pear trees could be trained in this manner without reducing fruit yields.

With peaches, nectarines, plums and apricots, the crop must be thinned, as well as pruned and harvested, and these three operations together can absorb up to 400 man-hours per acre per annum or 75% of the total man-hours. The problem for each of these operations is the same—namely, that of positioning a worker for each task and normally a ladder is employed. The mobile towers and platforms so far developed do not seem to have provided the answer for all these operations, particularly for harvesting, where the number required to achieve rapid removal would be prohibitive. To overcome these difficulties, the pomologists and the engineers have proposed planting the trees in the form of a hedgrow running north and south. The main branches would run in the plane of the row of trees and the fruiting branches would extend outwards, perpendicular to the row for no more than 3 ft. To carry out the three operations of pruning, thinning and harvesting, a self-propelled and arch-like structure is proposed ; it would span the row of trees and be fitted with operating platforms at two or three levels on either side. By this means, each operator would have his work presented to him at a convenient level and he could, when necessary, reach to the centre of the tree. It is not known whether present crop yields per acre could be maintained on this system, but it is probable that row spacing could be decreased from the present value of 20–22 ft. It should, perhaps, be mentioned in this context that chemical thinning of fruit crops is now beginning to be used on a limited commercial scale, but it is difficult to say at this stage whether this will supersede hand thinning.

One other method of harvesting fruit from trees has been tried with prunes : A pulsating air stream of high velocity was directed through a 10 ft. long pipe to within a few feet of the limbs. A centrifugal compressor with a capacity of 3,500 c.f.m. at 2·5 p.s.i. was used for this purpose and, by employing outlet pipes of 5 in. and 8 in. dia., air velocities at the nozzle ranged up to 200 m.p.h. The conclusion arrived at after two years' work with this device was that, in the case of fruits that would normally be picked in a succession of pickings as they became ripe, this system would be applicable, since it removed the ripest part of the crop, which normally has the lowest F/W factor (bonding force divided by fruit weight). Thus it is a selective method of harvesting, and will under favourable conditions remove, say, 95% of the fruit on the tree in four successive harvestings at weekly intervals. By comparison, the vibratory shaker will remove the same amount of fruit at the initial shaking.

Frost Protection of Vines, etc.

Many of the vineyards of California are situated in areas subject to sporadic frosts in Spring, and temperatures may fall a matter of two or three degrees below the danger point. Whereas at one time frost damage was considered merely as one of those gambles that had to be accepted, in recent years the price of grapes has risen sufficiently to make it economical to take steps to combat the frosts. The various methods of frost protection can be divided into two groups : (*a*) Those that can be described as " cultural," where the emergence of the buds is retarded, and (*b*) " mechanical " methods, used mainly to break up the temperature inversion over the vineyard.

Cultural Methods

Normal pruning, carried out at any time during the dormant period of the winter, has no noticeable effect upon the date of bud emergence. However, by delaying pruning until the Spring, the leafing of the buds on the remaining spurs can be delayed by a week to ten days. Similarly, by delaying pruning of the shoots on the higher parts of the vine, until they are perhaps 3 to 4 in. long, does not affect subsequent fruiting of the vine, but will delay the leafing of the buds by as much as two weeks. Either of these methods may well delay growth sufficiently to avoid the period of maximum frost risk. Double pruning may also be adopted—that is, removal in the winter of all canes except those wanted for spurs, the spurs themselves being cut back to 18 in. In the Spring, after the buds on these canes have produced shoots 2 to 4 in. long, the canes are then cut back to produce one to four buds, according to their diameter.

Another method used is to apply growth regulators such as gibberellin or napthalene—acetic acid. In some of the grape growing areas, damaging frosts have occurred in ten or twelve seasons out of the past 26 years, and any of these methods could be used to give protection during the vital period, April 1st to April 15th. The state of cultivation of the soil during the frost-hazard period can also diminish or increase the risk. A bare surface, well consolidated, provides good storage of heat, and on clear nights the air above such ground will be appreciably warmer than that above heavy weed growth or a cover crop. Vineyard tests have shown that, at a distance of 1 ft. above a well-consolidated bare soil, the temperature fell to 29·5° F., whereas at the same height above cultivated but unconsolidated ground the temperature fell to 27° F., and similarly, where the ground was partly covered with weeds, the temperature fell to 27·5° F.

" Mechanical " Methods

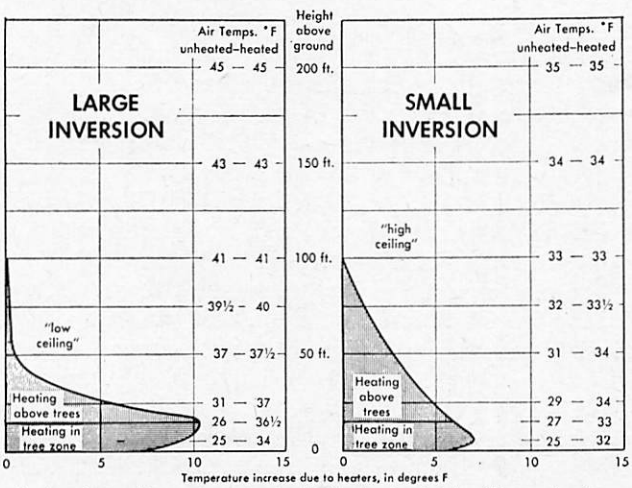
There can be much frost damage in cold air pockets, and these occur where the cold air flow, coming down a slope or along a valley, is arrested by some obstruction. Such features as banks, hedges, low-branched trees, barns, straw stacks, can check the flow of cold air, and this in turn prevents the warm air above from being drawn down. A striking example of a frost pocket in California was eliminated by the removal of a small copse backed by tall trees. As in this case, aerial photography of the district will reveal to the meteorologist the probable causes of persistent frost damage.

Sprinkler irrigation is used commonly in many parts of the State for the protection of a wide variety of crops. A suggested arrangement is six sprinklers per acre,with 11/64ths in. diameter nozzles, operating at 55 lb. pressure. With the spreader nozzles plugged, the sprinklers precipitate approximately 0·1 in. of water per hour, and this is sufficient for protection down to 24° F. under slight winds, sprinkling being continued right through the following morning until all the ice has been melted from the shoots. In vineyards, this method is usually used only on trellised vines where there is minimum risk of breaking off shoots due to the ice load. Normally, the sprinklers would be started as soon as the air temperature had dropped to 32° F., but frequently in California the air will be so dry that evaporative cooling takes place when sprinkler operation is started. Under these conditions, sprinkling will begin when the wet bulb temperature reaches 32° F. Due to the heat released by the formation of ice, temperature rises of 5 or 6° F. have been recorded in sprinkled areas, and this system of protection is particularly applicable to smaller plants such as strawberries, tomatoes, potatoes, cranberries. Plants of this type will sink to the ground due to the ice loading, and later recover, but with tree fruits the risk of limb breakage is considerable, although this may be preferable to total loss of the crop by frost damage.

Heaters

The economics of using heaters in orchards, whether deciduous or citrus, are somewhat marginal. In citrus orchards during a normal winter, when 50 hours of protection may be needed, the operating costs amount to about £50 per acre and the initial cost of 50 heaters and fuel storage to approximately £168 per acre. The temperature rise that can be expected from these heaters is very much dependent upon the inversion—that is, the difference in temperature at 5 ft. and 40 ft. above the ground surface in the orchard. When the inversion is small—say, 3·5° F.—this means that the warm air layer is at a considerable height and the convected heat is mainly dissipated between this and the tree zone. Conversely, when the inversion is large—say, 13·5° F.—

the majority of the heat will remain in the tree zone (see Fig. 4). Take the case of a 20-acre citrus orchard surrounded by other orchards ; for a 3·5° F. inversion, 0·9 million B.T.U. will be needed per acre-hour for a temperature rise of 1° F. With an inversion of 13·5° F., the equivalent heat input would be 0·5 million B.T.U's. The amount of heat needed also depends upon the natural wind speed and the size of the orchard.



Heating effects and temperatures at various heights, based on tests in a 15-acre orchard; average fuel consumption 33 gals. per acre per hour. The indicated temperatures for various heights are based on an assumed value of 25° F for the 5-foot elevation at the unheated station.

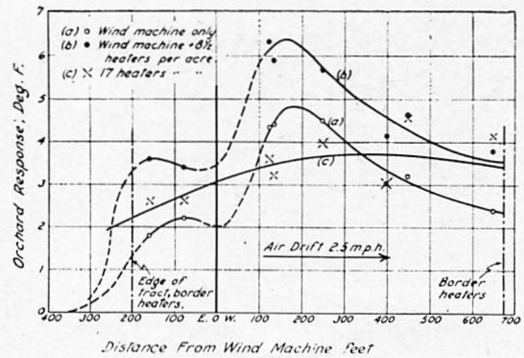
FIG. 4.

Wind Machines

Large power-driven fans, mounted on 40 ft. towers within the orchards, are used to direct air jets at 7° or so below the horizontal. Electric motors or petrol engines of about 90 b.h.p. are common for this duty, and one such fan unit is adequate for an area of 12–14 acres. The whole unit revolves on a fixed time schedule of four minutes for the downwind sector and 1·3 minutes upwind for optimum results. Applying heat directly to the fan inlet has not been found effective, as the jet then becomes buoyant and horizontal throw is reduced. However, a combination of a few conventional heaters on the ground and the wind machine has been found effective, the number of hours of heater operation being only about one-sixth of that needed with heaters alone. The combined running cost of wind machine and heaters for a 50-hour season is only £28 per acre, compared with £50 per acre for heaters alone. A comparison of the temperature rises for these two systems and for the wind machine alone is made in Fig. 5.

There are numerous other unique machines that have been or are being developed for the Californian grower to help him combat the effects of a rapidly dwindling labour force. He need have little fear of the future, however, for he has the enthusiastic support of machinery designers, agricultural engineers, and agricultural scientists of every discipline.

Among the principal harvesting research programmes being currently pursued at Davis, and not already mentioned in the Paper, are the following :



Temperature response along axis of air drift from one 93 b.h.p. motor with tower turning speed of 180° in four minutes in the downdrift direction and 180° in 1½ minutes when facing in the updrift direction. FIG. 5.

(1) *Tomato Harvester*. Already one manufacturer has about 20 such harvesters in operation in the State, the design of which originated in the Agricultural Engineering Department at Davis. The plant breeders have made a substantial contribution here in producing a bush-type tomato plant that ripens its fruit simultaneously and produces fruit of a shape that suffers minimal damage during separation and subsequent handling. Colour sorting equipment, to be mounted on the machine, is also being developed. The harvesting rate is approximately ½ acre per hour, and this represents the handling of some 10 tons of fruit per hour. A total crew of 12, including eight sorters, is needed for harvesting and transporting the tomatoes in bulk bins. This compares with a 60-man crew for hand harvesting, and at current rates saves about £6,000 in labour costs per 100 acres of crop in a season.

(2) *Lettuce Harvester*. Since the plant breeder has not as yet developed varieties of lettuce that will come to maturity simultaneously, a selective harvester is under construction and shows great promise. A device that " feels " each lettuce and decides whether it is of sufficient size and density controls the operation of a blade that cuts the selected lettuce. Over one million tons of lettuce are sold annually in the State, and the specialists who produce lettuce in the Salinas Valley have initiated this project.

Selective harvesters are also under development at Davis for asparagus and melons, two crops of considerable economic importance in the State.

Despite all the research and development effort that is being employed in agricultural engineering in California, much of which has, perforce, to be omitted from this review, there is no indication that the number of problems is diminishing. On the contrary, the number of agricultural engineers recruited for such work is increasing and, working in close touch with plant and animal scientists, entomologists, pathologists, soil physicists and food technologists, their future seems assured.

The author's grateful thanks are due to John Goss and other colleagues in the Department of Agricultural Engineering at Davis, who have helped in the collection of information and in reading the manuscript.

All the figures and tables are reproduced from " California Agriculture," by courtesy of the University of California Division of Agricultural Sciences.

Appendix I
1959
CALIFORNIA
LAND UTILIZATION

Total land area (1,000 acres)	100,207
% of U.S. area	5·3
Cropland	
Area (1,000 acres)	9,933
% of total land area	9·9
Pasture and rangeland non-forested	
Area (1,000 acres)	24,291
% of total land area	24·2
Total cropland, pasture and rangeland	
Area (1,000 acres)	34,224
% of total land area	34·1
Forest land, special use areas, miscellaneous lands	
Area (1,000 acres)	65,983
% of total land area	65·9

1960
FARM INCOME

% of U.S.	9·3
Rank among all States	1

1959
LAND UNDER IRRIGATION

California				United States		
		% Irrigated acres of				
% of farms reporting	*Acreage irrigated 1,000 acres*	*California cropland*	*U.S. irrigated areas*	*% of farms reporting*	*Acreage irrigated 1,000 acres*	*% of total cropland*
74·7	7,396	74·5	22·4	8·2	33,018	8·6

FARM ACREAGE, NUMBER, SIZE

	California			United States		
Year	*Number of farms*	*Land in farms 1,000 acres*	*Acres per farm*	*Number of farms*	*Land in farms 1,000 acres*	*Acres per farm*
1925	136,400	27,500	201·7	6,371,600	924,300	145·1
1959	99,300	36,900	371·6	3,703,600	1,120,100	302·4

	California 1935	California 1959	United States 1935	United States 1959
Farm Sizes	%	%	%	%
Under 10 acres	23	24	9	12
10 to 49	43	35	31	21
50 to 99	11	12	21	17
100 to 179	8	9	21	20
180 to 259	3	4	7	10
260 to 499	5	6	7	12
500 to 999	3	5	3	5
1,000 and over	4	6	1	3
Farm Values	$	$	$	$
Average value per farm	15,466	102,868	4,823	33,242
Average value per acre	76	379	31	121

CALIFORNIA
FARM TENURE

	Percentage Distribution by Tenure Status			
Year	*Full Owner*	*Part Owner*	*Managers*	*Tenants*
1935	66·1	7·6	4·5	21·8
1959	69·0	17·9	2·2	10·9

1960
FARM POPULATION

California					United States		
			Farm Population %				
Total Population 1,000's	*% of U.S. Population*	*Farm Population 1,000's*	*Calif. Total Population*	*U.S. Farm Population*	*Total Population 1,000's*	*Farm Population 1,000's*	*% Farm of Total*
15,721	8·8	334	2·1	2·5	179,326	13,445	7·5

TRACTORS

		California		U.S.
	Year	*Number*	*% of U.S.*	*Number*
Tractors: Wheel	1945	49,822	2·2	2,287,661
„ : Crawlers	1945	29,467	29·1	101,222
„ : Wheel	1959	104,597	2·3	4,487,449
„ : Crawlers	1959	42,793	21·7	197,619

FARM TRUCKS AND TRACTORS

	Motor Trucks	Tractors	
	% of all farms reporting	*% of all farms reporting*	*No. per 1,000 acres of cropland harvested*
United States	58·6	72·3	8·2
California	71·1	71·3	20·1

NUMBER OF FARMS, CLASSIFIED BY MAJOR SOURCE OF INCOME

Farms	%
Fruit and Nut	24
Vegetable	3
All other Field Crops	10
Dairy	8
Poultry	7
Livestock	9
General	4
Miscellaneous unclassified	35

Appendix II
1960
CALIFORNIA'S TEN LEADING FARM PRODUCTS: VALUE OF PRODUCTION

	% of Total Value (excluding pastures, horticultural specialties, minor miscellaneous crops)
Cattle and Calves	16·9
Milk	12·8
Cotton Lint	9·6
All Hay	5·6
Eggs	5·5
Grapes	4·3
Oranges	3·7
Lettuce	3·5
Potatoes	2·6
Barley	2·5
Per cent., first ten, of total value	67·0

1960
VALUE OF FARM PRODUCTION

	% by Value of U.S.	Production 1,000 tons
Food Grains		
Rye	0·5	4
Wheat	0·6	232
Rice	23·1	677
Feed Grains		
Maize	0·5	441
Oats	0·7	104
Barley	19·9	1,653
Sorghum	3·6	488
Field Crops		
All Hay	7·0	7,228
Cotton Lint	13·7	485
Cotton Seed	16·1	783
Dry Beans (cleaned basis)	26·4	162
Dry Field Peas (cleaned basis) (1959)	1·0	2
Flax Seed	3·6	27
Potatoes	15·7	1,438
Sweet Potatoes	13·6	45
Sugar Beets	23·8	4,160
Hops	19·9	4
Seed Crops (red, alsike and sweet clover, alfalfa, lespedeza, timothy)	23·9	27
Citrus Crops		
Oranges (including tangerines)	32·2	30,800 boxes
Lemons	93·4	17,100 boxes
Grapefruit	8·1	2,700 boxes
Fruits, Non-Citrus		
Apples	6·2	213
Apricots	93·7	230
Avocados	96·1	27
Cherries (sweet and sour)	19·8	24
Figs (fresh basis)	100·0	59
Grapes	80·2	2,694
Olives	100·0	65
Peaches	37·5	910
Pears	55·6	363
Plums (fresh basis)	94·3	82
Prunes (fresh basis)	91·5	348
Dates, pomegranates, pineapples, persimmons	100·0	26
Tree Nuts		
Walnuts	96·3	70
Almonds	100·0	53
Vegetables, Fresh		
Artichokes (for fresh market and processing)	100·0	21
Asparagus	54·1	34
Broccoli	66·9	78
Brussels sprouts (for fresh market and processing)	89·9	33
Cabbage (for fresh market and processing)	12·3	127
Cantaloupes	54·2	336
Carrots (for fresh market and processing)	60·4	294
Cauliflower (for fresh market and processing)	46·3	72
Celery (for fresh market and processing)	59·2	425
Sweet Corn	13·9	68
Cucumbers	16·4	29
Garlic	100·0	23
Honeyball Melons (1948–52)	100·0	3
Honeydew Melons	78·6	57
Lettuce	53·6	1,040
Onions (for fresh market and processing)	16·5	228
Peas, Green	73·4	9
Peppers, Green (for fresh market and processing)	18·4	35
Spinach	12·7	11
Strawberries	36·4	43
Tomatoes	38·6	338
Watermelons	16·5	179
Vegetables, Processing		
Tomatoes	49·8	2,249

1960
VALUE OF FARM PRODUCTION

	% by Gross Income of U.S.	Production 1,000,000 pounds
Livestock and Livestock Products		
Cattle and Calves	6·9	1,389
Hogs	0·5	88
Sheep and Lambs	8·3	115
Turkeys	18·8	288
Chicken	6·1	101
Wool	7·6	19
Mohair	0·1	·03
Milk	7·7	8,109
Eggs	9·2	5,678 (million eggs)

1960
COMMODITY VALUES

	% of Total for California
Livestock and Livestock Products	39·5
Field Crops	22·7
Fruits (non-citrus)	11·5
Commercial Vegetables for fresh market	10·5
Citrus Fruits	5·1
Feed Grains	3·7
Food Grains	2·3
Tree Nuts	2·1
Vegetables for commercial processing	2·7

Digestible composition of common California fruit, vegetable, and other by-products, with their values as compared with barley at $50 or £17 17s. per ton.

Feed	Nutrients in 100 pounds of Feed		Value Compared with Barley
	Digestible Protein	Total Digestible Nutrients	Price per ton
Fresh			$
Apples	0·3	13	8·23
Apricots	0·8	14	8·86
Asparagus butts	9·7	47	29·75
Brewer's grains (wet) ..	4·2	16	10·13
Cabbage waste	1·8	11	6.96
Grapes	1·0	19	12·03
Oranges	0·6	10	6·33
Peaches	0·5	17	10·76
Pears	0·4	15	9·49
Plums	0·8	19	12·03
Prunes	0·6	19	12·03
Almond hulls (silage) ..	0·0	23	14·56
Dried			
Almond hulls (soft-shell) ..	0·0	72	45·57
Apple pulp	1·7	64	40·51
Apricots	3·9	69	43·67
Brewer's grains	14·4	60	37·97
Citrus pulp	2·5	74	46·84
Distiller's grains	20·7	82	51·90
Flax hulls	0·8	35	22·15
Grape pomace	1·5	24	15·19
Olive pulp (pits removed) ..	7·7	69	43·67
Raisin pulp	2·3	48	30·38
Tomato pomace	16·3	57	36·08
Walnut meal (some shells)	13·0	62	39·24
Alfalfa hay	10·5	50	31·65
Beet pulp (dried)	4·3	68	43·04
Maize silage	1·1	18	11·39

BIBLIOGRAPHY

Hay Harvest in Wafers

DOBIE, JOHN B. " Production of Hay Wafers," *Agricultural Engineering*, Vol. 4, No. 6, June, 1960.

DOBIE, JOHN B. " Materials Handling Systems for Hay Wafers," *Agricultural Engineering*, Vol. 42, No. 12, December, 1961.

RONNING, MAGNAR. " Pelleted and Wafered Hay for Milk Production," Animal Husbandry Department, University of California, Davis.

CLEAVER, C., AND KELLY, C. F. " Drylot Feeding Facility Design for California," A.S.A.E., Paper No. 62–809, 1962.

DOBIE, J. B. " Hay Wafering," *California Agriculture*, Vol. 16, No. 4, April, 1962.

CURLEY, R. G., AND DOBIE, J. B. " Systems for Handling Wafered Hay," A.S.A.E. Paper, 62–602, December, 1962.

DOBIE, J. B., CURLEY, R. G., AND PARSONS, P. S. " Economics of Producing, Handling and Feeding Wafered Hay," A.S.A.E. Paper, No. 63–160, June, 1963.

Grape Harvesting

WINKLER, A. J., AND LAMOURIA,,LLOYD H. " Machine Harvesting of Grapes," *California Agriculture*, Vol. 10, No. 5, 1956.

LAMOURIA, LLOYD H. " Wine Grape Handling : Labor and Cost Analysis," A.S.A.E., 1955.

WINKLER, A. J., LAMOURIA, LLOYD H., AND ABERNATHY, G. H. " Mechanical Grape Harvest—Problems and Progress," *American Journal of Enology*, Vol. 8, No. 4, 1957.

LAMOURIA, LLOYD H., WINKLER, A. J., AND KASIMATIS, A. N. " An Economic Appraisal of Mechanical Grape Harvest," U.C.D.

LAMOURIA, LLOYD H., STUDER, HENRY E., AND BREWER, HAROLD L. " Advances in Pruning Productivity," U.C.D.

Fruit and Nut Harvesting

MCKILLOP, A. A., PERRY, R. L., AND SHULTIS, A. " Lightweight Catching Frames," *California Agriculture*, Vol. 9, No. 6, 1955.

LAMOURIA, LLOYD H., HARRIS, RICHARD W., ABERNATHY, GEORGE H., AND LEONARD, SHERMAN J. " Harvester for Canning Fruit," *California Agriculture*, Vol. 11, No. 8, 1957.

FRIDLEY, R. B., AND ADRIAN, P. A. " Fruit Pick Up Developments," U.C.D.

FRIDLEY, R. B., AND ADRIAN, P. A. " Development of Prune Harvester," *California Agriculture*, Vol. 12, No. 9, 1958.

FRIDLEY, R. B., AND ADRIAN, P. A. " Development of a Fruit and Nut Harvester," *Agricultural Engineering*, Vol. 40, No. 7, 1959.

FRIDLEY, R. B., AND ADRIAN, P. A. " Some Aspects of Vibratory Fruit Harvesting," *Agricultural Engineering*, Vol. 41, No. 1, 1960.

FRIDLEY, R. B., ADRIAN, P. A., AND MILLER, M. W. " Dry Bulk Handling of Prunes," *Western Fruit Grower*, 1960.
Handling of Prunes," reprinted from *Western Fruit Grower*, 1960.

FRIDLEY, R. B., AND ADRIAN, P. A. " Mechanical Harvesting Costs," reprinted from *Western Fruit Grower*, 1961.

FRIDLEY, R. B., AND ADRIAN, P. A. " New Tree Shaker," *California Agriculture*, Vol. 15, No. 8, 1961.

BREWER, H. L., FRIDLEY, R. B., AND ADRIAN, P. A. " Field Tests show Feasibility of Blower-Shaker for Mechanical Harvesting of Prunes," *California Agriculture*, Vol. 15, No. 9, 1961.

LAMOURIA, L. H., HARTMANN, H. T., HARRIS, R. W., AND KAUPKE, C. R. " Mechanical Harvesting of Olives, Peaches and Pears," *Transactions of the A.S.A.E.*, Vol. 4, No. 1, 1961.

LORENZEN, C., AND LAMOURIA, L. H. " Hydraulics as a Solution to Handling Fruit for Processing," A.S.A.E., Paper No. 63–316, 1963.

Frost Protection of Vines, etc.

BROOKS, F. A., RHOADES, D. G., AND SCHULTZ, H. B. " Frost Protection for Citrus," *California Agriculture*, Vol. 4, No. 9, 1950.

KEPNER, ROBERT A. " Orchard Heater Smoke Lessened," *California Agriculture*, Vol. 4, No. 10, 1950.

LEONARD, A. S., AND KEPNER, R. A. " Return-Stack Orchard Heater," *California Agriculture*, Vol. 4, No. 9, 1950.

LEONARD, A. S. " The Return-Stack Orchard Heater," *Agricultural Engineering*, Vol. 32, No. 12, 1951.

BROOKS, F. A. " The Action of Wind Machines and Heaters used for Frost Protection on Calm Clear Nights," *Washington State Horticultural Association Proceedings*, 48 : 193–198, 1952.

RHOADES, D. G., BROOKS, F. A., LEONARD, A. S., AND SCHULTZ, H. B. " Frost Protection in Almonds," *California Agriculture*, Vol. 9, No. 8, 1955.

SCHULTZ, H. B., AND PARKS, R. R. " Frost Protection by Sprinklers," *California Agriculture*, Vol. 11, No. 6, 1957.

BROOKS, F. A., AND SCHULTZ, H. B. " Orchard Heating Effectiveness," *California Agriculture*, Vol. 12, No. 8, 1958.

CRAWFORD, TODD V., AND BROOKS, F. A. " Frost Protection in Peaches," *California Agriculture*, Vol. 13, No. 8, 1959.

CRAWFORD, TODD V., AND LEONARD, ARTHUR S. " Frost Protection," *California Agriculture*, Vol. 14, No. 8, 1960.

CRAWFORD, TODD A., AND LEONARD, ARTHUR S. " Wind Machine —Orchard Heater System for Frost Protection in Deciduous Orchards," *California Agriculture*, Vol. 14, No. 8, 1960.

CRAWFORD, TODD V., AND GANSER, JOSEPH H. " Spring Temperature Inversions," *California Agriculture*, Vol. 15, No. 2, 1961.

CRAWFORD, TODD V., AND LEONARD, ARTHUR S. " Orchard Heater Plume Heights," *California Agriculture*, Vol. 15, No. 8, 1961.

SCHULTZ, HERBERT B. " Microclimates on Spring Frost Nights in Napa Valley Vineyards," *American Journal of Enology and Viticulture*, Vol. 12, No. 2, 1961.

BROOKS, F. A., LEONARD, A. S., CRAWFORD, T. V., AND SCHULTZ, H. B. " Frost Protection by Wind Machines and Heaters," *Transactions of the A.S.A.E.*, Vol. 4, No. 2, 1961.

CRAWFORD, T. V., AND LEONARD, A. S. " Frost Protection with Multiple Wind Machine-Heater Units," *California Agriculture*, Vol. 16, No. 8, 1962.

CRAWFORD, TODD V., AND LEONARD, ARTHUR S. " Observations of Buoyant Plumes in Calm Stably Stratified Air," *Journal of Applied Meteorology*, Vol. 1, No. 2, 1962.

Tomato Harvesting

LORENZEN, COBY, AND HANNA, G. C. " Mechanical Harvesting of Tomatoes," *Agricultural Engineering*, Vol. 43, No. 1, 1962.

DISCUSSION

MR. RICHARD WELLESLEY (Farmer, Berkshire) congratulated Mr. Finn-Kelcey on having very successfully evoked the atmosphere of California. He felt there was a great deal for people in Britain to gain from hearing of developments in California, in spite of major and obvious differences in climate. He had been most impressed by the spirit of co-operation which existed in America. Young people were trained first in the 4-H clubs and then in the Universities to think in terms of co-operation. It was the understood thing to get together, to share ideas and to contribute money in order to solve problems. In contrast to this, Mr. Wellesley was disappointed by the attitudes he had often found in this country.

In particular he deplored present straw handling methods in Britain. In one case of which he was aware, a farmer had devised a satisfactory straw-handling machine and had tried, unsuccessfully, to interest manufacturers in it. He had subsequently made and sold 150 machines, using his own inadequate facilities. Mr. Wellesley thought it " dismal and frightful " that such a situation should exist.

He was quite certain that there was no lack of brain-power in this country, but that full use of the talents existing in research institutes and elsewhere was frustrated by lack of co-operation. He instanced a problem of his own about which he had written to a very well-known experimental station, only to receive a reply which told him nothing. By chance, he had found out that there was some very good experimental work on this subject going on elsewhere, and he thought it appalling that the experimental station apparently did not know about it.

Mr. Wellesley thought Mr. Finn-Kelcey's Paper ought to provide the shaking-up that he felt was so badly needed—for the farmers first and for the Universities and Experimental Stations second. He hoped that the agricultural engineering world would appreciate the need to co-operate, and that the manufacturers would then produce the machines which farmers wanted. This was particularly important because we were still on the brink of the Common Market and there was tremendous scope for new development.

He thought that men who had been abroad like Mr. Finn-Kelcey had a very valuable part to play, and he hoped he would not be crushed and discouraged. So many Nuffield Scholars had come back to this country full of enthusiasm for improvement of various kinds, only to become dejected after a month or so of giving lectures around the country by the English attitude that new ideas " cannot work here." The most important slide Mr. Finn-Kelcey had shown, in Mr. Wellesley's view, was the early tomato-picking machine that made " ketchup " on the ground in the process of its work. This typified the American attitude, which was to accept a low standard of work initially, but to keep on experimenting until the machine worked properly—and, incidentally, to make a profitable business out of it.

MR. J. A. C. GIBB (University of Reading) asked Mr. Finn-Kelcey whether there was any evidence to suggest that, for climatic or other reasons, American varieties of tomatoes, apples and other crops were better able to stand up to rough-and-ready handling methods than those in this country. He also asked if Mr. Finn-Kelcey had seen any mechanized methods of moving sprinkler irrigation equipment.

Replying, MR. FINN-KELCEY said that he had not come across anything that he felt was really novel. Travelling sprinkler lines, up to half-a-mile long, were mounted on wheels, but it still took quite a long time to move them. He could only speak of tomatoes in connection with toughness. A type of tomato had been bred to give simultaneous ripening of the major portion of the crop, which was also particularly resistant to damage due to handling. It was not round, but slightly pointed. Toughness had certainly been bred into it intentionally.

MR. J. B. HOLT (National Institute of Agricultural Engineering) asked about the economic aspects of the Haro-bed bale handling equipment, and MR. FINN-KELCEY replied that it was very difficult to answer this question. There were two sizes of Haro-bed, each being obtainable either as a trailed or as a self-propelled machine. The smaller model loaded 36 bales in six layers of 6 bales, and in the trailed version would cost the equivalent of £900. Its rate of working would be about 4 loads per hour, equivalent to about 5 tons per hour, and requiring a tractor and one operator. The larger self-propelled model, picking up seven layers of 8 bales, cost about £3,000 and worked at about 15 tons per hour.

It would not necessarily work satisfactorily in this country without modification, since in California very high-density bales were made from hay at 6% or 8% moisture content and were tied with three wires. This made it possible to get 3½ tons on one load. Mr. Finn-Kelcey thought it might be necessary to use shorter bales in this country, perhaps 30 rather than 46 in. long, and it might be desirable to have a different stacking pattern, possibly using two tie-in layers instead of one.

He had been most impressed by the Haro-bed machine, and had seen it working at 15 miles per hour, picking up 56 bales on a load and making a round trip in 13 or 14 minutes—a tremendous speed of working. In his view, designers in this country had concentrated solely on picking up bales without considering the subsequent handling stages, so that the job as a whole was not mechanized. A machine to pick up, load and stack in one operation, like the Haro-bed, was an example of the forward thinking which had impressed him so much in California, and manufacturers there always seemed to be willing to tackle problems in this way.

MR. R. WELLESLEY then asked what size of enterprise, or farmers' co-operative, would justify the use of such hay-handling equipment, or of hay pelleting machines.

In reply, MR. FINN-KELCEY referred to a farm he had seen which had 3,500 acres of lucerne, on which five men and three pelleters were working on piece-work. From this, he would think that 1,000 acres of hay would warrant one pelleter, at a cost of about $10,000 (£3,500) for a self-propelled pick-up machine. Hay of a quality worth $20 per ton if baled would sell at $26 if pelleted, which was roughly £2 per hour extra. From these figures, it might be possible to form some idea of the economic picture, bearing in mind also the saving in labour in the storage and feeding stages.

In British weather conditions, the situation might be more difficult, and it would be necessary for pelleting machines to be able to work with hay of up to 35% moisture content. Drying would then be necessary, perhaps, in a simple type of drier like those used in the U.S.A. for ear corn.

The Haro-bed machine, Mr. Finn-Kelcey thought, could be justified on 200–300 acres of hay, and perhaps also be used to some extent for contract work on neighbouring farms.

MR. J. R. MOFFATT (Rothamsted Experimental Station) referred to the difficulties presented by the open channels associated with surface irrigation in California, and asked how these difficulties were overcome when using the expensive high-speed machinery which Mr. Finn-Kelcey had described.

MR. FINN-KELCEY said that there were indeed levees and checks in lucerne fields, and some 6 in. of water were applied after each cut. The checks were spaced at 30 ft. intervals, so that a 16 ft. swather would travel once down and back in each check. The two rows were then put into one by a side-rake, and the baler and Haro-bed travelled once only down each levee. The stacks were made in such positions that the machinery ran parallel to the leaves and not across them. The width of the swather was taken as a basic figure, and other measurements were multiples of that figure.

MR. W. G. COVER (Simplex Dairy Equipment Company, Ltd.) said Mr. Finn-Kelcey had given the impression that all grass was turned into hay, and asked if there were no silage or haylage in California.

In reply, MR. FINN-KELCEY said that very little silage was made in California, although a few areas of silage and dairy farms with silos were to be seen around the cities. Hay was now so well mechanised that silage seemed to be rather out of fashion in California.

MR. J. A. C. GIBB (University of Reading) asked if Mr. Finn-Kelcey could give any information about mechanization of root-crops in California, and MR. FINN-KELCEY said that a great deal of sugar-beet was grown, which was surface-irrigated and fully mechanized. Sugar-beet harvesting spread from October right through until June, and by that time almost every beet had bolted. Bolting up to 4 or 5 ft. high was apparently not detrimental to the sugar content until the seed began to form, but it then required the use of a flail harvester to top the crop, followed by lifting directly into road transport.

Finally, in reply to a question from the Chairman, MR. T. SHERWEN, MR. FINN-KELCEY said that great care was taken in removing wire bale ties before bales passed up into the disintegrator, of which he had shown a slide. Baling wire which had passed through a disintegrator would certainly form a hazard to livestock.

The CHAIRMAN thanked Mr. Finn-Kelcey for the fascinating picture he had presented of a part of the world where not only was everyone prepared to tackle problems of mechanization, but also farmers were willing to subscribe hundreds of pounds each in order to solve problems. If such an attitude existed in this country, he was sure that many problems could be dealt with much more quickly than was the case at present.

OBITUARY

Council records with deep regret the death of Mr. Alexander Senkowski, M.I.Mech.E., M.S.A.E., M.I. Agr.E., on 6th January, 1964, at the age of 66. Mr. Senkowski's earlier career was distinguished by his gallant service in the Polish Air Force, for which he won several decorations, including the Virtute Militari. He continued in aeronautics in a technical capacity and held many senior appointments in this field, first in Poland, and later in France and England. In 1947, turning from the sky to the land, he joined Harry Ferguson Ltd., where his outstanding ability in design soon manifested itself. His major work was concerned with tractors and hydraulic systems, and he became the Massey-Ferguson Chief Development Engineer, Eastern Hemisphere. In 1960 he joined Harry Ferguson Research Ltd. as Chief Engineer, and here, too, he worked on projects connected with tractor development. His Paper " Traction Problems of Agricultural Tractors " was presented in the last issue of the *Journal*.

IMPROVEMENT OF WORKING CONDITIONS FOR FARM MACHINERY OPERATIVES

Three Papers presented at an Open Meeting of the Institution in London on 30th January, 1964.

(1) Noise Measurement and Analysis

by S. W. R. Cox,* B.Sc., A.Inst.P.

SUMMARY

The status of noise as a subject of public importance is briefly reviewed, with reference to the final report of the Wilson Committee on the Problem of Noise. Some examples of noise studies in agricultural engineering are given. The measurement and analysis of noise is discussed in two main sections. The first deals with the measurement and analysis of the physical characteristics of sound, and includes a summary of the apparatus used. The second deals with subjective rating of noise, with special reference to scales of loudness and the use of standardised loudness computation procedures. Finally, some typical results of noise measurements made at the N.I.A.E. are presented, with comparative figures derived from different forms of measurement and analysis.

1. BACKGROUND TO NOISE MEASUREMENTS

1.1. The Overall Picture

CONCERN over the effects of noise—usually defined as unwanted sound—is increasing as the general noisiness of our environment rises. The resulting campaign for noise abatement has two main aims :

(1) Reduction or limitation of the effect of noise invading residential and other areas from external sources such as traffic and industrial or trade installations.

(2) Protection of workers against noise generated in their working environment.

In the prosecution of the former aim there has arisen a body of law which in some cases is directed to the abatement of specific noises and in others—notably the Noise Abatement Act, 1960—provides a channel for remedying noise nuisance generally. Remedy against a specific noise may also be sought in action at Common Law.

The Law relating to noise nuisance, and proposals for strengthening it, are presented in the Final Report of the Wilson Committee on the Problem of Noise,[1] together with useful summaries of many other aspects of the problem.

In contrast, this country has no legislation laying down maximum permitted levels of noise for working environments. Furthermore, the Wilson Committee does not recommend any early introduction of legislation, due to the many gaps in our knowledge of the effects of industrial noises on hearing. To fill in these gaps, the Minister of Pensions and National Insurance is sponsoring a programme of research, which is being carried out jointly by the Medical Research Council (M.R.C.) and the National Physical Laboratory (N.P.L.) in selected industries and is expected to extend over several years. The aims of the programme have been set out as :

(i) To compare the state of hearing of persons with their known noise exposures.

(ii) To monitor over a period of several years the state of hearing of people throughout the early years of working in noisy locations.

(iii) To determine whether a significant relation between permanent and temporary hearing loss exists.

(iv) To determine the physical features of industrial noise which constitute an effective criterion for measuring " exposure " as judged by correlation with its effect of hearing.

(v) To obtain data indicating the need for hearing conservation and to make recommendations on measures to be employed.

The results should be applicable to a wide range of industries, including agriculture, and may lead to the formulation of legislation for the protection of the worker, wherever this is indicated.

Recent developments provide a strong incentive to gather quantitative information on the noise environment in any particular industry, but it is not necessary to await the results of the M.R.C./N.P.L. investigation before the significance of such information can be assessed. A substantial amount of evidence already exists on the extent of temporary and permanent hearing loss associated with certain industrial environments.[2] Measured noise levels can also be viewed against proposed criteria[1, 2] from which levels acceptable to the public can be deduced. Further details of these criteria are given in section 2.2.6. There is no conclusive evidence of improvement in operator efficiency at low noise levels,[2] but at high levels an increase in the number of errors made can be expected when the task requires close attention. A further possibility is that the operator may limit his rate of work if, by this means, he can limit noise to a tolerable level.

* Head of Instrumentation Dept., National Institute of Agricultural Engineering, Silsoe, Bedfordshire.

1.2. The Noise Problem in Agriculture

The increase in noisiness of our environment is shared by the countryside, as the Wilson Committee notes. In its section on Noise from Agriculture, Forestry and Gardening, the Committee states its conclusions in paragraphs 495 and 496.

" 495. We do not think that noise from agriculture and forestry is a serious problem, but there are sources of noise in these industries which do cause annoyance to some people. These sources are agricultural machinery powered by internal combustion engines, devices for scaring birds by noise, and power saws.

" 496. All agricultural machines which are licensed to use the roads, such as tractors, come within the range of our recommendations regarding noise from motor vehicles.* We do not consider that it is necessary at present to devise similar procedures and fix maximum noise levels for other mechanically-powered types of agricultural machinery. However, we recommend that all agricultural machines which are powered by internal combustion engines should be fitted with efficient silencers."

To the list in para. 495 the author would add orchard sprayers, and possibly some drying installations.

Measurements of noise from agricultural tractors and machinery have been reported from many parts of the world in recent years, and a few of these reports have also dealt with the effects of the noise on the operator. For example, in 1962 an FAO/ECE publication[4] dealt with the effects of power saw vibration and noise, and in 1963 results of audiometric tests of tractor drivers in Australia were published[5] showing long-term hearing loss well in excess of the normal loss occurring with increasing age (presbycusis). Some evidence is also on record of the part played by noise in limiting the tractor speed chosen by operators in the field.[6]

The establishment of facilities for measurement and analysis of vibrations and noise was undertaken at the N.I.A.E. several years ago as part of a study of tractor operator comfort. Noise measurements have since been extended to other machines and installations. A selection of measurement results is presented in section 3.2.

2. NOISE MEASUREMENTS AND ANALYSIS

When it comes to quantitative statements of noise levels and effects a complex situation exists, due to the interrelated physical, physiological and psychological effects associated with sound and hearing. Work carried out over the past few decades has led to the establishment of various measurement techniques and scales which are now widely adopted, but the newcomer to the field may be forgiven if he finds the terminology and variety of techniques rather confusing.

It is therefore the main purpose of this Paper to summarise current measurement practice, with special reference to the units employed and their sphere of application.

* The draft regulations issued by the Ministry of Transport in 1963 are based on the Committee's Interim Report on Noise from Motor Vehicles.[3]

2.1. Measurement of the Physical Characteristics of Sound

To establish the nature of a noise environment, it is necessary to measure certain characteristic features of the sound itself. Sound is, of course, a sequence of alternate compressions and rarefactions in air (or any other medium) generated by vibration or turbulence of some kind and propagated at a speed dependent on the medium. In the case of air, the speed is about 340 metres per second (1,100 ft. per second) at 20° C.

The characteristics of importance in noise studies are :

(i) The frequency of the fluctuations. The range of interest is that to which the ear responds—roughly 15 c.p.s. to 15,000 c.p.s. A noise may contain frequency components covering all or part of this range.

(ii) The wavelength corresponding to a given frequency (equal to c/f, where c is the speed of sound in the medium and f the frequency). This is of special interest in determining resonance, reflection and diffraction effects arising from barriers and enclosures.

(iii) The fluctuating pressure of the sound wave, p, usually employed as the effective (root mean square) value. The ear responds to a wide range of pressures between the lower threshold of audibility and the upper threshold of painful sensation. This range is approximately 0·0002 microbar to 200 microbar, where 1 microbar* is very nearly one-millionth of standard atmospheric pressure.

(iv) The intenisty of sound, I, at a point. This is the average rate of sound energy transmitted in a given direction through the point per unit area at right-angles to that direction.

In a free, progressive sound wave :

$$I = \frac{p^2}{\rho c}$$

where p is the r.m.s. sound pressure at the point, ρ is the density of the medium, and c is, as before, the speed of sound in the medium.

The units used for intensity are microwatts per sq. cm.

(v) The total power output, W, of a sound source. This can be derived by integrating a series of measurements of intensity (in practice, sound pressure) all round the source at a fixed distance. Examples of sound powers are 0·001 microwatt for a barely audible sound and 1 watt from a pneumatic chipping hammer.[7]

(vi) Time variation of the sound. Noise occurs with varying degrees of intermittency, from sharp, transient sounds to prolonged sounds which, for analysis, can be regarded as continuous. The measurement techniques employed depend on the extent of this intermittency. Furthermore, the frequency components in continuous noise may fluctuate in amplitude, regularly or irregularly with time, and independently of each other. A

* 1 microbar = 1 dyne/cm.^{2}

complete representation of the noise spectrum may therefore call for specialised mathematical analysis.

2.1.1. *Steady State Sound*

Fortunately, for measurement purposes many vehicles and machinery noises can be treated as steady-state sounds, *i.e.*, sounds in which the time variation is not significant. The measurement in these cases involves only two quantities—namely, sound pressure level and frequency spectrum. These will be dealt with in turn.

2.1.2. *Sound Pressure Level and the Decibel*

Measurement of sound pressure is effected with a microphone of the pressure-sensitive type, working into an electrical meter circuit *via* an amplifier. Because the range of sound pressure to which the ear responds is so wide, it is inconvenient to measure or work with this quantity directly. Instead, the logarithmic scale of *sound pressure level* (S.P.L.), in decibels, is used.

The bel is a logarithmic power ratio, and the decibel is one-tenth of the basic unit, thus :

$$\text{Decibels (dB)} = 10 \log \frac{W_1}{W_2}$$

where the common logarithm to the base 10 is implied.

In acoustic terms, this is equivalent to a ratio of intensities, *i.e.*,

$$\text{dB} = 10 \log \frac{I_1}{I_2}$$

It has been stated that I is proportional to p^2 in a free progressive wave and, although this relationship does not hold for all sound fields, it is accepted practice to use the decibel scale to define :

$$\text{S.P.L.} = 10 \log \frac{p^2}{p_o^2} \text{ dB}$$

where p_o is a reference pressure.

This reduces to the form in which it is commonly quoted :

$$\text{S.P.L.} = 20 \log \frac{p}{p_o} \text{ dB}$$

The value of p_o should be specified when quoting S.P.L. ; it is usually either 0·0002 microbar or 1 microbar.

The range between the lower and upper thresholds of hearing is about 140 dB. (0–140 dB when p_o = 0·0002 microbar.)

Computing in dB requires a little practice at first. If, for example, it is necessary to know the combined effect of two sounds, with individual S.P.L.s :

$$\text{dB}_1 = 10 \log \frac{p_1^2}{p_o^2}$$

$$\text{and dB}_2 = 10 \log \frac{p_2^2}{p_o^2}$$

the resultant level, dB given by

$$\text{dB}_3 = 10 \log \left(\text{antilog} \frac{\text{dB}_1}{10} + \text{antilog} \frac{\text{dB}_2}{10} \right)$$

i.e., the combination is not effected by simple addition. Repetitive calculations of this type can be simplified by the use of conversion tables.[7]

Two related levels will be found in discussions of noise measurement:

(i) *Band pressure level* is the S.P.L. of the noise components within a specified frequency band.

(ii) In the special case of bands taken at 1 c.p.s. intervals, the term sound pressure *spectrum level* is used.

2.1.3. *Frequency Analysis*

For some applications a single dB measurement may be adequate, but for many purposes connected with noise control and loudness calculation (see Section 2.2.4) it is necessary to know the frequency composition of the sound. This is determined by analysing the electrical output from the microphone with frequency-selective circuits, which can be tuned (or switched) through the audio-frequency range, and recording the sound pressure level at each setting.

Three main classes of frequency-selective network are available :

(i) The tunable, constant bandwidth filter, which uusally has a narrow bandwidth of 5 to 10 c.p.s. This can be employed to locate single-frequency components, so helping with the identification and subsequent suppression of noise from particular sources in a machine. It has the drawback that it is difficult to obtain measurements at the upper frequencies unless the frequency stability of the sound is high.

(ii) The alternative for this narrow-band analysis is a tunable filter in which the ratio of the bandwidth, Δf, to the centre frequency of the band, f_o, is constant. This type is generally satisfactory for noise analysis.

(iii) Band-pass filters, having (ideally) uniform acceptance within a band of frequency and rejection of all other frequencies, are used in sets, spanning contiguous sections of the audio spectrum. These, like class (ii), have the constant bandwidth/centre-frequency characteristic. They are usually of the octave type (*i.e.*, the highest and lowest frequencies in the pass band are in the ratio 2 : 1) or of the ⅓-octave type, although ½-octave sets are sometimes used. Band analysis is convenient when the complete sound spectrum is under consideration and the loss of fine detail is not important. The form of the spectrum is often adequately represented by simple octave analysis.

Attenuation characteristics of practical octave and ⅓-octave filters are given in Figs. 1 (a) and (b) respectively. It will be seen that the frequency base in these diagrams is scaled linearly in octaves. The centre-frequency f_o is the mid-point of the pass-band on this scale (by definition), and one curve applies to all electrically similar filters, irrespective of the magnitude of f_o. The spacing of the ⅓-octave centre frequencies is by

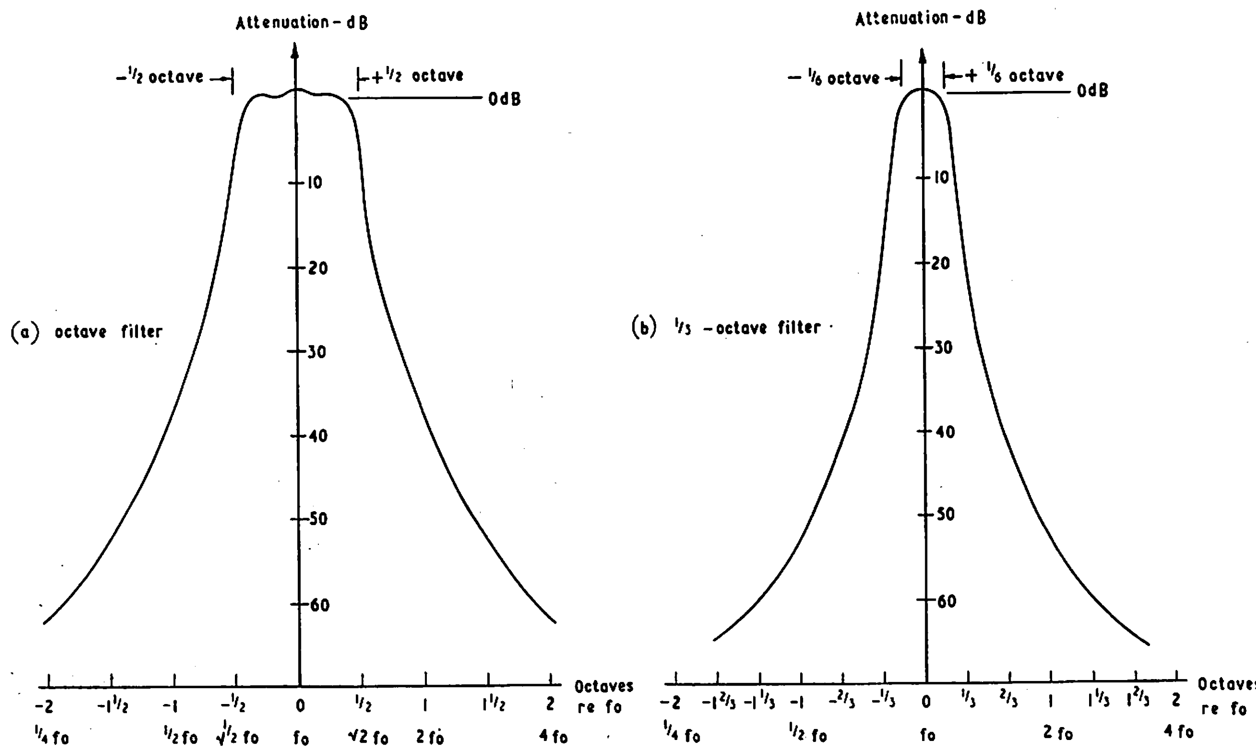


Fig. 1. Characteristics of band-pass filters-

multiplicative steps of 2 —*e.g.*, f_o, $2^{1/3} f_o$, $2^{2/3} f_o$, 2 f_o. Given one centre-frequency in this series, the remainder can be determined simply by reference to common logarithm tables, since the logarithms of consecutive numbers in the series differ by log $2^{1/3}$; *i.e.*, $\frac{1}{3}$ log 2, which is almost exactly 0·1. The performance of band-pass filters and a preferred range of centre-frequencies is the subject of national and international standardisation.

NOTE.—Any presentation frequency analysis must be accompanied by a reference to the type of analyser employed, since this affects not only the amount of detail present, but also the general trend of the result. For example, noise with uniform distribution throughout the frequency range will yield a level spectrum when an analyser of type (i) is used, but the result will be a linear increase of band pressure level with frequency if types (ii) or (iii) are used, because the latter have a band-width increasing with frequency.

2.1.4. *Non-Steady-State Sound*

Noises such as rattles, bangs and heavy impacts are not suitable for measurement by the normal meter used for registering r.m.s. pressure level of steady-state sound. These transient sounds require measurements taking account of peak levels and time decay rates.

Methods of anaylsing this type of sound[7] [9] are used in noise control problems. They may employ special peak-reading meters or oscilloscopes, with analysers working from a tape recording of the sound, played as a continuous loop. Results are expressed in terms of dB levels and time constants.

2.1.5. *Equipment*

A brief summary of the equipment needed for measurement and analysis of the physical characteristics of steady-state sound can now be made.

The essentials are :

(i) A pressure-sensitive microphone, for which the main requirements are high stability, linearity over a wide frequency range and well-defined directional response. Its output voltage is proportional to the sound pressure incident on it.

(ii) An amplifier and meter circuit. The amplifier takes the output from the microphone and multiplies it by a factor which can be selected in switched steps, spaced at 10 dB intervals in voltage level gain.* If the microphone output is V_1 and the amplifier output is V_2, the amplification is :

$$20 \log \frac{V_2}{V_1} \text{ dB.}$$

The meter indicates the r.m.s. value of V_2 on a logarithmic scale, marked in dB relative to a zero level, V_o. The main part of the scale covers the range 0 to +10 dB, but it extends above 10 dB and below 0 dB ($V_2 < V_o$) in order to provide overlap with the decade steps. In this way it is possible to measure any S.P.L. by setting the range switch to the nearest dB decade value and reading the excess (or deficit) dB value on the meter—*i.e.*, the two dB readings are summed algebraically.

* Voltage level is derived from power level in an analogous manner to S.P.L., since electrical power is proportional to the square of the voltage at constant impedance.

To express this point more fully, we may take the microphone output, V_1, as kp, where k is a constant and p the r.m.s. sound pressure, as before. Then, if the switch setting is dB_1 and the meter reading dB_2 :

$$dB_1 = 20 \log \frac{V_2}{V_1} = 20 \log \frac{V_2}{kp}$$

and

$$dB_2 = 20 \log \frac{V_2}{V_o} = 20 \log \left[\frac{kp}{V_o} \text{ antilog } \frac{dB_1}{20} \right]$$

or

$$dB_2 = 20 \log \frac{kp}{V_o} \; dB_1$$

If the instrument is designed to make $\frac{V_o}{k} = p_o$ (0·0002 microbar), then $20 \log \frac{kp}{V_o} = \text{S.P.L.}$

Hence, S.P.L. $= dB_2 - dB_1$.

In practice, the range switch is marked with the highest decade value corresponding to the lowest amplification setting, which effectively reverses the sign of the dB_1 term. The S.P.L. is then obtained by summation, as stated above.

The meter usually has two speeds of response —" fast " and " slow." The former gives a better indication of instantaneous S.P.L., but, if this quantity is varying rapidly, it may be necessary to obtain an average value, using the " slow " response.

(iii) Calibration facilities. It is normal to employ an alternating electrical signal of known amplitude to check the stability of the amplifier, and some form of standard sound generator to check the overall response of the microphone, amplifier and meter system.

(iv) Band-pass filter sets or tunable selective circuits for frequency analysis. Their output is fed to a switched amplifier and meter system as in (ii) to give band pressure level.

Other valuable equipment includes :

(v) Recording systems. It is often more convenient to record noise on magnetic tape and to play back for subsequent frequency analysis. High-quality recorders are essential for this purpose, and frequent recording of calibration signals should be made, to ensure the continued fidelity of the transcription. In addition, chart recorders—known as level recorders—can be used to produce spectrograms from the output of frequency analysers, giving the analysis in a very convenient form.

(vi) The cathode-ray oscilloscope, either for direct viewing of waveforms or for photographic recording.

2.2. Measurement of the Subjective Effects of Noise

It is fundamental to this subject that sound only becomes noise when it induces an adverse reaction in the hearer. Therefore, if we are to assess the effects of noise, we cannot stop at the physical measurements described in the previous section, and we must enter the field of psycho-acoustics. In this field the aim is to produce a quantitative scale for the annoyance potential of sounds. Some working criteria for annoyance effect have been adopted, but at present the subjective sensation most reliably represented on a numerical scale is loudness —a quantity deriving from physiological action in the ear.

2.2.1. *Loudness Level*

The loudness of sounds depends on their frequency as well as their sound pressure level in a way that can only be determined by carefully controlled experiments with groups of listeners (sound juries). In the simple case of sounds which are pure tones the relationship has been well established by such experiments. Briefly, the technique employed is to take a 1,000 c.p.s. reference tone of known S.P.L. and to find the S.P.L.s at which pure tones of other frequencies are judged to be equally loud. When these tests have been repeated with 1,000 c.p.s. tones at different S.P.L.s, a corresponding set of curves of equal loudness can be drawn on a graph of S.P.L. against frequency. Typical curves are shown in Fig. 2, from which it can be seen that equal loudness requires greater S.P.L. at low frequencies, and at the very high frequencies than in the range 500–5,000 cycles per second, the low frequency effect becoming less marked at higher levels.

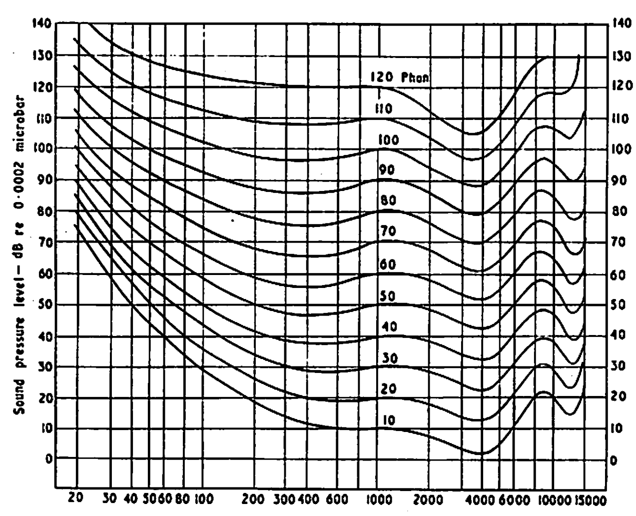


FIG. 2.
Equal Loudness Level contours for pure tones. Binaural free-field listening.

These curves define lines of equal *Loudness Level* for pure tones, the unit of loudness level being the *phon*. The phon value of any line is given by the S.P.L. at the 1,000 c.p.s. point on that line.

The latest International Standards Organisation (I.S.O.) recommendation for the shape of these curves is embodied in B.S. 3,383.[10]

2.2.2. *The Loudness Scale*

The scale of loudness level has the disadvantage that the phon values of two sounds do not directly reflect their relative loudness—*e.g.*, a 40 phon sound is not twice as loud as a 20 phon one. Fortunately, it has been shown that sound juries can agree sufficiently on the relative loudness of sounds to permit the establishment of a scale which does reflect this ratio. This is known as the Scale of *Loudness*, and its unit is the *Sone*. Experiments established that loudness is judged to double when the loudness level of a sound increases by approximately 10 phon over the range 20 to 120 phon. To a sufficient degree of accuracy, therefore, the loudness scale is defined by the following relation :

$$\text{Loudness (Sones)} = 2^{\frac{P-40}{10}}$$

where P is the Loudness level in phons. Thus, 40 phons is equivalent to 1 sone, and the sone values double at exactly 10 phon intervals.

Some sone values of common noises (based on figures published in the Wilson report) are given in Table I.

TABLE I
Loudness of Some Typical Sounds
(taken from the Wilson Committee Report)

Noise Source or Environment	*Sound Level (dBA)*	*Loudness (Sones)*
Soft whisper at 5 ft.	34	1·6
Busy restaurant or canteen ..	65	13
Inside small saloon car at 30 m.p.h.	70	24
Ringing alarm clock at 2 ft. ..	80	34
Heavy diesel propelled vehicle about 25 ft. away	92	111

2.2.3. *Sound Level and Sound Level Meters*

In an attempt to provide a simple objective measurement—related to loudness level—for more complex sounds, the sound level meter was devised. This incorporates the microphone, amplifier with stepped amplification, and r.m.s. meter circuit described in 2.1.2., and additionally one or more networks which can be switched into circuit to modify the amplification *v.* frequency characteristic of the amplifier. These *weighting* networks produce an overall meter response approximating that of the ear for pure tones. The three weightings labelled A, B and C are widely used—A and B approximating the 40 and 70 phon equal loudness contours for pure tones respectively, and C giving flat response over the range 25 to 8,000 cp.s. The weighted meter reading is said to indicate *Sound Level* (not S.P.L.), and, because the weightings are strictly only related to the loudness of pure tones, the levels are expressed in dB rather than phons.[12]

When quoting Sound Level results, the weighting network used must be stated. In the case of Sound Level A, it is usual, and sufficient, to write dBA.

The A, B, C levels were originally devised to give objective readings of quiet, moderately loud and loud noises respectively, but Sound Level A has been found to correlate sufficiently well with subjective assessments of traffic and other noises (see Section 2.2.6) for this measurement to be recommended where simplicity, rather than the best available accuracy, is the main concern.

For this reason, sound level meters with A weightings are the subject of Standard Specifications.[13]

2.2.4. *Calculated Loudness*

The establishment of equal loudness curves for the variety of complex sounds found in noise studies is far more difficult than in the case of pure tones. The method of jury assessment (with 1,000 c.p.s. reference tones) can be used, but this is clearly not convenient for general application. However, research has led to the introduction of methods for calculating loudness from the measured frequency spectra of noises. Two of these are now widely accepted, and the I.S.O. is considering recommendations for their use.

The simpler of the two, due to Stevens,[14] can be employed with octave, ½-octave or ⅓-octave analysis of the sound. Stevens takes account of the fact that the loudness of noise in separate frequency bands is not additive, by means of the formula $S_T = S_M + F(\Sigma S - S_M)$, where S_T is the total loudness, ΣS is the sum of the loudness in the separate bands, and S_M is the loudest of these bands.

F is a factor introduced to represent the " Masking " effect by which one band of noise reduces the contribution

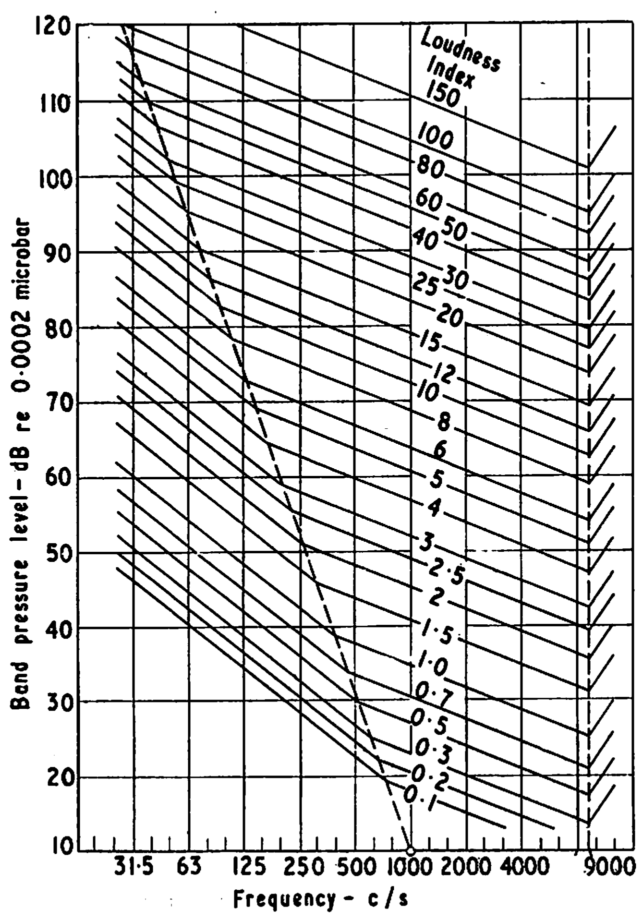


Fig. 3. Stevens MKVI method of loudness computation chart for conversion of measured band pressure level to loudness index.

of another to the combined loudness. In Stevens' theory, the loudest band predominates.

The values of S are determined from a set of empirical curves, which have been simplified by Stevens to the form shown in Fig. 3. The value of F has also been adjusted to simplify the calculation. It is taken as 0·3, 0·2 or 0·15 for octave, ½-octave and ⅓-octave analysis respectively.

The computation of S_T is thus a three-step operation :

(i) Convert the measured band pressure levels into their corresponding S values (loudness indices) by reference to Fig. 3.

(ii) Sum all the loudness indices except the largest (S_M) and multiply by the appropriate F factor.

(iii) Add S_M to the product to obtain the loudness in sones.

The method is strictly designed for steady-state noise in diffuse sound fields (*i.e.*, where the sound reaches the ears equally from all directions) and for broad-band noise. Errors may arise from the presence of line spectra or from sharp maxima separated by more than an octave, because the masking relationship implicit in the Stevens formula does not hold under these conditions.

The method of Zwicker[15] is of wider application, covering steady state spectra of all types and both diffuse and frontal (*i.e.*, directional) sound fields. It has the disadvantage that it is more laborious than the Stevens method unless a computer is employed.[2] Zwicker's method is based on the analysis of noise into "critical bands" of frequency (frequenz gruppen) which are related to the frequency-response of the inner ear. The loudness due to one of these critical bands may be obtained from the fourth root of the ratio of the sound intensity in the band to the lower threshold intensity of the band. Total loudness is arrived at by summing band loudness, after making allowance for masking effect (now introduced as the influence of any band over adjacent bands of higher frequency but lower band pressure level). Zwicker has simplified his original theory so that calculation of total loudness can be carried out graphically from a ⅓-octave analysis and a set of prepared charts. The critical bands are taken to coincide with standard ⅓-octave bands above 280 c.p.s. ; below this frequency the bands are taken to be multiples of ⅓-octaves. The set of charts covers band pressure levels from 5 to 110 dB in five ranges, with different charts for diffuse and frontal fields. A recent version of one of these charts is shown in Fig. 4 (*a*). The method of calculation is as follows :

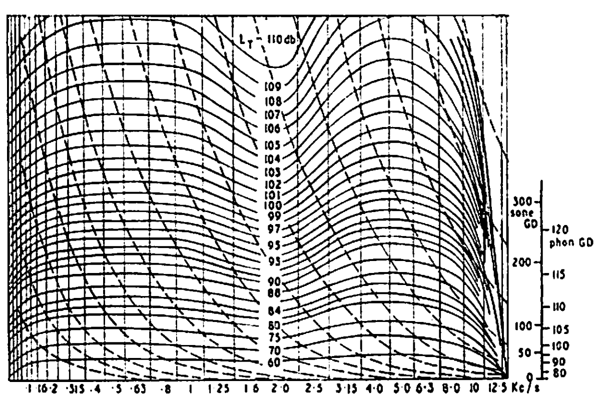


FIG. 4a.
Zwicker chart for loudness computation (diffuse field).

(1) Having measured ⅓-octave band pressure levels, compound those up to 90 c.p.s., those between 90 and 180 c.p.s., and those between 180 and 280 c.p.s. (employing the method outlined in section 2.1.2.). These three groups, with the remaining ⅓-octave levels, form the critical band levels.

(2) Choose the chart with the appropriate range band pressure levels. In each critical band, mark the horizontal level of the correct dB value with a heavy line spanning the band.

(3) Join up the consecutive lines in one of two ways, starting at the lowest critical band.

(*a*) Where there is an upwards step to the next band, the two levels are joined by a vertical line at the common abscissa.

(*b*) Where there is a downward step, draw a downward curve, parallel to the dotted lines, until a higher frequency band level is met. This takes account of the masking effect.

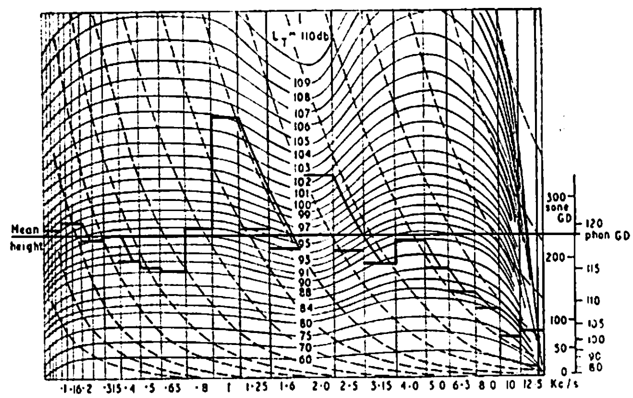


FIG. 4b.
Completed chart with critical band pressure levels and mean height line.

(4) Measure by planimeter, or estimate in any convenient way, the area under the resultant graph —see Fig. 4 (*b*). From this, work out the mean height of the curve.

(5) Draw in the mean height as a line on the chart, extending it to cut the phon/sone scale. The total loudness can then be read off in sones or phons.

Notes

1. When quoting results calculated by either of these methods, it is essential to state which one has been used. To distinguish calculated sones or phons from subjectively assessed values, the

I.S.O. proposals include a set of standard suffices.

O = Octave (the preferred band for the Stevens method).
G = Group (Zwicker frequenz gruppen).
D = Diffuse field.
F = Free field.

For example, the Stevens calculation yields sones $_{OD}$ and the corresponding Zwicker coding is sones$_{GD}$.

2. Under diffuse field conditions an omni-directional microphone should be used.

3. Both methods indicate the distribution of loudness within the frequency bands. (This can be very useful when deciding which part of a machine is contributing most to the overall loudness.)

2.2.5. *Loudness of Impulsive Noise*

The loudness of impacts and other impulsive noise is not easy to determine, even by sound jury, and calculated loudness methods do not apply. Sound level meters may be used in some cases—*e.g.*, to assess the change in loudness of a sound due to noise reduction treatment.[7]

2.2.6. *Scales of Annoyance and Noisiness*

Ordering of noises on the loudness scale does not necessarily rank them in order of unpleasantness. Nevertheless, any attempt to produce a scale of annoyance or unpleasantness which will give a better representation of subjective reactions introduces additional variation, due to differing personal tolerances toward noise of any one type.

There exists a scale of "noisiness," developed particularly for assessment of aircraft noise, which is widely used. This introduces a calculated "perceived noise level" in PNdB and a "perceived noisiness" in noys by a method parallel to that of Stevens. Latest evidence shows that Zwicker's calculated loudness procedure can be used equally well with these noises.

Work carried out by Motor Industry Research Association (M.I.R.A.), N.P.L. and Building Research Station on subjective classifications of vehicles, aircraft and street noises (see Appendices of Wilson Report[1]) has resulted in use of Sound Level A as a working scale for proposed maximum permitted levels of exposure of the public to noise from these sounds and from industrial installations. The proposed vehicle noise tests[3] are based on this work.

A further method of rating industrial noises is being considered by I.S.O. This introduces the concept of noise rating number, N, which relates to a set of curves on the band pressure level *v.* frequency chart (Fig. 5). The octave band levels of the noise are plotted on this graph, and the value of N corresponding to the line just above the peak level is the noise rating number. This number is used for comparison with maximum allowable

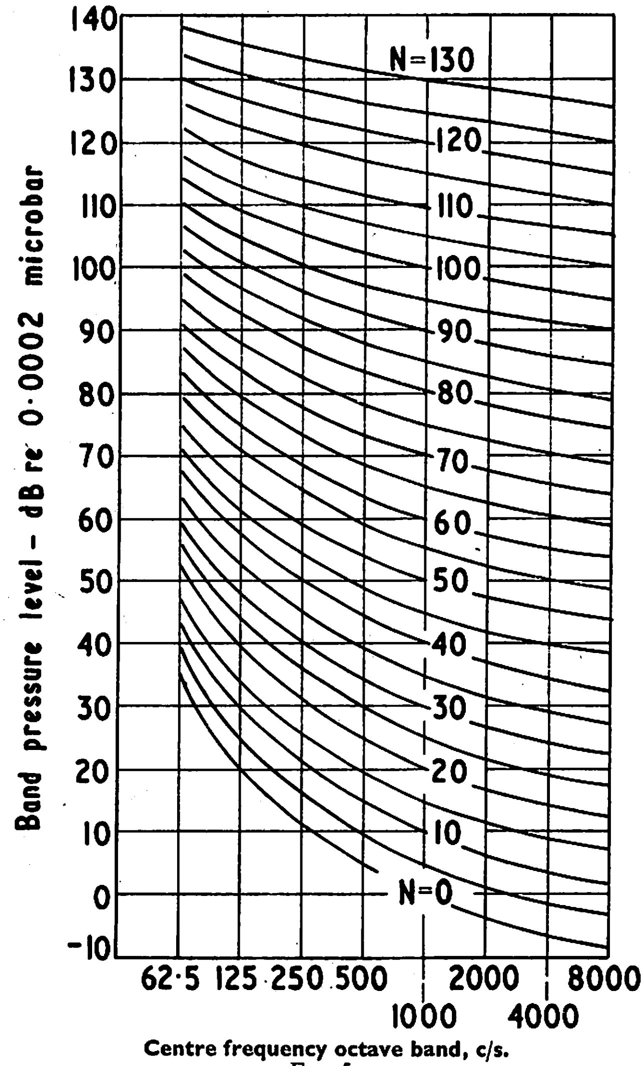


FIG. 5.
Acceptability criteria for noises. Curves for determination of noise rating number, N.

values of N under certain conditions, such as intrusion on residential areas, or for interference with the speech frequency range (250–4,000 c.p.s.). One of several very similar proposed criteria for adoption of hearing conservation measures employs N-85 as the critical level. This corresponds to the band pressure levels in Table II.

Note The levels apply to habitual exposure for more than five hours per day, but it is of interest to compare them with those quoted in Section 3.

2.2.7. *Other Measurements*

(i) For some noise investigations—*e.g.*, testing of fans—sound power is the quantity determined (Section 2.1.v) This may be expressed as Sound Power Level, defined by $10 \log \frac{W}{W_o}$, where W_o is a

TABLE II
Octave Band Pressure Levels Corresponding to Noise Rating Number 85

Octave mid-frequency (c.p.s.)	63	125	250	500	1000	2000	4000	8000
S.P.L. (dB) approximately ..	102·5	96	91	87·5	85	83	80·5	79·5

reference level, usually 1 picowatt (1 micro microwatt).

(ii) Noise control techniques introduce measurements relating to the absorption or confinement of noise and vibration. In this field, one unit specific to noise is the *sound absorption coefficient* of a material, which is defined as the ratio of the sound energy absorbed by the material to the sound energy incident upon it. This is determined from the change occurring in a reverberant chamber when a quantity of the material is introduced.[16] The coefficient varies with the frequency of the sound and its angle of incidence. Measurements are usually quoted for random angles of incidence and for frequencies at octave intervals from 125 to 4,000 c.p.s. The noise reduction coefficient (NRC) is the average of the coefficients at 250, 500, 1,000 and 2,000 c.p.s.

3. NOISE MEASUREMENTS AT THE N.I.A.E.

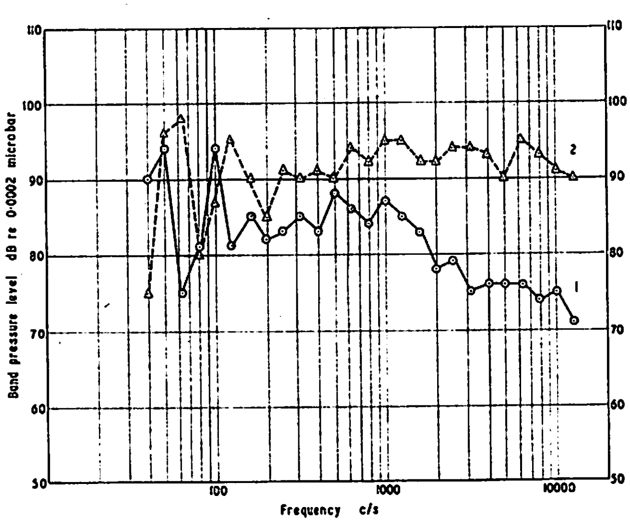
3.1. Presentation of Test Results

In view of the projected legislation on noise from road vehicles, including tractors, Sound Level A measurements to B.S. 3425[17] have been included in measurements of tractor performance at N.I.A.E. for the past two years. Also, during the past year noise levels as they affect the operator, rather than the public, have been brought within the scope of a number of tests. The latter development made it necessary to choose a standard form of measurement and presentation for these test reports. Although Sound Level A is widely preferred where limits on noise are proposed—because at present it provides the best available simple test—it is by no means fully satisfactory for this purpose, and it has the disadvantage that the dB scale is not very convenient for general comparison of noise levels.[1] Furthermore, the single Sound Level measurement provides no information on the spectral composition of the noise. In consequence, it was decided to quote results in the sone scale of loudness, so facilitating comparisons and general appreciation of the noise levels produced by agricultural machinery. The Stevens Mark VI method of loudness computation was chosen in preference to the more complicated Zwicker method, despite its relatively limited sphere of application, since there was existing experimental evidence of its adequacy for this type of noise. To take account of features in the noise spectrum which have high annoyance value, but contribute little to the total loudness, the test reports will draw attention to these in purely qualitative terms.

3.2. Analysis of Some Typical Results

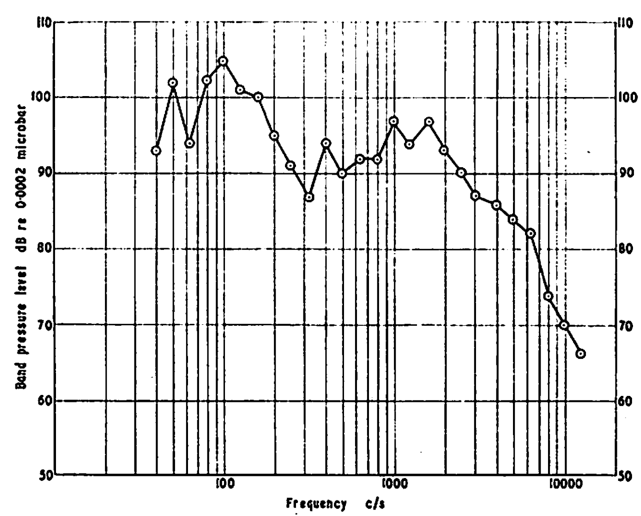
One of the recently developed sound level meters with provision for octave-band measurements is adequate for the Stevens method, in conjunction with the loudness index chart (Fig. 3), but the author prefers to take a $\frac{1}{3}$-octave analysis, since this gives a reasonably detailed picture of the noise spectrum and also permits comparison with the Zwicker loudness calculation, if required. The difference between sone values calculated from octave and $\frac{1}{3}$-octave analysis is slight.

Examples of $\frac{1}{3}$-octave spectra from test and other measurements are shown in Fig. 6 (*a*) to (*h*). Calculated sone values have been obtained from these figures, using the Stevens method and the Zwicker method for both free and diffuse fields. The results are given in Table III, together with the corresponding linear (overall) sound pressure level and Sound Level measurements with the A and B weightings. They have been ordered in their loudness ranking according to the Zwicker calculations, taking whichever figure is more appropriate in cases where the GD and GF values differ (*e.g.*, D for the grain drier installation ; F for the operator's head position on tractor (*a*) and with the chain saw).



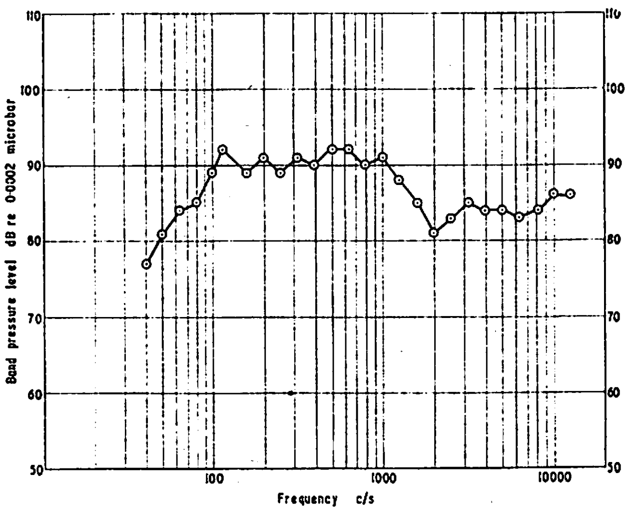
$\frac{1}{3}$ Octave analysis. Subject : 4-cyl. Diesel tractor. Maximum power : 1—Normal running, 2—exhaust silencer removed. Microphone position : Driver's ear. Overall S.P.L. (dB). 1—99, 2—107. dBA : 1—93, 2—103. Calculated loudness (sones) : (*a*) Stevens, Mk. VI : 1—90, 2—230. (*b*) Zwicker, GD : 1—130, 2—250. (c) Zwicker, GF : 1—120, 2—230.

FIG. 6a.



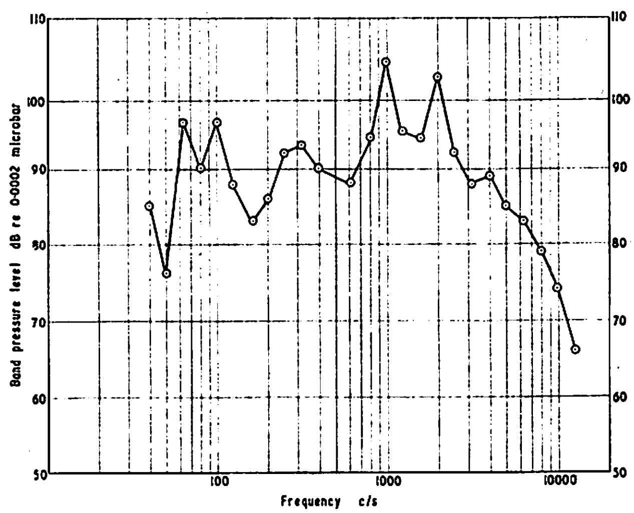
$\frac{1}{3}$ Octave analysis. Subject : Tractor with cab, rotavating at maximum revs. Microphone position : Driver's ear. Overall S.P.L. (dB)—111. dBA—103. Calculated loudness (sones) : (*a*) Stevens, Mk. VI—190. (*b*) Zwicker, GD—225. (*c*) Zwicker, GF—225.

FIG. 6b.



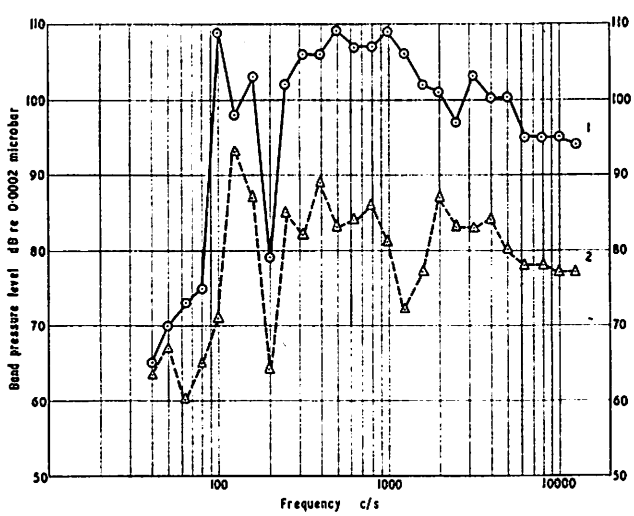
⅓ Octave analysis. Subject: 4-cyl. Diesel combine harvester. Microphone position: Driver's ear. Overall S.P.L. (dB)—102. dBA—97. Calculated loudness (sones): (a) Stevens, Mk. VI—135. (b) Zwicker, GD—170. (c) Zwicker, GF—170.

FIG. 6c.



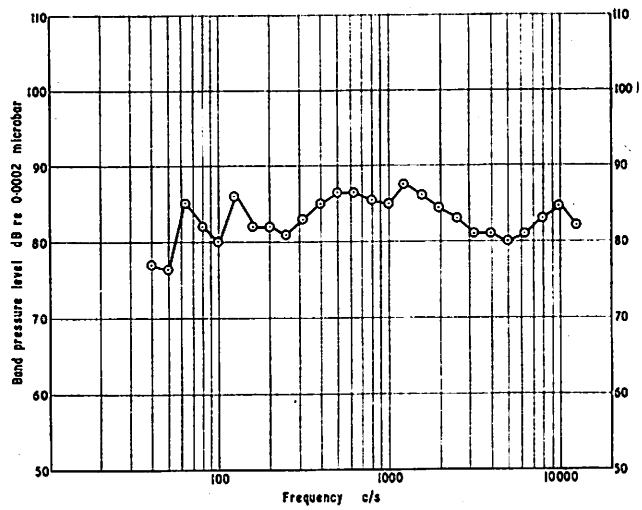
⅓ Octave analysis. Subject: Orchard sprayer, p.t.-o. driven. Microphone position: Driver's ear. Overall S.P.L. (dB)—107. dBA—105. Calculated loudness (sones): (a) Stevens, Mk. VI—220. (b) Zwicker, GD—240. (c) Zwicker, GF—240.

FIG. 6d.



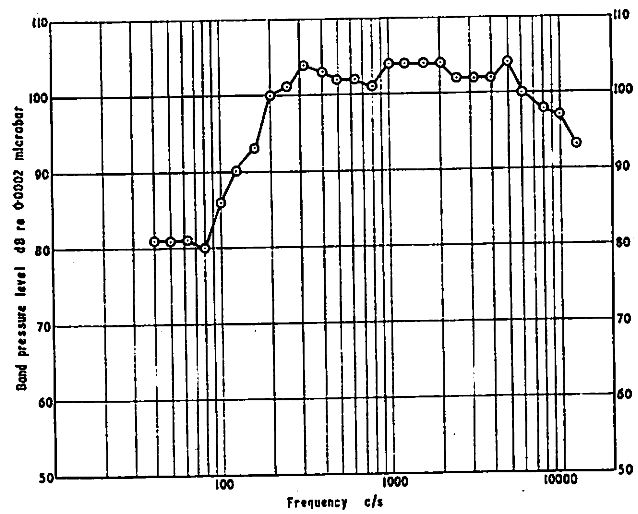
⅓ Octave analysis. Subject: Chain saw in work. Microphone position: 1—Operator's ear, 2—at 7,5 metres. Overall S.P.L. (dB): 1—118, 2—102. dBA: 1—115, 2—95. Calculated loudness (sones): (a) Stevens, Mk. VI: 1—395, 2—95. (b) Zwicker, GD: 1—430, 2—140. (c) Zwicker, GF: 1—400, 2—130.

FIG. 6e.



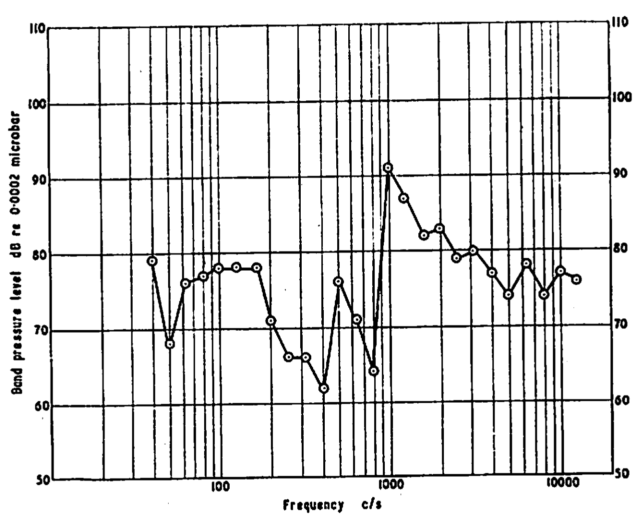
⅓ Octave analysis. Subject: Grain drier installation. Microphone position: Bagging-off point, operator's head level. Overall S.P.L. (dB)—97. dBA—95. Calculated loudness (sones): (a) Stevens, Mk. VI—115. (b) Zwicker, GD—150. (c) Zwicker, GF—130.

FIG. 6f.



⅓ Octave analysis. Subject: Small cattle feed; rolling mill in barn (rolling dry wheat). Microphone position: Bagging-off point, head level. Overall S.P.L. (dB)—114. dBA—112. Calculated loudness (sones): (a) Stevens, Mk. VI—420. (b) Zwicker, GD—380. (c) Zwicker, GF—380.

FIG. 6g.



⅓ Octave analysis. Subject: Lawn grass edge trimmer, electrically driven. Microphone position: Operator's head level. Overall S.P.L. (dB)—94. dBA—92. Calculated loudness (sones): (a) Stevens, Mk. VI—85. (b) Zwicker, GD—105. (c) Zwicker, GF—90.

FIG. 6h.

It will be seen that the dPA ranking accords with this ordering of results, but that the Stevens sone values are not in entire agreement. However, the accuracy of the loudness computation is not always better than 5 per cent., whether the Stevens or Zwicker method is used, and on this basis the only significant deviation on the Stevens scale is the relatively high value for the roller mill.

The overall S.P.L. and Sound Level B figures exhibit more prominent (and typical) departures from the Zwicker ranking, giving some indication of their poorer correlation with subjective response to noise of this kind.

Comparison of the figures in Tables I and II with those of Table III and the graphs in Fig. 6 shows that the operators of the machines and installations cited are subjected to noise of high and, in some cases, possibly injurious loudness. Temporary hearing loss results from quite short exposure to several of these sounds—a fact confirmed during the measurements, although not put on a quantative basis in the manner of Weston.[5] In the present context it is sufficient to note that temporary deafness persisted for hours in some instances, the worst offenders being the grain drier installation and the tractor cab environment during rotary cultivation. The chain saw and roller mill were only in operation for a few minutes during the noise measurement runs, otherwise they undoubtedly would have been more prominent in this respect.

The lawn edge trimmer is included because, although comparatively quiet, it is capable of considerable annoyance effect over a wide area. The fluctuating, high-pitched whine responsible for this effect is inadequately emphasised by any of the figures given in Table III, and this is clearly a case for some form of supplementary weighting or comment.

4. CONCLUSION

Attention has been drawn to the high level of noise obtaining in some agricultural environments. When this is related to growing public concern over industrial and residential noise levels, and the Government's decision to initiate a thorough investigation of the effects of industrial noise on hearing, it is clearly time to give the fullest consideration to protection of the farm worker against possible health hazard and, more generally, to practical means of achieving noise reduction in farm machines and installations. This introduces the need for agreed methods of measurement and appropriate scales for noise. The subject is still open to development, but the point has been reached at which quantitative noise limits appear in legislation and standardissed methods of loudness calculation are in preparation—accenting scales of Sound Level A and Loudness (in sones) respectively. The former scale is acceptable when a simple measurement is required, particularly in relation to set limits, while the latter presents results in a convenient form for comparative assessment. Using the Stevens method, sone values are obtained with minimum complexity in the measurement and computation.

TABLE III

Corresponding Values of Sound Pressure Level, Sound Level and Calculated Loudness

Machine	*Graph No.*	*Overall S.P.L. (dB)*	*Sound Levels (dB)*		*Calculated Loudness (Sones)*		
			A	*B*	*Stevens Mk. VI*	*Zwicker GD*	*Zwicker GF*
Chain Saw (Operator's Head)	(e)	118	115	117	400	430	400
Small Roller Mill	(g)	114	112·5	113·5	420	380	380
Orchard Sprayer	(d)	107	105·5	106·5	220	240	240
Tractor without exhaust ..	(a)	107	103	105	230	250	230
Tractor with cab, rotavating	(b)	111	103	107	190	220	220
Combine Harvester	(c)	102	97	101	140	170	170
Grain Drier Installation ..	(f)	97	94·5	95·5	115	150	130
Chain saw at 7½ metres (25 ft.)	(e)	102	95	99	95	130	140
Tractor, with normal exhaust	(a)	99	93	95·5	90	130	120
Lawn Edge Trimmer ..	(h)	94	92	94	85	105	95

REFERENCES

1. Committee on the Problem of Noise. Final Report, H.M.S.O., 1963.
2. "The Control of Noise." National Physical Laboratory Symposium, No. 12, H.M.S.O., 1962.
3. The Motor Vehicles (Construction and Use) (Amendment) Regulations, 196 .
4. "Noise, Vibration and Escape of Exhaust Gases in Power Saws." FAO/ECE/LOG/105, Geneva, 1962.
5. "A Survey of Tractor Noise and the Effects on Hearing." H. R. Weston, *J.Aust.Inst.Ag.Sci.*, March, 1963.
6. "The Use of Hydraulics in Agriculture." T. C. D. Manby, Proc. 12th Power Farming Conf., 1963.
7. Handbook of Noise Control. Ed. Harris, McGraw-Hill, 1957.
8. "Noise Measurement Techniques." N.P.L. Notes on Applied Science, No. 10, H.M.S.O., 1958.
9. "Acoustic Measurements." Beranek, Wiley, 1949.
10. B.S. 3383 : 1961. Normal Equal Loudness Contours for Pure Tones and Normal Threshold of Hearing under Free-field Listening Conditions.
11. B.S. 3045 : 1958. The Relation between the Sone Scale of Loudness and the Phon Scale of Loudness Level.
12. B.S. 3489 : 1962. Specification for Sound Level Meters (Industrial Grade).
13. B.S. 3539 : 1962. Sound Level Meters for the Measurement of Noise Emitted by Motor Vehicles.
14. "Procedure for Calculating Loudness," Mark VI. S. S. Stevens, *J.Acoustical Soc.Am.*, Vol. 33, No. 11, 1961.
15. "Ein Verfahren zur Berechnung der Lautstarke." E. Zwicker, *Acoustica*, 10, 304, 1960.
16. B.S. 3638 : 1963. Measurement of Sound Absorption Coefficients (I.S.O.) in a Reverberation Room.
17. B.S. 3425 : 1961. Method for the Measurement of Noise Emitted by Vehicles.

Thanks are due to the Director of the National Institute of Agricultural Engineering for permission to publish this Paper. The author also wishes to acknowledge assistance and support from T. C. D. Manby and other colleagues in the testing departments at the N.I.A.E. and from M. L. Day, who undertook most of the measurements.

(II) Better Tractor Ride Improves Driver Safety, Health and Productivity

by A. K. SIMONS *

Summary

MEDICAL reporting and physiological and psychological research all have shown that low-frequency vibration adversely influences tractor drivers' safety, health and productivity. Representative research is described in Britain, Germany and the U.S.A.

Typical data on the vibration behaviour of farm tractors and the human body is given and the general theory for vibration isolation is reviewed.

The influence of the tractor seat on tractor ride is shown and the requirements for protection from vibration in improved seat designs are discussed. Laboratory and field test results and user acceptance attest to the improvement in tractor ride provided by efficient suspension seating.

In recent years, millions of farm tractors manufactured in the Western World have met user demand for improved ride and greater driver safety, health and productivity by installing suspension seating at the factory.

Introduction

On farm tractors, man is subjected to vibration and jolt. These have many sources ; some result from the interaction between the ground and the rubber-tyred tractor, others from the engine and implements. These vibrations can be and have been measured on both the farm tractor and the driver under various working conditions. Whether and how they affect man and how important is their effect on man are the significant questions.

These questions have been a subject of research and enquiry on both sides of the Atlantic for a number of years. To date, the answers we have are incomplete ; however, we are increasingly confident that vibration and jolt do adversely affect man.

The Influence of Vibration and Jolt on Man

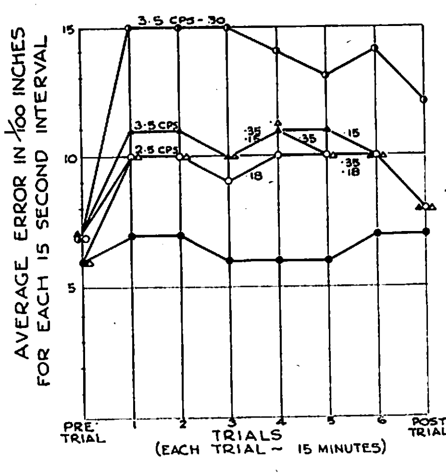
To review in detail all of the research that brings us to this conclusion would be a separate and elaborate task. However, it may be of interest to know something of the sources of information and the areas of research that are contributing to our knowledge.

The first, and perhaps still most important, source is man himself. Expressions by men exposed to vibration would range from bitter complaint of the discomfort they experience to awareness but acceptance of the condition as a part of their work. For the investigator, man is a difficult subject because of his adaptability and motivation. Because of these qualities, he endures things that are shown to be detrimental when it is too late—after physical damage, impaired performance or accidents due to fatigue have occurred.

Our second source of information are the opinion surveys and studies of the health and physical condition of men engaged in the work of driving vehicles. Fishbein and Salter(4), Clayburg(6), Rosegger(10), to name but a few, have shown that physical damage and impairment can be a result of the occupational exposure to severe vibration and jolt.

A third source is the increasingly important work done in the laboratories on the effect of vibration and shock on man's ability to perform tasks which are related to his occupation of driving and operating vehicles. Investigations in such studies have included compensatory tracking ability, simple and choice reaction time, vision, psychomotive co-ordination, hand and finger tremor, body equilibrium, and intellectual processes. For representative studies, see Dennis and Elwood, 1958(8) ; Drazen(12) ; Fraser, Hoover and Ash, 1961(14) ; Hornick, 1962(18) ; Mozell and White, 1958(9) ; Parks and Snyder, 1961(17) ; Schmitz, Simons and Boettcher, 1960(11), (13), (19), (20).

While there are discrepancies, there is general agreement that compensatory tracking ability shows a decrement which is related to amplitude of acceleration increases and vibration duration in the range of 1 to 30 cycles per second (Fraser *et al.*, 1961 ; Hornick, 1962 ; Parks and Snyder, 1961). Visual accuity suffers in the range of 5 to 90 cycles per second, and shows decrements related to specific frequencies at 15, 30 and 40–70 cycles per second (Dennis and Elwood, 1958 ; Drazin, 1960 ; Guignard, 1960). Reaction time seems not to be affected during low-frequency vibration, but there apparently is an increase in the reaction time following exposure to vibration below 20 cycles per second (Hornick, 1962 ; Schmitz *et al.*, 1960). Psychomotive co-ordination is impaired at specific frequencies, and body equilibrium may be affected after experiencing vibration (Guignard, 1960 ; Hornick, 1962). Figs. 1 and 2 are examples of some of the recent research on certain of man's performance abilities. Fig. 3 shows a subject on a multi-directional vibration table being



LEGEND		
f	g	·
0	0	●
3·5	·15	▲
2·5	·18	○
3·5	·30	◑
2·5	·35	△

FIG. 1 Showing the average total error for each fifteen second period for each block of fifteen minutes — compensatory tracking task.

* Managing Director, Bostrom Mfg. Co. Ltd.

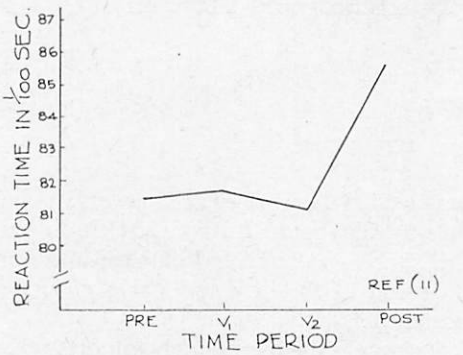


FIG. 2. Choice reaction time in each of the time periods for transverse vibration. (TIME PERIOD 15 MINUTES)

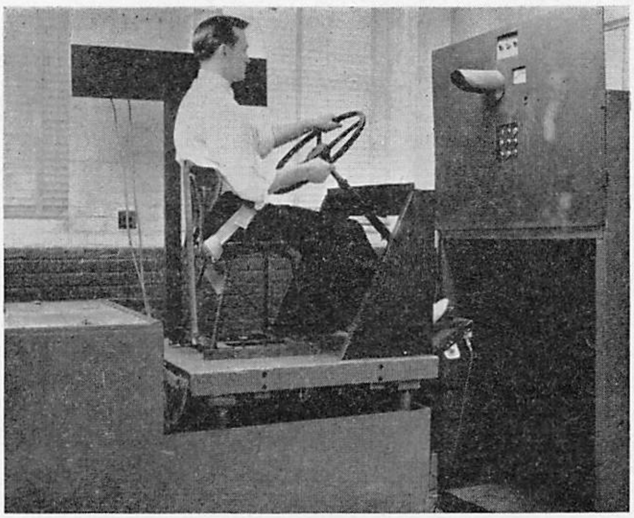


FIG. 3. Subject on multi-direction vibration table. Psychological testing.

tested. From these facts, we are increasingly more certain that vibration and jolt adversely affect man in his physical well-being, his safety and his ability to do his job efficiently.

How can Tractor Ride be Improved ?

All of these factors demonstrate that a serious problem exists and that a solution is necessary. How can we resolve this to the benefit of man ? There would appear to be three choices :

1. Remove the source of vibration and jolt.
2. Protect man from vibration source by improvements in seat design.
3. Select young men to drive tractors and limit their years of exposure.

A reduction of tractor chassis vibration and jolt can be achieved by reducing tractor speed, but this is not always desired. Neither is it desirable to limit tractor driving to men in prime condition for short periods.

From the standpoint of cost and practibility, the protection of man from the vibrating source by improvements in seat design has been shown to be an excellent solution.

A device capable of protecting a man on a farm tractor from hazardous vibration is called the *Suspension Seat.* The development of such a device involves a high order of engineering skill, knowledge of vehicle vibration, man's tolerance to vibration, vibration isolation, and considerable ingenuity to fit a suspension element in the very limited space found on most farm tractors.

As a start, we can represent the man, tractor and seat in the simplified model drawing shown in Fig. 4. We

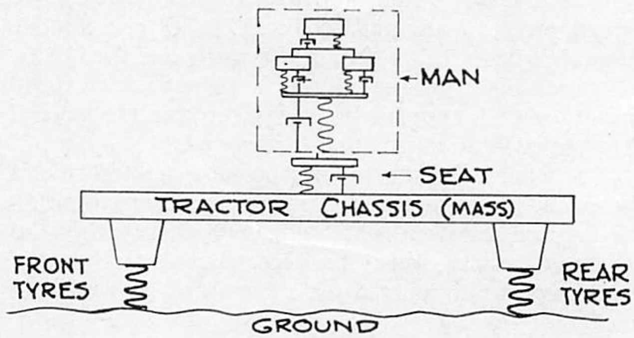


FIG. 4. Simplified model of tractor-seat man system.

then so design the element called the seat so that for any excitation of the tractor by its movement over the ground the response of the element called man will be below a prescribed level. To undertake the solution of the problem in its present form would be tedious, and we retreat to some simplifications.

It would be helpful before proceeding to review some of the laws of vibration isolation. The simple model would be a man (mass) supported on a spring with a damper or shock absorber in parallel with the spring. This simple system is shown in Fig. 5. If we excite the support in a periodic and uniform manner, the mass will respond in a way which can be described mathematically, as shown in Fig. 6. The terms are : T, transmissibility —ratio of the movement of the mass to the movement of the support ; N, support frequency ; N_o: Natural frequency of the mass on the spring—i.e.$N_o = 3{\cdot}135\sqrt{k/w}$; W, Wt. of mass ; K, spring rate ; g, acceleration of gravity ; c/cr, damping ratio.

Now that we have our very simple model, we can use it to explore some things about man, the suspension seat and farm tractors.

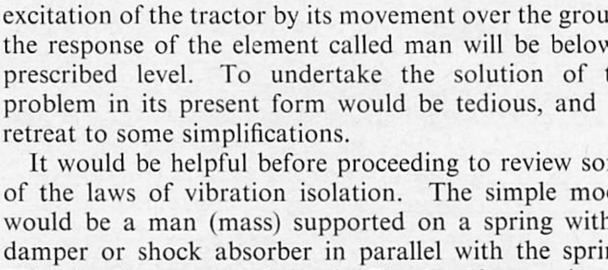


FIG. 5. Simplified model of vibration system

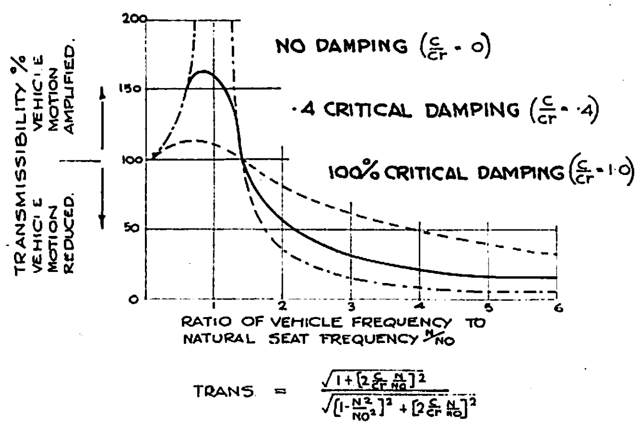


FIG. 6. Vibration Transmissibility Chart.

Does man fit our model ? Yes, not completely enough to satisfy the specialist in bio-mechanics, but enough to be helpful in our understanding both of man and his influence on the suspension seat design.

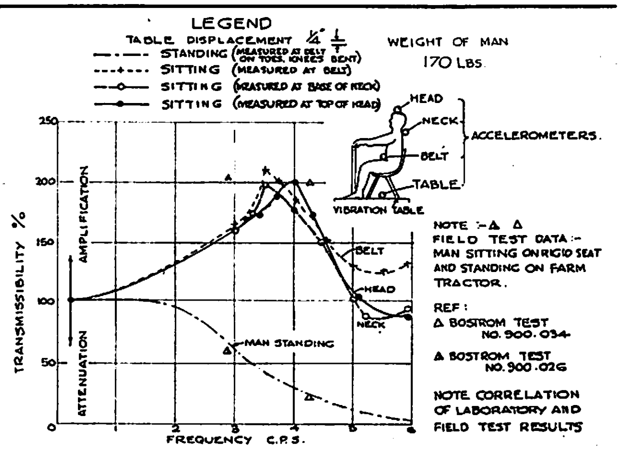


FIG. 7. Mechanical response of man to vertical vibration.

Human Tolerance Limits to Vibration

Fig. 7 shows how man responds to vibration, both in the standing and seated position on a rigid chair. If we change the frequency scale to the ratio frequencies, taking N_O as 4, we see the similarity to Fig. 5. It is of interest to see the better isolation man can achieve standing than over sitting. There are some relationships between man's " mechanical " response to vibration and his subjective tolerance of vibration. A number of investigators have arrived at subjective tolerance levels by exposing subjects to various vibration frequencies and amplitudes and having them describe each experience as " perceptible," " intolerable," " uncomfortable," etc. A list of contributors in this effort is growing and includes Jacklin(2), Reiher and Meister(1), Von Bekesy(3), Goldman(5), among others. On the basis of these, a number of proposals and recommendations for comfort tolerance, safe limits, etc., have been made.

Fig. 8 is typical of these scales of tolerance comfort. Dupuis(15) has shown a recommended limit for farm

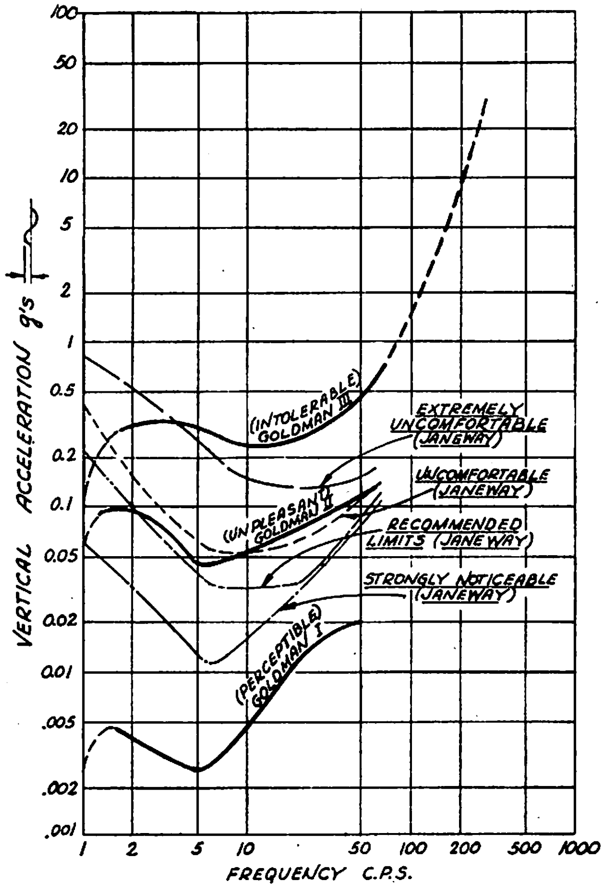


FIG. 8. Human reaction to vertical vibration mean thresholds by Goldman & Janeway.

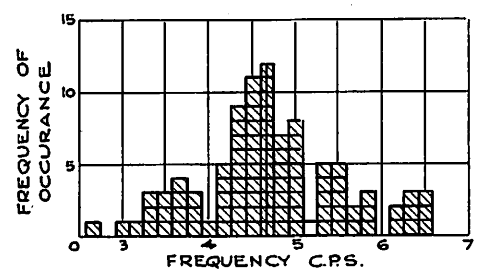


FIG. 9. Frequency of occurence of subjects reporting disturbing vibration (amp. 0.050 in) V^s frequency - Jacklin & Liddel.

tractors of ·40 Gs. It is noted that Fig. 9, as well as Fig. 8, indicates greater vibration sensitivity in the four to six cycle range, and this corresponds roughly to the maximum mechanical response of man to vibration (Fig. 7).

Average Vibration Levels for Farm Tractor Operation

In turn, we now examine the source of vibration and shock imposed on the driver. While the dynamical behaviour of the farm or industrial tractor might be predictable mathematically or computer models might be used, the measurement of vibration and shock in the actual vehicle under operating conditions is relatively simple and has been our principal tool for determining the vibration and shock characteristics of tractors. We are, of course, helped in this regard by the fact that tractors designed to perform certain operations or functions tend to have similar characteristics. Fig. 10 shows the frequency range and acceleration amplitudes for a number of types of vehicles, including farm tractors(7). Fig. 11 shows typical traces of acceleration *v.* time over a random terrain.

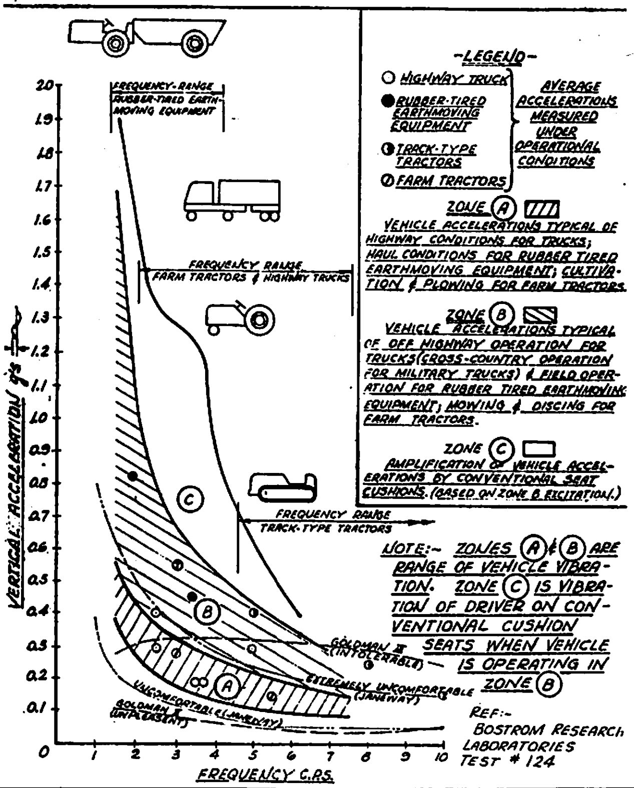
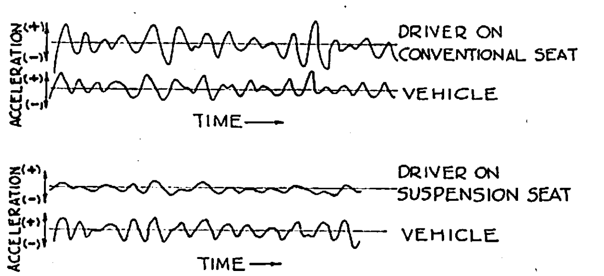


FIG. 10. Vibration environment on commercial & military vehicles.



Ref: Bostom Research Laboratories. Test 9900·042.
Note the correspondence of the drivers acceleration and the lack of isolation on the conventional seat compared to the isolation on the suspension seat.

FIG. 11. Acceleration — time response of driver to vehicle — test over random rough couse.

While these acceleration traces were initiated by random excitation, there is surprisingly a good uniformity or regularity. To a great extent, the tyres act as filters, amplifying the effects of frequencies nearer the natural frequency of the tyre and chassis, and reducing the effect of others.

With some knowledge of the requirements of man and the input of the tractor vibration to the man, we can now consider the functional requirements of the suspension seat. In this regard, it would be appropriate to review the adequacy of the conventional seat cushion.

As a protective device to isolate the driver from jolt and vibration, the seat cushion has this principal limitation—the requirement of the cushion is first to provide static comfort ; consequently, the deflection of the man into the cushion must be restricted.

The problem of " static " or sitting comfort is a significant one in itself, and only some general observations will be made here. Static comfort is related to the proper distribution of the man's seated weight over the area of his buttocks. It has been shown that the areas associated with the Ischial Tuberosities are alone capable of enduring considerable pressure ; the surrounding areas, including the under-thighs, have relatively small pressure capacity. A too deep deflection into the cushion would then place a disproportionate pressure on these areas and result in severe discomfort and perhaps damage. For this reason, either by design or experience, the deflection of the man into the cushion has been limited to something less than 3 in. Fig. 12 shows a load

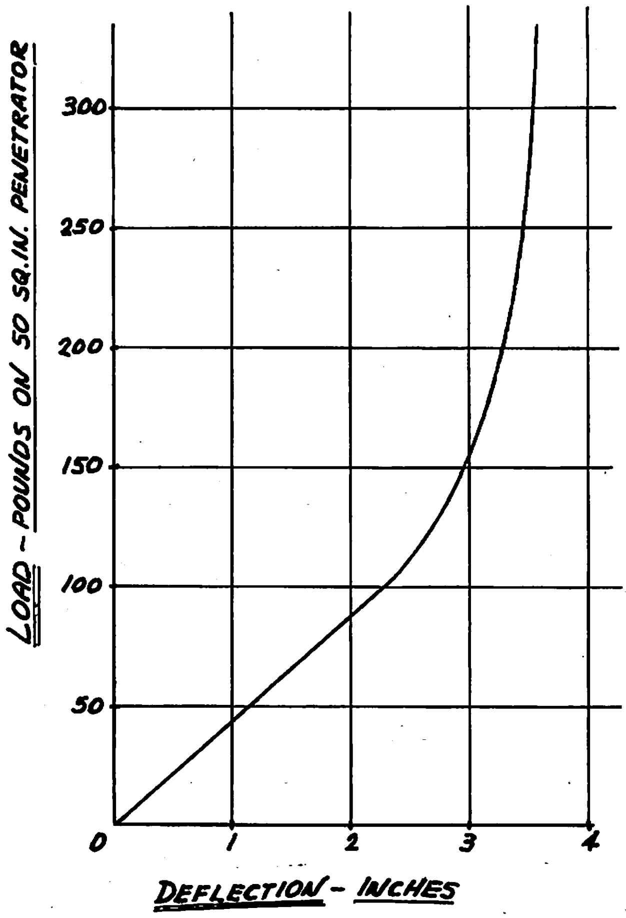


FIG. 12. Load-deflection for typical cushion (cushion 4″ thick)

deflection curve of a fairly typical cushion. If the deflection rate of the cushion were linear, the natural frequency of the man on the cushion could be determined

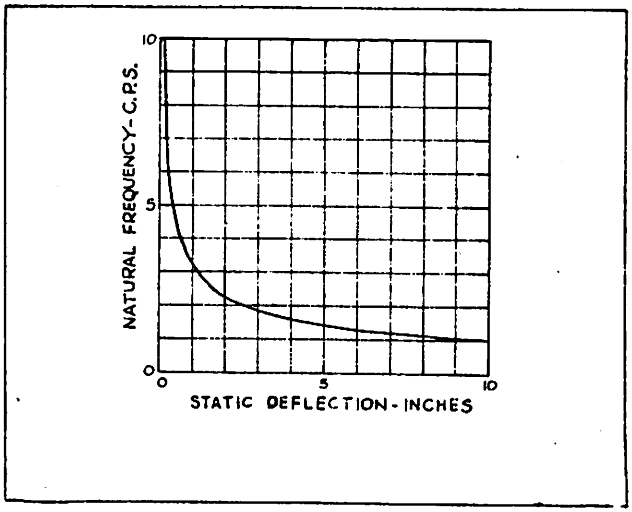


FIG. 13. Natural frequency V^s static deflection.

with reasonable accuracy by Fig. 13. From this relationship, the frequency No for the 3 in. deflection is determined to be approximately $1\frac{3}{4}$ cycles per second. Most cushions, as illustrated in the figure, show an increasing spring rate, so that we would expect the natural frequency of the man on the cushion to be somewhat

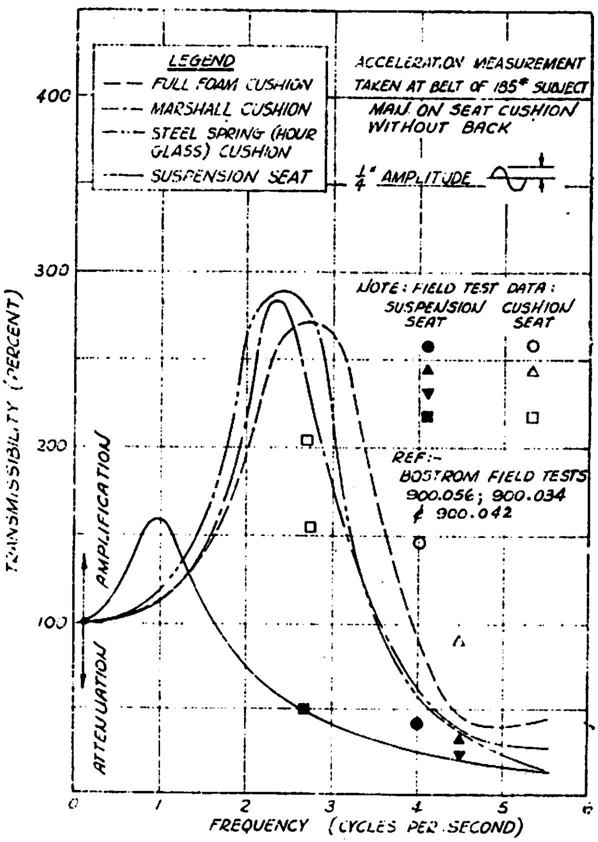


FIG. 14. Effect of seat construction on transmissibility.

higher. Fig. 14 shows the response of a man on three fairly typical cushions. Note that the characteristics are essentially the same, regardless of the cushion construction. As the firmness of the cushion increases, the natural frequency increases and the transmissibility curve approaches that of the man on a rigid seat.

From the data it is evident that the two–four cycle per second range is commonly found on farm and industrial tractors. We can appreciate immediately that a conventional cushion will amplify this vibration. That this is true is easily confirmed by referring to the ride records which show that the man is enduring a considerably higher acceleration than the tractor is exhibiting.

We have seen that the difficulty with the conventional cushion is that its natural frequency falls in the range of important tractor frequencies. On referring to our simple model and Fig. 6, the ratio of vehicle frequency to man's seat natural frequency is at or near 1. If we are to avoid this problem and to provide significant isolation, we see that we must increase the frequency ratio. Since we have no opportunity to change the tractor frequency, we are obliged in some way to reduce the seat-man natural frequency. This is done by reducing the value of the spring rate. Here we introduce a problem of the cushion with its high rate of stiffness avoided—that of providing a means of adjusting the spring to compensate for the differing drivers' weights in order to provide a reasonable seat control relationship, and to bring the system into static equilibrium for each driver.

So far, we have not considered the role of the damping in the suspension, whether obtained by rubber hysteresis or hydraulic control. Fig. 6 would indicate that if we have a sufficiently high-frequency ratio a damping effect would only reduce the degree of isolation. While this is true, unfortunately we cannot take full advantage of it. First we must recognise that it is possible for the tractor frequencies, if only rarely, to approach the seat-man natural frequency. Second, because of space limitation and driver-control relationships, we must limit the relative motion between the seat and the tractor and consequently limit the ability of the suspension to accommodate all tractor amplitudes. This, of course, is not a problem exclusive to seat suspensions. The bottoming of automotive or tractor suspensions, while not frequent, is not unknown. The amount of damping is a matter of judgment based on the best knowledge of the vehicle characteristics, terrain and vehicle task or function.

Requirements of a Suspension Seat

At this point, the ingenuity of the designer is tested. The low spring rate indicated will require a large spring, and yet space is limited. The suspension linkage must provide the proper control and stability and yet must be small enough and so located as to permit the best functional use of the space available. The adjustments (pre-load, back, fore and aft, etc.) must be easily operated and conveniently located. The shape of the seat and back, their proportions relative to the driver and his driving task are as important as the suspension for the overall well-being and performance of the driver. The seat shown in Fig. 15 is representative of this approach. The control arms, which also activate the rubber torsion springs, are located at the sides of the contoured seat, the torsion spring and housing is nested to the rear of

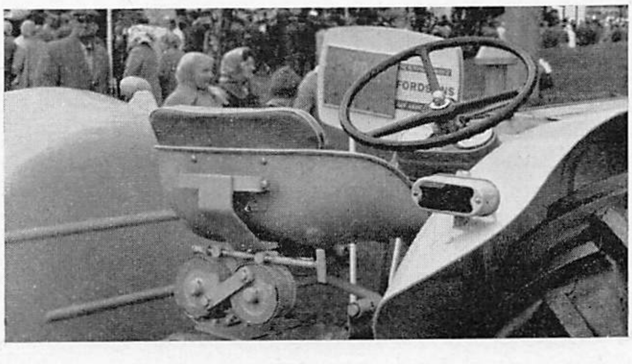


FIG. 15.
FIG. 15. Tractor fiitted with Rubber Torsion Spring Seat Suspension. (*Courtesy Ford Motor Co., Dagenham.*)

the seat, all to reduce the total height of the seat. Additional hydraulic damping to augment the hysteresis in the rubber springs is available where operating conditions require it.

At this point, recalling some of the rather broad assumptions that were made in order to simplify the problem, we are curious to know if we have indeed succeeded in reducing the intensity of the vibration to which the driver is exposed. Fig. 14 shows a comparison of laboratory vibration transmissibility test of a suspension seat similar to Fig. 15 to conventional seat cushions. The points plotted are results from field ride tests and indicate that the assumptions did not invalidate the approach. The field tests on prototype suspensions and standard cushion seats again indicate that the design based even on our simple model is valid.

Conclusion

The ultimate evaluation of the design is, of course, in the hands of the user. Here its value is attested to by the fact that in the last ten years suspension seating has become standard or optionally available on many farm and industrial tractors manufactured in the Western World. Suspension seating has contributed a worthwhile improvement to tractor ride and has resulted in greater driver safety, improved health and increased productivity of the man and machine combination of driver and tractor.

REFERENCES

(1) REIHER, H., AND MEISTER, F. J. " Empfindlichkeit des Menschen gegen Erschütterung." *Forschung (VDI-Berlin)*, vol. 2, 22, 1931, pp. 381–386.

(2) JACKLIN, H. M. " Human Reactions to Vibration." *Journal of the Society of Automotive Engineers*, vol. 39, 1936, pp. 401–407.

(3) VON BEKESY, G. " The Sensitivity of Standing and Sitting Human Beings to Sinusoidal Shaking." *Akustische Zeitschrift*, vol. 4, 1939, p. 360.

(4) FISHBEIN, W. I., AND SALTER, L. C. " The Relationship Between Truck and Tractor Driving and Disorders of the Spine and Support Structures." *Industrial Medicine and Surgery*, 1940, 19, 9, 444–445.

(5) GOLDMAN, D. E. " A Review of Subjective Responses to Vibratory Motion of the Human Body (1–70) cps." Project NM 004001, Naval Medical Research Institute, March 16th, 1948.

(6) CLAYBERG, H. D. " Pathological Physiology of Truck and Cab Driving." *Military Surgeon*, 1949, 299–311.

(7) RADKE, A. O. " Vehicle Vibration—Man's New Environment." ASME Paper, 57-A-54. December, 1957.

(8) DENNIS, J. P., AND ELWOOD, M. A. " The Effects of Vibration Experienced in Different Seating Positions" Ministry of Supply, Directorate of Pysiological and Biological Research, Clothing and Stores. Experimental Establishment, 1958, 78.

(9) MOZELL,. M. M., AND WHITE, D. C. " Behavioural Effects of Whole Body Vibraton." *Aviation Med.*, 1958, 29, 716–724

(10) ROSEGGER, R. "Das harmonische Zusammenwirken von Fahrer und Schlepper." (Tagungsberichte der Deutschen Akademie der Landwirtschaftswissenschaften, 19), Berlin, 1959.

(11) SCHMITZ, M. A. SIMONS, A. K., AND BOETTCHER, C. A. " The Effect of Low Frequency, High Amplitude Whole Body Vertical Vibration on Human Performance." Final Report, Contract DA-49-007-MD-797, Bostrom Research Laboratories Report, 130, January, 1960.

(12) DRAZIN, D. H. " The Effects of Vibration on Vision." Paper read at Annual Conference of the Ergonomics Research Society, March, 1960.

(13) GUIGNARD, J. C., AND IRVING, A. " Effects of Low-Frequency Vibration on Man." British Association at Cardiff, September, 1960.

(14) FRASER, T. M., HOOVER, G. N., AND ASHE, W. F. " Tracking Performance During Low-Frequency Vibration." *Aerospace Med.*, 1961, 32, 829–835.

(15) DUPUIS, H. " The Investigation of Vibrations in Tractors on Test Stands." Max-Planck Institut für Landarbeit und Landtechnik (Paper presented at A.S.A.E., June, 1961).

(16) HORNICK, R. J., BOETTCHER, C. A., AND SIMONS, A. K. " The Effect of Low-Frequency High-Amplitude Whole-Body Longitudinal and Transverse Vibrator upon Human Performance." Contract DA - 11 - 022 - 509 - ORD - 3300. Bostrom Research Laboratories. Report 135, July, 1961.

(17) PARKS, D. L., AND SNYDER, F. W. " Human Reaction to Low-Frequency Vibration." Boeing document D3-3512-1, The Boeing Company, Wichita, Kansas, July 24th, 1961, AD261330.

(18) HORNICK, R. J. " Effects of Whole-Body Vibration in Three Directions upon Human Performance." *J.Engng.Psychol.*, 1962, 1, 3, 93–101.

(19) SIMONS, A. K., AND HORNICK, R. J. " Effects of the Vibration Environment in Mobile Systems on Human Performance." *Ergonomics*, vol. 5, 1, p. 321, January, 1962.

(20) MATHEWS, J. " Ride Comfort for Tractor Operators: Part 1—' A Review of Existing Information '." *J.Agric. Eng.Res.*, 1964, 9 (1), p. 3.

III Safety Aspects of Tractor Cabs and their Testing

by T. C. D. MANBY,* M.Sc.(Eng.), B.Sc., A.M.I.Mech.E., M.I.Agr.E.

Introduction

FOR a number of years an intense publicity campaign has been aimed at road users to create and increase awareness of inherent dangers when using motor vehicles. These arise mainly from two sources—a road vehicle driver may be killed as a consequence of his or her own mistakes, or because of the actions of other road users. For every 8,000/8,500 cars registered, one car driver is killed each year. The ratio for goods vehicles is only slightly better at about 1 in 9,000 (for drivers of motor cycles, mopeds, scooters, etc., the overall figure is about 1 in 1,500).

Only in very recent years has any effort been directed to improve farm safety and, as yet, there is no realistic requirement of proof of proficiency imposed on a would-be tractor driver. As a result of tractor overturning accidents alone the ratio is about the same as with cars or goods vehicles—approximately one fatality per 9,000/10,000 per year. Danger as a consequence of other drivers' activities does not exist, but this factor is offset by the more severe environmental conditions of agricultural work and the general awkwardness of many types of loads to be handled.

The total number of deaths of farm tractor drivers killed in overturning accidents during the five-year period 1958–1962 is 192, an average of 38 per year. Details and a breakdown of the types of accidents in which these deaths occurred have been prepared in Table I ; the number of deaths due to operators being run over are included separately. When examined on a monthly basis, the pattern of occurrence of overturning accidents shows no unusual characteristics ; accidents occur fairly evenly spaced throughout the year, sometimes correlating very approximately with the peak periods of use. In some years there is a peak in the spring months of May or June, with a minimum number in December. The number of overturning accidents which do not cause death is not known, but a reasonable estimate would be between 150–200 each year.

The number of overturning fatalities in the various counties in which they occurred between 1958–1962 is given in Table II. These are interesting, in that they show how widespread fatal accidents are distributed around England and Wales, and that they are not confined to the very hilly areas where they could be most expected to occur. In fact, some very hilly districts have been almost free from accidents. The results of this type of analysis, together with a more detailed study of the accident reports, provide the best guide to the drawing up of a test code and indeed a specification for safety devices on tractors.

First it must be pointed out that the majority of occurrences (85%) in which a driver is crushed involve a tractor overturning sideways. Sideways overturning may occur when a tractor is driven too near a ditch, or when turning on a slope, or at the headland or ditch at the foot of a slope, or when temporarily out of control and the tractor is pushed by the load. Most reports of the accidents give little detail—often too little—concerning the actual sequence of events or the results of a careful examination of the tractor, but it seems probable that unbalanced brakes, causing an unexpecteds werve,

TABLE I

Number of tractor driver fatalities caused by various types of overturning accident
Number of drivers killed when run over also included

	Overturning sideways					*Overturning rearward*					
Year	*Error on headland —e.g., into ditch or pond*	*Off road or track*	*Turning too fast on level*	*Steep slope or silage*	*Downhill out of control*	*Machine stuck or too heavy load*	*Into ditch*	*Hitch too high*	*Steep hill or bank*	*Total No. overturning fatalities*	*Run over*
1958	6	8	3	9	5	3	2	2	—	38	11
1959	9	2	3	5	11	1	—	2	—	33	12
1960	2	5	1	9	7	4	1	—	—	29	8
1961	10	8	1	10	14	1	1	6	2	53	11
1962	14	10	—	9	7	1	—	2	1	39	11
Av. No. per year	7·6	6·6	1·6	8·0	8·8	2	0·8	2·4	0·6	38·4	10·6
	Av. No. turning over sideways, 32·6					Av. No. turning over backwards, 5·8					

* Head of Tractor Performance Department, National Institute of Agricultural Engineering (N.I.A.E.).

TABLE II
Fatal accidents from tractors overturning—distribution by counties, 1958–1962

	1958	1959	1960	1961	1962	Total
Anglesey	–	–	–	1	–	1
Bedfordshire ..	–	3	–	1	1	5
Berkshire.. ..	–	1	–	2	–	3
Breconshire ..	1	–	–	1	2	4
Cardiganshire ..	–	1	2	4	–	7
Cambridgeshire ..	1	–	–	1	–	2
Carmarthenshire..	2	1	–	2	2	7
Cheshire	–	–	–	2	1	3
Cornwall.. ..	1	1	1	3	2	8
Cumberland ..	2	–	–	1	–	3
Denbighshire ..	1	–	–	1	–	2
Derbyshire ..	1	1	–	–	–	2
Devon	–	2	4	2	3	11
Durham	1	–	–	2	1	4
Essex	1	–	2	–	1	4
Flintshire.. ..	–	–	1	–	–	1
Glamorganshire..	–	–	1	1	1	3
Gloucestershire ..	–	1	2	–	1	4
Hampshire ..	–	2	–	–	–	2
Herefordshire ..	–	–	1	–	3	4
Hertfordshire ..	–	–	1	3	–	4
Huntingdonshire..	1	–	–	–	–	1
Kent	–	–	2	4	–	6
Lancashire ..	1	1	2	–	–	4
Leicestershire ..	–	–	–	1	–	1
Lincolnshire ..	2	–	1	2	1	6
Merionethshire ..	–	–	–	1	1	2
Monmouthshire..	–	1	1	2	–	4
Montgomeryshire	2	1	2	1	1	7
Norfolk	4	2	–	–	–	6
Northamptonshire	1	–	–	–	–	1
Nottinghamshire..	1	–	–	–	–	1
Oxfordshire ..	–	2	–	3	1	6
Pembrokeshire ..	1	–	–	–	–	1
Shropshire ..	1	4	1	1	1	8
Somerset.. ..	1	1	3	2	–	7
Staffordshire ..	1	–	–	1	4	6
Surrey	3	–	–	–	1	4
Sussex	1	1	–	1	3	6
Warwickshire ..	1	1	–	1	–	3
Westmorland ..	–	1	1	1	–	3
Wiltshire.. ..	1	1	–	–	3	5
Worcestershire ..	1	–	–	1	2	4
Yorkshire E.R.	1	1	–	–	1	3 } 16
Yorkshire W.R.	3	2	1	3	1	10 } 16
Yorkshire N.R.	–	1	–	1	1	3 } 16
	38	33	29	53	39	192

are not infrequently a contributory cause. Only about 15% of the accidents are rearward and thus belong in a category in which an engine stopping device might be expected to reduce fatalities (always assuming that perhaps after years of inactivity such a device works satisfactorily when required and with the necessary split-second timing). During sideways-roll accidents it is difficult to imagine conditions in which the accident would have been prevented by shutting the engine off at a pre-chosen angle of tilt. It is most probable that the general use of such devices for normal work could increase the likelihood of accidents occurring rather than decrease them. Many drivers, knowing that "a safety device to prevent a tractor overturning" was fitted, but not fully understanding the limitations to its effectiveness in preventing "rolls" in all circumstances, would be bolder, more careless and thus in increased danger.

The exception to this general castigation of engine shut-off devices as a safety feature is their use on tractors fitted with rear-mounted winches. In this case tractor rearing is often the factor limiting winch performance and overturning accidents can doubtless be prevented by a suitable, reliable device.

Developments in design to improve tractor functional abilities—particularly by improving driver convenience and comfort—may tend, by various means, to increase stability. Even allowing for this possible trend, together with an increase in the general educational level of drivers, it seems probable, however, that any beneficial effect may well be offset by the need to increase working speeds if the increased power potential of modern and future designs are to be utilised efficiently. As a result, overturning accidents will probably continue at about the same rate as now.

The use of a safety frame or cab to prevent a driver from being crushed during an accident, although regarded by some observers as a defeatist approach, is the most positive way immediately available to reduce fatalities. If the design also prevents a roll from continuing through more than about 90° movement—sideways or rearward—then risk of fatality, except by driving off a cliff, is negligible. The value of projections near each corner of the tractor protruding from an overhead structure to prevent rolling has been proved in many tests and illustrated during the making of the film on tractor safety for M.A.F.F.* ; during this film a tractor was required to overturn on many occasions to depict the various reasons for and causes of accidents—it would have made its production most difficult and expensive if a normal tractor had continued to roll on each occasion ! Even before this proof was obtained, the N.I.A.E. had realised the value of such a feature, obtained patent coverage (1958), and this was abandoned after completion to allow its use in the widest number of applications. Since then considerable experience has been and still is being obtained of the effectiveness and limitations of various designs utilising members forming projections overhead. It was interesting to find that investigations made in New Zealand during the last five years had led to similar conclusions and also stressed the need to prevent tractors from continuing to roll, as well as giving anti-crush protection to the driver.

In Sweden, a country in which the safety consciousness of its government is renowned, the fitting to new tractors of a "safety frame or cab" giving anti-crush protection has been obligatory since 1959.

If safety cabs or frames are to be offered for general sale, then the establishment of a standardised test procedure becomes the first vital necessity. It is not possible, with due regard to economic aspects, to manufacture a safety frame which would be 100% effective under all the circumstances which conceivably could arise. Nevertheless, test conditions must be sufficiently severe so that a "pass" implies provision of a high degree of protection to a driver ; if isolated fatalities still occur under extreme conditions, then parties responsible for the sale of the device must be

* The Ministry of Agriculture, Fisheries and Food.

able to obtain some degree of protection in law against claims for compensation. It may be expected that evidence that a device had passed a test having official standing would be a vital part of their defence. Because in English Law it is only the High Court which can finally decide such an issue, it remains to be seen whether this expectation is well founded. The first step is to reach agreement as to the definition of a safety cab or frame and implicit in this is the requirement to define a standard test. This is the task at present before B.S.I.* Committee AGE/9. Some designs of existing weather cabs offer a moderate degree of protection to a driver and could be considered as safety cabs for less severe operating conditions. However, there are obvious risks of misunderstanding if more than one classification of cab is contemplated.

Before attempting to formulate definitions for use in U.K., it is helpful to study the experience to date in Sweden.

Experience and Procedures in Sweden for Testing Safety Cabs

Development and details of the test technique. When the law requiring all new tractors sold in Sweden to be fitted with a protective device was introduced, the responsibility for acceptance of any design for sale as a safety frame was placed upon the National Workers' Protection Board. To enable the appropriate decision to be taken concerning suitability of a frame, tests are carried out in the presence of one of their representatives by the National Institute for Testing Agricultural Machinery. The law requiring compulsory fitment to all new tractors was not introduced until the N.I.T.A.M. had decided upon a test scheme which they believed enabled a reasonable demarcation between safe and unsafe designs. This was achieved, in essence, by making trial cab frames, rolling tractors fitted with these from a platform about 3 ft. above ground level and finally choosing a frame which provided an acceptable degree of protection from crushing. A laboratory test procedure was then devised in which a blow is struck by pendulum at either of the rearmost corners of a cab or frame likely to strike the ground if the tractor rears ; this is followed by a second blow to the side of the frame, and finally a crushing force equal to twice the tractor weight is applied by a beam placed across the top of the frame. The severity of the blows is a function of tractor weight and was originally chosen so that the deformation of the trial frame, considered acceptable during the rolling tests from a platform, was matched by similar deformation in the impact tests.

A small number of confirmatory tests were then made by rolling a tractor down the side of a steep slope. The personnel at the testing station devised their own procedure for restraining the movement of the tractor during the impact tests. The degree of rigidity achieved is an important factor associated with the energy of the pendulum blow. Steel ropes are placed round the axle housings and attached to the drawbar and to the front axle and fastened to ground anchor points ; chocks are placed against the rear wheel furthermost from the side about to receive the blow. When tests were first made a pendulum weighing one metric ton was used, but it was found to be difficult to obtain sufficient height of fall to provide the large energy required for the blow when testing frames on very heavy tractors. A weight of two tons is now used.

Fig. 1 gives the relationship between tractor weight and energy of the pendulum at the moment of impact ; Figs. 2, 3 and 4 show details of tests witnessed during a visit made in 1962 with Mr. J. W. Holliday (then the Chief Safety Inspector of M.A.F.F., now retired and succeeded by Mr. G. S. Wilson). In Appendix A are reproduced in detail the regulations issued by the National Road Board (the body issuing licences to tractors and vehicles), and confirming the recommendations of the Workers' Protection Board.

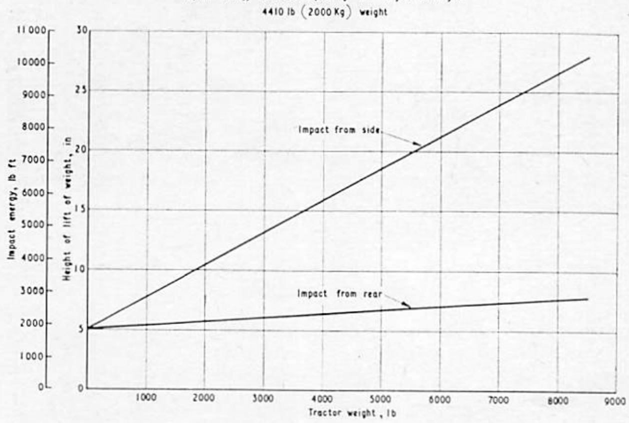


FIG. 1.

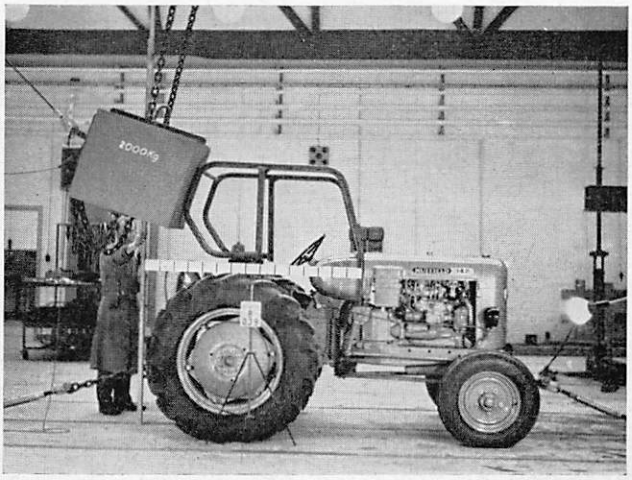


FIG. 2.
Rear Impact Test at Swedish Testing Station for Agricultural Machinery. (Alnarp)

* British Standards Institution.

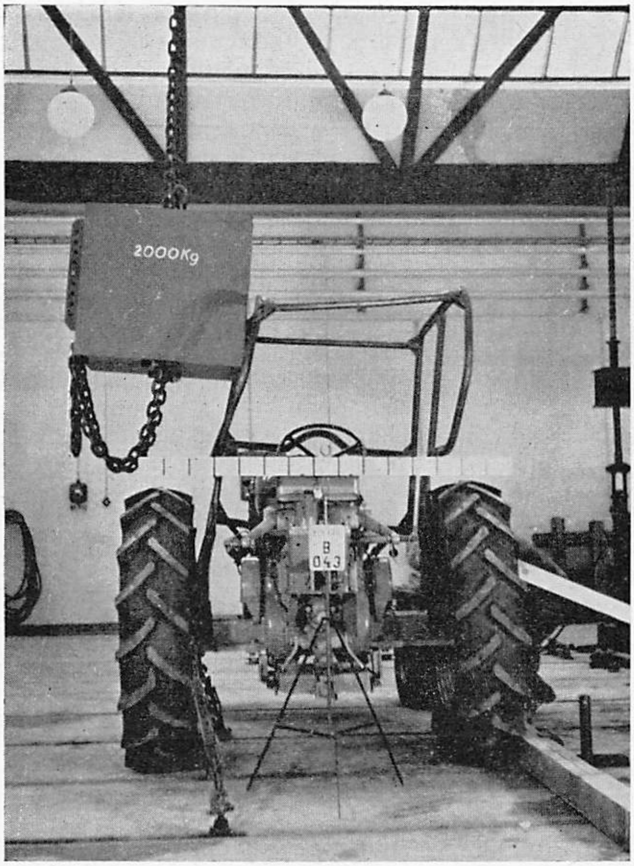


FIG. 3.
Impact Test to Side Swedish Testing Station for Agricultural Machinery (Alnarp)

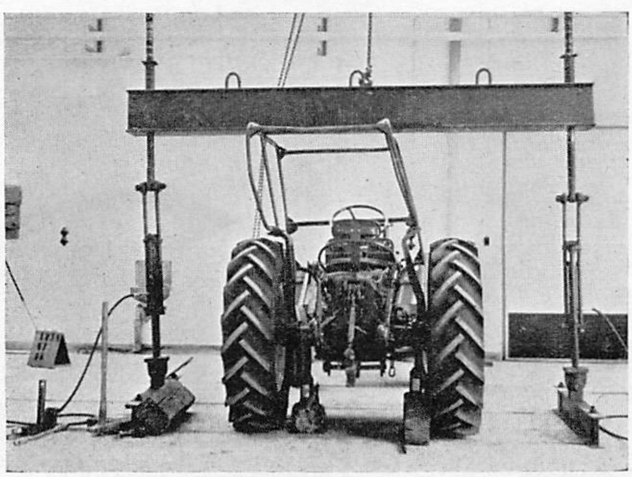


FIG. 4.
Crushing Test at Swedish Testing Station for Agricultural Machinery (Alnarp)

Aspects Associated with the Laboratory Type of Test as Conducted in Sweden

1. It will be noted from the Appendix A that the strength of the cab is considered sufficient if the tests are undergone " without deformation which may imply danger for the driver or passenger." The Swedish regulations do not set down any detailed requirements to help interpret this requirement into permitted dimensional changes. The Workers' Protection Board representative and the officer from the N.I.T.A.M. usually interpret it as (*a*) freedom from cracks or fractures discernible by eye, (*b*) a deformation of the top of the frame of less than about 5 cm. forward and about 25 cm. sideways—although a larger value would be acceptable on a cab of wider than average width. The value of the final crushing tests is that it helps the observers to make a decision on the acceptability of a cab deformed to about the limit by the impact tests.

2. Although any testing officer, by applying his own individual judgment, may achieve a reasonable similarity in the degree of restraint obtained in each of a number of tests (when using " over-centre " timber lashing chains), it is essential to standardise and define precisely the method to be used. This is a " must " if this type of technique is to be adopted as a National or International standard and so be usable by widely differing types of testing personnel.

3. Experience has shown that most frequently the weakest parts of the cab or frame are the sections nearest the attaching brackets, and also the brackets and means of attaching them to the tractors. Thus it seems inevitable that tests must be made finally on the production models of each adaptation for each tractor model, in addition to tests on prototypes to assist development. This increases the cost of developing and marketing a satisfactory range of safety frames or cabs.

4. During impact tests on frames of somewhat unconventional shape—perhaps because they are designed to be used in conjunction with a rear-mounted loader or a specialised piece of mounted equipment—a problem can sometimes arise as to the most appropriate position to be struck or direction in which the blow should be aimed. These aspects can be settled in Sweden by discussion at the time of test between the inspector of the Workers' Protection Board (who is responsible for the final decision concerning pass or failure), the testing personnel and manufacturers' representatives. It is not, however, very easy to anticipate all possibilities and postulate appropriate instructions when trying to write a Standard Specification for general use.

This difficulty has already been illustrated to us, at N.I.A.E., in a rather disturbing manner. We have installed impact and crushing equipment at Silsoe which is as nearly identical as can possibly be arranged to that in use at the Southern Swedish Station (Alnarp) of N.I.T.A.M. (Fig. 5). In one test we made, a prototype frame made by a British manufacturer was tested and judged to have conformed to the standards of acceptance required in Sweden. This particular frame had a rear section extending backwards from the main frame with the object of preventing a tractor falling upside down, or continuing to roll when rearing. In accordance with understood practice, the blow was struck by the pendulum to a rearmost corner of the frame, and thus simulated what might be expected to happen as the frame came violently in contact with the ground surface and deformation was within acceptable limits. Because, at this stage, we have not yet finalised our British recommendations for safety cab tests, and are interested in comparing laboratory test results with those from live tests, we

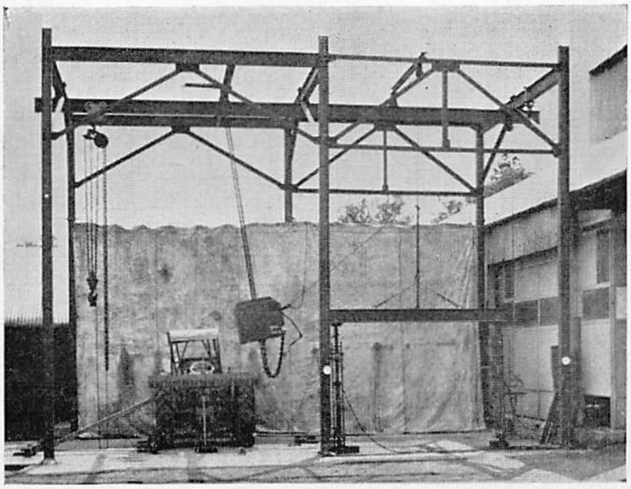


FIG. 5.
Impact and Cruseing Testing at N.I.A.E.

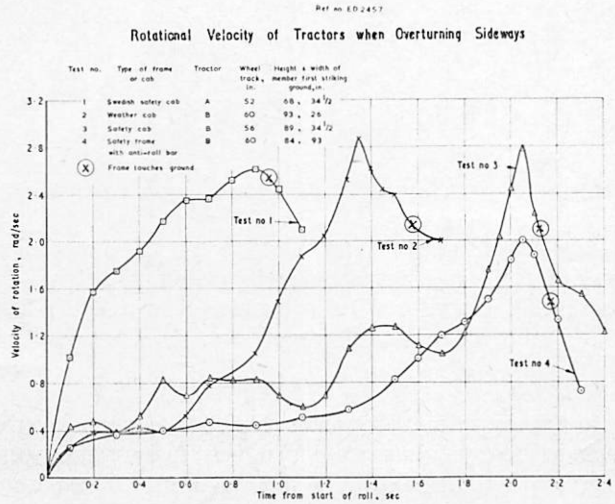


FIG. 6.

drove the tractor up a hill slope of 1 in 3 so that it reared when a chain attached between the top link and a ground anchor became tight. On immediate impact the frame withstood the stresses imposed, but, because at this stage in the development of the frame the rear members were insufficiently far back to prevent rolling on this slope, the tractor continued to roll rearward. The rearmost section of the frame was then subject to a bending moment of a magnitude which varied with the instantaneous position in the arc of rotation. Shortly after the roll commenced, the supporting struts buckled and the rear section folded downwards.

The object in describing these details is to point out that no single blow can be relied upon to reproduce the worst stress condition which can be inflicted on all shapes of structure as rolling takes place.

5. If regarded strictly from academic considerations, the principle of basing the severity of blow upon tractor weight used in the Swedish test is not the most appropriate way to obtain valid, comparative performance data. A more applicable tractor parameter to be used in selecting the energy level of the blow to be struck in a test would seem to be the moment of inertia of the tractor in the respective direction of overturning. Unfortunately, hitherto the moment of inertia values for tractors have not been measured as a routine procedure. However, although academically incorrect, this aspect may not be causing any very serious reduction in comparative value between tests on different tractor models because they are roughly of similar shape geometrically.

To assist calculation of stresses likely to occur in safety frames, curves are given in Figs. 6 and 7 showing rotational velocity plotted against time during test overturnings. These have been derived from frame-by-frame analysis of cine photography records of the tests. Fig. 6 shows the variation in sideways rotational velocity during the period of the first roll preceding impact during (*a*) tests on three cabs with no anti-roll horns fitted ; relevant dimensions of tractor wheel track and cab height and width at top are given in Fig. 6j (*b*) a test with anti-roll bars fitted to the top of a frame.

It will be noted that the maximum velocity occurring in any of the tests on the tractors not fitted with the anti-roll bars was almost 3 rad./sec. During the test with the cab frame and anti-roll horns (7 ft. 9 in. across from tip to tip) the maximum velocity was approximately 2 rad./sec.

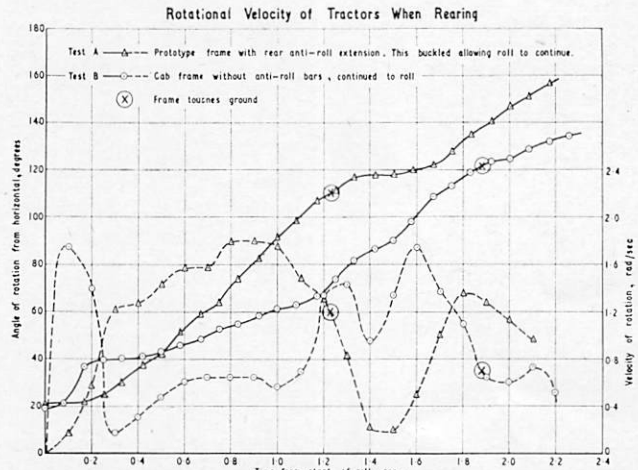


FIG. 7.

In Fig. 7 the angular displacement and the rotational velocity curves are shown for two tests when rearing. In test A the maximum angular velocity became about 1·8 rad./sec. and then slowed to about 1·25 rad./sec. at the time when the rearmost section of the frame hit the ground (at 1·2 secs.). This test was made with the prototype framework mentioned in 4, and the curve from 1·2 secs. shows the reduction and subsequent increase in velocity as the frame buckled and rolling continued ; the second peak occurs when rolling commenced around a mid-section cross-member. Test B shows the changes in velocity during a rearing test made without anti-roll horns fitted on a different cab frame and illustrates the behaviour when wheelslip occurs intermittently. However, the maximum velocity is also about the same as in test A ; *i.e.*, about 1·8 rad./sec. Unfortunately, accelerometers have not yet been fitted to the cabs to establish the maximum rate of deceleration likely to be encountered. Neither have investigations yet been made using artificial bodies which could enable measurements to be made on the accelerations, and particularly the decelerations, on parts of the human body—such as the head.

6. An impact, or any other type of laboratory test to investigate the strength of a frame, cannot give an indication of the effectiveness of overall shape or of any special features of shape (such as anti-roll bars) in preventing a tractor from overturning beyond the first 90° or so of an overturning sequence.

Experience of " Live " Tests made at N.I.AE.

For many years the complete N.I.A.E. test on a tractor included tests made ascending slopes on grassland overlying on a chalk hillside in the Chilterns. These were made when exerting a drawbar pull up a hill or increasingly steepening grade until the working limit was reached because of wheel-slip, engine stall or lack of steering control.

When asked in 1959/60 to make a test of a Swedish cab, imported by an agricultural machinery manufacturer to assess sales potential, it was natural for tests to be planned on this hillside test site at Ivinghoe Beacon.

The first test was made by driving a tractor fitted with the cab obliquely across and down a gradient of about 1 in 5 so that the lower wheels slipped over the edge of a gully. This test was made when travelling at a normal field working speed, and the result was only very minor denting of the cab ; the tractor remained on its side. When a tractor without a cab was driven in the same manner, it made one complete roll and would almost certainly have crushed a driver severely. This type of accident was simulated initially because it seems typical of the cause of more than 25% of the side-roll fatalities.

A second " sideways roll " at higher speed—about 7 m.p.h.—was induced by driving down a much steeper gradient (1 in $2\frac{1}{2}$-1 in 3) and turning sharply across the slopes so that centrifugal force, created by the turn, caused overturning. This test was intended to simulate accident conditions which exist when a tractor is out of control or when familiarity of the driver to work on steep slopes has " bred contempt " or a hidden obstacle is seen too late and instant avoiding action taken. Although the tractor fitted with the Swedish cab overturned many times, causing breakage of the tractor transmission housing components, the distortion of the cab was surprisingly small. However, this particular cab, which was of double skin and in part treble skin steel construction, was never imported in quantity because it was considered to be too expensive for the U.K. market.

In June, 1962, a further series of tests of the above type were begun and included a sequence in which the tractor was caused to rear backwards on a 1 in 3 gradient. The procedures and facilities were demonstrated at that time on Ivinghoe Beacon for Press and T.V. news cameramen. The occasion was made possible by the interest of a British equipment manufacturer in having tests made on a prototype cab frame which had the additional, optional facility of being fitted with anti-roll horns. The results of these publicly-held tests were impressive, both so far as the anti-crush properties of the frames were concerned and also because of the value of the horns in preventing rolling continuing (test results on production models were published in N.I.A.E. test report Nos. 359, 366). From these early tests made using a tractor driven in a gear giving 7 m.p.h., it was found that sideways rolls were just prevented from continuing on slopes of 1 in 2 – 1 in $2\frac{1}{2}$, when anti-roll horns were attached to the top of a cab frame (89 in. above ground level). At the front these projected sideways at right-angles to the longitudinal axis of the tractor, and the tip-to-tip distance was 68 in. At the rear the horns projected rearward at an angle of 45° and the tip to tip dimension was 64 in. (tractor wheel track was 56 in. on 11-36 tyres).

Without the " horns," rolling—once commenced—continued for eight complete rolls until the gradient was less than about 1 in 7. The cab frame was sufficiently robust to prevent a driver from being crushed, but there seemed every likelihood of serious injury occurring. (Fig. 8—after a total of 11 sideways and 2 rearwards rolls.)

Fig. 8. Safety Frame after eleven sideways and two rearward rolls.

Although during the high-speed sideways roll tests the tractors were eventually caused to overturn, these initial and many subsequent tests have demonstrated the difficulties of causing a tractor to overturn " to order " —even on a gradient of 1 in $2\frac{1}{2}$—and also in an exactly reproducible manner. Subsequently, " live " tests made on production cab frames from the same manufacturers (which had front anti-roll " horns " bent forwards at 45°) confirmed these difficulties. In spite of using the same section of hillside during all repeat tests, ground conditions were inevitably slightly different, and the test team developed more experience in controlling the tractors remotely by reins. Hence the rate of turn across the slope probably increased on some occasions—depending usually upon the extent of side-slip which occurred. As a result, it was found that during six tests, on two occasions using forward bent front horns, and on one occasion using straight front horns, the tractor was allowed to roll for at least one-and-a-quarter revolutions. On the other occasions rolling was prevented. During tests using two other tractor models, sideways rolls on 1 in 2½ were arrested, but on one other occasion using a prototype design of " horn," which was expected to have a greater margin of safety than the production " horn," again rolling continued.

Thus experience to date has shown (*a*) that when tractors are operating on steep hillsides a suitable cab shape or the position and shape of extremities can make a most valuable contribution to operator safety, even if the operator is housed in a non-crush cab; (*b*) there is a need to develop a more standardised technique for assessing performance of such features than can be achieved by the present procedure if the tests are to be applicable in the form of a British Standard Specification or O.E.C.D. and I.S.O. procedures ; (*c*) the final distortion of frame designs tested in accordance with the Swedish procedure and then tested by overturning a tractor rearward and sideways on a gradient of 1 in 2½—1 in 3 are reasonably comparable.

Proposals for Improving Test Techniques

The foregoing suggests that if the definition of cab requirements and test procedures are considered from a strictly academic viewpoint, then appreciable development of test technique details must be achieved before a test procedure can be written which provides the certainty of exact comparison of results between all types of safety cab. Even then it is more than a little doubtful whether it is possible to cater for all eventualities.

Against this can be cited the example that in Sweden no fatalities have occurred among drivers in safety cabs since they were introduced in 1959. Conditions of terrain between U.K. and Sweden are not exactly comparable, however, because most of the hillside work in Sweden is in forests and not on steep open hillsides as in many parts of U.K.

Thus while being in favour of a laboratory test as a more convenient and cheaper form of test procedure to establish crush resistance than rolling tractors " live " on hillsides, we must include, in any overall assessment, a test to evaluate special features of shape or of anti-roll bars. To date in U.K., where the response to use of safety cabs has been slow, I know at least two lives have been saved in 1963 without even a minor injury—a young man ploughing a steep hillside in Brecon and another lime—spreading near Kendal. It seems most probable from the reports of these accidents that but for the anti-roll features then rolling would have continued with increased danger of injury. There may already be other examples.

The main requirement to make the existing N.I.A.E. technique for overturning tests more efficient is to improve control of the rate of overturn. One possible means would be to create a permanent hillside test site and cause overturning by using tracks supported by ramps across a slope 1 in 3, so arranged that the uppermost track becomes progressively steeper until rolling is inevitable. Forward speed could be controlled to close limits, and the only variable would then be the changes in the soil conditions which the tractors would strike on loading. Initially, as now, suitable weather would have to be chosen at the discretion of the N.I.A.E. staff as the only way to mitigate this variant. Eventually, if the technique is otherwise successful, simulated firm soil conditions could be provided using an artificial medium.

Improved standardisation of some details of the Swedish impact tests are already being contemplated and tried out ; for example, strain-gauged dynamometers have been included in the harness lashing the tractors to the ground anchor points. In a recent test a pre-load in the cables of about 1,000 lb. exerted a total vertical component of approximately 3,000 lb. on the axle housing on the side of the tractor about to receive the blow. Recorder charts showing the response in the strain gauge dynamometer when a blow was delivered to the top member 7 ft. above ground confirmed that a vertical component of approximately 5,000 lb. was exerted by the anchoring cables when a blow was struck having 7,150 ft. lb. energy. Likewise, the forces in the rearward restraining lashing can be monitored. Alternative methods of restraint will probably also be tried out experimentally.

An additional laboratory test must be made in the future at least on all tractors having a frame extending rearward to any appreciable extent to try to ensure that collapse does not occur when rolling rearward. (The risk of this occurring sideways is not so great.) A blow from a much steeper angle than the first blow delivered as now, or a vertical load test made at the rearmost position, are possibilities which will be demonstrated to a working group of B.S.I. committee AGE/9 in the near future.

The maximum temporary deflection which can be permitted at time of impact is a subject on which a decision must be taken, but this is a vitally important and difficult aspect with cabs which incorporate some form of suspension between cab roof and tractor body. Overturning tests witnessed on a weather cab of German origin, having such a suspension, showed that final deformation was surprisingly small except under the most severe test conditions .

The means of defining tractor stability are being studied with the intention of including an assessment of potential stability in a Standard tractor test report. These studies are as yet incomplete and outside the scope of this Paper.

Other Practical Aspects of a " Safety Cab " of Importance to a Driver in addition to Non-Crush and Anti-Roll Features

Driver comfort and in particular the noise loudness levels, freedom to attach and use mounted equipment, ease of entry and exit from a cab, including alternatives for use in emergency, interference with vision when accuracy of steering is of importance—*e.g.*, when splitting ridges, or hoeing—are all vital criteria as to whether any cab will be acceptable, whether it is designed for safety or only for weather protection. A test must try to provide information on all these aspects. With existing tractor configurations it is difficult to provide a cab with adequate access width, and drivers of only average bulk must often mount or dismount most carefully, otherwise they become stuck !

Recommendations for the maximum dimensions of the interior of a cab can be found in the Swedish Regulations in the Appendix A (1 m. above the driver's seat when carrying a load of 70 kg. ; 45 cm. width from steering wheel centre ; 6 cm. clearance in front of steering wheel ; 8 cm. elsewhere round the wheel). I believe that any test report should give the potential user an assessment noisiness—*i.e.*, loudness of noise. For reasons given in S. W. R. Cox's Paper, " Noise Measurement and Analysis," we have chosen Stevens sones (Mk. VI) as giving the most appropriate evaluation, together with a comment concerning the freedom, or otherwise, of the noise in the cab from any particular feature which could prove particularly irritating to the driver (although not necessarily contributing appreciably to the loudness of noise as derived from sound pressure measurements). A sliding side window which was too loose and rattled, or a panel drumming, would be good examples of this type of irritating occurrence on which comment should be made. As it is not possible to measure noisiness at all conditions of speed and load, it is proposed to give in reports on cabs the values when developing 75% of maximum power in the gear, giving the speed nearest to 4½ m.p.h. and also with a very light load in top gear. For comparison, the loudness values are given of the tractor without cab, with complete cab and with any relevant part-stripped assemblies.

As there has been little, if any, use made in the tractor industry of the Stevens sones scale in the past, the following remarks (in addition to those in Mr. Cox's Paper) may be helpful in building up a working background.

(1) The scale is linear—hence a measurement of 200 sones will represent a noise twice as loud as one having a 100 sones value (as compared with the decibel scale on which—being logarithmic—an increase of 3 decibels from, say, 86 to 89 would indicate twice as much noise intensity).

(2) I have carried out trials to obtain my personal correlation between my own reactions to tractor noise and loudness measurements expressed as loudness in Stevens sones Mk. VI. In one of these I drove a tractor (approx. 50 brake h.p.), without cab fitted, for four hours when pulling a tined cultivator ; noise measurements were made subsequently, so that the results were not known at the time the working trial was made.

Observations were as follows :

(*a*) I would only have been prepared to work continuously at full engine speed (approx. 1,800 r.p.m.) when knowing that there was some urgency in getting a task done quickly or when economic reward made it worthwhile. The loudness was 125 sones (93 decibels—A weighting).

(*b*) I was content to operate continuously at an engine speed of 1,450 r.p.m. ; loudness was 72 sones (84 decibels —A weighting).

(*c*) At an even slower engine speed of 1,220 r.p.m. the noise was also acceptable for continuous work without creating fatigue, but was slightly more unpleasant than at 1,450 r.p.m., because the individual firing strokes were discernible. Loudness was 79 sones (68 decibels—A weighting).

Thus the values for loudness expressed in Stevens sones for conditions (*b*) and (*c*) were almost the same, with condition (*c*) being very slightly the louder noise, and these results confirmed the views of myself and also two other observers. The values expressed on the decibel scale (A weighting) show very different results, because the sound pressure at the lower frequencies is depressed very much more than with the Stevens Mk. VI treatment. Consequently, in addition to being a non-linear scale the decibel results do not seem to conform to practical evaluation when the lower frequency intensities predominate.

In another trial using a different tractor fitted with a cab when rotavating, I found that a " singing in the ears " and a definite reduction in hearing sensitivity continued for at least two hours after work finished when the tractor was operated at maximum engine speed. The loudness was 187 sones. The best setting that could be used with the outfit still able to perform a satisfactory job was 122 sones.

TABLE III

		Loudness value, Sones Stevens Mark (VI)			
	Tractor loading	*Tractor 1 Cab A*	*Tractor 1 Cab B*	*Tractor 2 Cab A*	*Tractor 3 Cab A*
No cab fitted	100% max. power	140	140	100	145
	75% max. power	127	122	101	133
	Light load	123	127	92	122
Frame fitted and includes sheet steel roof. No doors, panels or windows fitted	75% max. power	134	N.A.	150	162
	Light load	143	N.A.	161	150
Cab complete less doors and rear screen	75% max. power	144	190	139	138
	Light load	139	168	137	128
Complete cab	75% max. power	124	175	167	152
	Light load	117	150	156	147

Note : (*i*) the accuracy of individual values is believed to be about ± 2%.
(*ii*) gears used for 75% max. power measurement were those giving a speed nearest to 4½ m.p.h. Light load measurements were in top gear.

(3) The effect on loudness of noise when fitting either of two types of cab on to one model tractor is shown in Table III ; cab B was very much more roomy than A and also expected to be more quiet—but not so ! The loudness with various conditions of completeness of cab type A on three different tractor models is also shown (some small differences existed in dimensions of cab). All measurements were made at a driver's ear position, and the tractors were fitted with vertical exhaust pipes. In general, it can be said that fitting the cabs always increased loudness of noise for the driver, but the results varied with each combination. Without cabs fitted, the reduction in power from the maximum value to 75% was accompanied by only a small reduction in loudness—always less than approx. 10%.

(4) Eleven farmers' tractors were visited when carrying out normal work during the spring, and loudness measurements made at the driver's ear. Each tractor was fitted with a weather cab and, in all, four makes of cab were involved and nine different tractor models. Almost all tractors were being driven at about three-quarters (or less) of the maximum engine speed setting, and thus on seven the loudness levels were about 100 sones (Stevens Mk. VI) or less. Of the other four, one driver commented that he thought the cab rather noisy, but accepted noise rather than be cold and wet ; the loudness was 135 sones under the part speed conditions being used. At maximum speed the loudness was 150 sones. The tractor working hardest, rotavating heavy ground, was also noisy, 140 sones, and the others had values of 125, 115 sones—both were ploughing, but were fitted with canvas-covered cabs. Canvas-covered cabs had been selected on four of the eleven tractors because they were considered to be quieter than metal-clad cabs. The most recent experience in Sweden is that most farmers are now showing a very marked preference for canvas-covered safety frames instead of metal cabs.

Conclusion

Use of safety cabs or frames is the most positive way of preventing fatalities during overturning accidents.

A test procedure for safety cabs or frames is already available at N.I.A.E. and is being improved as experience increases and investigations and observations on tractor stability aspects are undertaken.

Within about a year a B.S. test procedure along the lines of the Swedish test, but incorporating detailed improvements, and a "live" test when applicable, should be finalised and would be available should a legal requirement to fit new tractors in safety cabs be introduced in the United Kingdom.

There is sufficient evidence already available to show that in general the test will demand a performance giving a satisfactory margin of safety to accommodate usual production differences, including variations in manufacturing skills and normal variations in material specification.

The B.S. specification must include definitions of the minimum strength requirements of a safety cab ; it is believed that there can be only one class of safety cab.

To draw up a B.S. specification at this stage of our experience and knowledge is rather early by normal practice, and the possibility of future changes must be envisaged, particularly as international interest increases. Nevertheless, the need is immediate and must be tackled at once. As the first test procedure to be written as a National Standard, a B.S. will provide a most useful lead for international standardisation. Arrangements are already in hand for international study to be commenced through O.E.C.D.

Once the necessary robustness in design has been achieved, the most important requirement to be tackled by manufacturers concerning cabs, rather than frames, and one which is difficult and expensive to overcome with tractors of existing design types, is noise. A tractor designed initially with operator comfort aspects as major desiderata would, perhaps, offer fewer difficulties in this respect. Other important features missing from most designs are really good access, general roominess and good vision ; the absence of these, together with noisiness, have caused many drivers in the past to abandon the use of cabs.

A factor seriously affecting the cost to a farmer of providing his drivers with anti-crush protection is the lack of convenient points for fixing safety cabs to tractors. In some cases this amounts to lack of any appropriate attaching point in the original tractor design. This is a most vital aspect which also should be tackled by the tractor manufacturer—perhaps in conjunction with the B.S.I.—and would provide better possibilities for interchangeability of cabs when new models are purchased. That is the minimum requirement ; a better solution is that the original tractor design should provide overhead strength as part of the main structural layout or at least include provision of a manufacturer-promoted design as part of the list of original equipments available.

It is impossible, when concluding a Paper dealing with tractor fatalities, not to draw attention to the number of drivers run over—an average of some ten lives each year. Safety cabs will reduce this number, but a big reduction could so easily be effected on all tractors by incorporating a safety interlock mechanism in the gear change lever arrangement preventing accidental engagement when knocked, as well as making it impossible to start the tractor when in gear.

Finally, when considering compulsory use of safety cabs the question must be asked as to whether the test requirements are, perhaps, too severe. Instead of aiming at a very high degree of success—approaching 100%—would it be sufficient to aim at, say, a 90% survival level ? This would be achieved with somewhat reduced outlay to the farming industry. Hence we arrive at one of the most important ethical and economic questions of our age. What sum of money should a community spend upon saving a human life ? Furthermore, should the cost be extracted from the section of the community specifically concerned or be spread more widely ?

The author gratefully acknowledges the help given by the Director and staff of the Swedish National Testing Institute for Agricultural Machinery in providing information and arranging opportunities to see the work which they are doing.

APPENDIX A

NATIONAL ROAD BOARD (SWEDEN) AL

February 2nd, 1962 4/10/62

Notice No. T655–620924

Regulations concerning cab or protective frame on tractor

According to a resolution, passed by the National Workers' Protection Board on April 1st, 1958, and the Royal Resolution of July 28th, 1958, new tractors, delivered after June 30th, 1959, shall be supplied with a cab or protective frame. For that reason the National Road Board, after consultation with the National Workers' Protection Board and in virtue of para. 1 in the Road Traffic Proclamation, informs the following regulations :

1. A cab shall have sufficient tenacity and be adequately fixed to the tractor so as to provide satisfactory protection for the driver and the passenger inside the cab against injury, if the tractor overturns sideways or backwards.

Note. The tenacity of the cab is to be considered sufficient, if the cab, without deformation which may imply danger for the driver or the passenger, goes through the following tests carried out on one and the same cab and in the order mentioned below :

(*a*) Impact test with a pendulum in horizontal direction from behind to that part of the cab which can be expected to catch the bump when the tractor overturns. The weight of the pendulum shall be at least 1 ton. The impact power, L_b kpm, shall be $L_b = 250 + 0{\cdot}04\ G$, where $G =$ the tractor's weight in kg.

(*b*) Impact test with a pendulum in horizontal or somewhat downward-sloping direction from the side perpendicularly to the upper part of the cab. The weight of the pendulum shall be at least 1 ton. The impact power, L_s kpm, shall be $L_s = 250 + 0{\cdot}3\ G$, where $G =$ the tractor's weight in kg.

(*c*) Static load vertically to the upper part of the cab with a power corresponding twice the tractor's weight. The load is divided amongst carrying parts by means of suitable spacer.

With the tractor's weight means the weight of the tractor with filled tanks and half-track equipment, if the tractor is supplied with such an equipment, but without liquid in the tyres and without attachment weights and driver. While carrying out the test, the tractor shall be firmly fixed to the ground.

2. A cab shall be made so that projecting parts—*e.g.*, iron-rods, angles or edges, are not likely to cause injury. Covering for reducing bumps can be necessary—*e.g.*, for windshield cleaner's motor. Attention shall be paid to construction of the ceiling, especially over the driver's head. Furthermore, see the National Workers' Protection Board's regulation No. 29 (General Machine Regulations), which can be ordered from Svenska Reproduktions AB, Stockholm 6, as form No. 4368, and which shall be noticed in relevant provisions.

3. There shall, whenever possible, be a door on both sides of the cab. When necessary there shall be steps and handles so as to facilitate ascending and alighting.

A cab shall also in other respects be constructed so as to make it easy for the driver and the passenger to get out, if the tractor has overturned or reared backwards. Evacuating ways shall be easy to open from inside the cab.

What is prescribed by the National Workers' Protection Board (see Appendix) as regards driving with tractor on frozen water shall be observed.

Note. The requirements in the second section are considered to be carried out, if the cab is open or can be opened backwards and in addition has either a door on both sides or a door on one side and a door in the roof or removable roof. The same is the case if a cab without a side-door is provided with door in the roof and is open or can be opened backwards and admits further at least one possibility to get out.

4. A cab shall be constructed so that it does not prevent applying on or attaching to the tractor such machines, tools, trailers, etc., which normally are used together with the tractor. It shall be so spacious that the driver has satisfactory freedom of movement when driving and when handling machines, tools, trailers, etc. The driver shall in elbow-level have a free space of at least 45 cms. at each side, counting from the centre of the steering-wheel. The space between loaded seat (about 70 kg.), fitted with standard pad, and the lowest part of the roof shall be at least 1 m. The minimum free space round the steering-wheel's periphery shall with the length of the tractor be 6 cms. and for the rest 8 cms.

5. A seat with soft underneath layer should be arranged for at least one passenger. In that case there shall be necessary and easy accessible handles.

6. A cab shall be provided with windows which give necessary sight. The window-panes shall be of material that does not give sharp nibs at crushing.

7. Doors, windows (able to open) or any other movable part shall be of lasting construction.

8. A cab shall be provided with electric windshield cleaner and direction indicator.

9. A cab shall be made so as to prevent the passenger from becoming annoyed by draught. There shall, however, be accommodation for adequate ventilation. The cab shall, when required, be permitted to be quite well aired.

10. A cab shall as far as possible be so constructed and mounted on the tractor that annoying noise will not arise inside the cab.

11. Material in welded construction shall be suitable for welding. Welding may be carried out only by competent welder.

12. The relevant provisions in points 1–11 shall also apply concerning protective frames.

13. In a cab or frame there shall be a sign with clear and permanent text as follows :

CAUTION

Keep firm hold of the steering-wheel if the tractor turns over. Do not jump.

Power take-off shaft and clutches shall be enclosed over its entire length.

No room for passenger. (Alternatively : Room for – passenger(s) only.)

14. For cab or protective frame which meets with the above-mentioned requirements and for the rest is suitable, the National Workers' Protection Board gives type approval. On a suitable place cab or frame shall be furnished with stamped manufacturing number and the type marking which the Workers' Protection Board gives at the type approval. If cab or frame is furnished with a sign, intended to replace certificate in accordance with the National Road Board's " Notification to the supervisors " No. 03–07–01 (letter T 126–170/60), the type marking need not be stamped in the frame.

These regulations shall come into force on April 1st, 1962, and shall substitute the Board's notification No. T 2/59, dnr T 2377–170/59.

Approval previously issued by the Workers' Protection Board are held in force until the Workers' Protection Board has otherwise announced.

SWEDISH NATIONAL ROAD BOARD,
L.G. Bertil Götherström.

INDEX TO ADVERTISERS

	Page
ELECTRICAL DEVELOPMENT ASSOCIATION	*ii of cover*
JOHNSON'S (ENGINEERING), LTD.	4
MASSEY-FERGUSON, LTD.	7
WOLVERHAMPTON TECHNICAL COLLEGE	8
SHELL-MEX & B.P., LTD.	*iv of cover*

FORUM

DISCUSSION—PAPER I

COMMANDER F. D. BINGHAM (Association of Hydraulic Equipment Manufacturers) asked if there were certain noises—such as that of a gas turbine—which were so loud that they could not be heard, but became vibration effects.

MR. COX agreed that such effects were sometimes experienced.

MR. P. H. BAILEY (National Institute of Agricultural Engineering) said that while the sone method was obviously the best compromise for assessing noise levels at the position of an operator's head, it required a large number of readings, taken while the sound level was constant. He was interested in assessing the noise field round fixed installations, such as grain driers or grain cleaners, from the point of view of the passer-by or in connection with a legal requirement for quietness.

He asked if Mr. Cox would agree that the field of equal sound pressure, or equal noise level, round a fixed installation could more conveniently be assessed by the dBA method. This would involve single readings at each given position, with a total of 30, 40 or 50 readings for the whole area. He had plotted contours of equal sound pressure level using this method in units he called "isobels," which seemed to offer a practical possibility, even if it did not show the quality of the sound. He asked if Mr. Cox thought this was a satisfactory method of indicating sound level as a passer-by would hear it.

MR. COX said that he could not accept the "isobel" as a standard unit, but he agreed that the dBA method was useful for rating public reaction to noise, and for simplifying the production of noise level contours. There was an alternative public reaction system, as mentioned in his Paper, involving octave analysis. He felt the dBA system would probably be preferred in this country for public reaction purposes. He could envisage a design for a Stevens sone calculator which would make the measurement of Stevens sones easier in the circumstances Mr. Bailey had mentioned. However, he was not sure that it was worth developing such a device until the general pattern of noise measurement had become clearer.

MR. T. SHERWEN (Consultant Engineer) asked for information on the irritation effect on the human ear of noises of the same loudness, pressure or other value, depending on the continuity or discontinuity of their nature. A typewriter, for example, was irritating, although it did not make a very loud noise.

MR. COX said that fluctuating noises such as that of a lawn edge trimmer or a chain saw were found to be irritating. There was, no doubt, a scientific explanation, but it seemed to him that there might be some mechanism in the brain which was continuously hunting to try to shut out such noises, and could not do so because of their intermittent nature.

MR. A. G. HORSNAIL (National College of Agricultural Engineering) asked if there was a correlation between noise level and speed with certain types of machinery. If this was so, might there be a case for the production of high-torque, low-speed machines for field work ?

MR. COX said that he would only answer the instrumentation part of that question. In work by Drs. Austin and Prideaux, published in the Reduction of Engine Noise Symposium, 1958, there was much information about noise from diesel and petrol engines, and the factors causing it.

MR. D. R. BOMFORD (Bomford Bros., Ltd.) asked for information about the relationship between noise and power. He had once asked about this relationship and had been told that 10,000 trombones would absorb only one-quarter of a horse-power. He himself felt that 10,000 men each blowing a trombone would develop quite considerable power, and that this analysis must therefore be wrong.

MR. COX replied that the amount of power involved in audible noise was very small. Quite loud sounds were equivalent to small fractions of a watt.

THE PRESIDENT (Mr. W. J. Priest—Editor, *Farm Implement and Machinery Review*) asked Mr. Cox to comment on the effect of noise in relation to the working conditions of farm machinery operatives. Was it possible to become conditioned to noise so that it became unimportant ? What effects of wear and tear on the physical frame might be attributable to working in noisy conditions ?

MR. COX said there was little evidence of permanent damage to hearing except in the boiler-making and riveting trades. He had recently come across an Australian reference to appreciable measured losses of hearing, over periods of 8 – 15 years, in men driving tractors of about 70 h.p. for periods of a month or so each year. He could not say to what extent an individual could become conditioned to noise. Temporary hearing loss could protect one to some extent, but it was open to question at what point this would become a permanent loss of hearing. This he understood was one of the main fields under enquiry of the joint Medical Research Council/ National Physical Laboratory research unit. This unit would be studying noise conditions in selected sectors of industry, and relating noise levels to changes in hearing acuity of new entrants to the industries concerned. More information was required ; at present it was difficult to find proof of anything in this field.

MR. J. A. C. GIBB (University of Reading) asked if atmospheric conditions could make any important difference to levels of noise.

In reply, MR. COX said that refractions in the atmosphere, caused by temperature variations and wind effects, could cause concentrations of sound in some places, or put other places in sound shadows. To that extent, atmospheric conditions could alter sound levels as they might affect the general public. There would be no difference from the operator's standpoint.

MR. D. R. BOMFORD said that, in his opinion, the biggest offender in agriculture was engine exhaust noise. It was the engine, not the saw, of a chain saw which made the noise. If negligible power was required to make a noise, surely it ought to require negliigble power to dissipate noise? If the discussion was to have a practical application, it must deal with silencing. Could something approaching absolute silence be obtained without serious power losses?

MR. COX replied that it was now possible to silence engine noise without introducing back pressure, and that the new Institute of Sound Vibration at Southampton was taking very great interest in the silencing of engines. The matter was not a simple one, and he thought one could not obtain a completely effective silencer at an economic cost. It was very likely that there would be improvements in silencing in the future.

MR. E. ATKINSON (Shell-Mex & B.P., Ltd.) said that Mr. Cox's Paper was most useful in defining the parameters of noise for the layman. It was very desirable that more people should know more about noise. Individual tolerance of noise varied very greatly, and he felt that further information was needed on the effect of noise on people. He asked Mr. Cox if he could see any immediate ways of employing further information on the acceptability of noise in connection with agricultural machinery.

MR. COX said that some information on the effects of noise in relation to the use of farm tractors was beginning to be assembled. The effects of noise on the individual varied greatly; there was a wide range of susceptibility, which probably made average figures meaningless. Answering Mr. C. A. Cameron Brown (Electricity Council), Mr. Cox agreed that many of the noises to which agricultural workers were exposed were of an intermittent nature. He did not know of any scientific work which explained the nature of human reaction to intermittent noise.

MR. P. HEBBLETHWAITE (National Institute of Agricultural Engineering) said he would like to comment on sounds in agriculture which were valuable. In trying to suppress noise, one should not go so far as to suppress sounds which gave an indication of the operation of a machine. Examples of such noises included the audible slip clutch, the combine-harvester drum, and the noise of a cutting arm. These irritating noises were essential to the operator if he was to be ready to correct faults.

Prompted by his colleagues' interest in noise, he had tried operating a combine-harvester while wearing an effective pair of ear-muffs. As a result, he thought that an operator sitting in a silent world would be much less efficient.

MR. COX agreed that there was some advantage in small amounts of noise, and that many operators would lose valuable information if they used muffs or earplugs. He did not know what type of ear-muffs Mr. Hebblethwaite had been wearing, but he would have expected them to cut off sounds with frequencies above rather than below 1 kC/sec., and therefore not to have much effect on engine noise.

Making the final contribution to the discussion, MR. P. H. BAILEY said that he would question the validity of Mr. Hebblethwaite's conclusions. While he might well feel deprived of noise information to which he was accustomed, this was in a situation in which he had moved suddenly from noise to no noise. Reaction to such noises could be a matter of habit, and Mr. Bailey thought that an operator accustomed to silence might become just as efficient as one used to noise.

MR. J. A. C. WILLIAMS* (Chelsea College of Aeronautical and Automobile Engineering): It is germane to a full discussion of Mr. Cox's admirable Paper to refer to the effect on the worker of the high noise levels at frequencies about 10,000 cycles/sec. in Fig. 6. The values of over 90 decibels for the four-cylinder tractor with silencer removed, the chain saw in work and the rolling mill bagging-off point show levels which would be damaging to the ear for any worker exposed to this continuously. Deterioration of hearing ability over the high-frequency range would occur before permanent damage occurred, but permanent damage could ensue. This would impair the social life of the worker, as well as possibly affect his ability to do a job where this depends upon hearing ability; in many cases with engineering equipment the worker does often rely upon unconscious listening to equipment noise and detection of any variation from the normal (which betokens changes in the equipment's functioning) is a part of the skill he has.

Two courses of remedy are open to the engineer—either to give rest allowances as one does in time study, or to treat the equipment acoustically so that the noise is lower, especially at the high-frequency end of the spectrum. The rest allowance normally given in published tables of time study allowances is no more than 5% in all the tables known to this contributor, and this is entirely unrealistic in preventing impairment of hearing. Most workers and managements are totally unaware of the dangerous nature of the high noise level found with equipment, and Mr. Cox's Paper is extremely valuable as one showing the potentially damaging levels found at present.

DISCUSSION—PAPER II

MR. G. HOOK (National Union of Agricultural Workers) asked for information on the effect of the vibration transmitted from the steering wheel on an operator's hands and arms. In seeking to minimise the effect of the seat on his body, some of the vibration effects might be transferred to the operator's arms and legs, and there had been one or two cases in which it had been suspected that a degenerative condition of a man's wrists was due to the vibration of the steering wheel.

MR. SIMONS said in reply that although his main interest had been in studying the influence of seat design on tractor vibration, with respect to man, measurements had also been made on the operator's other contacts with the tractor. Because his feet were resting on controls of various kinds, some vibration was felt through his legs, regardless of seat design, while—as had been pointed out—there was some vibration of the hands due to the steering column of the vehicle. There was information in the literature on the effect of vibration in causing what some doctors had called " white hands " in very extreme operator conditions such as using a rivetting machine or a vibrating machine. There were many instances of disability due to such occupations, but Mr. Simons was not aware of any such extreme conditions of vibration on farm tractor or vehicles. Nevertheless, these sources of vibration should not be discounted.

MR. J. MATTHEWS (National Institute of Agricultural Engineering) first congratulated Mr. Simons on his very clear explanation of the vibration problems of tractor driving. He also extended his congratulations to Mr. Simons' company in respect of the valuable research they had carried out.

The medical evidence Mr. Simons had cited in his Paper was very black. Each of the three Papers he had mentioned had given evidence of serious health degradation. In the East German work the majority of tractor drivers were, in fact, provided with suspension seating. The physical data on these seats were not available, and possibly one general aspect of the seating in question was that its movement was of a pivoting, rather than truly parallel, nature. This had been found by other workers to provide less stress-isolation. The problem was a serious one and even with suspension seating some difficulties still remained.

Alternative methods of isolating drivers from vibration were being considered, and one—which had not been ruled out—was the possibility of a suspended cabin in which the driver and controls could be sited. Some Continental tractors were fitted with a partial vehicle suspension, typically between the front wheels and the body of the tractor. A disadvantage of providing an optimal seat was that the isolation of all movement relative to the ground introduced movement relative to the controls. Of these, the steering wheel was the most important, and seat design must be optimised with movement relative to the steering wheel in mind. A cabin or some other form of isolation might overcome these difficulties.

Mr. Simons had mentioned the employment of young men only for tractor driving for a limited number of years. Presumably they would then be given other jobs. In fact, however, the medical evidence suggested that it was young men who were most prone to the effects of vibration. The Roseggers had discovered that, of a group of tractor drivers whose average age was only 26, 70% had spinal deformities compared with 10% of the general population.

Regarding the adoption of slower operating speeds to minimise vibration, at the Power Farming Conference in 1963 Mr. Manby had reported on a survey in which 50% of the tractor drivers questioned were working below the maximum speed because they wanted increased comfort. Improved comfort was certainly required if maximum efficiency was to be obtained.

DR. J. D. E. TROUP (Guy's Hospital) referred to Mr. Hook's remarks on degeneration of the joints at the wrist and said he knew of no work on this subject. Mr. Simons had mentioned conditions due to circulation disturbances. The supply of blood to the hands and wrists was very much reduced, so that the skin went white, and so on. Of the three surveys mentioned, Dr. Troup thought that by the Roseggers was admirable and extremely interesting. It was also very frightening in the evidence it gave regarding not only degeneration of the spine, but also the equally serious matter of deformation of the posture of the spine, and incidence of gastric disturbances.

He thought the other two authorities deserved less attention. Fishbein and Salter circularised a large number of orthopaedic surgeons in the U.S.A. asking for their opinions as to how many of their patients were suffering from spinal troubles, and in how many cases this was thought to be due to driving tractors or trucks. Each surgeon's opinion on an individual case was interesting, but the result was unscientific and the 400 replies merely amounted to 400 unsupported opinions. The other authority, Clayberg, gave no figures at all, but reported on a number of officers thought to be suffering from disc troubles as a result of riding in jeeps—probably as passengers rather than drivers.

Dr. Troup asked Mr. Simons questions on three points. Did the suspension seat he had described damp lateral movements ? Did it damp any angular movement of the seat, such as the sort of angular changes which would otherwise occur when one wheel rode over a stone ? Finally, were there any studies on the effect of these angular movements on the tractor driver ?

MR. SIMONS answered Dr. Troup by saying that most suspension seats on the market, including those made by his company, did not allow for compensation of any lateral (left to right) movement. On the second point, angular movement had vertical and horizontal components, of which the vertical component was usually the greater, and was allowed for by the suspension mechanism. The angular movement of the tractor in relation to the driver was being scientifically investigated by Dr. Dupuis, of the Max Planck Institute. He was being given competent medical assistance in taking X-ray cine photographs of a man moving in angular directions and being subjected to vibration.

Referring to Mr. Matthews' remarks, Mr. Simons said that there was evidence to show that in the 3–4 cycles/sec. range man's resistance to vibration in the vertical plane was much greater than in the horizontal plane, fore and aft. The threshold of resistance to fore-and-aft movement was much lower, and a pivoting seat which included a fore-and-aft component of vibration became uncomfortable at a lower amplitude than in a design with vertical movement only.

Turning to another point, Mr. Simons said that obviously there must be relative movement between a man sitting on a device isolating him from vibration and shock, and the steering column and controls, which would continue to move up and down with the vehicle. But the relative movement between the controls and a man sitting on a resonant cushion might be three to four times as great. In such a case, with a tractor vibrating at 3 cycles/sec., with an amplitude of $\frac{1}{2}$ – $\frac{3}{4}$ in.—a typical farm tractor tyre frequency on a gravel road—the driver would be vibrating at an amplitude of 1 – $1\frac{1}{2}$ in. The effect would be magnified.

MR. K. M. THOMAS (Goodyear Tyre Co. Ltd.) said that nearly all tractors had no suspension other than that provided by the tyre equipment. He asked for information on the order of natural frequency of tractor tyres, and asked how this was affected by such factors as tyre size, pressure and loading. Was any work proceeding on these lines, and why was no work in hand on tractor suspension as such ?

In reply, MR. SIMONS said that his company had carried out many tests on commercial tractor tyres, empty and liquid-filled. In comparing unballasted tyres with tyres ballasted with up to 80% of water, the characteristic frequency had increased from about 3 cycles/sec. up to 4 or $4\frac{1}{2}$ cycles/sec. The influence of tyre pressure made a difference of about $\pm\frac{1}{2}$ cycle/sec., ranging from $2\frac{1}{2}$ cycles/sec. on the very softest tyre to $3\frac{1}{2}$ or 4 cycles/sec. on very stiff types at high pressures. With commercially-available tyres the characteristic frequency of the tractor mass ranged between 2 and 5 cycles/sec. On very large earth-moving machines with wheels of 10–12 ft. diameter, the frequency might be as low as 1 cycle/sec. Isolation against such a characteristic required different measures than simply fitting a suspension seat.

MR. J. MATTHEWS (National Institute of Agricultural Engineering) referred to the dynamic characteristics of tractor tyres. Very limited information was available, and work had now begun at Silsoe on the stiffness and damping characteristics of tyres, which were the important parameters. Unfortunately, both these parameters changed with varying amplitude, which made a rigorous mathematical consideration difficult. There were also difficulties in calculating the effects of the tangential load force on the dynamic parameters. He felt it was necessary to get away from laboratory tests and put loading cars behind tractors to find out the effect on bounce and stiffness.

He felt that alternative forms of suspension were desirable, but that these were not fitted to tractors because of the difficulty of devising suspensions suited to the high load chracteristics of the tractor. The problem was much more difficult than with road vehicles.

MR. SIMONS commented that a simple springing system had been quite satisfactory in the days of steel-wheeled tractors moving at slow speeds. The introduction of pneumatic rubber tyres, causing the tractor to vibrate at more nearly the natural frequency of the human body, had made the problem more severe.

MR. P. HEBBLETHWAITE (National Institute of Agricultural Engineering) referred to designs of tractor which allowed the driver to stand up. A change of posture was a great thing from the point of view of fatigue, and figures had been quoted earlier showing the efficiency of the standing position in respect of damping. He asked if, in addition to the provision of suspension seating, it was desirable that operators should be able to drive tractors while standing.

MR. SIMONS replied that most farm tractors he was aware of made some provision for stand-up driving by allowing the seat to be tipped back or to move on long slide rails. Some kinds of vehicle were not provided with seats at all, so that operators had to stand all day. This allowed good vibration isolation, but meant that operation was fatiguing.

MR. T. H. E. HARRISON (David Brown Industries, Ltd.) asked if any work had been done on intermittent vibration. Mr. Cox had said earlier that the human body was less able to withstand intermittent than continuous noise. Was there a similar effect with vibration ?

MR. SIMONS replied that the best definition of an intermittent vibration was a single shot. Much work had been done on the ability of the human body to resist single and repetitive shots, and had been published by the United States Air Force. This included work done in this country on the effectiveness of crash helmets in protecting the head. When a vehicle wheel hit a bump it became energised, and tended to regain its position by going through a decay curve at the natural frequency of the mass of the chassis on its tyre. Isolation from this natural frequency was the objective he was concerned with, rather than the provision of a single shock absorber mechanism which just operated during the onset of a single shock.

MR. D. R. BOMFORD (Bomford Bros., Ltd.) referred to vibration effects experienced commonly in earlier days—when operating steam engines with steel cross-heads, or steam-handled cultivators, or on horseback. Was the problem one of a different kind of vibration period, or had the human race weakened in the spine—or in the heat ?

MR. SIMONS said that Mr. Bomford's examples confirmed that man found the general frequency at which he walked and ran to be preferable. At a resonant frequency of about 4 cycles/sec., man vibrated violertly and was very uncomfortable.

DR. J. D. G. TROUP (Guy's Hospital) said he had the impression that it had been assumed that all the damage to health caused by tractor driving was due to vibration. Undoubtedly, there was a good deal of truth in this supposition ; vibration caused a lot of distress, and might even cause damage. In their admirable Paper, the Roseggers merely instanced the amount of ill-health, with X-ray evidence of degeneration and so on, associated with tractor driving. Whether or not that was due to vibration was entirely open to question. More work had been done on vibration that on any other aspect, and valuable work in the Bostrom laboratories in the U.S.A. had made it quite clear that vibration was one of the most important factors.

In his Paper, a translation of which had appeared in "Agricultural Engineering," Dupuis had referred to many of the factors of good tractor seat design—the shape of the seat, its inclination, the angle of the knee for clutch operation, etc. The whole business of clutch layout was very important. If the back was not properly supported when the feet were pressing pedals, rotational stressing might occur. The one-sided jolting of the tractor axle, causing a change in the angle of the seat, caused lateral deflection, and so on. A lot of stresses on the lumbar spine, particularly angular and rotational stresses, might be contributing to spinal damage. No work on this aspect had been done so far, but it was important that it should be investigated eventually.

Dupuis had not said very much about the shape of the seat or the height and inclination of the seat and the back, and Dr. Troup thought all of these were important. Studies in other industries had made it quite clear that the shape and form of the seat were of great importance in connection with lumbar troubles. The adjustment of the seat for different sizes and shapes of tractor driver was another factor again, about which he would like to hear comments.

Dr. Troup felt that, quite apart from actually sitting on and driving the tractor, the handling and hitching of implements to the tractor drawbar or 3-point linkage were activities which could cause very serious stresses in the spine, and that this aspect should be investigated.

MR. SIMONS said he wished to confirm the importance of adjustment for varying sizes of driver, and of his location with respect to the steering wheel and controls. A telescopic steering wheel could be a very important feature in catering for various heights of driver, which might vary within the British export market for 5 ft. to over 6 ft.

DISCUSSION—PAPER III

MR. J. KILGOUR (National College of Agricultural Engineering) said that, in his view, safety cabs would be useless unless they were equipped with safety belts for the driver, or padding inside the cab. Either of these measures would restrict the driver's ability to operate the tractor, and he thought the only practicable way to avoid accidents was to educate the driver.

Replying, MR. MANBY said that in Sweden there had only been one fatal accident since 1959, when the fitting of safety cabs became compulsory. This was in the case of a man who tried to jump clear and was rolled on. Up to 1959 there were about 25 fatalities a year.

He agreed that safety belts would not be used in practice, but the evidence had not shown the bruising and injury sustained by operators, in cabs that would withstand crushing, to be unduly severe. He was more concerned about the whiplash effect on the neck experienced when a backward roll was suddenly stopped. He had consulted Dr. Troup about this, and on the whole it seemed better to stop the roll than to let it build up unchecked. Further evidence was required.

Two deaths, to his knowledge, had been prevented in this country within the last year by using safety cabs with anti-roll horns—one incident in Brecon, and one near Kendal. Both drivers were able to go on working after their tractors had been pulled back on to their wheels.

MR. H. C. MASON (National Farmers' Union, London) said that, although the legislation in Sweden applied to new tractors, the majority of tractors in use were still not fitted with safety cabs. It seemed to him that there was an important psychological effect, and that the operators not protected by safety cabs were so much more aware of the possibility of overturning that they were correspondingly more cautious.

MR. MANBY said that there had, in fact, been accidents in Sweden with tractors not fitted with safety cabs. However, he agreed with Mr. Mason's suggestion about increased awareness of the dangers involved. The number of fatalities due to tractors overturning in Britain in 1963 was about 27, which was a reduction of about 10 or 12 compared with the average of previous years. This could well be due to a psychological effect.

MR. J. M. CHAMBERS (Harry Ferguson Research, Ltd.) said that his colleagues in Sweden had investigated some 50 cases of tractors fitted with safety cabs which had overturned. There had been no fatalities, and it was estimated that without safety cabs probably 48 of these accidents would have been fatal.

MR. G. M. YOUNG (Salisbury) asked if a safety hatch in the cab roof, as shown in one of Mr. Manby's films, was a desirable feature.

MR. MANBY replied that the safety cab in question was a Swedish design used in connection with logging operations in the forests. These involved driving on frozen rivers and lakes, and there was a danger that the ice would give way, so that an overhead exit was vital. The current trend in Sweden was to use safety frames covered by canvas cabs which could be taken off when conditions made it desirable. It was thought, in any case, that canvas cabs were quieter and more acceptable to users. In drawing up the British Standard for safety cabs, they were ensuring that there would be at least two avenues of exit and not just one as in some cabs at present.

Answering further questions by Mr. Young, Mr. Manby said that there was a possibility with canvas cabs that the driver might be pushed through the canvas and seriously hurt if rolling continued. It was most important to prevent further movement after the initial overturning, and then the risk of fatal injuries would not be very great. Eventually there would inevitably be fatal accidents with so-called safety frames, and the legal question of responsibility would have to be decided. A manufacturer's defence in such a situation could well be that the safety cab had passed an official test. The type of windscreen fitted to a cab was clearly of importance, and provision had been made for this in the drafting of the British Standard.

MR. C. V. BRUTEY (National Farmers' Union) referred to the absence from most tractors of suitable fixing points for cabs, and asked if sufficient was known about the requirements to enable them to be specified.

In reply, MR. MANBY said that manufacturers could either provide fixing points for the attachment of proprietary cabs, or might make use of such fixing points for cabs of their own manufacture, which he would have thought a more logical development. Provision continued to be made for implements supplied in far smaller numbers than the potential market for tractor cabs, and he felt that the situation must change.

Answering a question from Mr. Hook (National Union of Agricultural Workers), Mr. Manby confirmed that the tractor manufacturers were not only in close touch with the work on safety cabs in progress at the National Institute of Agricultural Engineering, but also that they had been playing a large part in assisting safety cab manufacturers to develop and market their designs.

MR. YOUNG asked if the Ministry of Agriculture proposed to make it compulsory for safety cabs to be fitted to tractors in this country.

MR. MANBY said that he was not in a position to answer for the Ministry. His personal view was that it was desirable that safety cabs should be fitted to all tractors after, perhaps, 1965 or 1966. The capital cost would not be out of proportion to the cost of replacement tractors as a whole, and the " value per life saved " was likely to be a very high figure. In Britain all that was required was a safety frame with canvas weather protection when needed.

MR. A. G. HORSNAIL (National College of Agricultural Engineering) asked if one could assume that on the tractor of the future the driver would still be in the same place and require the same limit of protection. He noted that the tractors used in the tests described by Mr. Manby did not have implements attached, and he asked what effect attached implements might have.

MR. MANBY replied that he thought the driver's position in relation to the four wheels would not change very much. The driver still had to look forwards and, occasionally, to the rear. He should be given better means of access, better suspension and increased visibility, but he would probably continue to operate with implements designed very much on present-day lines, and any major change of his position was unlikely.

The effect of attached implements was in many cases to increase the likelihood of accidents. A lifted implement gave a higher centre of gravity, a load behind a tractor might exert a greater gravitational force, a trailed machine might start to jack-knife, and so on.

Apart from simply driving over the edge of a ditch, it was very difficult to make a tractor overturn, and for this reason the N.I.A.E. tests introduced an artificial factor in the form of speeds of operation which no sensible driver would use on steep hills, simply to insure overturning. Automatic hitch releases were unlikely to be helpful for the same reason that automatic engine shut-off devices could not help, because they could not act quickly enough to prevent the movement which had triggered them from reaching its normal conclusion, resulting in overturning of the tractor.

MR. D. R. BOMFORD (Bomford Bros., Ltd.) said that in rolling sideways a tractor pivoted on an axis between the pivot point of the front axle and the point of contact between the rear wheel and the ground. This was part of a triangle which became broader behind the rear wheels, and it seemed to him that moving the centre of gravity backwards—for example, by mounting a plough —would increase stability rather than reduce it.

MR. MANBY agreed with these remarks and added that these conditions no longer applied when the front axle moved up against its stop, as then the axis of rotation was about a line joining the outer edges of the front and rear wheels on the side in question.

MR. HAM (Safety Officer, Adam Lythgoe, Ltd.) said that he had not found operator education to be a satisfactory answer to the overturning problem. In his view, the only solution was to fit safety cabs. His company had fitted over 20 such cabs, and he described an incident—one of those referred to by Mr. Manby— in which the cab, fitted with horns, had without any doubt saved the operator's life. The cab itself had sustained very little damage, and he was convinced that horns were a vital feature to prevent continued rolling.

MR. J. H. W. WILDER (John Wilder, Ltd.) said that Mr. Manby had discarded the idea of using safety belts, but he felt there was a case for doing so in order to prevent the operator from trying to jump out of the cab when the tractor overturned. There was one kind of safety belt which allowed the driver complete freedom of movement under normal circumstances, but which locked at once on deceleration. He thought safety belts of this type would be very suitable for use on tractors.

MR. MANBY replied that he had no doubt that safety belts could be very beneficial, if, in fact, they were used. But, because a tractor driver had to get on and off his tractor frequently, he felt sure that in practice they would not be used, and that the farmer would therefore not buy them.

DR. J. D. G. TROUP (Guy's Hospital) referred to Mr. Manby's earlier remarks, quoting his opinions on the question of allowing tractors to continue to roll or to check rolling at once. He emphasised that it was only a matter of opinion at present ; when it was possible to specify a standard hill and a standard fall or tumble of the tractor, it would be possible to measure the various decelerations, by using accelerometers in suitable places, for different types of roll. One would then be able to say with certainty whether a roll should be checked at once or not.

Finally, MR. MANBY said he was grateful to Dr. Troup for making clear what he had said about checking tractors from rolling. He hoped in the very near future to do some work with accelerometers and strain-gauged cabs in order to provide some information on which designers could work.

INSTITUTION REPRESENTATIVES ABROAD

AUSTRALIA

J. A. Atkinson, M.I.A.Mech.E., A.M.I.Agr.E.,
Department of Agriculture,
Box 36, G.P.O., Sydney, New South Wales.

CANADA

K. J. M. Godlewski, M.I.Agr.E.,
419, Glencairn Avenue, Toronto, Ontario, Canada.

EAST AFRICA

W. H. Boshoff, B.Sc.(Mech.Eng.), M.Sc.(Agric.Eng.), A.M.I.Mech.E., A.M.I.Agr.E.,
Makerere College, P.O. Box 262, Kampala, Uganda.

INDIA

D. P. Lalvani, B.Sc., A.M.I.Agr.E.,
c/o Tractors & Farm Equipment, Ltd.,
P.O. Box 3302, Madras 34, India.

ITALY

A. S. Trotter, A.M.I.Agr.E.,
Villa Ferrari, Via Montesanto, Cernobbio, Como, Italy.

NEW ZEALAND

M. W. Cross, A.M.I.Agr.E.,
Massey Agricultural College,
Palmerston North, New Zealand.

NIGERIA

R. T. Lewis, B.Sc.(Agric.), M.Sc., A.M.I.Agr.E.,
University College, Ibadan, Nigeria.

RHODESIA

L. Tourle, M.I.Agr.E.,
c/o C. B. R. Bentall, Ltd.,
Box 1875, Salisbury, Southern Rhodesia.

REPUBLIC OF SOUTH AFRICA

C. S. L. Frances, M.I.Mech.E.(S.A.), M.I.Agr.E.,
c/o T. F. Mackenzie, Esq.,
P.O. Cramond, Natal, South Africa.

UNITED STATES OF AMERICA

To be appointed