

DEVELOPMENT OF NEW METHODS: ERGONOMIC ASPECTS

by J. D. Matthews

Summary

When developing a new method very careful consideration must be given to the ERGONOMIC aspect. The International Labour Office has defined ergonomics in the following way: "The application of the human biological sciences in conjunction with the engineering sciences to achieve the optimum mutual adjustment of man and his work, the benefits being measured in terms of human efficiency and well-being."

From this definition it can be seen that many and varied factors require consideration. In factory or workshop conditions sight, lighting, ventilation and heating spring immediately to mind. In forestry, noise and vibration are important in the use of chainsaws, the comfort of tractor drivers in having sprung seats and these being in such a position that no undue strain is involved in getting to the controls.

The National Institute of Agricultural Engineering commenced its work as a Department of Oxford University in 1924. Later, after the Second World War, it became the responsibility of the Minister of Agriculture via the Agricultural Research Council. They are responsible for a considerable part of the design and testing of agricultural machinery. In particular they have studied the effects of this machinery not only on the agricultural crops and land, but on the farm workers themselves.

The Institute has given considerable assistance to the Forestry Commission with regard to the question of chainsaw noise and vibration, the construction and testing of safety cabs and the testing of tractor seats. The outcome of the work has been of great value to the Work Study Branch and therefore to both management and men in the Forestry Commission.

Introduction

1. Ergonomics may be defined as a scientific study of the factors affecting a man at work. The terms human factors or human engineering are often used particularly in the United States of America to describe a very similar area of interest. The subject of ergonomics developed during the last World War when equipment for military use had become much more sophisticated and needed to be operated efficiently within an environment

which was both physically and mentally extremely taxing. To help ensure this efficient operation, teams of specialists in different scientific disciplines including engineers, medical personnel, physiologists and psychologists were drawn together and it is this marriage of the engineering, physics and mathematics on the one hand and the human biological sciences on the other hand from which the technology of ergonomics has sprung. However, although this wartime period undoubtedly saw the organisation of the technology and a very great increase in the rate of staffing and the rate of acceptance of the area it is correct to point out that as early as the 1930's formal studies were being made, notably in Germany, of the arrangement of certain agricultural equipment in order that it should best suit the physical characteristics of the operator.

2. Nowadays the majority of technological countries employ small numbers of researchers to deal with aspects of ergonomics in relation to agricultural or forestry equipment. Ergonomists are being trained in graduate and post-graduate courses at universities in many countries although it is probably still the convert to ergonomics from an original training in some other subject who is carrying out the greatest amount of ergonomics research in these fields.

3. At the National Institute of Agricultural Engineering we have been carrying out research into noise and vibration on agricultural equipment for approximately a decade and for the last five or six years have had an ergonomics research section with a wide programme of research into a variety of subjects dealing with the environment, the design of an operator's workplace, the efficiency of work, particularly in repetitive tasks such as fruit picking or inspection, and safety. This paper will describe some of the studies only which appear to have significance to forestry work.

4. The relationship between ergonomics and work study has unfortunately seldom been sufficiently close. Clearly the aims of designing a task which can be efficiently carried out with an adequate provision for the welfare of the worker is common to the two subjects. The knowledge which the ergonomist has about the methods of measuring the workload on the operator and his knowledge of the factors affecting working efficiency clearly must be borne in mind by the work study specialist whereas the latter's methods of analysing the task

and the way in which it is being carried out should be of great use to the ergonomist in detecting and quantifying such aspects as fatigue, the effect of stresses on performance and the effect of many equipment design variables on performance. A paper describing physiological and psychological methods which might be employed by work study specialists to measure work has recently been prepared by Tomlinson.¹

Handle Vibration

5. Mechanical vibration is generated in most equipment which incorporates a power unit due to either unbalance of rotating parts, inertia forces of reciprocating parts, mechanism impacts or friction, or reactive forces between the powered equipment and materials on which it is being used. An example of such a piece of equipment is clearly the power saw and the vibration of chain saws driven by internal combustion engines is well-known. Vibration of a mechanism is likely ultimately to have a damaging effect on the mechanism itself but in many cases including the power saw, the vibration is also transferred to a human operator and can be a source of physiological damage, discomfort or annoyance to the operator. On chain saws, this vibration which arises mainly from unbalance within the rotating and reciprocating members of the engine, is transmitted to the hands of the operator where it has been identified as the cause of neuro-vascular diseases commonly called Reynaud's Phenomenon. This group of diseases have long been recognised in connection with power tools used in shipbuilding and engineering industries² but surveys over the last decade and more have shown the complaint to be common among regular chain saw operators.³ The symptoms of the disease are numbness of the fingers, blanching, and, particularly in cold weather, pain. Considerable medical attention has been and is being focused on this complaint within the United Kingdom by the University of Dundee and the Forestry Commission, although N.I.A.E. work has generally been limited to the measurement and analysis of handle vibration on chain saws and as well as on many other tools and to support of the Commission in their attempts to persuade manufacturers to produce saws with decreased vibration of the handles. We remain convinced that the incorporation of anti-vibration mounts on the handles is the most practicable and acceptable solution at this stage, but it is probable that in many individual cases there is still scope for improving the amount of vibration reduction by a correct choice of anti-vibration mount type, its stiffness and inherent damping.

Table 1
SUMMARY OF VIBRATION AMPLITUDES
OF THE HANDLES OF "TRADITIONAL" (FIXED)
AND "ANTI-VIBRATION" CHAIN SAWS

Type of Handle	Vibration Amplitude in Microns	
	Front Handle	Rear Handle
Traditional (Fixed)	290	700
"	330	580
"	360	440
"	420	490
"	440	490
"	530	580
"	810	530
Anti-vibration mounted	95	210
" " "	107	230
" " "	110	290
" " "	150	170
" " "	160	390
" " "	160	150
" " "	300	560

Table 1 shows the comparative magnitudes of vibration of the front and rear handles of saws available up to two or three years ago where the handles are rigidly mounted and more recent models fitted with resilient mounts. Clearly the resilient mounts have greatly reduced the vibration level which in this case is given as the assumed vector value calculated from the root mean square magnitude of the amplitude of each of the three mutually perpendicular components. The principal frequency component of the vibration normally corresponds with the rotational speed of the engine and is likely therefore to be up to 150 Hz at the highest engine speeds and perhaps as low as 20-30 Hz when the engine is idling. For maximum vibration attenuation the natural frequency of the mounts should be as low as practical and preferably not greater than half of the frequency of any principal component of vibration present.

In practice the very large range of vibration frequency due to the large range of engine speed makes this extremely difficult but we find that a mount having a natural frequency on the saw of 15-20 Hz gives a good attenuation. Although coil springs have been successfully used in this service, rubber mounts have the advantage that there is some inherent damping which avoids serious resonance problems when the incident vibration happens to correspond with the natural frequency of the mount.

Noise

6. By far the greater proportion of our researches into the effects and the abatement of noise has been concentrated on the agricultural tractor. To a large degree, however, these effects and the solutions of the problem investigated are applicable to other equipment, particularly to other types of vehicle and applications of the combustion engine. More limited studies have been carried out on noise from chain saws, including brief investigation of optimum engine silencing arrangements and on noise from plant and animals housed in farmstead buildings in relation both to the workers within those buildings and the nearby residents.

7. The terminology used in the analysis of noise could occupy a paper in itself⁴ and will only be very briefly dealt with here. Whether one is considering the effect of noise on hearing, on personal comfort, on communication between individuals, or as a stress affecting the work of a person, since the intensity of noise varies over such a wide range with that likely to cause permanent immediate hearing damage for example being approximately 10^7 times that just audible, it is most usual to describe the magnitude of noise intensity on a logarithmic scale using units of decibels (dB). The most important relationships to bear in mind are that a difference of 10 dB represents a ratio of ten times the noise intensity or that the addition of two separate noise components of equal intensity will result in a total noise having an intensity 3 dB higher than either of them. As with most human sense organs the subjective sensation of noise loudness is not linearly related to the intensity but is in itself of a logarithmic nature, and from experiments with large panels of listeners it has been concluded that a difference of 10 dB in intensity is normally rated as a loudness ratio of 2 : 1.

8. It is well-known that the ear is not uniformly sensitive to different sound frequencies or tones and this therefore requires that the spectrum of the noise be known at least crudely if a proper assessment is to be made of noise loudness. Similarly each of the other factors, hearing damage, speech interference or annoyance are also affected to a different degree by different sound tones. In describing the tone content of a noise it is usual to analyse the total noise into octave or 1/3 octave frequency components although for more rapid analysis a form of electrical filtering, which can be incorporated in measuring instruments has been derived enabling the frequency components to be weighted in proportion to their effect on the ear. Noise measurements made with an instrument including this filter would commonly be reported

as decibel A (dBA) units. Decibel A has particularly been found to give a good measure of the loudness of combustion engine noises and other noises having a similar spectrum; it also appears likely at this stage to be adopted as the commonly used noise unit to describe the hearing damage potential of a noise. However it must be borne in mind that a degree of approximation is present in dBA measures and that for a more detailed and accurate assessment of a noise it may be thought desirable to use many other more specific criteria to describe the noise such as the decibel B or decibel C, Sone, Phon, Noy or Noise Rating Number.

9. In measuring and analysing a noise it is common to use a sound level meter, which consists essentially of a microphone fitted with various devices to improve the omnidirectional sensitivity or to reduce the wind effects, coupled to filtering networks to enable dBA or other measures to be directly indicated and a meter which typically covers the range 0-140 decibels. Where a frequency analysis of the noise is required this meter may be coupled to octave, 1/3 octave or narrower band filters, whilst more sophisticated equipment is likely to include automatic graph plotters and automatic filter switching arrangements to enable these analyses to be carried out automatically. A simple portable sound source is usually available for calibration of the equipment. Where the noise is not continuous as in the case of a chain saw cutting logs, a burst of sound may be recorded on a precision tape recorder and replayed into the filtering and measuring equipment either continuously by making a loop of the tape holding the noise record or on repeated occasions to allow values to be determined for each octave of 1/3 octave band frequency.

Table 2

NOISE-INDUCED HEARING DAMAGE
INDICATED BY AN AUDIOMETRIC SURVEY OF
TRACTOR DRIVERS

Age range of tractor operators	Proportion of men with defective hearing	Proportion of men with speech frequencies affected
18-24 years	5/11	0/11
25-34 years	6/14	3/14
35-44 years	14/26	7/26
45-54 years	5/11	2/11
55-64 years	6/8	4/8
	Total 36/70	Total 16/70

10. On tractors we have, from a survey carried out in the area surrounding the N.I.A.E., shown that noise-induced hearing loss is a serious problem. (Table 2).⁵

It is probably significant also that at the time this survey was carried out in 1967 and the majority of tractors were not fitted with any form of cab whereas since then cabs have become very much more common and our very extensive measurements in connection with tests of safety cabs suggest that in the large majority of cases noise levels will have been increased by the presence of the cab.⁶ Our studies of possible solutions to the noise problem on the tractor indicate that because of the multiplicity of primary and secondary sources including the engine exhaust outlet, the engine walls, the engine air intake, the transmission casing, the cab structure, the auxiliaries such as the fuel tank and fenders and in some cases the implement, several separate measures are required in order to achieve a satisfactory noise level for the operator.^{7,8}

Despite earlier remarks about the effect of cabs, we conclude that an acoustically designed cab can reduce the noise level very significantly below that with no cab fitted and moreover on the majority of tractors could probably be designed to reduce the level below 90 dBA which we would propose ought to be the aim if 95% of users are to be protected from some damage to the hearing over a lifetime of use of the tractor.⁹ We consider that the more important treatments to the cab are:

- (a) to include sufficient acoustic absorbent material as lining to the roof, sides and the doors to reduce the reverberation of the cab and subsequent build-up of noise.
- (b) to effect a good seal particularly on the front walls of cabs in order to reduce the ingress of noise from the engine walls and other components surrounding the engine.
- (c) to isolate the cab structure from the vibration of the engine transmission unit to which it is normally attached by the use of resilient mounts.
- (d) to include a floor to the cab to reduce the entry of noise from the transmission housing.

In addition further attention needs to be given to the siting of the exhaust outlet and air intake and in some tractors to the design of the fan blades. Table 3 shows the progressive effect of various treatments carried out in our research work and indicates the practicability of achieving 90 dBA at least on some vehicles. However, we are concerned that on smaller tractors in particular where the operator sits virtually astride the transmission housing, some more revolutionary changes to the

design may be necessary in order to achieve this level.

Table 3

SUMMARY OF NOISE REDUCTIONS
ACHIEVED BY PROGRESSIVE TREATMENTS
OF A TRACTOR AND CAB

Treatment	Typical Reduction*		
	dBA	Sones	NR
Absorber in roof, on doors and mudguards	5	12	3
Sheet metal bulkhead and floor	4	30	3
Anti-vibration mounts fitted to safety frame	2	30	2
Safety frame filled with sand	1.5	20	3
Bonnet Treatments	1	14	3.5

* Original levels typically 101 dBA, 160 Sones, NR 98.

Seating and Ride Vibration

11. There are two main aspects to the design of seating on vehicles, the anthropometric design in providing a secure and anatomically correct support for the body and the control of vibration induced by motion of the vehicle over often very rough terrain to reduce the discomfort and the damage to health both known to be caused by ride vibration particularly from off-the-road vehicles.¹⁰

12. The optimum shape of vehicle seating and its positioning in relation to principal controls has been the subject of study for many years and Table 4 shows recommended dimensions for agricultural tractor seating. That the provision of a correct seating arrangement to allow optimum posture can be important in determining working efficiency has been shown by experiments which we have carried out on a transplanter.¹¹ Relative positions of seat and footrests to the planting wheel and hence to the hand positions, were varied on a commercial machine and whilst this was being used in a simulated laboratory task, recordings were made of the electrical activity in the lumbar muscles of the back. These recordings indicated the posture on the machine as originally provided by the manufacturer to be inferior to others which could be arranged and in subsequent field trials, in which the original machine and one modified to provide the posture indicated to be best by the electromyogram recordings were operated side by side, the performance of operators

Table 4

RECOMMENDED ANTHROPOMETRIC CHARACTERISTICS OF A TRACTOR SEAT

Dimension	Recommended Value	
	Min.	Max.
Horizontal distance from front edge of seat pan to the seat reference point (S)	34 cm	42 cm
Width of seat pan measured on seat surface	43 cm	—
Width of seat pan measured at a point 8 cm above and 15 cm forward of the seat reference point (S)	45 cm	—
Height of lumbar support	24 cm	—
Downwards angle of tilt of seat pan to rear	3°	10°
Range of seat suspension bodyweight adjustment	50 kg	125 kg
Horizontal adjustment of seat with pedals operating in a predominantly horizontal direction	15 cm	—
Horizontal adjustment of seat with pedals operating in a predominantly vertical direction	10 cm	—
Forward horizontal component of motion of seat reference point (S) for full suspension travel	—	2.5 cm
Rearward horizontal component of motion of seat reference point (S) for full suspension travel	—	1.5 cm
Transverse tilt for a load of 100 kg applied alternately 15 cm either side of the longitudinal median plane of the seat 20 cm forward of the seat reference point (S)	—	5°
Height of seat reference point (S) above the normal resting place for the feet	38 cm	48 cm
Vertical distance, lowest part of steering wheel to front of seat pan surface	20 cm	—
Horizontal adjustment, seat reference point (S) to central transverse axis of the steering wheel	—	55 cm
Square root of the sum of the horizontal and vertical distances from the seat reference point (S) to the fully depressed pedals with the vertical plane of the seat reference point (S) not less than 40 cm from the rearmost part of the steering wheel	—	100 cm

was compared by recording the number of errors made by the operators as a result of which plants were inadequately rooted in the ground. Table 5 shows that the modified machine gave rise to fewer errors than that as originally provided.

13. There is evidence from more than one country of a relationship between spinal and stomach health and tractor driving and it would certainly appear likely that in forestry where terrain is extremely uneven and the operators are likely during extraction and other work to frequently turn the body to the side or rearward that a similar risk to health could exist. There is much evidence that the incidence of these complaints is related to vibration level and certainly the vibration severity we have measured on agricultural tractors is in excess of that considered acceptable in an I.S.O. recommendation proposal, probably soon to be published. Suspension seating may reduce the vertical vibration level by about a half and one section of our research has been directed to the development of a British Standard¹¹ and latterly an international (OECD) test procedure for tractor suspension seats. As with the resilient mounts for chain saw handles, the correct choice of suspension stiffness and damping is vital if

good vibration reduction is to be achieved. Table 6 summarises the vibration performance of some of the seats tested at N.I.A.E. and demonstrates the large range of performance with the absorption of vibration being about 50% on the best seats, but changing to a significant amplification of vibration on poorly designed models.

14. Suspension seats show two limitations which suggest a more fundamental approach will be needed to deal with the ride problem in the future. They do not absorb horizontal or pitch and roll components of vibration and they do lead to a relative motion between the partially stabilised man and his controls which move with the vehicle. A vehicle cabin mounted on a suspension designed for vertical and horizontal ride vibration attenuation is one solution which is being studied.¹² The use of wheel suspension also warrants research if the problem of variable weight distribution of the tractor can be overcome.

Conclusions

15. It has only been possible to deal with a few examples of the application of ergonomics and because of the nature of our organisation these

Table 5

COMPARISON OF PLANTING ERRORS
ON ORIGINAL AND ANTHROPOMETRICALLY
IMPROVED TRANSPLANTERS

Trial details	Duration of run (min.)	Errors— original machine	Errors— modified machine
Inexperienced operators	—	4	2
	3.5	6	3
	3.7	7	1
	4.0	7	3
(Mean number of plants per run = 85)	4.0	4	4
	3.7	5	2
	4.0	3	1
	3.8	3	2
	MEAN	4.8	2.2
Experienced operators	18	2	1
	17	1	9
	15	10	3
	16	2	8
	19	3	4
(Mean number of plants per run = 540)	17	8	4
	16	11	5
	14	15	6
	MEAN	6.5	5.0

Table 6

VIBRATION TRANSMISSION OF SOME
SUSPENSION SEATS FOR TRACTORS
TESTED AT N.I.A.E.
(Vertical component only)

Seat	Smoother surface (15 Km/h)	Rougher surface (5 Km/h)
A	0.45	0.70
B	0.50	0.65
C	0.65	0.75
D	0.70	—
E	0.80	0.90
F	0.90	1.00
G	0.90	1.05
H	0.95	0.95
I	0.95	0.75
J	1.00	0.95
K	1.10	1.05
L	1.25	1.10

have been mainly connected with research into individual and relatively narrow problems connected with welfare or working efficiency. However, in agriculture and probably also in forestry the greater improvement at this stage is likely to result from a much greater application of known information rather than from further research. Because of this we have devoted some of our time to the production of a handbook for the designers of equipment.¹³ It is to be hoped that in addition to being read and used by these people, sufficient notice will be taken by advisory staff and by other research scientists including work study specialists with the effect that we representatives of various specialisations may draw somewhat more closely together. A difficulty which both ergonomists and work study specialists will have recognised at a very early stage in their career is the great variability from person to person in rates of work, in requirements for workplace or environment, or in motivation. Although inevitably, this limits the precision with which we may quantify requirements and effects, it should not limit the enthusiasm or the thoroughness with which we approach our subjects since by allowing for this variability and harnessing its effects the relative improvements we achieve may be all the greater.

References

1. Tomlinson, R. W. *Ergonomics methods in Work Study*. Ergonomics Research Society/Institute of Work Study Practitioners/Trades Union Congress Joint meeting, London, 19 January, 1970.
2. Agate, J. N., Druete, H. A. A study of portable vibrating tools in relation to the clinical effects which they produce. *Brit. J. Industr. Med.*, No. 4, p. 141. 1947.
3. Keighley, G. D., Taylor, W., Pearson, J., Kell, R. L. Vibration syndrome in Forestry Commission Chain Saw Operations. *Brit. J. Industr. Med.*, Vol. 28, p. 83. 1971.
4. Cox, S. W. R. Noise measurement and analysis. *J. Inst. Agr. Eng.*, Vol. 20(1). 1964.
5. Stone, E. J. Occupational deafness and the hearing acuity of employees in the agricultural industry. *Proc. of Agric. Engng. Symp. Silsoe, U.K.* 1967.
6. Matthews, J. Tractor and Cab Noise—the Problem. *Proceedings of the N.I.A.E. Subject Day*, July 1970.
7. Matthews, J. The Control of Tractor Noise. *Proceedings of the N.I.A.E. Subject Day*, July 1970.
8. Talamo, J. D. C. The acoustic treatment of tractor cabs. *Proceedings of the N.I.A.E. Subject Day*, July 1970.

9. Tomlinson, R. W. A tractor noise limit according to predicted drivers hearing loss. *Proceedings of the N.I.A.E. Subject Day*, July 1970.
10. Matthews, J. Ride comfort for tractor operators. *J. Agric. Engng. Res.* Vols. 9, 10, 11. 1964-66.
11. British Standards Institution. B.S. 4220: 1967. *Methods of test for seats on agricultural wheeled tractors. Part 1. Tests on artificial track.*
12. Hilton, D. J. *Design considerations relating to tractor cabin suspensions.* Paper to the I.Mech.E Symposium on Agricultural and Allied Industrial Tractors. October 1970.
13. Matthews, J., Knight, A. A. *Ergonomics in Agricultural Equipment Design.* N.I.A.E. Silsoe. 1971.