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ERGONOMICS IN MACHINE DESIGN

(A CASE-STUDY OF THE SELF-PROPELLED COMBINE HARVESTER)

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1. SCOPE OF THE STUDY

1.1. SCOPE OF THE STUDY

In the framework of modern economics agriculture cannot possibly work without rationalization and mechanization, which replace human work with machines and contribute to raising productivity. An important part of this process is the desire to make the job easier and shorten the working hours.

Mechanization not only changes the character and structure of labour in agriculture, but also influences the nature of the work load. Instead of delivering energy, the main issue now is the perception and processing of information, as well as controlling and regulating the work being done by machines. More and more the accent is shifting to tasks which appeal to the capacity of man to process information.

There is a need for increased capacity that will lead to higher speeds in the future, whilst bigger and heavier machines will be used. It cannot be assumed that human beings will be able to continue adapting themselves to the machine and – as a consequence of too high a load – will hazard occupational diseases and reduced performance.

By means of principles, parameters, procedures and criteria from various disciplines, ergonomics can contribute to:

a. The design of an optimum man-task system;
   (Primary or preventive ergonomics)
b. The testing of a man-task system;
   (Secondary or curative ergonomics)
c. The prediction of capacity and work load by using a man-task system.

The operation of the self-propelled combine harvester has been selected as the object of this study. The operator of this machine regulates the movement – direction and speed –, the mowing and threshing, the separation of kernel and straw, as well as the delivery of the product. Based upon the information obtained from crop, terrain and machine the operator has to decide on such an adjustment of the machine, which results in a process with a high capacity and a high quality of work.

Increase of the capacity can be realized by increasing the ground speed and/or the working width, which, however, involves higher information speed, more actions for operation per time unit and a higher operator's work load. This increase of capacity is limited by the work load of the operator, of whom great accuracy is expected.

The area of the main crops suitable for combine harvesting, as well as the production and number of combines in the world, have been listed in table 1. To indicate to what extent the crops are combine harvested: in Europe, North America and Oceania eighty percent and more of the cereals, maize, rice and

TABLE 1. Area of main crops suitable for combine harvesting, the annual production and the total of combines in use.

	Crops – in 1000 ha –					Combines		
	cereals	maize	rice	soya beans	total	annual production	in use	ha/ machine
Europe	169.830	14.397	642	865	185.734		1.258.556	147
N.-America	58.148	22.664	941	16.382	98.135		1.042.565	94
Latin America	14.000	24.500	5.500	600	44.600		36.300	1.228
Asia	167.500	25.000	115.000	15.000	322.500		37.000	8.716
Africa	42.800	16.000	3.300	40	62.140		24.000	2.589
Oceania	11.531	83	30	—	11.644		73.500	158
World	463.809	102.644	125.413	32.887	724.753	250.000	2.471.921	293

(Source: Claas-Marktforschung; 1969)

soya beans are combine harvested; elsewhere most of the work is still done by hand. The area of cereals and the total of combines in the Netherlands have been listed in table 2.

Suppose an average of 100 hectares per machine then almost 30% of the world area of the crops suitable for combine harvesting is combined at present; with an average capacity of 1 hectare per hour 250 million hours are annually spent on combine harvesting.

The study consists of the following parts (ZANDER; 1967):

1. Collecting data about the location and displacement of the controls for operating the machine, as well as the forces to be exerted, the body movements and their frequencies (lay-out studies);

2ª. Collecting data about the character and the extent of the loading components, as well as the influence they have on the work load of the man operating the machine (field experiments);

2ᵇ. Studying and analysing the loading components, as well as their influences on the performance and the work load of the man, by means of a simulator (indoor experiments);

3. Formulation of ergonomic parameters and criteria to design an optimum man-task system.

TABLE 2. Area of cereals and total of combines in the Netherlands.

	Cereals	Combines	
	– in ha –	in use	ha/machine
1950	495.107	1204	411
1960	511.694	3025	169
1965	485.215	6105	79
1970	363.828	7439	49

1.2. OBJECTIVES OF ERGONOMICS

One of the processes which led to the development of ergonomics was time and motion study. Credit for the development of time and method study is usually given to F. W. TAYLOR (1856–1915), for motion study to F. B. GILBRETH (1868–1924), an engineer, and his wife Mrs. L. M. GILBRETH, a psychologist, who studied the effective pattern of movements on selected foremen (BARNES; 1958). TAYLOR's approach implied the elimination of all unuseful work elements, so the remaining elements could be carried out in a more efficient way; his accent has principally been on the increase of productivity. The crux of these studies was the division of the whole job into small elements, which were separated by measurable points; by means of this division the process could be better analysed. GILBRETH thought the division made by TAYLOR still too rough and developed a system of elements (therbligs), which enabled him to analyse and to record each work element exactly. TAYLOR and GILBRETH may be looked upon as the precursors in the development of more modern analysing techniques, which are known as Predetermined Motion and Time Systems (MAYNARD; 1948).

In the beginning of this century work physiology was developed intensely in Europe as a reaction to the disadvantages of time and motion study, in particular the high work load and the high working rate. The work physiologists were less interested in an increase in productivity and concentrated their studies on a reduction of the work load. The research results were published in periodicals on physiology; they hardly influenced work-space lay-out in practice. Instead a divergence could be noticed between the theoretical people on one side and the practical people on the other side (LEHMANN, 1962; BOER, 1967).

Since 1920 in the United States of America modern scientific management techniques entered industry by the integration of man into complex man-task systems. This development was based upon the work of TAYLOR, GILBRETH, et. al., as well as the results of research on work physiology and experimental psychology. However, major emphasis was placed upon efficiency, as measured by speed and accuracy of human performance. At first this concept – 'human engineering' or 'human factors engineering' – had a disagreable sound, because people thought it inferred manipulating the workers (VAN WELY and WILLEMS; 1966).

During the Second World War human engineering had grown so much as a result of the need to extract maximum operational efficiency from the sophisticated equipment being developed and used in the very stringent environmental and psychological conditions dictated by the hostilities. The war brought closer together psychologists, physiologists, mechanical engineers and industrial engineers; this intensive approach in the military sector led to methods and results of research, which are useful in other sectors as well (LEHMANN; 1962). Another approach of human factors came more and more in the foreground; this approach implied that task and environment should be adapted to the man and led to a multi-disciplinary approach and systematic cooperation of technicians and other people in studying human factors. An immediate need was to find a name for this field. In England it was finally decided to coin the new word 'ergonomics' (ergos: work; nomos: laws in Greek). From this simple word other parts of speech could be derived and it was capable of translation into other languages (German: Anthropotechnik; French: l'Ergonomie) (MURRELL; 1965). Although in Western Europe the field is referred to as 'ergonomics', the title 'human factors engineering' is preferred in the U.S.A.

At the IV[th] International Congress on Ergonomics (Strasburg, 1970) CHAPANIS discussed some qualitative differences between 'ergonomics' and 'human factors engineering'. He stated:

> 'There is a genuine difference in flavour between ergonomics and human factors engineering: ergonomics seems to be more physiologically-oriented than does human factors engineering.
>
> Perhaps another way of saying it is that in America we have been somewhat more concerned with the integration of man into large machine systems; in Europe you have been more concerned with the welfare of the individual worker'.

Many definitions have been given of ergonomics from which more or less clearly the objectives can be derived. In the General Rules of the British Ergonomics Research Society, founded in 1949, the objective of this Society is described as follows:

> 'The object of this Society is to promote the study of the relations between man and the environment in which he works, particularly the application of anatomical, physiological and psychological knowledge, to the problems arising therefrom'.

In this concept we should interpret the word 'environment' in a broad way; it includes the direct work environment, as well as the organization of human labour (BOER; 1967).

The International Labour Office in his definition of ergonomics is recommending a balance between human interests and efficiency (I.L.O.; 1960):

> 'The application of the human biological sciences in conjunction with the engineering sciences to achieve the optimum mutual adjustment of man and work, the benefits being measured in terms of human efficiency and well-being'.

Starting from the technical and human possibilities, but leaning strongly towards the objective of occupational medicine, is the following wording, in which we see the scope and object of ergonomics (BURGER and DE JONG; 1962):

> 'The application of biological knowledge in the field of anatomy, physiology, experimental psychology and occupational medicine to the purpose of achieving an optimum man-machine system, in which a proper balance is maintained between work load and work capacity by seeing to it that the possible use is made of the worker's power and capabilities, in the interests of his own health (and dignity) and in the interests of productivity'.

Since ergonomists handle the knowledge of various disciplines in a specific way, every discipline, studying the relation between the man and his task, can contribute. This approach, as well as the duality in the other wordings – the welfare of the worker (a) and an efficient production (b) – underlies the following definition of ergonomics (ZANDER; 1965):

> 'Ergonomics is engaged with the work situation (man – task – environment) with the objective to come to a rational use of the human capabilities and to an optimum adaptation of the work situation to these capabilities'.

Ergonomics is a multi-disciplinary activity, it crosses the boundaries between many scientific and professional disciplines and draws upon the data, findings and principles of all of them. In analysing a man-task system there is primarily the contribution of many sciences like anatomy, physiology, psychology, engineering and management.

1.3. AN ERGONOMIC MODEL

The multi-disciplinary characteristic of a man-task system is shown in figure 1. A continual stream of information is received from the machine and the environment by the working man using his senses: *perception* (1), leading to perceptual load. The perception is followed by testing on the memory, and then to make decisions between alternatives to guide a specific operation: *selection* (2), leading to mental load. The output of man is muscle activity: *action* (3), leading to physical load. Through the action changes take place: *performance*. During this closed-loop process the man will continuously observe the effects of his actions, he will take new decisions and new actions to bring the system closer to its goal; this process is called *feedback*. Human beings must fit spatially in a man-task system; *anthropometry* is the discipline which is concerned with these aspects of the human body.

In the ergonomic model the term 'load' has been introduced. A working committee of the Commission for Labour Medicine Research of the Dutch Health Organization of T.N.O. proposed a concept of the physical load (CARGO; 1965); from this KALSBEEK (1967) came to a universal concept.

The following concepts are distinguished:

a. External load

The external load will be ascertained by the combination of the factors, which are inherent to the work situation and which cause reactions of man.

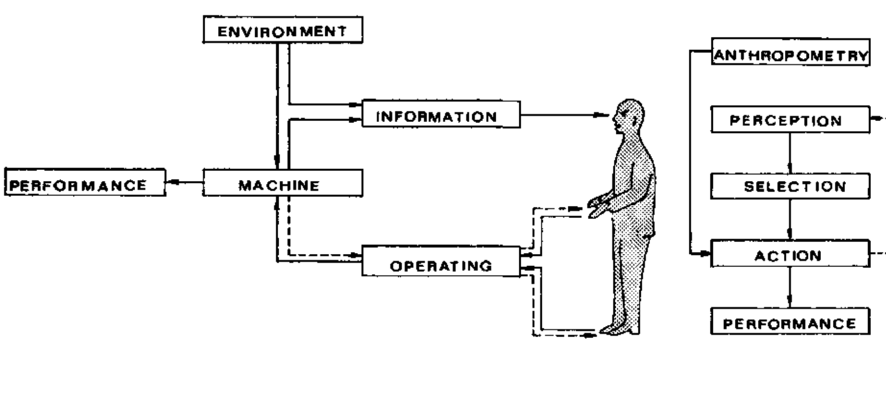


FIG. 1. Man – task system.

b. Functional load

By functional load is meant the combination of the phenomena caused by the external load.

c. Working capacity

By working capacity is meant the highest possible energy, that a human being is supposed to carry out in a given way of working during a certain period of time.

d. Degree of loading

The degree of loading is the relation between the functional load and the working capacity.

1.4. Features of a combine harvester

A brief description is given of the operations and product flow of a modern self-propelled combine harvester (figure 2):

a. Mowing

The crop is separated from the remaining crop by dividers (1) and guided to a cutterbar (3) by means of a reel (2). To pick up a previously cut swath there can

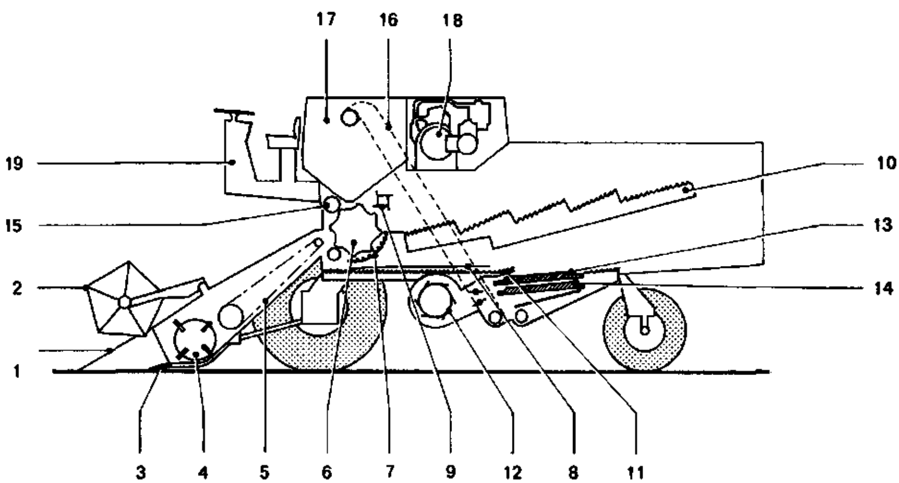


Fig. 2. Self-propelled combine harvester.

1 – divider	11 – collecting pan
2 – reel	12 – dressing fan
3 – cutterbar	13 – top sieve
4 – feed table auger	14 – bottom sieve
5 – conveyor chain	15 – return auger
6 – drum	16 – elevator
7 – concave	17 – grain tank
8 – preparing floor	18 – engine
9 – beater	19 – operator's platform
10 – shaker	

be installed on the platform a pick-up attachment; besides the cutting unit can be exchanged by a unit for picking maize. An auger (4) transports the crop to a conveyor chain (5); this will transport the crop to a threshing mechanism.

The reel is adjustable in horizontal and vertical directions and in speed; the cutterbar is adjustable in a vertical direction to realize a certain stubble-height.

b. Threshing

The threshing mechanism consists of a drum (6) and a concave (7). Most of the kernels fall with chaff and short straw through the concave on the preparing floor (8). Straw and some kernels come via the beater (9) on shakers (10), that free the kernels; through return gutters these kernels land on an extension of the preparing floor.

The number of revolutions of the drum is adjustable during work; the distance between drum and concave is sometimes adjustable during work.

c. Cleaning

The kernels falling through the concave or shakers come on the grain collecting pan (11). In front of the sieves is a dressing fan (12), which causes an air stream to blow all light material like chaff out of the machine; over the top sieve (13) the coarser dirt and short straw are removed. The kernels and unthreshed ears fall on the bottom sieve (14); the lastmentioned move on the sieve to the back and fall in an elevator (15), which brings this material once more to the drum. The kernels fall through the bottom sieve; by a second elevator (16) they are collected in a grain tank (17). By means of an auger the product can be delivered into a wagon.

An engine (18) not only takes care of the propulsion of the various elements, but also of the movement of the machine. The controls for operating the various components of the machine are located on the operator's platform (19).

1.5. Survey of the study

The study has been developed as follows:

1. The anthropometric characteristics of the human body, as well as the nature and frequency of the motions, are dealt with in Chapter 2 (Anthropometry); the data from the lay-out studies are discussed.
2. The activities in a man-task system are dealt with in Chapter 3 (Perception), Chapter 4 (Selection) and Chapter 5 (Action).
   It will be indicated which parameters from various disciplines have to be used, as well as the measuring procedures and criteria belonging thereto; the data from indoor and field experiments are discussed.
3. The results of the ergonomic system-analysis are dealt with in Chapter 6 (Ideal concept) and Chapter 7 (Summary and conclusions); the integration of the results from lay-out studies, indoor and field experiments is discussed.

2. ANTHROPOMETRY

2.1. INTRODUCTION

Human beings must not only fit spatially in a man-task system, they must also be able to move in the work-space. The data about the location and displacement of the operating controls, as well as the forces to be exerted, the nature and frequency of the movements – of primary importance for the work-space lay-out of a system – are determined by the characteristics of the human body.

Anthropometry deals with the measurements of the human body, including body dimensions, and the mechanical aspects of human motions, including consideration of range and frequency. With the aid of anthropometric data we can – by providing an optimum work-space lay-out, including a good posture – contribute to a considerable decrease of the work load and an improvement in performance as well.

2.2. BODY MEASUREMENTS

By statistical research carried out for the clothing industry and the military forces, the knowledge of body dimensions of large population groups has been considerably extended for several years. Various publication mention the dimensions of the human body, specified by sex, age and race (DREYFUSS, 1960; WOODSON, 1960; CHAPANIS, 1963; LUND, 1963; MORGAN, 1963; MCCORMICK, 1964; KELLERMANN, 1965; MURRELL, 1965; DAMON, 1966; LAZET, 1967). When using these data we must not look only at the mythical average, but at the large and small brothers (DREYFUSS; 1960). The ranges of body heights for different percentiles of the Dutch population are shown in table 3 (LAZET; 1967); these data are suitable for Europe and America (DREYFUSS; 1960).

In the design of work-space or other facilities, various considerations need to be taken into account, in particular: the type of data (1.) that would be most appropriate and the types of people (2.) who are to use the facility as related to the types of peoples for whom appropriate data are available (MCCORMICK; 1964).

TABLE 3. Body heights (in cm) for the Dutch population in age of 18–64 years.

Ranges	Males	Females
5th percentile	161,5	151,5
50th percentile	175,0	162,5
95th percentile	186,0	172,0

1. The type of data

For the designer's purpose, it is not really necessary to work with data on all 100 percentiles. Normally, collections of human engineering data skip the first and last five percentiles.

Where a facility can be adjusted (such as the position of a seat), it should be designed to accomodate a reasonable range of individuals, usually from the 5th to 95th percentiles; for deviating sizes there has to be sufficient space for an adaptation (DREYFUSS, 1960; MCCORMICK, 1964).

2. The type of people

The relevant body measurements for Dutch adults (50th percentile), necessary to define the dimensions of the work-space, are listed in table 4 (LAZET; 1967); the codes are shown in fig. 3.

Based upon the data in tables 3 and 4 the relevant body measurements for the other percentiles and other population groups can be obtained. When some dimensions of a population group are available (such as the body height), the relevant data for work-space lay-out can be calculated by a proportional enlargement or reduction (VAN WELY and WILLEMS; 1966).

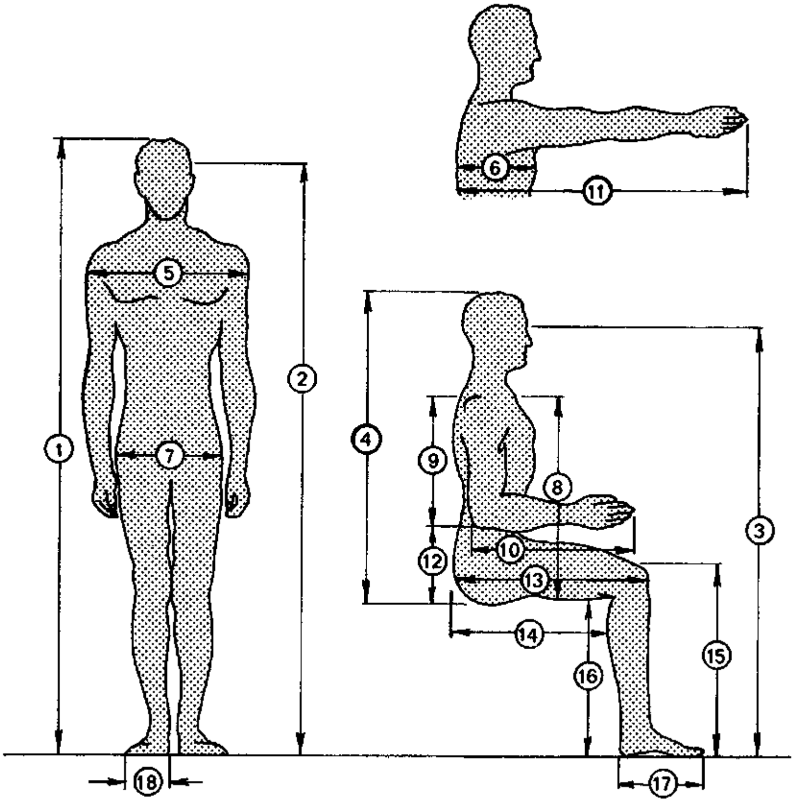


FIG. 3. Codes for body measurements (see Table 4).

TABLE 4. Relevant body measurements (in cm) for Dutch adults (50^{th} percentile).

Code	Measurements		Males	Females
1.	Height		175,0	162,5
2.	Eye height	: standing	163,5	152,5
3.	Eye height	: sitting	124,5	113,5
4.	Sitting height	: erect	93,0	82,5
5.	Shoulder breadth		45,5	40,0
6.	Chest depth		24,0	26,0
7.	Hip breath	: standing	33,5	36,0
	Hip breath	: sitting	35,5	38,5
8.	Shoulder height	: sitting	62,0	55,5
9.	Shoulder – elbow		41,0	36,5
10.	Forearm – hand		46,0	36,5
11.	Arm reach		72,0	68,0
12.	Elbow height	: sitting	21,0	19,0
13.	Buttock – knee		60,0	56,5
14.	Seat length		48,5	46,5
15.	Knee height	: sitting	55,5	51,5
16.	Seat height		45,0	42,5
17.	Foot length		28,0	24,5
18.	Foot breath		10,0	9,0

When operating a machine in a sitting position the way of working is strongly governed by the work-space. The seat must be adjustable – in a fast, easy and safe way – in horizontal and vertical directions to realize an adaptation to the measurements of various population groups (DUPUIS; 1955).

The anthropometric data for a seat are listed in table 5 (DREYFUSS, 1960; DUPUIS and HARTUNG, 1966; DUPUIS, 1967).

2.3. BODY MOTIONS

In order to realize a good performance it is necessary, that the movements of the body members are such that a favourable load originates. By moving symmetric body members in synchrony, simple and logical motions are made, which can be performed almost automatically by the central nervous system. The bigger the mass of a body member, the more energy it takes to start the motion and keep it moving; motions should flow into one another smoothly. If the mass of a body member increases – with constant external load – the number of motions per unit of time must be reduced; this is given by the following research results (STIER; 1959):

- Finger : 6 motions
- Hand : 3 motions
- Forearm: 1 motion

These results are according to the principles of motion economy, which say that motions should be confined to the lowest classification with which it is possible to perform the job satisfactorily.

TABLE 5. Anthropometric data for a seat for vehicles.

Code	Features	Criteria
5.01	Shape	rectangular, rounded
5.02	Dimensions (mm)	
	· length	380
	· width	450
5.03	Force (N)	-
5.04	Displacement (mm)	+50 and −50 (minimum)
5.05	Location	see fig. 4[a] and 4[b]
5.06	Motion	only vertical
5.07	Inclination	
	· direction	backwards
	· angle	3–5°
5.08	Material	warmth-isolating, ventilating
5.09	Surface	waterproof cover, profiled
5.10	Adjustment (mm)	
	· horizontal	+75 and −75
	· vertical	+50 and −50
5.11	Support	
	· sidewards	150 mm above seat (maximum)
	· backwards	240 mm above seat (minimum) 400 mm above seat (maximum)
5.12	Miscellaneous	
	· seat height (mm)	400

TABLE 6. Maximum movements of relevant body members.

Body member and movement		Degrees
1. Head		
rotation	(right + left)	158
flexion	(dorsal)	61
flexion	(ventral)	60
2. Arm at shoulder		
flexion	(forward)	138
extension	(backward)	44
3. Forearm at elbow		
flexion	(bend)	143
pronation	(turn in)	113
supination	(turn out)	77
4. Hand at wrist		
flexion	(bend down)	85
extension	(bend back)	45
5. Leg at knee joint		
flexion	(backward)	160
rotation	(inside)	31
rotation	(outside)	30
6. Foot at ankle joint		
flexion	(bend down)	38
flexion	(bend up)	35

Since the work-space lay-out should be determined also by the possibilities of moving the various body members, the maximum movements of relevant body members – males between 20 and 40 years of age – are listed in table 6 (LAZET; 1967); data for other population groups are not available.

2.4. LAY-OUT STUDIES

2.4.1. *Optimum work-space*

Anthropometry can be of major value in designing and testing equipment; various sets of reference data have been developed. In practice these data are often inserted in drawings, transparancies and patterns; the use of manikins and body-form models can be of practical use in designing work-space by trying them out on tentative designs.

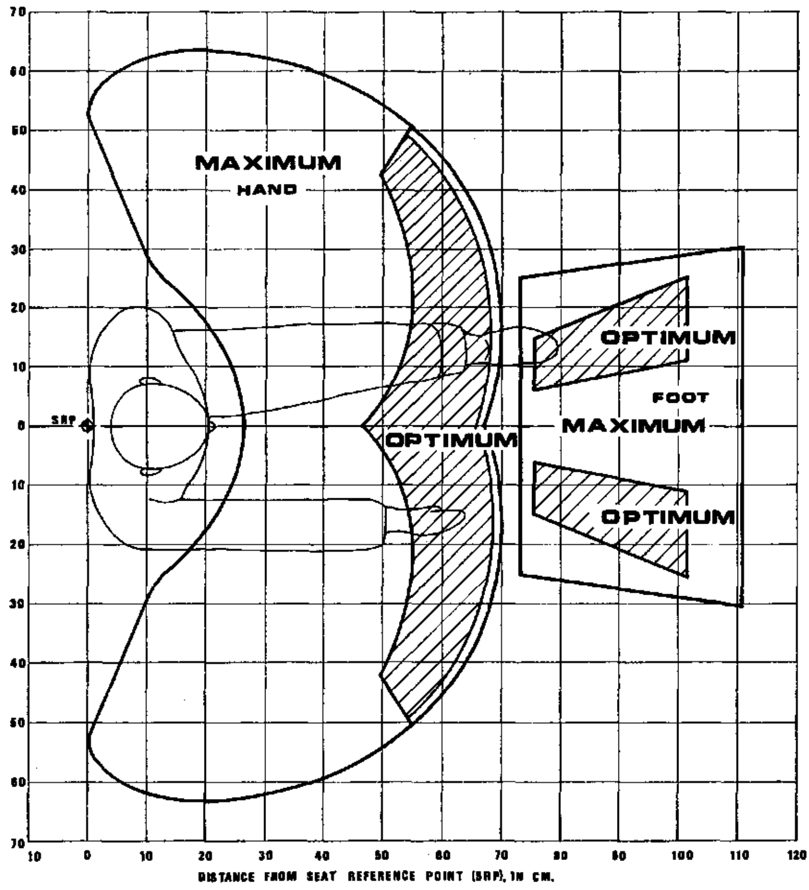


FIG. 4ᵃ. Optimum work-space lay-out for a self-propelled combine harvester (horizontal plane); 18 cm above seat-reference point (SRP).

The data for an optimum work-space lay-out have been shown in fig. 4[a] and 4[b]; using this figure the following points must be kept in mind (DREYFUSS, 1960; MCCORMICK, 1964; LAZET, 1967):

a. Maximum area

The maximum area is the area that can be reached by extending the arms from the shoulders and without moving them. This area is maximum only in terms of

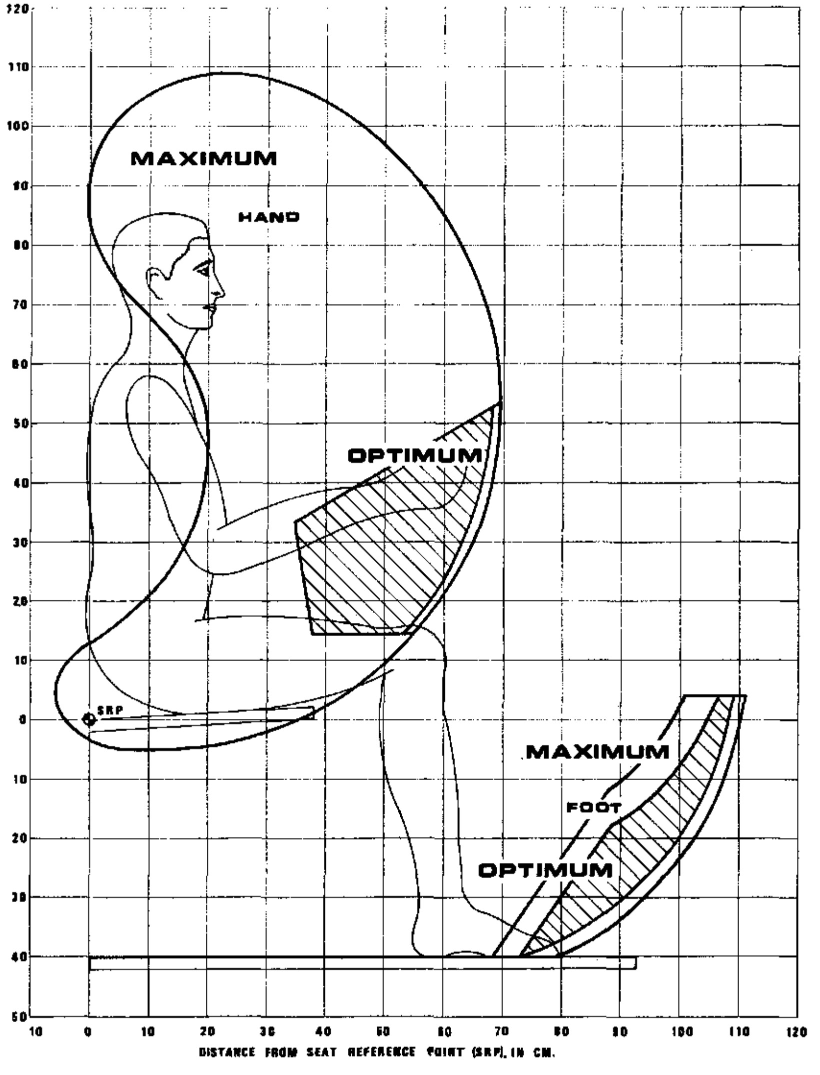


FIG. 4[b]. Optimum work-space lay-out for a self-propelled combine harvester (vertical plane). SRP – seat-reference point maintaining body posture; by leaning forward or sideways a greater reach can be made.

For adults (50th percentile) the maximum areas for hand-operated controls are:

- Males : 60–70 cm
- Females: 55–65 cm

Locating hand-operated and foot-operated controls in the maximum area is unfavourable, since the motions in these areas are more difficult to control and require more energy. This area is suitable, however, for hand-operated controls, which require much force. No operating controls should be placed outside the maximum area, unless the operation frequency is very low (see 2.6).

b. Normal area

The normal area is the area that can be reached conveniently with a sweep of the forearm, the upper arm hanging in a natural position at the side.

For adults (50th percentile) the normal areas for hand-operated controls are:

- Males : 40–50 cm
- Females: 35–45 cm

Within the normal area the motions of hand and feet are the most comfortable; frequently used controls have to be placed within this area.

2.4.2. *Measuring procedure*

In determining the dimensions which are appropriate, it is necessary to have details on location and displacement of the controls for operating the machine, as well as the forced to be exerted.

a. Equipment and method

To fix the location and displacement with respect to a reference point, special measuring equipment and methods have been developed (ZANDER; 1965).

The instrument consists of an underframe (fig. 5: A), which is placed on the object to be measured and set horizontally with adjusting screws (B), so that a column (C) will be placed vertically.

At the bottom of the column, which can be rotated over the underframe, a needle (D) is fixed, which is placed over a graduated scale; at the upper side of the column a pipe (E) is fixed. In this pipe another pipe (F) is sliding horizontally; at the end of the pipe, equipped with a millimeter calibration, there is a spring rule (G), equipped with a plummet (H).

When measuring firstly the underframe is set horizontally and fixed, as well as the reference point of the object to be measured; the depressing caused by the instrument is taken into account. Then the radial, horizontal and vertical co-ordinates of the reference point are read on the scales. By rotating the vertical column, moving the horizontal pipe and extending the spring rule, the plummet can be moved to all positions desired and the co-ordinates can be ascertained with respect to the reference point. At last the location and the dimensions of foot-board and cutterbar are fixed.

Data concerning the dimensions, shape and material of the operating controls, as well as the forces to be exerted, are recorded.

The dimensions of the controls are determined by means of a spring rule, whilst the forces to be exerted are measured. To measure the dynamic steering forces a strain gauge meter (make: PEEKEL; type: 101 DN) is used, which can be coupled to a recorder (make: SANBORN; type: 321).

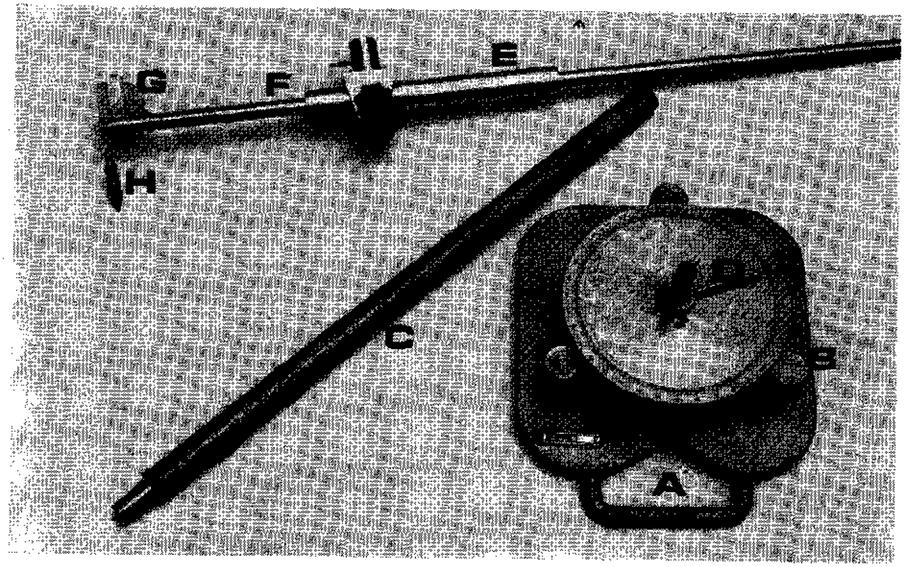


FIG. 5. Measuring equipment for lay-out studies.
A – underframe
B – adjusting screws
C – column
D – needle
E and F – pipes
G – spring rule
H – plummet

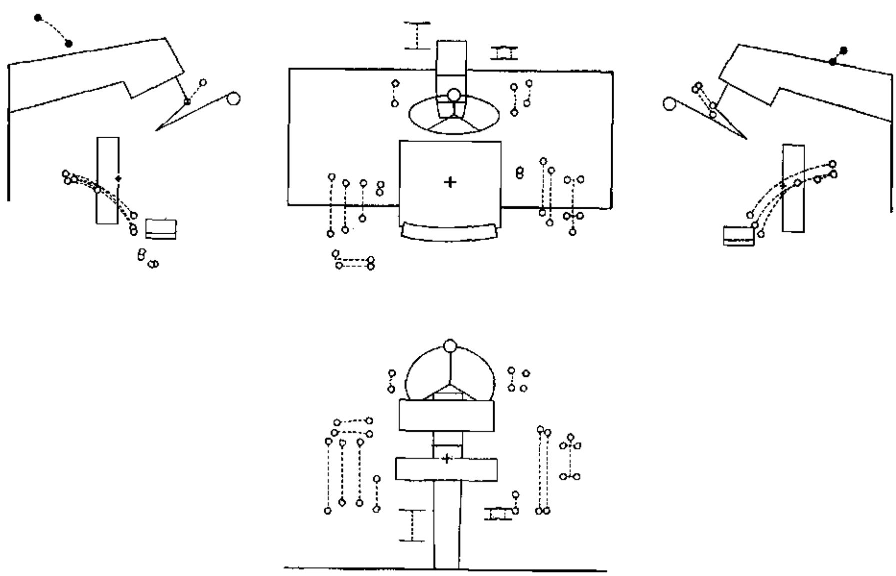


FIG. 6. Work-space lay-out of a self-propelled combine harvester.
O – hand-operated control
● – foot-operated control
- - - – displacement

b. Treatment

With the data obtained the location and displacement of seat, steering wheel and controls are drawn, as well as the location of the foot-board and cutterbar. All positions of the operating controls – in use and not in use – are given. As a result the work-space lay-out of a combine is shown in figure 6.

To interpret the drawings use has been made of transparent paper on which the areas for an optimum work-space lay-out (fig. 4[a] and 4[b]) are given.

Such a manikin makes it possible to get reliable data on the anthropometric qualities of a work-space lay-out in a relatively short time.

This procedure of lay-out studies is not only suitable for testing work-spaces already made, but must be used in equipment design.

2.4.3. *Combine harvesters*

In 1966 and 1968 data were collected about the location and displacement of the seat and steering wheel, as well as the controls of a number of combine harvesters; the scale drawings of the work-space lay-outs have been inserted in Appendix B.

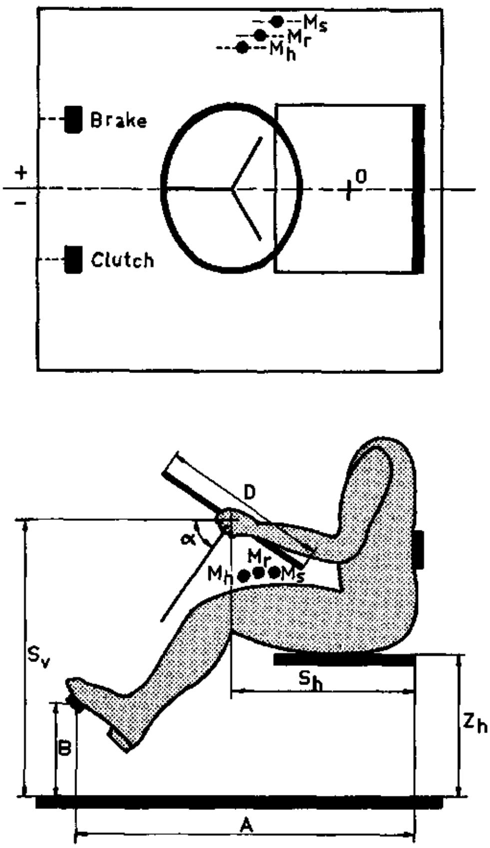


FIG. 7. Codes for the lay-out studies (see Table 7).

TABLE 7. Results of lay-out studies of combine harvesters (in mm). Locations: with (+), at the end (?) and beyond (—) the normal area.

		Manufactured in 1966						Manufactured in 1968		
	machines:	1	2	3[a]	4	5	6	7	8	9
Seat	+[1]	45	0	0	15	40	0	30	50	0
	Z_h	560	585	600	505	585	570	600	580	510
	–	12	55	125	20	120	70	120	50	0
Steering wheel (location)	α	81	88	83	27	85	78	82	80	80
	D	500	425	500	420	450	440	425	425	400
	S_h	700	745	675	515	605	555	690	810	620
	S_V	830	645	805	850	795	850	760	790	705
		(+)	(?)	(+)	(+)	(+)	(+)	(+)	(+)	(+)
Header height (*location*) – M_h –		(+)	(+)	(?)	(+)	(?)	(+)	(?)	(+)	(—)
Reel position (location) – M_r –		(+)	(+)	(+)	(+)	(+)	(+)	(?)	(+)	(—)
Ground speed (location) – M_s –		(—)	(+)	(?)	(+)	(?)	(+)	(—)	(+)	(—)
Clutch-pedal (location)	A	770	800	690	815	625	660	755	675	755
	B	220	195	255	270	205	170	170	160	180
		(+)	(+)	(+)	(+)	(+)	(+)	(+)	(—)	(+)
Brake-pedal (location)	A	750	760	755	770	690	660	715	700	700
	B	215	245	250	280	210	190	180	165	190
		(—)	(+)	(+)	(+)	(+)	(?)	(?)	(+)	(+)

[1] vertical adjustment.

The results of the studies have been listed in table 7, the codes are shown in fig. 7.

The dimensions (shape and size), the seat material and surface of the seat meet the requirements set. The seat height ($\bar{Z}_h$ = 566 mm) is too high (requirement: 400 mm). To adjust the seat to the dimensions of different population groups, often an adjustment in horizontal and/or vertical direction is available, which, however, is insufficient. Besides, the horizontal and vertical adjustments are coupled to each other.

The diameter ($\bar{D}$ = 443 mm) of the steering wheel meets the requirements set (requirement: 400–500 mm); in almost all cases the steering wheel is placed within the normal area. The inclination ($\bar{\alpha}$ = 79°) is less favourable (requirement: 45°). It is noticeable, that there is great variation of height of the steering wheel above the foot-board ($\bar{S}_v$ = 781 mm), as well as of the horizontal distance ($\bar{S}_h$ = 657 mm).

The controls that are frequently used – particularly: header height, reel position and ground speed control – have been located within or at the end of the normal area. The other controls are often found far beyond the normal area. The clutch and brake-pedal have been located at the end or beyond the normal area.

Based upon the lay-out studies of a number of self-propelled combine harvesters, we can conclude that the figures concerning the location of the steering wheel and the controls differ considerably.

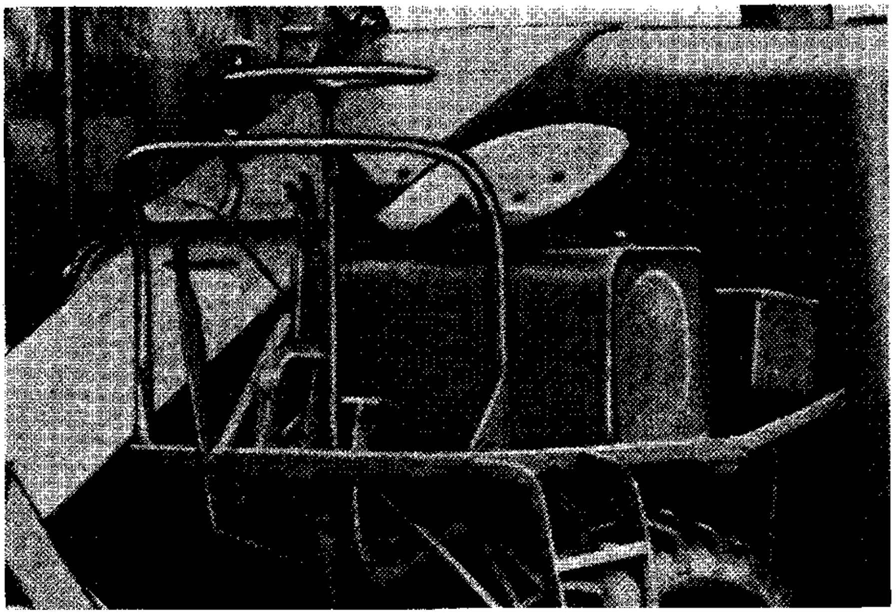


FIG. 8. Work-space lay-out of an old type of combine.

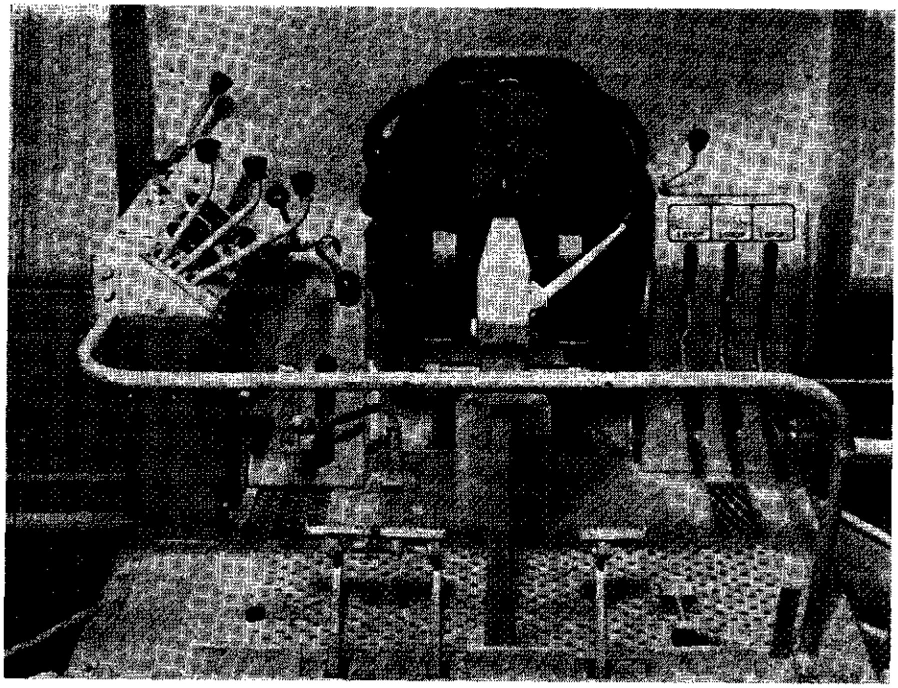


FIG. 9. Work-space lay-out of a modern type of combine.

It is recommended that the frequently used hand-operated controls are located close to each other and within the optimum area. With the aid of these and other recommendations some manufacturers of combine harvesters have already modified the lay-out of the operator's platform. In fig. 8 the lay-out of an old type of machine is shown; the lay-out of a modern combine harvester is shown in fig. 9.

2.5. FORCES

A human being is able to exert varying forces upon the objects surrounding him. The forces, which can be exerted, depend on the group of muscles, the body posture, the direction and size of the forces, as well as the duration. A human being is capable of maintaining 10–15% of the maximum force of a muscle during a long period of time (LEHMANN, 1962; GRANDJEAN, 1963).

2.5.1. *Hand-operated controls*

The horizontal pushing power, which can be exerted by the arms, depends on the angle between the upperarm and the fore-arm (MORGAN, a.o.; 1963); the maximum power to be exerted by the arm – in a sitting position and in various positions of the elbow – is laid down in tables (LUND; 1963). Controls, demanding maximum force, have to be located at a distance of an armlength; pull is greater than push (WOODSON; 1960).

The anthropometric data for hand-operated controls are listed in table 8 (DUPUIS, 1955; DREYFUSS, 1960; LUND, 1963; MCCORMICK, 1964).

TABLE 8. Anthropometric data for hand-operated controls.

Code	Features	Criteria	
		Levers	Knobs
8.01	Shape	round, rounded	bulb-shaped, round, rounded
8.02	Dimensions (mm)		
	· diameter	25 – 45	25 – 45
	· length	⩾ 75	
8.03	Force (N)		
	· hand	< 100	< 100
	· finger	< 20	< 20
8.04	Displacement (mm)	⩽ 200	⩽ 200
8.05	Location	dependent on the frequency, more or less in the optimum area (see fig. 4)	
8.06	Motion	· rearward or toward the operator for stopping · forward or downward to lower	
8.07	Inclination	preferably vertical to the forearm (not applicable with knobs)	
8.08	Material	warmth-isolating	
8.09	Surface	smooth	
8.10	Adjustment	–	
8.11	Support	–	
8.12	Miscellaneous	accurate setting, stepless or in small steps	

2.5.2. *Steering wheel*

The forces that need to be exerted on the steering wheel depend on the diameter of the steering wheel, the transmission of the steering mechanism and the friction of the bearings; at a high gearing ratio the speed of steering is reduced. The minimum diameter of a steering wheel should be 400 mm; a too big steering wheel makes the entrance to the work-space too difficult. The inclination between the steering column and the horizontal determines the maximum force that can be exerted (DUPUIS; 1961).

The anthropometric data for a steering wheel are listed in table 10 (DUPUIS, 1955; DREYFUSS, 1960; DUPUIS, 1961; MCCORMICK, 1964).

2.5.3. *Foot-operated controls*

The force to be exerted by the leg in a sitting position, is determined by the angle between the upper leg and the lower leg, as well as by the angle between the leg and the symmetrical plane of the body. If the angle between the lower leg and the upper leg is 155°, on a pedal – just in front of the body – maximum force can be exerted. It is undesirable to design foot-operated controls too far from the centerline; a distance of zero to 80–120 mm to the left or to the right of the symmetrical plane is optimal (DUPUIS; 1955). The height of the pedal with regard to the seat determines also the maximum exertable force; a location off to the side is more unfavourable than an elevation of the seat.

In table 11 the anthropometric data for foot-operated controls are listed (DUPUIS, 1955; DREYFUSS, 1960); the optimum areas are shown in fig. 4[a] and 4[b].

2.5.4. *Combine harvesters*

In 1966 and 1968 data were collected regarding the steering forces, as well as the forces for operating the clutch and the brake-pedal, of a number of combines. The force needed for operating the brake-pedal was determined at the same speed deceleration.

The results of the studies are listed in table 9.

The steering wheels of the second series ($\overline{T}_l = 1\frac{1}{4}$; $\overline{T}_r = 1\frac{1}{2}$) meet well the requirements, those of the first series ($\overline{T}_l = 2\frac{1}{2}$; $\overline{T}_r = 2\frac{1}{4}$) not. Except machine Nr. 1 – further on not taken into account – all combines were equipped with power steering. The forces for steering are consequently ($\overline{F}_s = 17$ N) low.

The forces for operating the clutch of the second series ($\overline{F}_c = 230$ N) meet nearly the requirements; the forces needed in the first series ($\overline{F}_c = 370$ N) not, they are far too high.

The forces for operating the brake-pedal of the second series ($\overline{F}_b = 180$ N) meet well the requirements, whilst these forces are also too high ($\overline{F}_b = 350$ N) for the first series; all combines are equipped with mechanical braking systems.

TABLE 9. Turns of the steering wheel and the forces for operating the controls of combines (1966: 1 to 6; 1968: 7 to 9).

Machine – Nr. –	Steering wheel turns left	Steering wheel turns right	Steering wheel force (F_s) (N)	Clutch force (F_c) (N)	Brake force (F_b) (N)
1	3	2	130	400	380
2	$1\frac{3}{4}$	$1\frac{3}{4}$	20	380	280
3[a]	3	3	15	400	300
4	3	$2\frac{1}{2}$	16	400	450
5	2	2	13	280	300
6	$1\frac{3}{4}$	$1\frac{3}{4}$	15	380	400
7	$1\frac{1}{2}$	$1\frac{1}{2}$	16	300	200
8	$1\frac{1}{4}$	$1\frac{1}{4}$	16	200	180
9	$1\frac{1}{4}$	$1\frac{1}{2}$	23	200	150
Requirement	$1\frac{1}{2}$	$1\frac{1}{2}$	10–50	100–200	100–200

TABLE 10. Anthropometric data for a steering wheel.

Code	Features	Criteria
9.01	Shape	round
9.02	Dimensions (mm)	
	· steering wheel	400–500
	· rim	20– 50
9.03	Force (N)	10– 50
9.04	Displacement (maximum)	to the right : 1½ turn to the left : 1½ turn
9.05	Location	in the optimum area
9.06	Motion	clockwise = right
9.07	Inclination (α)	sitting : 45° standing : 90°
9.08	Material	warmth-isolating
9.09	Surface	profiled and shaped to the hand, space for the fingers in the lower side
9.10	Adjustment	telescopic
9.11	Support	not wanted
9.12	Miscellaneous	none

TABLE 11. Anthropometric data for foot-operated controls.

Code	Features	Criteria		
		clutch	brake	accelerator
10.01	Shape	rectangular	rectangular	rectangular
10.02	Dimensions (mm)			
	· length	50– 75	50– 75	175–200
	· width	100–120	100–120	75–100
10.03	Force (N)			
	· optimum	100–200	100–200	30– 50
10.04	Displacement (mm)	80–100	80–100	< 40
10.05	Location · see figure 4	left-foot operated, in the optimum area	right-foot operated, in the optimum area	right-foot operated, in the optimum area
10.06	Motion	forward and/or downward for disengagement	forward and/or downward for stopping	forward and/or downward to increase speed
10.07	Inclination	70°	70°	70°
10.08	Material	solid	solid	solid
10.09	Surface	non-slipping	non-slipping	non-slipping
10.10	Adjustment	–	–	–
10.11	Support	Bent-up at the side	Bent-up at the side	–
10.12	Miscellaneous	–	–	–

2.6. FREQUENCY

The work load of a man not only depends on body measurements, body motions and forces, but also on the frequency and the sequence in which different operations and movements have to be carried out. The data, collected in measuring the operation frequency, indicate the priority of the lay-out of controls; moreover, they are helpful to explain the operator's work load (DUPUIS, 1955; DREYFUSS, 1960; MCCORMICK, 1964).

2.6.1. *Controls*

In operating a combine harvester a combination of factors – in particular: crop, terrain, plot and machine – determines the operation frequency and causes the reactions of man. In literature only one reference concerning the operation frequency of a combine harvester was available (GLASOW and DUPUIS; 1960); the results are listed in table 12.

TABLE 12. Operation frequency (n) during combining of a combine harvester (cutting width: 205 cm).

Crop	n/min
Barley predominantly laying, moderate weedy, smooth and wet soil, level terrain	3,88
Wheat standing, not weedy, hard and dry soil, level terrain	2,06

The operation frequency of the header height control appears to be strongly dependent upon the existing circumstances, in particular the condition of the crop (standing or laying). The frequency of the reel position control is considerably less, namely 6 to 34 per hour. The operation frequencies of the header height control, the reel control and the ground speed control are a good parameter for studying the qualities of the lay-out of a certain type of machine.

2.6.11. Frequency-analysis

In 1964 an investigation was carried out to study the frequency of control operations of self-propelled combine harvesters in different crops.

The measurements were carried out during harvesting on straight, homogenous parts, by counting the operating elements in coordination with a time study; interruptions didnot occur.

Since the operation frequency of a number of controls – e.g. the adjustment of the mowing and threshing mechanism – appears to be extremely low, special attention was paid to the header height control (M_h), the reel position control (M_r) and the ground speed control (M_s).

The results of the studies are listed in table 13.

TABLE 13. Operation frequency of combine harvesters.

Crop	Machine - Nr. -	Measured time - min -	Operations				Frequency - n/min -
			M_h	M_r	M_s	Total - n -	
Barley			117	72	38	227	3,87
80%*	2	58,58	(51,6)	(31,7)	(16,7)	(100,0)	(100)
Wheat			188	21	27	236	3,30
85%	2	71,49	(79,7)	(8,9)	(11,4)	(100,0)	(85)
Rye			155	39	50	244	1,98
90%	3[a]	123,34	(63,5)	(16,0)	(20,5)	(100,0)	(51)
Barley			148	86	10	244	1,38
100%	3[a]	176,45	(60,7)	(35,2)	(4,1)	(100,0)	(36)
Wheat			65	42	30	137	1,11
100%	6	123,44	(47,4)	(30,7)	(21,9)	(100,0)	(30)
			673	260	155	1088	
	Total	553,30	(61,7)	(24,0)	(14,3)	(100,0)	
	n/min		1,21	0,47	0,28	1,97	

* – Condition of the crop (% standing) was estimated.

Of all controls the header height, the reel position and the ground speed control are most important; the location and displacement of these controls deserve priority in the design of the work-space lay-out.

The distribution of operation of these controls is:

- header height : 61,7%
- reel position : 24,0%
- ground speed : 14,3%

With an increase of the percentage standing the operation frequency decreases.

In 1965 an investigation was carried out to study the time-interval between two control operations and the operation frequency of the header height (M_h), the reel position (M_r) and the ground speed control (M_s).

The results of these studies are listed in tables 14 and 15.

The results in table 14 show clearly, that time-intervals of 0–15 cmin (59%) are predominant.

Based upon the results in table 15 it is possible to calculate the following distribution:

- header height : 74,1%
- reel position : 13,2%
- ground speed : 12,7%

In view of the operation frequency found (table 13: 1,97 per minute; table 15: 2,83 per minute), the use of an automatic header height control seems to give a decrease of the work load (see chapter 5).

TABLE 14. Time-interval between two control operations (in cmin).

Time-interval	Field A[1] – in % –	Field B[2] – in % –	Total – in % –
0– 5	10	10	10
6–10	20	20	20
11–15	27	32	29
16–20	15	20	18
21–25	12	12	11
26–30	6	6	6
31–35	6	–	4
36–40	3	–	1
41–45	1	–	1
>45	–	–	–

[1] – Machine: Nr. 2; crop: wheat (100% standing).
[2] – Machine: Nr. 6; crop: wheat (100% standing).

TABLE 15. Operation frequency (Field A, see Table 14).

Machine – Nr. –	Measured time – min –	Crop	Operations				Frequency – n/min –
			M_h	M_r	M_s	Total – n –	
2	132,50	Wheat, 100% standing	278 (74,1)	50 (13,2)	47 (12,7)	375 (100,0)	2,83
n/min			2,11	0,38	0,36	2,83	

2.6.12. M.T.M.-analysis

If we know the time needed for the motions and combine those with a certain operation frequency, it is possible to relate them to the motions made, specific for a certain work-space lay-out, on the one hand and the operating element time on the other. With a system of Predetermined-Motion-Time-Systems, i.e. M.T.M. (Method-Time-Measurement), human activities are split up in basic work elements – for the eyes, hands, fingers, legs and arms – and described by means of a classified code. The work elements are provided with timevalues (in time-measurement-unit or TMU), specific to a number of influencing factors (distance, weight, skill, object, etc.). The calculated timevalues can be used to obtain reliable data of the ergonomic quality of the lay-out of a certain machine (MAYNARD; 1948).

From the results of the lay-out studies a detailed drawing was made of the switching pattern. Then a motion-analysis was made of this task; difference was made to the kind of motion and the appearing influencing factors. At last a timevalue (unit: 1 TMU = 1×10^{-5}h) was attached by means of a MTM-table.

From the results of the lay-out studies (2.4.3) and the frequency-analysis, M.T.M.-analyses were used to establish the elemental time for each control. Further the timevalues per minute were calculated taking into account a ratio of 75.0–12.5–12.5 for the header height, the reel position and the ground speed control. Moreover, the time was calculated for machines equipped with an automatic header height control (ratio: 0.0–12.5–12.5).

The results are listed in table 16.

TABLE 16. M.T.M.-values, corrected with the operation frequency, for some controls of combines (in TMU).

Machine	Time per element				Time per 100 elements	
– Nr. –	M_h	M_r	M_s	Total	(75.0–12.5–12.5)	(0.0–12.5–12.5)
1	14.1	33.1	56.8	104.0	2181.25	590.00
2	18.0	36.8	43.4	98.2	2352.50	657.50
3[a]	20.2	49.6	45.8	115.6	2707.50	775.00
3[b]	12.3	33.1	31.3	76.7	1727.50	520.00
4	10.2	29.2	52.8	92.2	1790.00	492.50
5	15.9	31.1	50.3	97.3	2210.00	827.50
6	8.2	28.4	29.2	65.8	1335.00	457.50
7	10.2	31.0	48.9	90.1	1763.75	515.00
8	12.3	29.2	40.0	81.5	1787.50	518.75
9	12.3	32.5	29.3	74.1	1695.00	520.00
Average	13.4	33.4	42.8	89.5	1995.00	587.37

Based upon the ratio used, the operating element time for the header height control becomes relatively more important. The importance of a good location for this control is already distinguished, as demonstrated in the small amount of time ($\overline{T}_h$ = 13.4 TMU) with regard to the reel position control ($\overline{T}_r$ = 33.4 TMU) and the ground speed control ($\overline{T}_s$ = 42.8 TMU). Using a foot-operated control (see: Nr. 5; location: at the end of the normal area of man) is less suitable here. A small modification (Nr. 3[a]: 2707.50 TMU; Nr. 3[b]: 1727.50 TMU) leads to a favourable change (36%) in the operating element time; this modification consists of grouping together header height, reel position and ground speed control within the normal area. If the machines are equipped with an automatic header height control (ratio: 0.0–12.5–12.5), less time is needed (without: 1995.00 TMU; with: 587.37 TMU). The reduction in operating element time is 70%; the differences between the machines become less.

Fingertip control – header height, reel position and ground speed control grouped together – opens favourable possibilities (see: Nr. 6, Nr. 9 and Nr. 3[b]). Anthropometric data for fingertip control are listed in table 17 (DREYFUSS, 1960; LAZET, 1967).

The M.T.M.-values for a combine harvester equipped with fingertip control are listed in table 18.

Fingertip control leads to a decrease of the operating element time of 53%, resp. 61%. If the machines are also equipped with an automatic header height control, the element time is reduced by 75%.

TABLE 17. Anthropometric data for fingertip control.

Code	Features	Criteria
17.01	Shape	square, rounded
17.02	Dimensions (mm)	
	· length	12
	· width	12
17.03	Force (N)	
	· optimum	5–8
17.04	Displacement (mm)	10
17.05	Location	in the optimum area (see fig. 4)
17.06	Motion	only vertical
17.07	Inclination	not required, pressing surface horizontal
17.08	Material	warmth-isolating
17.09	Surface	smooth,bent
17.10	Adjustment	–
17.11	Support	–
17.12	Miscellaneous	–

TABLE 18. M.T.M.-values for a combine harvester equipped with fingertip control (in TMU).

Time per element			Total	Time per 100 elements	
M_h	M_r	M_s		(75.0.–12.5–12.5)	(0.0–12.5–12.5)
9.2	9.2	9.2	27.6	920.00	230.00

2.6.13. Design of controls

By means of differences in colour, dimensions or shape, controls can be distinguished one from the other; related functions must be grouped together. Universal symbols for operator controls are recommendable to avoid confusion and to achieve faster perception and safety (CHAPANIS; 1963).

Universal symbols for operator controls of combine harvesters are recommended in the U.S.A. (ANON; 1967[a]); they are shown in figure 10. This recommendation is based upon the principle that a given location and direction of movement of a control produces a consistent and expected effect; it is also recommended that the effect of control movements must be clearly and permanently labeled, so the operator can determine the proper movement without trial and error or reference to a manual ('foolproof').

2.6.2. *Steering wheel*

When steering a machine the movements of the steering wheel – next to the force to be exerted – are loading components.

In 1966 and 1967 investigations were carried out to study the movements of the steering wheel of combine harvesters in different crops.

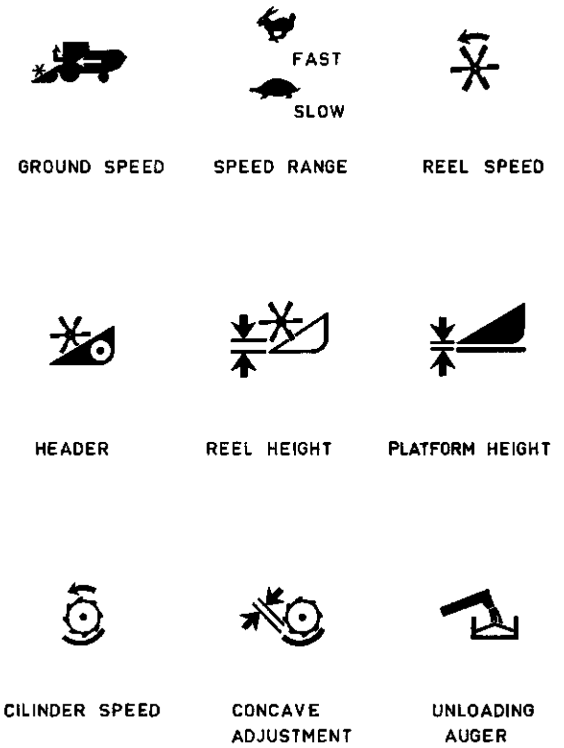


FIG. 10. Recommended universal symbols for some controls of the combine.

a. Equipment and method

The measurements were carried out during combining on straight, homogenous parts, by connecting the steering wheel with a precision potentiometer (make: ELLETRONICA; type: 510), which is connected to a recorder (make: SANBORN; type: 321) in the field laboratory driving next to the machine.

In calibrating the steering angle, recorded by means of an oscillogram, is registered by turning the steering wheel to the left and to the right in units of 1/6 of a turn. For an accurate analyses it is necessary, that the deflection of the potentiometer is relatively large.

b. Treatment

A number of parallel lines, corresponding with each unit was drawn on the oscillograms obtained, based upon the calibrating. By recording in what division the top of a certain deflection of the steering wheel lies, it is possible to make a distribution of the frequencies of the turns.

c. Results

The results of the measurements in 1966 (crop: oats (100% standing); machine: Nr. 2) and 1967 (crop: wheat (100% standing); machines: Nr. 2 and Nr. 3[a]) are listed in table 19. During the measurements we have tried to work with the same ground speed and the same stubble-height.

TABLE 19. Movements of the steering wheel of combine harvesters (in % of total operating time).

	1966			1967		
Turns	Left	Right	Total	Left	Right	Total
0 - 1/6	40.0	39.4	39.7	36.5	37.4	37.0
1/6 - 2/6	34.6	30.9	32.8	32.3	37.0	34.7
2/6 - 3/6	17.5	23.9	20.7	20.0	18.7	19.3
>3/6	7.9	5.8	6.8	11.2	6.9	9.0

The movements of the steering wheel of combine harvesters do not differ for different crops. The movements have only a correcting character = ± (0–3/6 turn): 91.0–93.2%; accent: ± (0–2/6 turn): 71.7–72.5% =, at least in the straight parts of the plots.

2.7. SUMMARY

The characteristics of the human body determine the location and displacement of the operating controls, as well as the forces to be exerted, the nature and frequency of movements. Based upon the relevant measurements and motions of the human body, the anthropometric data are given for designing an optimum work-space lay-out of a combine harvester.

1. Lay-out studies

To determine the location and displacement of the controls, as well as the forces to be exerted, special measuring equipment and methods have been developed.

The lay-out of the various machines appeared to differ considerably. With the available anthropometric data can be contributed to an improvement of the existing work-space lay-outs; it is recommendable that frequently used controls are located close to each other and within the normal area.

The forces needed for steering are low, because of the application of power steering; the forces for operating the clutch and the brake-pedal are too high for the older combines, for the newer combines they meet the requirements.

2. Frequency

The frequency with which different operations and movements have to be carried out, determines mainly the operator's work load. Of all controls of self-propelled combine harvesters the header height, reel position and ground speed control are most important. The location and displacement of these controls deserve priority in the design of the work-space lay-out. The operation frequency is not only important for indicating the priority in lay-out design, it is also a good parameter to explain the operator's work load in studying the influence of a lay-out of a certain type of machine.

Based upon the results of the lay-out studies and the frequency-analysis, the operating element time has been calculated by means of M.T.M.; fingertip control is desirable.

With the developed measuring equipment and methods for lay-out studies, as well as the formulated anthropometric data, it is possible – by providing an optimum work-space lay-out, including a good posture – to contribute to a decrease of the work load.

3. PERCEPTION

3.1. INTRODUCTION

The perception of the continual stream of information, that a worker receives from work-space and environment, takes place via the senses, which are sensitive to specific impulses (MURRELL; 1965). For each of these senses the human body commands perceptive sensations: sight, hearing, scent, taste and feeling, which are specific for the physiological activity derived from a certain amount of physical or chemical energy (HOCHBERG; 1964).

The reaction on the information depends upon the sense organ that is stimulated, the strength of the stimulus and the place where the stimulus arrives (WOODWORTH; 1938). The average reaction time (RT) for various sensations is listed in table 20 (DREYFUSS; 1960).

If adequately offered the RT of auditive signals varies from 140 to 160 msec, for visual signals from 180 to 200 msec; the tactual reaction is somewhat shorter ($<$ 125 msec) if the signal is offered at a sensitive place (SANDERS; 1967).

Based upon the knowledge of the nervous system the following model can be given for perception (WOODWORTH, 1954; BEVAN, 1958; ATTNEAVE, 1959; GAGNÉ, 1962; CHAPANIS, 1963; HOCHBERG, 1964; MURRELL, 1965):

The objects present in a work-space, stimulate the human nervous system by reflecting the energies, that reach the sense organs (distal stimulation). The pattern of energy, that reaches and stimulates the sense organs (e.g. electromagnetic and sound waves), is called proximal stimulation. The sense organs (e.g. eyes and ears) transform the energies of the proximal stimulation into neural impulses, which are transported to the central nervous system. These neural impulses enter the central nervous system through the sensory end organs, ultimately resulting in sensations (e.g. sight and hearing).

In order to realize a rapid and adequate perception the presentation of information has to meet the following requirements (WOODSON, 1960; CHAPANIS, 1963; MCCORMICK, 1964):

a. Perceptible by the sense organ;
b. Clearly detectable in the stream of information;
c. Detectable intensity.

TABLE 20. Reaction time for various sensations.

Sensation	Reaction time (msec)
visual	190
auditive	125–215
odor	290
warmth	220
cold	200
tactual	170

Furtheron a certain relationship has to exist between stimulus and response (FITTS; 1953), in order to achieve a simplicity of decision and action (ZANDER; 1965); a clockwise rotation of the steering wheel shall effect a right turn, etc. (Table 10).

3.2. SIGHT

Sight plays an important role in man-task systems, since most information enters the central nervous system via the eyes; moreover, most actions are executed under optical control. With his eyes a human being cannot only observe colours and light, but also estimate the location, direction and speed of moving objects (HOCHBERG; 1964).

3.2.1. *General*

The conversion of electromagnetic waves into neural impulses resulting in a sight sensation, takes place on the retina, consisting of photosensitive coating – rods and cones – and connecting cells. A type of light is characterised by the spectral division of the occuring wavelengths. Within the visible spectrum (range: 380–740 nm) each wavelength contributes to the sensation of colours (MURRELL; 1965). The perception of visual information depends also upon the object (speed and size), the environment (brightness and contrast) and the distance between eye and object. The sensation of sight is primarily restricted by the visual acuity, that can be corrected, and the visual field (LAZET; 1967).

3.2.2. *Visual field*

The characteristics of the visual field are important to realize a rapid perception. The body posture when controlling a machine in a sitting position is also determined by the visibility of the work, in which no fixed vision has to exist (DREYFUSS; 1960). The visual field can be enlarged by body motions, which, however, lead to loss in quality of the body posture (LAZET; 1967). They also cause an increased work load and a decreased performance (SANDERS, 1963; MCCORMICK, 1964).

In figure 11 the visual field is given for the horizontal plane (DREYFUSS, 1960; SANDERS, 1963; MCCORMICK, 1964; LAZET, 1967; SANDERS, 1967). Three fields are distinguished:

a. Stationary field (A)

This field, which is covered effectively with pheripheral vision, can be judged at a glance; the visual acuity is quickly reduced in the periphery, but the system is sensitive enough to detect moving objects. RT is relatively short at a visual angle of 0° (SANDERS; 1967); an increasing angle causes an increase of RT.

b. Eyefield (B)

The field, where eyemovements are needed to complement peripheral vision. In this field during an eye fixation at a high rate impressions are obtained concerning the nature and location of the objects within the periphery, which is

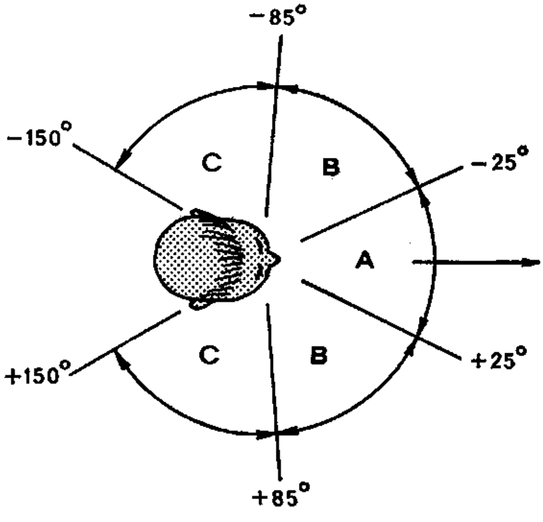


FIG. 11. Visual field (horizontal plane).
A – stationary field
B – eyefield
C – headfield

verified by eyemovements, continuously testing these impressions and hypotheses formed previously.

c. Headfield (C)

The field, where headmovements are required to get a minimum RT for these conditions. In this field no impressions can be obtained and a re-orientation implies a completely new percept.

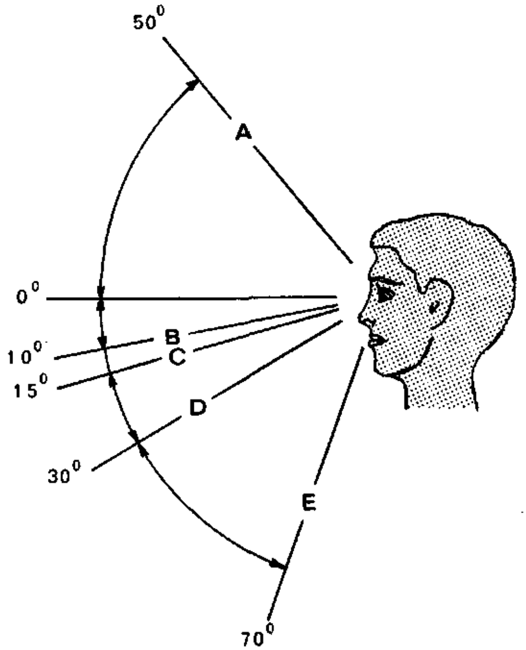


FIG. 12. Visual field (vertical plane).
A – upper limit
B – view angle (standing)
C – view angle (sitting)
D – optimum view angle
E – lower limit

A transition from one field to another is attended with a considerable change in RT. An increase in the amount of information and the need for more complex judgements, reduce the stationary field and the eyefield (LAZET; 1967).

In figure 12 the visual field is given for the vertical plane (DREYFUSS, 1960; LAZET, 1967). The upper limit of the visual field is 50° (A). For a standing, respectively a sitting position, the RT is small at visual angles of 10° (B), respectively 15° (C); the reaction is relatively optimal at a visual angle of 30° (D) for a distance of 3000 mm between eye and object (DREYFUSS; 1960). An increasing view angle causes a decreasing steering accuracy and an increasing work load (CHAPANIS, 1963; MCCORMICK, 1964). The lower limit is 70° (E).

3.2.3. *Combine harvesters*

Based upon visual information obtained from crop (e.g. standing, weed and obstacles), terrain (e.g. unevennesses and obstacles) and plot (e.g. size and shape) the operator of a combine regulates the ground speed to realize a constant product flow to the conveyor chain. Moreover, the operator regulates the direction of movement of the machine to realize a maximum utilization of the working width as well as to achieve a certain stubble-height.

It is necessary to obtain information from the feed table auger just in front of the conveyor chain and of the separation from the previously cut swath. In the horizontal visual field it is necessary that the information becomes visible within the stationary field (fig. 11: A), where even moving objects can be detected by the peripheral system. It is desirable, because of the relatively short RT at a visual angle of 0° and the decrease of the stationary field and eyefield in more complex tasks. In the vertical visual field it is necessary that the information is visible under optimum conditions namely at a view angle of 30° and a direct distance of 3000 mm (vertically: 1500 mm; horizontally: 2600 mm) between eye and object.

TABLE 21. Location of the cutterbar on combines.

Machine – Nr. –	distance in mm			view angle – in ° –
	direct	horizontal	vertical	
1	3735	1810	3265	61,0
2	4000	1920	3520	62,0
3[a]	3520	1340	3255	68,0
4	3525	1290	3280	69,0
5	3320	1520	2945	63,0
6	3290	1455	2940	64,0
7	3670	1570	3315	64,5
8	3710	1710	3285	62,5
9	3545	1895	2990	57,5
Average	3590	1612	3199	63,5
Requirement	3000	2600	1500	30,0

In 1966 and 1968 (2.4.3) data were collected about the location and visibility of the cutterbar on a number of combine harvesters. The results are shown in table 21, fig. 13 and fig. 14.

Based upon a body height of 175,0 cm (50th percentile) and no body assistance applied, the results of the studies lead to the following conclusions:

In the horizontal plane (fig. 13) the centre of the cutterbar is located at a visual angle of nearly 0°, which is favourable; a great part of the cutterbar can be seen from the stationary field (A). On two machines (Nr.: 6 and 8) the centre of the cutterbar is located eccentrically, so the operator gets a better impression of the separation from the previously cut swath. The horizontal distance ($\bar{D}_h$ = 1612 mm) between eye and cutterbar is small, which appears to be an advantage.

In the vertical plane (fig. 14) the average view angle ($\bar{\alpha}$ = 63,5°) differs so much from the optimum, that the lower limit of the visual field is being approached. The direct distance ($\bar{D}_d$ = 3590 mm) between eye and cutterbar clearly is too far, which is caused mainly by the vertical distance ($\bar{D}_v$ = 3199 mm), which is too large.

Improvement of the visibility is possible by reduction of the view angle and the vertical distance. The designer must lower the operator's platform to bring it closer to the field. Because of the location of the operator's platform on present machines – above the conveyor chain – this construction will give difficulties: the motions of the conveyor chain are reduced, since more dust is circulat-

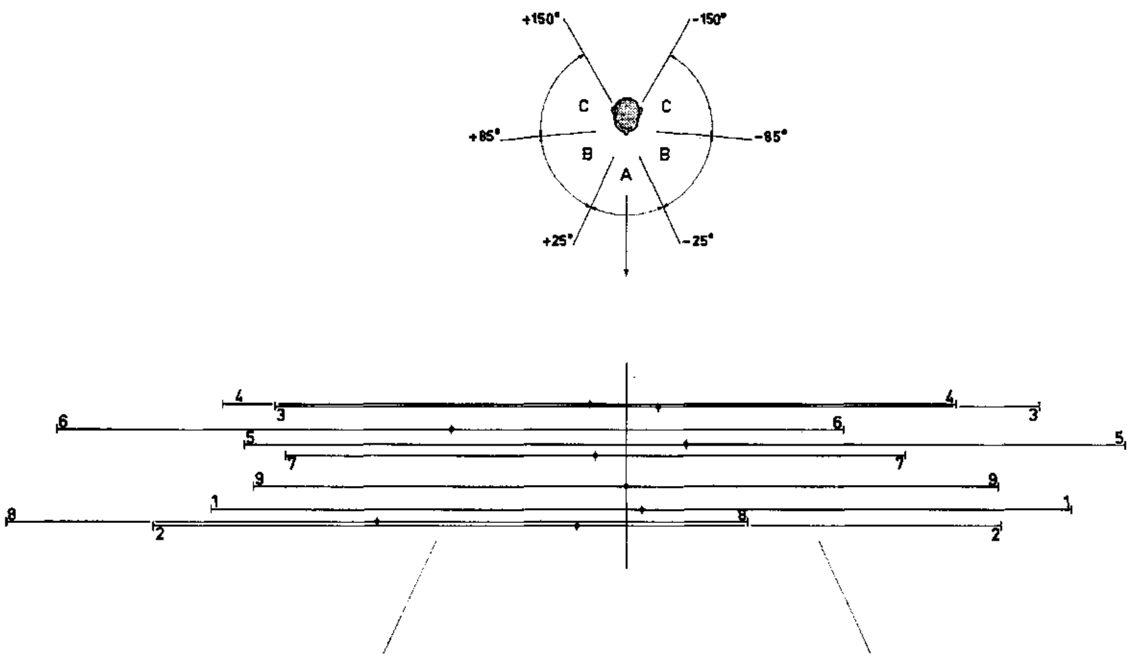


FIG. 13. Visibility of the cutterbar on combines (horizontal plane).

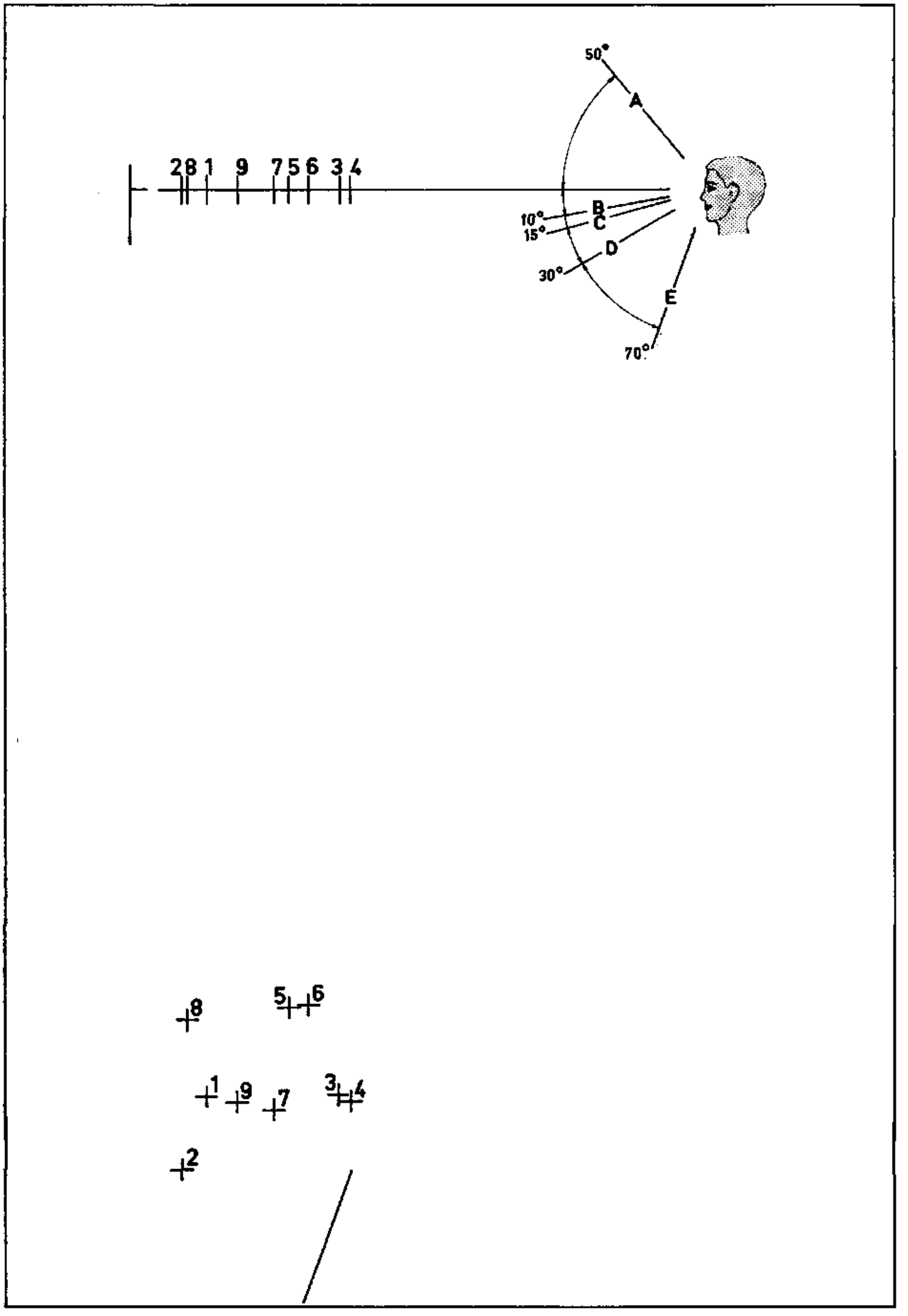


FIG. 14. Visibility of the cutterbar on combines (vertical plane).

ing around the operator. An eccentric location of the operator's platform offers more favourable possibilities, since the platform can be located next to the conveyor chain and closer to the field.

It is necessary that a self-propelled combine harvester is equipped with windows to make controlling the fillings of the grain tank more simple.

3.3. HEARING

Communication between man and task, as well as between men mutually, takes place through hearing, in which variations of pressure act as a medium. The physical properties of sound are frequency (in Hz), sound pressure level (in dB) and duration of the exposure.

3.3.1. *General*

The function of the ear is to convert sound waves into neural signals, that can be transmitted to the brain. Sound waves impinge on the outer ear and cause the ear-drum or tympanic membrane to vibrate. The tympanic membrane actuates a lever system of very small bones, the auditory ossicles, situated in the air-filled cavity of the middle ear. The third ossicle sets up vibrations in fluid and certain structures contained in a complex system of coiled canals in the bone of the skull, known as the inner ear. These canals include the semicircular canals, concerned with balance, and the cochlea, in which the organs are situated where mechanical vibrations set up nerve impulses in the fibres of the auditory nerve (MURRELL; 1965).

The ears are capable of making a frequency analysis (PLOMP; 1965) and of detecting periodicities (RITSMA; 1965). A man can detect pure tones between 20 and 20.000 Hz, dependent on the age; ear sentivity is least at low frequencies and increases to reach its maximum at above 1.200 Hz (MURRELL; 1965). The risk of deafness and damage of the ear is therefore not uniform over the whole frequency spectrum but appears to reach a maximum with sounds between 3.000 and 4.000 Hz.

The range of values of sound pressure is inconveniently large for normal arithmetical expression. For this reason and taking into account the structure of the hearing mechanism, it has become customary to express the magnitude by means of a logarithmic scale.

Sound pressure (in decibel or dB), is defined as follows:

$$n\ dB = 20.\ \log P_n/P_o \qquad (1)$$

In this equation P_n is the effective value (r.m.s.-value) of the sound pressure at a point (in N/m^2) and P_o is the effective value (r.m.s.-value) of the reference sound pressure in the air (2×10^{-5} N/m^2).

3.3.2. *Sound measurements*

The basic instrument for an objective measurement of sound is known as the sound level meter. It consists of a microphone, an amplifier and some indicating device, normally a meter which gives visible readings (in dB) on a scale. The sound level meter has to meet international requirements (I.E.C.; 1961); the measuring procedure has been standardized (I.S.O.; 1964).

Mostly, the sound level meter incorporates electrical circuits known as weighing networks. These provide for various sensitivity to sounds of different frequencies, in order to simulate the characteristics of the sensitivity of the ear. These characteristics known as A-, B- or C-scale operating conditions, can be selected on the sound level meter; measurements with a weighed response, e.g. sound level A, are expressed as dB_A. Least sensitivity is provided at frequencies in the A-scale, highest in the C-scale, in order to simulate the sensitivity of the human ear for different intensities of sound. For many purposes the statement of the total, or overall sound pressure or intensity is not enough. Sound has to be investigated in detail from the point of view of mechanical considerations, annoyance or potential damage to hearing and in such cases examination of the distribution of intensity in the frequency spectrum must be undertaken.

A draft set of empirical curves relates octave band sound pressure level to the centre frequency of the octave bands, each of which is characterised by a 'noise rating' (in NR), which is numerically equal to the sound pressure level at the intersection with the ordinate at 1.000 Hz. The 'noise rating' of a given noise is found by plotting the octave band spectrum on the same diagram and selecting the highest noise rating curve to which the spectrum is tangent (I.S.O.; 1961).

3.3.3. *Effects of sound*

Depending on frequency, sound pressure level and duration of the exposure, sound has an annoying to damaging effect. Serious hearing losses are mostly of a permanent nature and irreversible. It has been generally accepted at the moment that a permanent exposure to sound pressure levels of 85 dB and more necessitates protection of the ears to avoid damage (JANSEN, 1962; LEHMANN, 1962; GRANDJEAN, 1963; BRUNET and LAVIEUVILLE, 1966; LEHMANN, 1967). A production of sound exceeding the limit of NR 80 and lasting for more than five hours daily might have damaging effects on the hearing in the long run (I.S.O.; 1961).

Experimental psychologists have for many years been interested in the effects of sound on work, and laboratory investigations designed to elucidate these problems have been pursued for more than forty years. In general, the effect of noise is not a reduction of the speed at which work is carried out, but a decrease of accuracy; in particular tasks, asking a high concentration for a longer period (BROADBENT; 1958). In general, sound levels with high frequencies are more affecting than those with low frequencies (BROADBENT; 1954).

Protection is by technical means (machines making less sound, isolation of the sound source, reduction of sound transmission and application of acoustic interference) or personal means (larger distances between source and man, ear protection by wearing some form of plugs in the ear canal, or external cups usually known as ear muffs) (ZANDER; 1965). One of the most common methods to solve the sound problem is the enclosure of the source, as well as the application of an enclosed cabin, to reduce the sound level to bearable levels (HUANG and CHEN; 1969); when using a cabin the sound pressure level in the work-space is determined by the attachment of the cabin, in particular: the avoidance of sound transmission, and the quality of the isolation material.

3.3.4. *Combine harvesters*

By the functioning of the engine and other parts of the machine, in particular: the threshing mechanism, the operators of combines are submitted to sound.

In literature some results are mentioned of research regarding the sound pressure levels of combines, measured at ear level.

It appears from research in the Netherlands (ANON; 1967[b]), that for six machines – all equipped with water-cooled diesel engines; engine power: 87–110 h.p. – the average sound pressure level was 97,7 dB, respectively 89,0 dB_A; for the same group of machines the average Noise Rating Number amounted to 85,3 (table 22).

From research in England (MATTHEWS; 1967) it appeared, that the average sound pressure level for fifteen machines was 91,8 dB_A (table 23).

From these studies the conclusion can be made, that – measured at the operator's ear – the sound pressure level of combines is too high.

TABLE 22. Sound pressure levels of combines (ANON; 1967[b]).

Machine	Sound pressure level		Noise Rating Number
	– in dB –	– in dB_A –	– in NR –
BM-Volvo [1]	96,5	87,0	85,0
Claas [2]	96,0	88,0	84,0
Clayson [2]	99,5	87,0	83,0
John-Deere[2]	97,5	93,0	85,5
Laverda [2]	97,0	89,0	85,5
M.F. [3]	99,5	90,0	86,5

[1] Engine located under the grain tank, behind the front axle.
[2] Engine located behind the grain tank.
[3] Engine located in front of the grain tank and next to the operator.

TABLE 23. Sound pressure levels of combines (MATTHEWS; 1967).

	Working width	Engine power	Sound pressure level
	– in feet –	– in b.h.p. –	– in dB_A –
Group A	6–10	24–45	92
Group B	10	65–80	91
Group C	12	85–94	90

(i) Effect of cabin

In 1967 sound measurements were carried out to study the effect of a cabin (attachment: screwed on the operator's platform, without absorbing material; isolation material: none) on a self-propelled combine harvester. By means of a sound pressure level analyser (make: PEEKEL; type: GRA) the sound was measured, at the operator's ear, on a machine (Nr.: 3[a]; working width: 18 feet), equipped with a water-cooled diesel engine (location: behind the grain tank). In fig. 15 the machine is shown with a cabin.

The results of these measurements (fig. 16) show, that a cabin on a combine (Noise Rating Number: 80) did not lead to an important decline of the sound pressure level, compared with a combine without cabin (Noise Rating Number: 83).

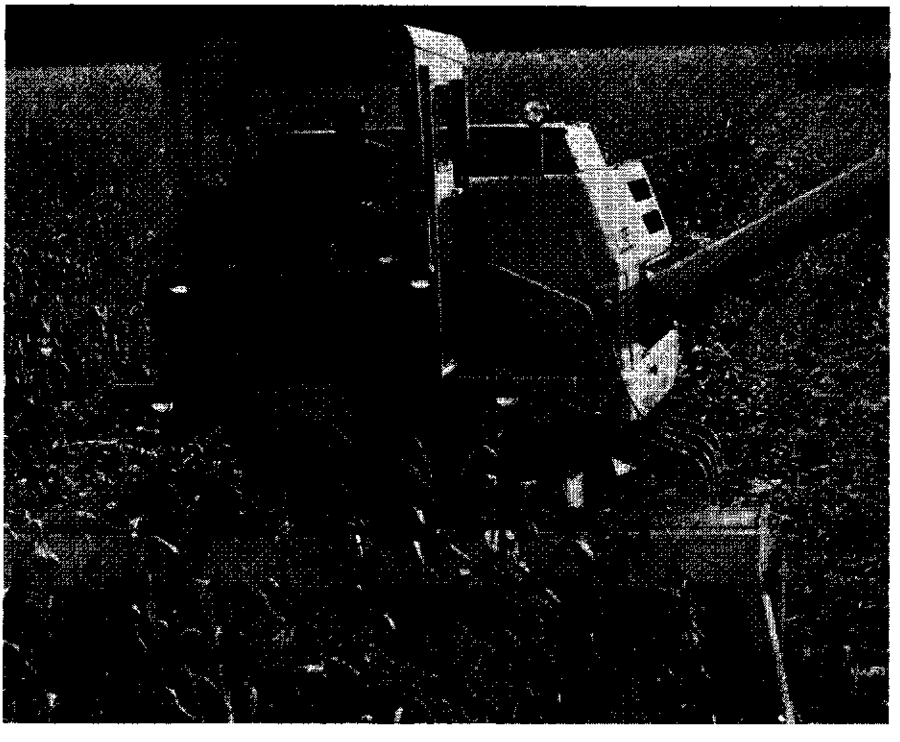


FIG. 15. Self-propelled combine harvester with a cabin.

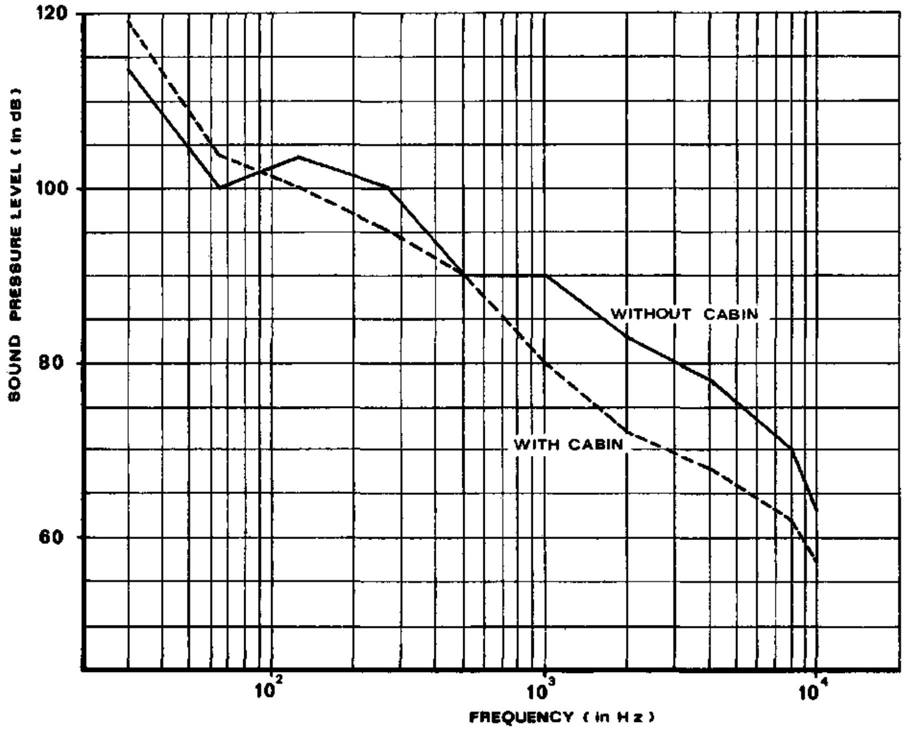


FIG. 16. Sound pressure level of combines.

(ii) Effect of ground speed

In 1968 sound measurements were carried out to study the effect of ground speed during combining and during unloading.

The results are listed in table 24.

From this study we may conclude, that – measured at the operator's ear – the sound pressure level of these machines is too high. Moreover, it appeared that the ground speed during combining did not influence the sound pressure level.

TABLE 24. Sound pressure levels of combines.

	Sound pressure level (in dB)	
	3[a]	3[b]
Ground speed (km/h)		
2,5	105	103
3,5	105	103
4,5	105	103
5,5	105	103
Unloading	99	101

3.4. SCENT AND TASTE

From an ergonomic point of view scent and taste are less important, because only a small number of actions appeals specifically to these senses. Physical variables of the operator's environment may be broken down into the major areas of carbon monoxide – if equipped with petrol engines – and dust.

3.4.1. *Carbon monoxide*

Carbon monixide – as a result of an incomplete combustion – will be absorbed rapidly by the hemoglobin in the bloodstream, resulting in an oxygen deficiency which may at first be unnoticed by the individual. The initial symptoms of carbon monoxide poisoning are headache, dizziness or nausea, accompanied by reduced attention, difficulty with concentration and retention, slight muscular incoordination and a mental and physical lethargy; further exposure may lead to collapse or even death. Exposure for several hours to a small concentration of 0,01 per cent (100 ppm), has no perceptible effects. However, it should not be continued over long periods of time. It is recommended that 0,003% CO (30 ppm) is used as the standard limit for a long term exposure. For shorter exposure terms higher concentrations are permitted (MCFARLAND; 1953).

The need for a routine inspection of work-spaces and personnel, as well as instruction of personnel, in precautions in the presence of carbon monixide can never be overemphasized, but environmental control and design for adequate protection are indispensable. Agents that cannot be eliminated at the source can be reduced in intensity by ventilation and personal protective equipment. An effective procedure is to use local exhaust ventilation systems, e.g. the exhaust outlet (MORGAN, et. al.; 1963). Work remains to be done on investigating alternative positions for the exhaust outlet and the effect on operator's environment; a poor outlet – in construction and direction – can create serious dangers (ZANDER; 1965). The ideal is the complete enclosure of the process generating the contaminant.

3.4.2. *Dust*

During combine harvesting dust is created, that whirls around the machine and may be inhaled by the operator. Next to the danger for the operator's health, dust is very annoying and it influences the operator's performance. In the Netherlands* a dust concentration of 15 mg/m^3 of air is thought to be the maximum permissible.

In England measurements were made of dust concentrations on combines of 7,2 to 21,6 mg/m^3 of air (MATTHEWS; 1967). FIER and MCCONVILLE measured the average dust concentration on combines in Minnesota and found 18,0 mg/m^3 of air. They recommended the use of a cabin and the use of filters in the cab ventilation system (FIER and MCCONVILLE; 1966).

* personal communication

In 1967 the author measured the dust concentrations on a combine (Nr.: 3[a]); for a part of the tests the machine was equipped with a cabin.

a. Equipment and method

The dust concentration of the air around the operator was measured by means of two aluminium filterholders – on the left and right sides of the operator's chest –, in which paperholders were fixed. Before sampling the filters were weighed in the laboratory under known conditions of temperature and humidity of the air; during sampling a registered quantity of air was sucked through the filters. After sampling the filters were weighed in the laboratory under the same conditions as before; the difference in weight is the dust, remaining behind on the filters.

From the weight of the dust and the quantity of air sucked through the filters the dust concentration – in mg/m^3 of air – was calculated. After weighing the dust of the left and right side was put together for determining the percentage of quartz.

b. Test conditions

The measurements were made during harvesting winterwheat (condition: 100% standing; humidity: 19,0%) at a ground speed of 4,5 km/h. During sampling 4 × 200 m on the left side and the right side of the plot were harvested. During all tests the wind blew in the longitudinal direction of the plot, so that harvesting took place once with and once against the direction of the wind (air velocity: 3 m/sec).

The results of the study are listed in table 25.

TABLE 25. Dust in the air around an operator of combines (with and without cabin).

	Concentration – in mg/m^3 of air –	Quartz percentage of dust sample
Without cabin	149	2,37 (100)
With cabin	10	9,67 (408)

The results show that the use of a cabin reduced the dust concentration considerably. The difference in quartz percentage in these samples is remarkable; this can be explained by the difference in specific gravity and the size of the particles. The smaller particles can penetrate better into the cabin and remain present.

In 1968 the author measured the dust concentrations of two combines (Nr.: 3[a] and 3[b]) in different crops.

a. Test conditions

With both machines the measurements were made during harvesting springbarley (condition: 40% standing; humidity: 18,6%) and winterwheat (condition: 100% standing; humidity: 21,0%) at a ground speed of 4,5 km/h. During sampling 4 × 200 m on the left side and the right side of the plot were harvested. During all tests the wind blew in the longitudinal direction of the plots, so that harvesting took place once with and once against the direction of the wind; the wind velocity was 5 m/sec, respectively 4 m/sec in springbarley, respectively winterwheat.

The results are listed in table 26.

TABLE 26. Dust in the air around an operator of combines (harvesting barley and wheat).

Machine - Nr. -	Concentration - in mg/m³ of air -		Quartz percentage	
	barley	wheat	barley	wheat
3[a]	122	304	4,93	4,00
3[b]	40	118	7,56	1,74

Based upon the results of this experiment we can conclude, that during harvesting springbarley less dust (40–122 mg/m³ of air) is circulating around the operator than during harvesting winterwheat (118–304 mg/m³ of air).

Examined in the same crops we can determine differences of 30 to 40% in dust concentrations between the machines investigated, in favour of machine Nr. 3[b]. This can be explained by the technical set-up of this machine, where the operator's head is far above the grain tank and more in the fresh air. In consequence, the filterintakes on this machine have a higher and better position.

Summarizing the results of these experiments we can conclude, that the dust concentration in the air around operators of self-propelled combine harvesters is exceeding the permissible limit of 15 mg/m³ of air. It is evident that the figures mentioned are only related to the quantities of air to be inhaled; with respect to the duration of the harvesting period the possibility of developing silicosis must be considered to be low.

Protection of the operator of a combine is possible by ventilation (blowing away or sucking off the particles) and personal protective equipment. The ideal concept is the enclosure of the operator in a cabin with a small over-pressure, so that particles cannot penetrate into the work-space.

3.5. FEELING

Though rather little operational information is entering the central nervous system through feeling, in detecting mechanical vibrations it has much impact on the operator's health and performance.

3.5.1. *General*

Feeling is a collective term for the senses of touch, pain, temperature, pressure, position and movement. There are various modalities of feeling (JONGBLOED; 1954); the sensitive nerveendings are not diffusely spread over the entire body area, but they are located at certain points of the body (MURRELL; 1965). A specific sense organ for mechanical vibration is missing (KEIDEL; 1956). A human being is capable of perceiving vibrations of 0,5 Hz till 100 Hz, and even 10.000 Hz at high intensities. Low frequencies with large amplitudes are perceived by means of depth sensibility (SOLIMAN; 1968), for this there are sense organs in the muscles, tendons and joints (HOCHBERG; 1964). Accelerations of the whole body are detected by a balancing organ, that is located in the inner ear; the neural impulses of this organ are transported to the central mechanism. Semicircular canals in the inner ear are used for the perception of angular accelerations of the head. Higher frequencies are perceived by tactual sensations in the hairless parts of the skin (JONGBLOED; 1954).

3.5.2. *Mechanical vibrations*

By unevenness of terrain and road surface, the profile of the tyres and functioning of the engine and other parts of the machine, the operators are submitted to mechanical vibrations. Vibrations will be transmitted to a man through those parts of his body in contact with the source of vibration, usually the buttocks, the hands, arms and feet. Sometimes the hands or arms only are under vibration, in other cases the whole body. The impact of mechanical vibrations can differ from some annoyance to performance degradation and damage to man's health.

3.5.21. Parameters

Vibration is characterized by a more or less regular swinging around a certain equilibrium. Six components of vibrations can be distinguished, see fig. 17; in the direction of the coordinate axis (X-axis: back–chest; Y-axis: shoulder–shoulder; Z-axis: foot-head) are translations, around one of the axis are rotations (I.S.O.; 1967). About the significance of translations much is known, in contrast with rotations; the movements in the direction of the Z-axis are mostly investigated (MATTHEWS, 1964; DUPUIS, 1969).

A simple harmonic motion is described by the projection of the motion of a point moving round a circle at a constant rate; the equation for the displacement (x) is:

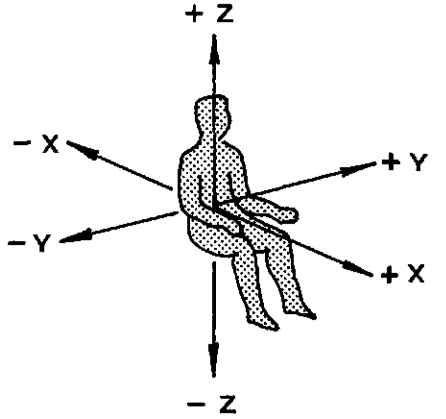


FIG. 17. System of coordinates for mechanical vibrations (I.S.O.; 1967).
X-axis: back-chest
Y-axis: shoulder-shoulder
Z-axis: foot-head

$$x = A \cdot \sin(\omega . t + \varphi) \quad (2)$$

in which:

x = displacement of the point

A = amplitude or maximum displacement with respect to the equilibrium

ω = angular velocity

t = time

φ = phase-angle

The equation for the velocity ($\dot{x}$), the first derivative of displacement, is:

$$\dot{x} = A \cdot \omega \cdot \cos(\omega . t + \varphi) \quad (3)$$

The equation for the acceleration ($\ddot{x}$), the second derivative of displacement, is:

$$\ddot{x} = -A \cdot \omega^2 \cdot \sin(\omega . t + \varphi) \quad (4)$$

$$\ddot{x}_{max} = A \cdot \omega^2 \quad (5)$$

The equation for the angular velocity (ω), expressed in radiants per second, is:

$$\omega = \frac{2 \cdot \pi}{T} \quad (6)$$

Each cycle will occupy a finite interval of time (T); the reciprocal of this period is called frequency (f), the unit is the hertz (Hz) or cycles per second (c.p.s.). The equation for maximum acceleration (5), modified by substituting the angular velocity (6) and the cycle-time (T), is:

$$\ddot{x}_{max} = A \cdot f^2 \cdot (2 . \pi)^2 \quad (7)$$

$$\ddot{x}_{max} \approx 40 \cdot A \cdot f^2 \quad (8)$$

Each vibration is characterized by a frequency (f) and an amplitude (A), in which the relation between them is expressed as an acceleration ($\ddot{x}$). The acceleration is determined in m/sec^2 or in g-value, in which g is the gravitational acceleration; the magnitude of the vibration should be expressed as a root-mean-square (r.m.s.) value (I.S.O.; 1968). Since perceptibility, effect and impact of mechanical vibrations depend on the frequency, when measuring vibrations a frequency-analysis has to be made (DIECKMANN, 1957; I.S.O., 1968; DUPUIS, 1969). Most vibrations in practice are non-harmonical, but by means of a Fourrier-analysis every periodical motion can be transformed arithmetically into a superposition of a number of sinusoidal components and a constant term (VAN SANTEN, 1950; DEN HARTOG, 1956).

3.5.22. Effects

The human body may be considered as a very complicated system of masses, elasticities and viscous dampers, each connected to the other (COERMANN; 1963). The various body parts are elastically coupled by bones, muscles and ligaments. Resonances occur in the body when it is exposed to a vibration environment of critical combinations of frequencies (BERTHOZ, 1966; DUPUIS, 1969).

Although a general model covering the body's response to a wide range of frequencies is available (COERMANN; 1963), a simplified, lumped-parameter model has been found satisfactory within the range of 1 Hz to 70 Hz. It is in this range that the energies of vibrations from vehicle sources are likely to be most important to man. For the human body a large number of natural frequencies for mechanical vibrations in the vertical direction (Z-axis) are known (table 27).

For the range of 3 Hz to 6 Hz especially the peripheral blood circulation is sensitive (COERMANN, et. al.; 1965), whilst in the range of 13 Hz to 30 Hz troubles in speaking occur (MAGID, et. al.; 1960). For vibrations in the horizontal direction (X-axis) the natural frequency of the human body lies in the range of 1 Hz to 3 Hz (DIECKMANN; 1958); at 2 Hz the head makes nodding movements and above 5 Hz most of the motion of the head is vertical.

About the significance of vibrations in the direction of the Y-axis it is only known, that the head comes into resonance at 1,5 Hz (HORNICK, et. al.; 1961).

Summarizing, it is evident that the human body is most sensitive to mechanical vibrations within the range of 2 Hz to 6 Hz.

During recent years special attention has been paid to various body deficiencies and infirmities, related to exposure to mechanical vibrations. However, until now criteria have not been available to judge whether or not these influences can cause damage to man's health; moreover, the chronic effect of vibrations can be determined only after a long period of time. It appears that the back (LAVAULT; 1961), the spine (FISHBEIN and SALTER, 1950; ROSEGGER and ROSEGGER, 1960; ZIMMERMAN, 1966) and the stomach (ROSEGGER and ROSEGGER, 1960; KUBICK, 1966) are sensitive. Danger is present for young people (CHRIST and DUPUIS, 1963; DUPUIS and CHRIST, 1968; DUPUIS, 1969) and women (FREUNDORFER; 1964).

Performances are influenced by mechanical vibrations; the major effects of

TABLE 27. Natural frequency of body parts for mechanical vibrations in the vertical direction.

Body part	Natural frequency – in Hz –	Author	
Head	20–30	DIECKMANN	(1957)
Body	4–6	DIECKMANN	(1957)
		SCHMITZ and SIMONS	(1959)
		GUIGNARD	(1960)
Heart	4–6	COERMANN	(1965)
		DUPUIS and CHRIST	(1966)
Stomach	4–5	DUPUIS and CHRIST	(1966)
Spine	3,5–4	CHRIST and DUPUIS	(1966)
Entrails	3–7	COERMANN	(1965)
Hand–arm system	5	DIECKMANN	(1963)

physiologically tolerable accelerative forces are those associated with visual and motor performances. The evidence available regarding effects on thought process, decision-making, and the like are so far not sufficient to draw conclusions. Visual acuity – i.e.: the ability of the eyes to resolve details – is affected by moderate g-values (MORGAN, et. al.; 1963), in particular at frequencies round 4 Hz (COERMANN and LANGE; 1962) and round 30 Hz, as well as in the range of 40 Hz to 70 Hz (DRAZIN, 1960; GUIGNARD, 1960), the visual acuity can be impaired. Because visual acuity decreases with increasing acceleration, it can be expected that an operator subjected to vibrations may commit errors in instrument reading. In 'scale reading' many errors and mistakes are found in the range of 3 Hz to 4 Hz (DRAZIN; 1962).

Submitted to mechanical vibrations a human being is loaded by correcting body posture, pursuit motions and extra concentration in perception, causing an increasing RT, uncontrolled movements and performance degradation. Notwithstanding the fact that the results of the various investigations differ to some extent, there is agreement on the point, that compensatory tracking ability in the range of 1 Hz to 30 Hz decreases with an increasing acceleration and duration of the exposure (FRAZER, et. al., 1961; SCHMITZ, et. al., 1961; HORNICK, 1962).

Summarizing, the tests of performance degradation either during or after periods of mechanical vibration, show a very definite, although not alarming, loss of capability (MATTHEWS; 1967).

3.5.23. Impact

The range of frequencies, in which annoyance by mechanical vibrations takes place, extends from 0,5 Hz till 100 Hz (TEN CATE, 1966; DUPUIS, 1969). At lower frequencies air and sea sickness occur; frequencies above 100 Hz usually not occur in practice.

With respect to the impact of mechanical vibrations on human beings, we have to distinguish objective, measurable characteristics and subjective sensations. The first category consits of direction, frequency, magnitude and duration of the vibration; the second of the magnitude of the perceptibility at the moment and the annoyance. The level of vibration that can be tolerated by an individual can only be determined in a subjective way. Measurements of objectively determinable phenomena do not provide a satisfactory base (TEN CATE; 1966).

Various authors have recommended threshold values for perceptibility, comfort, annoyance and safety (REIHER and MEISTER, 1931; MEISTER, 1935; ZELLER, 1949; SPERLING and BETZHOLD, 1956; DIECKMANN, 1957; GOLDMAN and VON GIERKE, 1961; V.D.I., 1963; I.S.O., 1968; SOLIMAN, 1968). For each frequency a certain point can be indicated, where a certain annoyance is attained; in a frequency-acceleration diagram, these points form a curve, representing equal vibration perceptibility or sensation. The degree of hindrance can be indicated, like: just noticeable, annoying, etc.; it can also be indicated by figures. The figures and related degrees of hindrance together build a scale of intensity.

The first studies regarding the impact of mechanical vibrations were carried

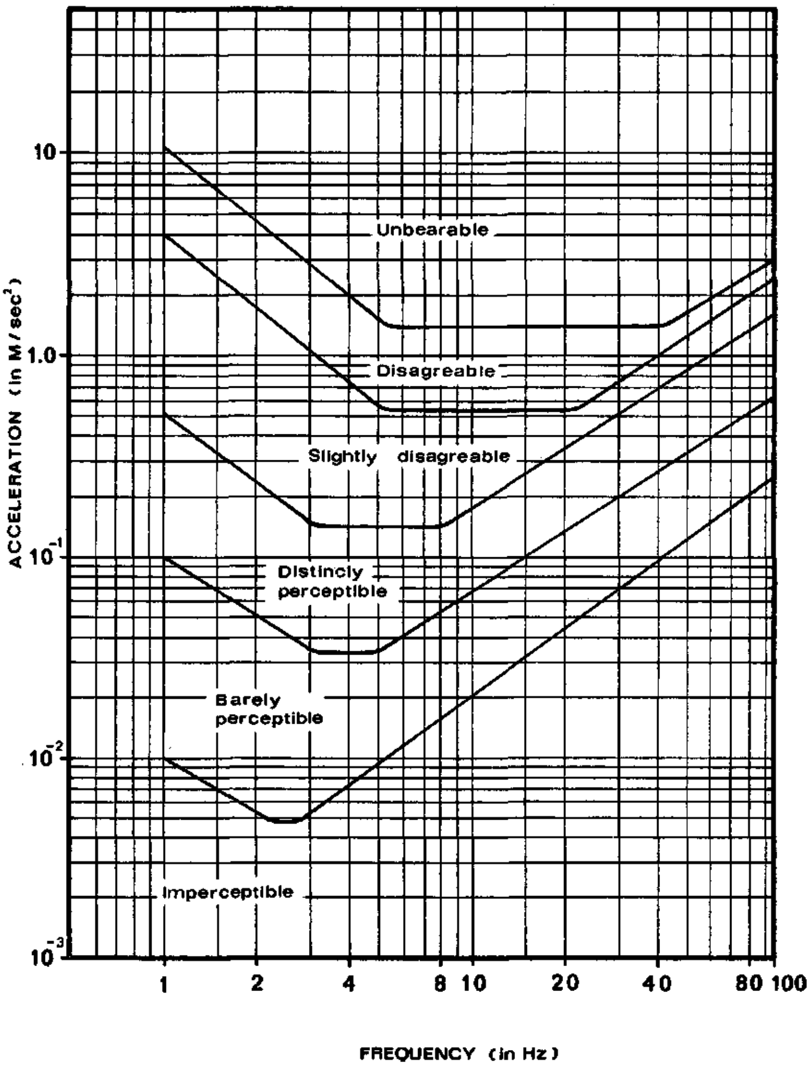


FIG. 18. Sensibility of standing individuals to vertical vibrations (REIHER and MEISTER; 1931).

out by submitting standing persons to vertical, harmonic vibrations (REIHER and MEISTER, 1931; MEISTER, 1935). They classified the vibration into six zones as shown in figure 18. It appears from the diagram that at low frequencies, as well as at higher degrees of hindrance, the acceleration is the indicator; at higher frequencies this is the velocity.

Curves of equal sensation to vibrations (K-value) were elaborated by DIECKMANN (1957); the values are listed in table 28.

Based upon the K-values an intensity scale was prepared (table 29).

TABLE 28. Definition of the K-value (DIECKMANN; 1957).

Frequency range	K-value
$f \leqslant 5$ Hz	$a \cdot f^2$
$5 < f \leqslant 40$ Hz	$5 \cdot a \cdot f$
$40 < f \leqslant 100$ Hz	$200 \cdot a$

TABLE 29. K-values for people subjected to vibrations (DIECKMANN; 1957).

K-value	Classification	Work
0,1	Threshold value, vibration just perceptible	not affected
0,1–0,3	Just perceptible, scarcely unpleasant, easily bearable	not affected
0,3–1	Easily noticeable, moderately unpleasant, if lasting over an hour, bearable	still not affected
1–3	Strongly noticeable, very unpleasant if lasting an hour, still bearable	affected, but possible
3–10	Unpleasant, can be tolerated an hour, not tolerated more than an hour	considerably affected, still possible
10–30	Very unpleasant, cannot be tolerated more than 10 minutes	barely possible
30–100	Extremely unpleasant, not tolerable more than 1 minute	impossible
> 100	Intolerable	impossible

A number of curves, representing equal sensation from vertical vibrations, are shown in figure 19.

Based upon DIECKMANN's work a correlation between the measurable, objective characteristics and the subjective hindrance experienced has been effected in a Recommendation (V.D.I.; 1963). Of practical importance is the relation between the K-value and the manner in which the hindrance can be endured under different conditions, as listed in table 30.

A number of curves of equal K-values are shown in figure 20. It appears from this diagram that for frequencies up to 5 Hz the K-value is proportional to the acceleration. From 10 Hz the K-value is proportional to the velocity. The range of 5 Hz to 10 Hz is indicated by an interrupted curve, because of some uncertainty about the relation in this range.

For the vibration exposure as a function of frequency, in which, as a basis for judging the exposure time for the normal daily working time of eight hours has to be considered, criteria have been proposed (I.S.O.; 1968); the weighing curves are shown in figure 21. These curves fall in the range from 0,5 Hz to 4,0 Hz at the rate of $\sqrt{1/f}$; in the range from 4,0 Hz to 8,0 Hz the curve is flat and in the range from 8,0 Hz to 90 Hz it increases proportionally to f.

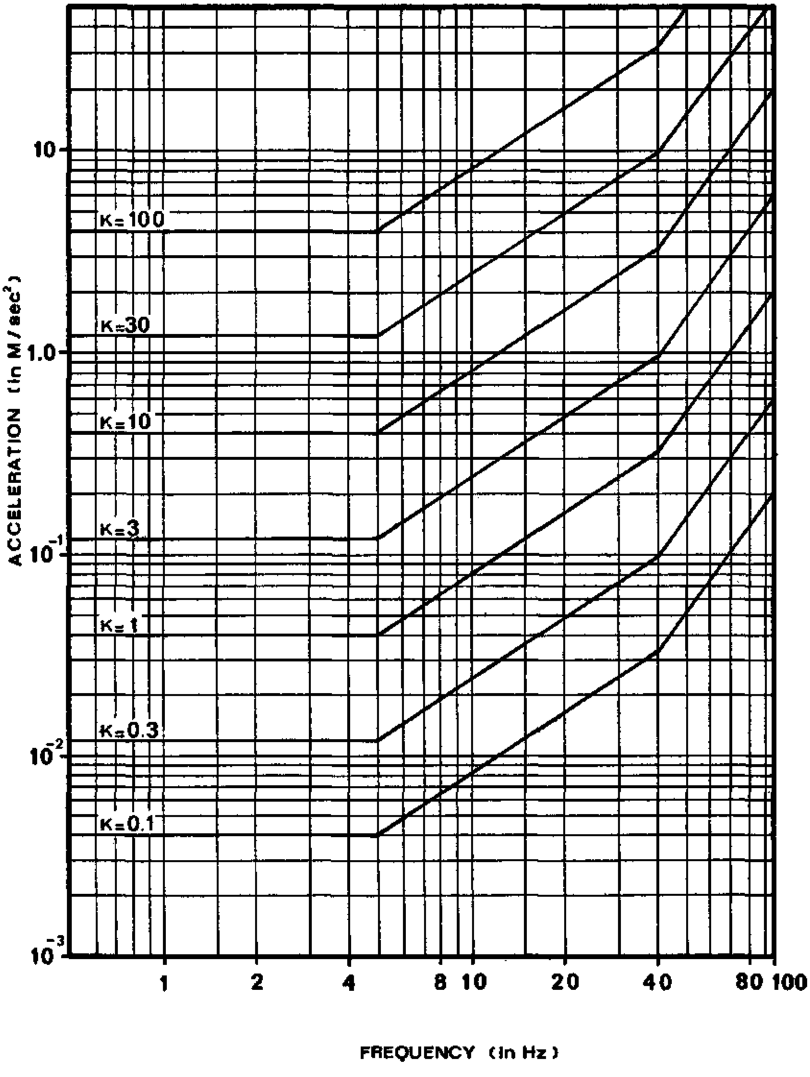


FIG. 19. Curves of equal sensation from vertical vibrations (DIECKMANN; 1957).

With respect to the impact of mechanical vibrations it has generally been accepted, that the experienced vibration sensation varies with the frequency. About the incline of the curves of tolerable intensities in the low frequency range there is unanimity between the authors cited (TEN CATE; 1966). Based upon the data in table 30, as well as present state of technology and the data determined in practice (DUPUIS, 1964; SJØFLOT and DUPUIS, 1968), it is necessary that the value K = 4 of the VDI-Recommendation is not exceeded in designing the operator's platform of farm machinery.

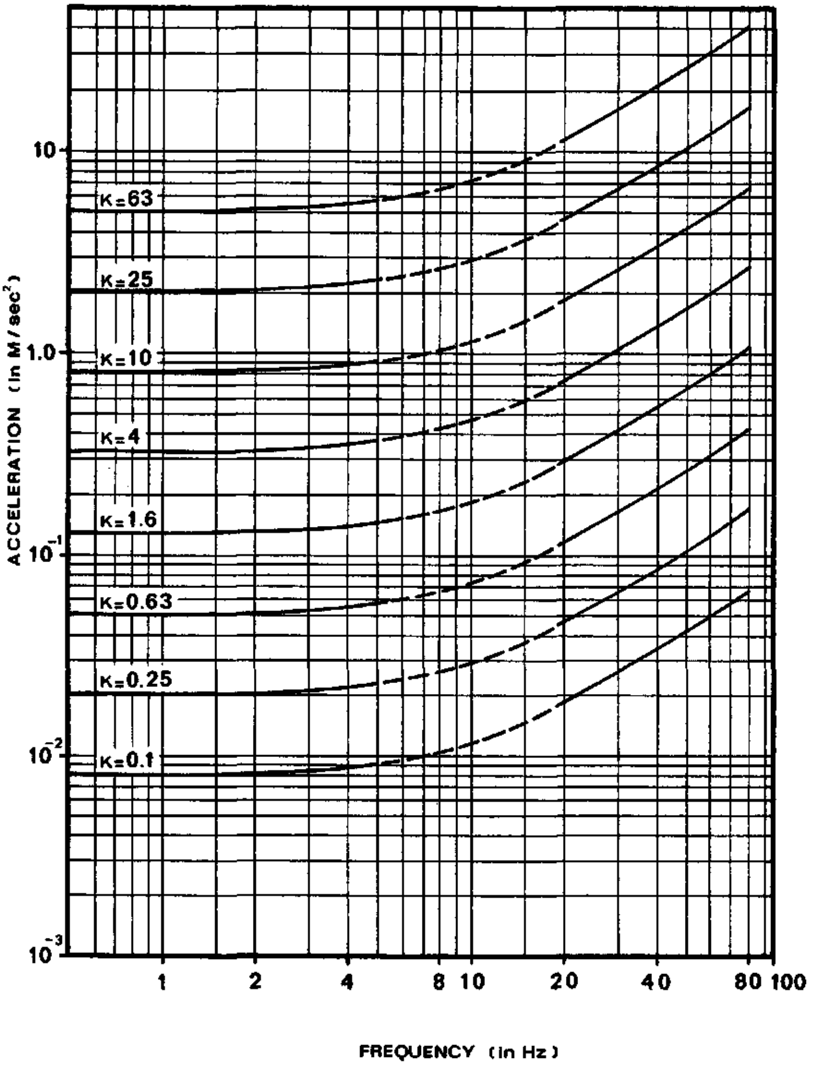


FIG. 20. Curves of equal K-values (V.D.I.; 1963).

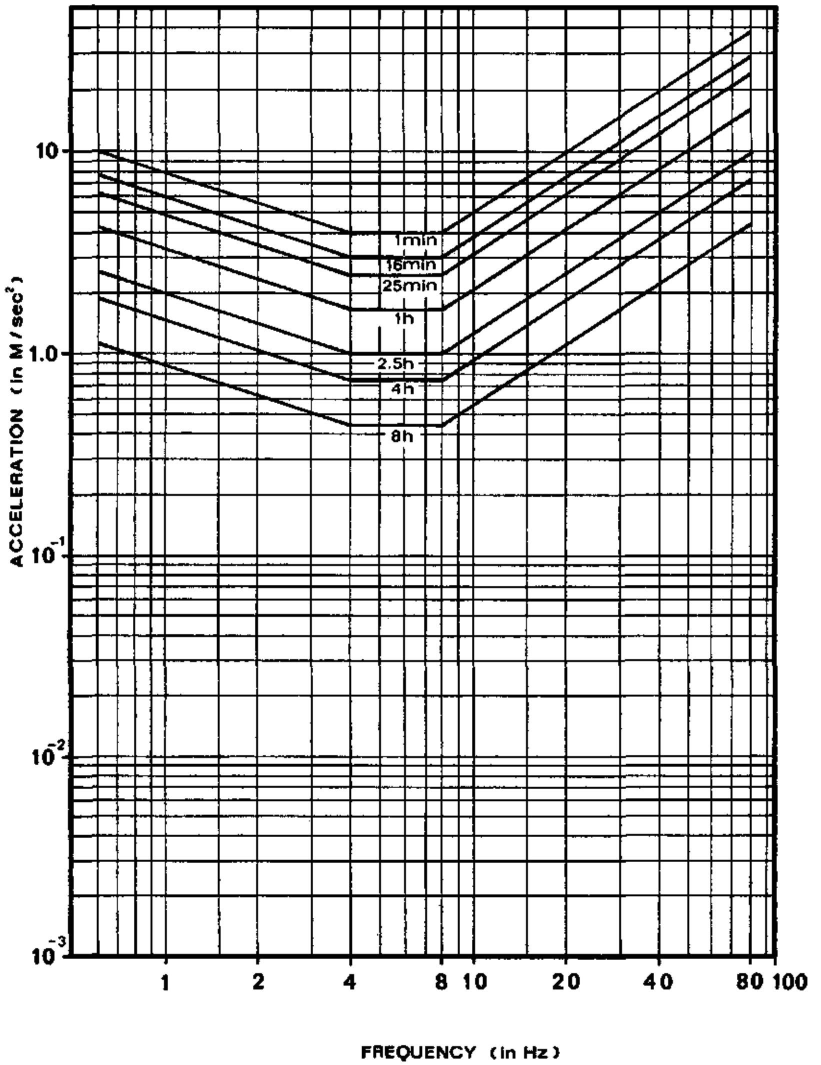


FIG. 21. Recommendation for the exposure time on mechanical vibrations as a function of frequency (I.S.O.; 1968).

TABLE 30. K-values and classification for various conditions (V.D.I.; 1963).

K-value	Level	Conditions	Classification
	A		imperceptible
0,1		(Threshold value)	
	B		barely perceptible
0,25			
	C	Stay in houses with short or without interruption[1]	perceptible
0,63			
	D	Stay in houses with long interruptions[2]	well perceptible
1,6			
	E	Physical work without interruptions	strongly perceptible
4			
	F	Physical work with short interruptions	very
10			
	G	Physical work with long interruptions; driving in vehicles over longer periods	strongly
25			
	H	Driving in vehicles over shorter periods	perceptible
63			
	I		

[1] Short interruption – Interruption (lasting about 10 minutes), in which the ratio interval/exposure period is 0,1;

[2] Long interruption – Interruption (at least 60 minutes), in which the ratio interval/exposure period is between 0,1 and 1,0.

3.5.24. Protection

Protection against mechanical vibrations is of a technical nature (reduction and isolation of the vibration source, reduction of the vibration transmission) or of a personal nature (cushions, suspension seat or suspended cabin).

Desirable suspension characteristics have been summarized (DUPUIS and HARTUNG, 1966; LASSER, 1966; DUPUIS, 1967; ZANDER and VAN DER HORST, 1967). As the human body is most sensitive to vibrations in the frequency range from 2 Hz to 6 Hz, this type of vibrations has to be avoided; so the natural frequency of a seat has to be less than 2 Hz (BERTHOZ, 1966; BJERNINGER, 1966; DUPUIS, 1967). Moreover, the value $K = 4$ is not or only barely permitted to be exceeded, whilst only movements in vertical direction are permitted to be executed (DIECKMANN; 1957). By stepless adjustment or in small steps, the seat has to be adaptable to the operator's weight (range: 600–1250 N) with clear indication of the weight.

At present, the most obvious way to reduce ride vibration is to fit a correctly designed suspension seat (MATTHEWS, 1967; DUPUIS, 1969). In passive control, attenuation is achieved by means of one or more resilient elements located between the source of vibration and the mass to be isolated. Reasonably good isolation can be achieved if the frequency of the disturbing vibration is four times or more the natural frequency of the isolated mass (SUGGS and

STIKELEATHER; 1969). The addition of cushions dampens the system at higher frequencies but results in a resonance at a lower frequency (MORGAN, et. al.; 1963). An active vibration system for isolating an operator from the vertical vibrational input is developed (SUGGS and STIKELEATHER; 1969). Active control devices – characterized by a vibration displacement detector, a circuit to phase correct and amplify the signal – seek to control a variable by applying energy from an independent output source.

The benefit of a good suspension seat is limited by the increasing movements between the operator and the controls; to eliminate this the vibrations of the whole vehicle or the whole of the operator's work-space should be reduced (SUGGS and STIKELEATHER; 1969). A suspended enclosed cabin – in which controls, seat and operator move simultaneously – is an approach, which combines the need for considerably improving ride with greater protection from noise and climatic influences (MATTHEWS; 1967).

3.5.3. *Combine harvesters*

The intensity of mechanical vibrations on combine harvesters is only slight, as a result of the low ground speed, the weight of the machine and the ground surface not being critically uneven (SCHILLING, 1965; MATTHEWS, 1967).

A study in Germany showed (UZ; 1964), that for a combine harvester – 56 h.p., 5,9 km/h; dry and even soil – the r.m.s.-value of the accelerations in the vertical direction amounted on the average of 0,1066 g (range: 0,1020–0,1098 g). In another German study (SJØFLOT and DUPUIS; 1968) the mechanical vibrations of a self-propelled combine harvester – 87 h.p., 4,2 km/h – have been measured in three directions. The amplitudes of the accelerations were very low. Regarding the frequency above 4 Hz a clear relation existed between the three directions of vibration, that, according to the authors, indicated bumping of machine parts; details have not been mentioned. In the vertical direction maxima arise in the frequency range from 1,5 Hz to 3,5 Hz, caused by the natural frequency of seat and machine. At frequencies below 2,5 Hz a clear relation could be indicated for the X-component. Below 1,5 Hz the riding characteristics of the machine cause a strong increase of the intensity of the Y-component.

(i) Intensity of vibrations

In 1966 and 1967 measurements were carried out on three self-propelled combine harvesters (Nr.: 2, 3^a and 4) to study (direction: Z-axis, 4,5 km/h) the intensity of mechanical vibrations.

a. Equipment and method

The vibrations on the seat were measured by means of accelerometers (make: HOTTINGER;type: B 1 M/170), which were connected with a recorder (make: SANBORN; type: 321); the results were recorded as an oscillogram.

b. Treatment

The oscillogram was analysed in respect of:

1. Acceleration

From the oscillogram, recorded at a constant paper speed (V_p = 100 mm/sec), a frequency distribution was made of the accelerations; the number of scannings amounted to 10 Hz. From this distribution the r.m.s.-value ($\ddot{x}_{eff}$ in g) of the accelerations was calculated (HAAS, 1962; UZ, 1964).

2. Frequency

For analysing the frequency a procedure was used according to the 'method of passage of time between two zero-crossings' of the oscillogram, of which the paperspeed is known and constant. The interval of time needed for each cycle of vibration is the reciprocal of the frequency; with the paperspeed it is possible to convert the distance between two zero-crossings of the oscillogram into the interval of time needed for a semicircle (T/2), of which the frequency (in Hz) can be calculated (HAAS, 1962; UZ, 1964).

As a result of the analysis the relative numbers (in %) in the various frequency bands can be calculated; the results are listed in table 31.

TABLE 31. Mechanical vibrations of combines (f and $\ddot{x}_{eff}$).

Frequency – Hz –	Machines			
	Nr. 4	Nr. 2		Nr. 3[a]
< 1	0,3	–	–	–
1– 2	2,2	0,4	0,2	–
2– 3	3,8	2,4	1,8	–
3– 4	25,2	13,3	13,8	–
4– 5	26,3	37,4	36,9	10,0
5– 6	19,1	22,0	21,6	49,6
6– 7	11,2	12,2	12,1	24,4
7– 8	4,9	7,1	6,2	7,6
8– 9	3,2	2,9	4,3	6,0
9–10	2,3	1,3	1,6	1,6
>10	1,5	1,0	1,5	0,8
$\ddot{x}_{eff}$	0,068g[2]	0,078g[2]	0,085g[1]	0,105g[2]

[1] –dry and smooth soil; [2] –dry and hard soil.

The intensity of the vibrations is low ($\ddot{x}_{eff}$ = 0,068–0,105 g), which conforms to the literature.

The spectral distribution of the frequencies shows that the frequency range from 4 Hz to 7 Hz is strongly represented. The low intensity and the specific frequency range lead to the assumption, that during combining the machine determines the appearing mechanical vibrations and the circumstances of the terrain make little or no contribution to the vibrations; by additional measurements on a standing combine (Nr.: 2), this assumption was confirmed. The engine (1500 revolutions/minute) causes an acceleration of 0,036 g, with a clear frequency of 25 Hz. The engine, threshing and cleaning mechanism – shaker: approx. 300 revolutions/minute – together cause an effective acceleration of

0,097 g and a frequency band of about 5 Hz. The engine, mowing, threshing and cleaning mechanism – shaker: approx. 300 revolutions/minute – together cause an effective acceleration of 0,073 g with a clear frequency band of 5 Hz.

Based upon these results we may conclude, that the natural frequency of a self-propelled combine harvester lies in the frequency range from 4 Hz to 7 Hz, in which bumping is caused by machine parts. This conclusion conforms to literature (SCHILLING, 1965; MATTHEWS, 1967; SJØFLOT and DUPUIS, 1968).

(ii) Effect of ground speed during combining

In 1968 measurements were carried out on two self-propelled combine harvesters (Nr.: 3^a and 3^b) to study (directions: X-, Y- and Z-axis) the effect of ground speed during combining.

a. Method

The vibrations on the seat were measured by means of accelerometers (make: HOTTINGER; type: B 1 M/170) and recorded with an instrumentation-recorder (make: AMPEX; type: FR 1300). At the Vehicle Research Laboratory of the University of Technology in Delft, the data were analysed.

The results are listed in table 32.

TABLE 32. Mechanical vibrations ($\ddot{x}_{eff}$ in g) of two combines during harvesting at different ground speeds.

Ground speed - in km/h -		Working width: 3,00 m			Working widht: 3,90 m		
		X	Y	Z	X	Y	Z
2,5	3^a	0,016	0,0073	0,150	0,013	0,0034	0,104
	3^b	0,021	0,0002	0,054	0,022	0,0027	0,053
3,5	3^a	0,016	0,0046	0,160	0,014	0,0028	0,107
	3^b	0,027	0,0003	0,055	0,026	0,0027	0,051
4,5	3^a	0,016	0,0065	0,139	0,013	0,0023	0,110
	3^b	0,019	0,0002	0,045	0,019	0,0020	0,066
5,5	3^a	0,015	0,0042	0,135	0,012	0,0023	0,100
	3^b	0,018	0,0002	0,043	0,019	0,0019	0,061

The movements in the Z-directions are more numerous (Z: 81,3%) than in the other directions (X: 16,2%; Y: 2,5%). As to the intensity ($\bar{Z} = 0{,}098$ g; $Z = 100{,}0\%$) the movements in the X-direction ($\bar{X} = 0{,}018$ g; $X = 19{,}9\%$) are small; the movements in the Y-direction ($\bar{Y} = 0{,}0027$ g; $Y = 3{,}0\%$) are of minor importance.

The intensity of the vibrations is different for the two combines; machine 3^b ($\bar{X} = 0{,}021$ g; $\bar{Y} = 0{,}0013$ g; $\bar{Z} = 0{,}053$ g) is more favourable than machine 3^a ($\bar{X} = 0{,}014$ g; $\bar{Y} = 0{,}0042$ g; $\bar{Z} = 0{,}126$ g). Change of speed gave no difference in intensity; at a greater working width the intensity is slightly smaller.

The spectral distribution of the frequencies shows an identical picture. The frequency-band of 5,0 Hz is predominant in the spectrum; the intensity of machine 3^a is higher than the intensity of machine 3^b. In the frequency range from 14,6 Hz to 15,6 Hz and 34,3 Hz to 40,0 Hz small peaks appear, which are caused by the threshing drum and the engine respectively. These frequency-bands only appear in the Z-direction; the X- and Y-direction appear very little or not at all in the spectrum of frequencies.

(iii) Effect of road speed

In 1968 measurements were carried out on two self-propelled combine harvesters (Nr.: 3^a and 3^b) to study (directions: X-, Y- and Z-axis) the effect of terrain during driving on the road.

The results are listed in table 33.

The movements in the Z-direction are more numerous (Z: 81,1 %) than in the other directions (X: 16,1 %; Y: 2,8 %). As to the intensity ($\bar{Z}$ = 0,066 g; Z = 100,0 %) the movements in the X-direction ($\bar{X}$ = 0,013g; X = 19,7 %) are small; the movements in the Y-direction ($\bar{Y}$ = 0,0023 g; Y = 3,5 %) are of minor importance.

The intensity of the vibrations of the two machines during driving on the road ($\bar{X}$ = 0,013 g; Y = 0,0023 g; $\bar{Z}$ = 0,066 g) is lower than during combining ($\bar{X}$ = 0,018 g; $\bar{Y}$ = 0,0027 g; $\bar{Z}$ = 0,098 g); during driving on the road the mowing, threshing and cleaning mechanisms have been disengaged. With increasing ground speeds there appears – in particular in the vertical direction – an increasing intensity; the intensity of the movements in the horizontal directions hardly varies. The intensity of the vibrations during driving on the road is lower than the intensity measured during combining. The intensities are not equal for the machines examined; machine 3^b ($\bar{X}$ = 0,015 g; $\bar{Y}$ = 0,0020 g; $\bar{Z}$ = 0,058 g) is more favourable than machine 3^a ($\bar{X}$ = 0,011 g; Y = 0,0027 g; $\bar{Z}$ = 0,075 g), also taking into account the frequency of the vertical movements.

The spectral distribution of the frequencies shows an identical picture. In none of the directions does a clear frequency-band exist.

TABLE 33. Mechanical vibrations ($\ddot{x}_{eff}$ in g) of two combines during driving on the road at different ground speeds.

Ground speed - in km/h -		X	Y	Z
5,5	3^a	0,010	0,0023	0,045
	3^b	0,011	0,0033	0,035
10,0	3^a	0,011	0,0028	0,086
	3^b	0,015	0,0023	0,044
15,0	3^a	0,012	0,0029	0,093
	3^b	0,020	0,0003	0,095

Summarizing, the conclusion can be made that on combine harvesters the machine is determining the character and extent of the mechanical vibrations; the circumstances of the surface the machine must usually move on affects the vibrations little or not at all. The intensity of the vibrations is low and the movements in the vertical direction are more numerous than in the other directions. Combining at different ground speeds appears to hardly affect the intensity. During driving on the road with increasing ground speeds there appears an increasing intensity, which level, however, is lower than during combining; with greater working width the intensity is slightly smaller.

The spectral distribution indicated the existence of specific frequency ranges; the natural frequency of a combine harvester lies in the frequency range from 4 Hz to 6 Hz, in which bumping is caused by machine parts (threshing and cleaning mechanisms).

3.6. Summary

The perception of information, that a worker receives from work-space and environment, takes place via the senses, which are sensitive to specific impulses. The reaction to the information depends upon the sense organ that is stimulated, the strength of the stimulus and the place where the stimulus arrives.

1. Sight

The perception of visual information – playing an important role in man-task systems – depends upon the object, the environment and the distance between eye and object.

For combine harvesting it is necessary to obtain information from the feed table auger just in front of the conveyor chain and of the separation from the previously cut swath. On the machines examined the visual angle, as well as the horizontal distance between eye and cutterbar, are favourable in the horizontal plane. In the vertical plane the view angle is extremely unfavourable; besides the distance between eye and cutterbar is too long, which is caused by the large vertical distance.

2. Hearing

The hearing ensures mutual communication between man, machine and environment. Depending on frequency, sound pressure level and duration of the exposure, sound has an annoying or a damaging effect.

The sound pressure levels – measured at the operator's ear – of the machines examined are too high, whilst the presence of a cabin does not lead to an important decline of the sound pressure level; moreover, the ground speed during combining does not affect the sound pressure level.

3. Scent and taste

Although the scent and taste are less important, attention must be paid to the dust in the air around an operator of a combine. The dust concentration in the air around operators of the machines examined is too high; with respect to the duration of the harvesting period the possibility of developing silicosis must be considered to be low. On a machine without cabin the dust concentration is considerably higher than on a machine with cabin; during harvesting barley less dust is circulating around the operator than during harvesting wheat.

4. Feeling

The operators of machinery are submitted to mechanical vibrations, which adversely affect their health and performance. The effect and impact of vibrations varies with the frequency, as the human body is most sensitive to mechanical vibrations within the range from 2 Hz to 6 Hz.

The intensity of mechanical vibrations on combine harvesters is low, whilst the movements in the vertical direction are more numerous than in the other directions. Combining at different ground speeds appears to affect hardly the intensity; with greater working width the intensity is slightly smaller. When driving on the road with increasing ground speeds there appears an increasing intensity, which is lower than during combining. The spectral distribution indicates the existence of specific frequency ranges, which are explicable from the machine.

Since machines, performing functions of perception, do not exist or are very rare, the designer of a man-task system must take into account the attainments of the investigations regarding perception. For the self-propelled combine harvester this means primarily an adequate presentation of the relevant information; by improving the visibility of the cutterbar (reduction of the view angle and the vertical distance) this can be realized. Besides, the redundant and non-relevant information – sound, dust and mechanical vibrations – has to be eliminated; the suspended enclosed cabin – in which controls, seat and operator move simultaneously – is an approach, which combines the need for improving ride with greater protection from sound and dust.

4. SELECTION

4.1. Introduction

The transport of data from stimulated sense organs to the effectors is not simply and solely transport; the data are processed by the complex mechanism of neural circuits in the peripheral and central nervous system (MURRELL; 1965). From the various possibilities the right answer is chosen and – by giving signals to the muscles – transformed into action.

In information processing we distinguish the following main items (MURRELL, 1965; SANDERS, 1967):

1. Input
   The number of incoming signals per unit of time (Identification of information and association with the knowledge stored in the memory).
2. Choice
   The number of directed switches per unit of time.
3. Output
   The number of outgoing signals per unit of time (Central conducting, leading to the periphery and guided action of the effectors).
4. Feedback
   The restatement of the results of the action.

For the output of a man-task system it is important to know how much time elapses before a signal is transformed into an adequate performance; it is evident, that – apart from the characteristics of the signal – learning processes are playing an important role. There are three general ways in which the performance of the human decision element in a system might be improved (SCHRENK; 1969):

a. To select good decision makers;
b. To train persons to be good decision makers;
c. To provide, through appropriate system design, machines and tools that facilitate appropriate decision.

In the field of ergonomic research major emphasis is upon the third possibility; we therefore have to go further into the mechanism of information processing, as well as into the assessment of mental load.

4.2. Theory

Information is that what we get when some man, machine or environment tells us something we did not know before (GARNER; 1962). As a result of the developments of the theory of information, to be used in telephony and telegraphy (SHANNON and WEAVER; 1949), the interest in the processing system was stimulated considerably, so that we have at our disposal a quantitative parameter for information, namely the bit (= binary digit) (SHANNON; 1948).

The amount of information (H) or entropy depends upon the number of probable, alternative possibilities (n). In formula:

$$H = {}^{2}\log n \qquad (9)$$

In this formula it is assumed, that each possible signal has the same chance of appearing. If this is not the case, each alternative has to be considered; redundant information has to be avoided (ATTNEAVE; 1959).

The decision mechanism determines the information processing, i.e.: in task performance the number of directed switches per unit of time from input to output determines the information processing (ETTEMA, 1967; KALSBEEK, 1967). Several authors paid attention to the function of the decision mechanism in information processing (MILLER, 1956; BROADBENT, 1958; WELFORD, 1959; CROSSMAN, 1960; GARNER, 1962; HERMAN, 1965). These investigations led to the theory of 'a single channel decision mechanism', which all signals (simple or complex) have to pass; the term 'a single channel' was introduced, because only one directed switch at a time can take place ('tourniquet function').

During each input-output switching the decision mechanism is blocked up, whereby other information has to wait ('queueing up') until the blocked condition is abolished (WELFORD; 1959). The capacity of the channel is determined by the minimum duration of the blocked condition; this minimum duration is called elementary time-quantum (KALSBEEK; 1967).

If too much information is presented, it is impossible to transfer all perceptive material in an adequate code; this will be expressed by mistakes, misses or errors in the output.

The capacity of processing information is primarily determined by the capacity of the central decision mechanism; the more complex the circuits to be followed, the less the capacity. The maximum capacity of a single cell amounts to 1000 bits per second; for a separate organ this maximum is 50 bits per second, for the whole organism the maximum is 5 bits per second (MILLER; 1962). As a theoretical maximum a value has been calculated of 10 bits per second (CROSSMAN; 1960). For binary choice tests, without any previous information ('preview') and a slight tolerance, a maximum of 1,25 bits per second has been found (ETTEMA; 1967). Generally, a value of 2 to 3 bits per second is assumed to be the limit for adequate information transmission (MILLER, 1956; CROSSMAN, 1960; GARNER, 1962); the admissable limit – for a normal task performance during four hours – is between 20 and 60 signals (binary choices) per minute, in fact closer to 20 signals per minute (ETTEMA; 1967).

Next to the process of information processing and the capacity of this system, it is necessary to mention aspects of selection, namely:

1. Learning

When periodic or otherwise predictable inputs are recognized and learned, the operator begins to respond with well practised movements and is effectively tracking precognitively (YOUNG; 1969). The learning effect consists of an easier, quicker and better reaction on the information presented. The motions gradually become more sure and more supple and accurate movements, as well as a right coordination, can be achieved; this will lead to automation (RIEMERSMA; 1969). Research in the field of learning can offer possibilities to design machines with improved learning qualities.

2. Vigilance

Vigilance is related to the attentiveness of the subject and his capability for detecting changes in stimulus events over relatively long periods of sustained observation (FRANKMAN and ADAMS, 1962; MCGRATH, 1963; SMITH, 1969).

In increasing automation the monotonuous control and inspection work not only vigilance will be found more frequently, but grow in importance too. In these circumstances we have to prevent too low a mental load, so that boredom and absence of mind can not occur (SMITH; 1969).

4.3. ASSESSMENT OF MENTAL LOAD

In the great variety of structure and operation of the sense organs, as well as the complex character of the decision mechanism, it is hardly thinkable that one universal parameter could be found for the assessment of mental load.

The following categories may be distinguished:

4.3.1. *Performance measurements*

An increase of the reaction time (RT) to react upon an increasing number of alternative possibilities, can be considered as the relation between the mental load, as well as the complexity, more or less, of the information to be identified (HICK; 1952). It is possible to correlate the RT with the amount of information (H), so that we have a parameter for mental load available in this case (WESTHOFF, 1962; HILGENDORF, 1966); RT-measurements have the disadvantage of laborious analysis, whilst it is unknown by way of which neural circuits the response is taking place (TOMLINSON; 1970).

In view of the output, the work load can be estimated by means of the task performance (qualitatively: mistakes, misses and errors; quantitatively: time per unit of task, task per unit of time) (SINAIKO; 1961).

4.3.2. *Psychological measurements*

The psychological measurements are based upon the limited single channel decision mechanism, in which the task performance appeals to a part of the channel and the other part ('spare mental capacity') remains unused. By a simultaneous performance of two tasks the spare mental capacity is being occupied completely and the mental load can be determined in an indirect way (BROWN and POULTON; 1961). By selection of the tasks in such a way, that during simultaneous performance the channel capacity is not exceeded, deterioration of the tasks will occur; this deterioration – mistakes, misses and errors – is a parameter for the mental load. The secondary task should not interfere functionally with the basic task; for example, a secondary task involving mental arithmetic should be not combined with a basic task involving numerical assimilation (MICHON; 1966).

This method of secondary tasks – already known for a long time in the experimental psychology (POFFENBERGER; 1927) – has been introduced for the assessment of mental load (BORNEMANN; 1942). Two categories should be differentiated:

4.3.21. Subsidiary task

During the performance of the basic task a simple, repetitive task is added, which last task can be controlled and measured qualitatively and quantitatively, so that full use is made of the spare mental capacity; the basic task has priority and must be performed faultlessly. The level of performance of the secondary task – number of mistakes, misses and errors – is a parameter for the mental load, caused by the basic task.

Various types of tasks have been proposed and tested for suitability:

(i) Motor tasks, as rate of key-tapping, in which the irregularity of an oscillating series – the operating of a foot-operated control – is used as a parameter for the mental load. The expectation is, that – when increasing the mental load of the basic task – the secondary task will be performed more irregularly (MICHON; 1964, 1966, 1967).

(ii) Verbal responses to programmed tasks, usually presented by tape-recorders, as reaction to digit groups or performing simple arithmetic calculations (HAIDER; 1962). An interesting method is the presentation of 8-digit groups, in which each following group differs in one position in comparison with the previous combination; the altered position has to be detected and labeled. (BROWN and POULTON, 1961; BROWN, 1962; BROWN, 1967). For agricultural tasks this method is under research, whereby sequences of pairs of tones – one tone in a pair changes from the previous pair – are used (TOMLINSON; 1970).

4.3.22. Experimental distraction

By a systematic increase of the amount of information in the secondary task, less capacity remains for the basic task and deteriorates the performance of this task (BERTELSON; 1966). The secondary task is a simple, dosable – controllable and measurable – and repetitive task which has to be performed as well as possible.

A number of experiments has been carried out with dual tasks, in which the mutual effect of basic and secondary task has been studied (SCHOUTEN, 1962; KALSBEEK, 1964). In these experiments – mental arithmetic, solving of mazes and setting bolts and nuts – the performance in the basic task decreases, if – with an increasing amount of information – the secondary task is being performed faultlessly (ETTEMA, 1967; KALSBEEK, 1967).

4.3.3. *Physiological measurements*

Various physiological parameters appear to be dependent on the varying mental load. Measurements have been carried out to study which physiological changes can function as parameters for the assessment of mental load.

Mental load – in the context of information processing – is accompanied by:

a. An increase of the heart rate

It has been known for a long time, that the increase of the average number of heart beats per minute is not only caused by a physical load (GILLESPIE, 1924; BARTENWERFER, 1960[b]; RUTENFRANZ, 1960; BARTENWERFER, 1961; MELLEROWICZ, 1962; BENSON, 1965; GRAF, 1965).

During experimental distraction – by means of the binary choice generator – it has been ascertained that the average heart rate increases in comparison with the situation during rest (ETTEMA; 1967).

b. A decrease of the sinus arrhythmia

For a resting subject the beat-to-beat intervals of the heart rate are relatively irregular, a phenomenon known as sinus arrhythmia. If additional processing of information is placed on the nervous system, the irregularity decreases (WIERSMA, 1911; ANREP, 1936; BARTENWERFER, 1960[a]; PARIN, 1965).

By a systematic increase of the amount of information the irregularity is more strongly suppressed.

In principle it is possible to discriminate between mental loading tasks by means of the percentual suppression of the sinus arrhythmia measured in comparison with the situation during rest; the scoring method is rather reliable (ETTEMA; 1967).

c. An increase of the blood pressure

On account of mental loading tasks the diastolic and systolic blood pressure are increasing (GILLESPIE, 1924; ETTEMA, 1967).

This increase is systematic, but rather low so this method seems to be less useful to discriminate between mental loading tasks. Possibly the blood pressure can be an important indicator in heavy mental loads of long duration (ETTEMA; 1967).

d. An increase of the respiration rate

On account of mental loading tasks the respiration rate increases, whilst the take up of oxygen increases slightly (WIERSMA, 1913; BENSON, 1965).

During experiments the subjective hindrance for individuals is an interfering factor in judging the results, so this method is less useful (ETTEMA; 1967).

During mental loading tasks of short duration the relative change of the sinus arrhythmia – measured in comparison with the situation during rest – is bigger than the changes of the other physiological parameters.

4.3.4. *Summary*

The assessment of mental load presents a great challenge to the psychologist and psychophysiologist and, despite a plethora of techniques, few are of general applicability and those that are, have still question marks regarding their validity (SANDERS, 1967; TOMLINSON, 1970). In the author's view, and based upon the results of investigations available, the best results for the assessment of mental load can be expected from:

(i) The method with dual tasks (subsidiary tasks and experimental distraction), whereby the spare mental capacity is occupied by supplying an additional task.

(ii) The heart rate, in particular the relative suppression of the sinus arrhythmia, measured in comparison with the situation during rest.

4.4. MENTAL LOAD ON COMBINE HARVESTERS

4.4.1. *Literature*

Dependent upon the condition of the crop and the situation of the terrain, the operator of a combine harvester regulates the movement, the mowing and threshing mechanisms, the separation of kernel and straw, as well as the delivery of the product. The operator's task is probably the most taxing of all work with agricultural machinery (MATTHEWS; 1967).

Under normal circumstances a skilled operator is capable of information processing into adequate actions, without a reduction of the quality and quantity (WIENEKE; 1967); the information speed of self-propelled combine harvesters, given on account of estimations in practice, are listed in table 34.

TABLE 34. Information speed (in bits/second) of combines (WIENEKE; 1967).

Primary information	Secondary information
crop : 9	threshing quality: 4
terrain : 2	sound : 2
working width: 2	

Increase of the capacity is realizable by increasing the ground speed and/or the working width, which, however, involves higher information speed, more actions for operation and a higher operator's work load.

Because of these limitations the mechanization in agriculture has reached a stage of automation, in which many actions are carried out mechanically, hydraulically or electiically, whilst deviations are corrected by feedbacks without human interference. In literature some possibilities for automation of the self-propelled combine harvester are reported (EIMER, 1966; KÜHN, 1968), in particular the movement – in direction (KÜHN; 1968) and speed (KÜHN; 1969) –, the header height (KAMINSKY and ZOERB, 1965; GRUNER, 1967; BREDFELDT, 1968) and the threshing mechanism (FRIESEN and ZOERB, 1966; KÜHN, 1969). Based upon the conditions of the crop and terrain the operator has to settle the norm and tolerance of the whole process, next to it he has to control the adjustments and, if necessary, to re-adjust.

4.4.2. *Indoor experiments*

4.4.21. Ergonomic simulator

For studying the loading components in a man-task system under controlled conditions, a simulator has been built. This makes it possible to obtain information regarding the ergonomic qualities of an operator's platform of a certain machine, as well as of the consequences of modifications, of the work-space layout. Moreover, such a simulator offers possibilities for further experiments, such as the training effect.

The simulator (fig. 22) consists of a platform (A), an instruction (B) and a scoring (C).

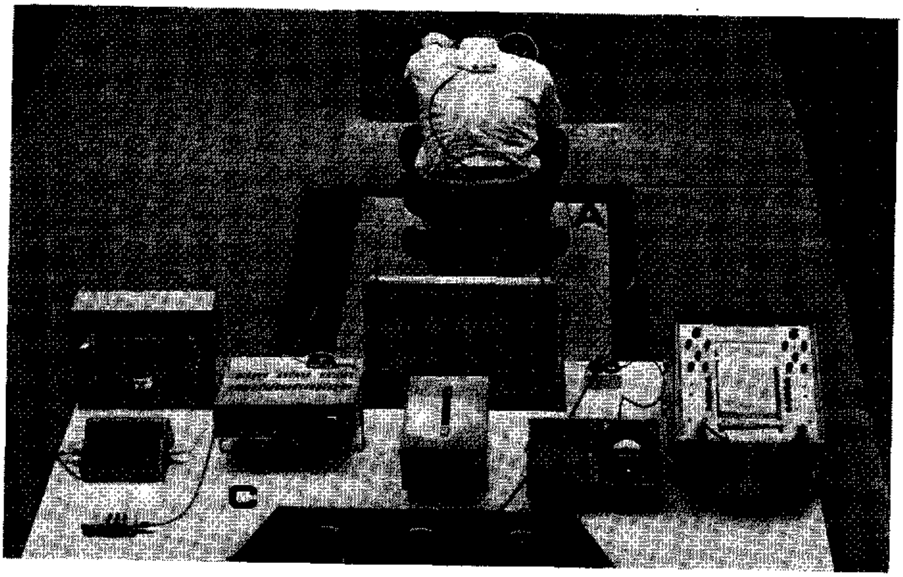


FIG. 22. Simulator for man – task systems.
A – platform and vibration table
B – instruction
C – scoring

FIG. 23. Instruction of the ergonomic simulator.
A – pointer (instruction steering task)
B – pointer (reaction steering wheel)
C – stimuli (instruction secondary task)

a. Platform

The platform is the upper side of a vibration table, of which the frequency (F = 0,5–20,0 Hz) and the amplitude (x = 0–15 mm) of the harmonic movement in a vertical direction (Z-axis), are continuously adjustable ($\ddot{x}_{max}$ = 20,0 m/sec^2).

On this platform the controls of a man-task system can be installed; the mutual position can be varied and different types of controls can be attached.

b. Instruction

For instruction the method of performance under experimental distraction has been chosen; with this method the subject has to perform the following tasks:

(i) Basic task

In front of the subject – within the optimum visual field – two pointers are located, of which the upper one (fig. 23: A) moves in a horizontal slide and is directed by a programme on a rotating drum; the programme is based upon the results listed in table 19. The lower pointer (fig. 23: B) can move in a horizontal slide by turning the steering wheel on the platform.

Besides the performance of the secondary task the subject has to follow the motions of the upper pointer by turning the steering wheel as well as possible.

(ii) Secondary task

In front of the subject – within the optimum visual field – six lamps are located (fig. 23: C), which can flash. These signals correspond with the highest, resp. the lowest position, of the controls for header height, reel position and ground speed of the combine. The sequence and frequency of the stimuli is sent from a punched tape with adjustable speed; the program is based upon the results listed in table 15.

According to a trained method, the subject has to respond to the stimuli by positioning the control indicated in the location desired; this simple repetitive task has to be carried out faultlessly. During a test the execution of all actions is controlled carefully.

c. Scoring

For each test the following parameters are measured:

(i) Tracking ability

The pointers (fig. 23: A and B) are connected with counters (make: SODECO; type: TCE Z4E). A pulsegenerator gives a current (24 V) on the upper pointer exactly ten times per second; this current is also conducted to the total counter (a). If both pointers are opposite to one another, the current is conducted by means of a slide-contact through the lower pointer to the corresponding counter (b). The tracking ability is calculable from the ratio of the numbers on the counters (b/a).

The tracking ability or steering accuracy per test (in %) is used as input for the analysis of variance.

(ii) Load

For the assessment of the subject's work load during a test (W) the heart rate is used. For this registration a cardiotachometer (make: CNR; type: 104) is used, by which the number of heart beats can be registered by a six-digit counter. Before each test the heart rate during resting (R) is determined; during this registration the subject has taken a completely relaxed posture.

The work load is expressed as a ratio of the heart rate during testing and during resting (MELLEROWICZ; 1962); the quotient (W/R) is used as input for the analysis of variance.

(iii) Subjective findings

Immediately after completion of the test the subject is asked for his experiences.

(iv) General

During all experiments special attention is paid to achieve a steady state of the subject; for this reason each test (duration: 5 minutes) is preceded by a period of one minute, in which the subject is executing his tasks, but no registration takes place. After the test all registrations are continued for one minute.

Besides the equipment, that is part of the simulator, a tape-recorder (make: PHILIPS; type: EL 3573) and a sound level analysator (make: PEEKEL; type: GRA) are used. The experiments are carried out in a room with artificial light; sound from outside can hardly penetrate in the work-space and is suppressed by a sound of 60 dB.

The temperature during the experiments was about 22°C, the humidity of the air varies between 45 and 60%; these are favourable conditions for ergometric experiments (MELLEROWICZ; 1962).

d. General

When planning the experiments the necessary preparation of the subjects was taken into account; special attention was paid to:

(i) Instruction

In extensive talks with all persons involved – subjects and research officers – the scope of the study and the application of the test procedure, as well as the results, were discussed and explained thoroughly.

(ii) Medical examination

All participants have been submitted to a medical examination, including a bicycle-ergonometer test, in order to obtain information regarding their health, condition and to make them acquainted with the equipment.

(iii) Preliminary study

The survey of the environmental factors, as well as training period of about an hour to get acquainted with the test procedure and the operating actions to be executed, have been instructed and learned before the experiments; this training has been executed with a view to avoid mistakes.

4.4.22. Experiments

(i) Comparative tests of operator's platforms

In 1968 measurements were carried out to compare the ergonomic qualities of the work-space lay-out on four machines (Nr.: 2, 3^a, 3^b and 4) in simulating the operating of a combine (MUYS; 1969).

a. Method

These tests were carried out with twelve subjects, the experimental design was chosen in such a way that – to eliminate a possible effect of the daily rhythm of the physiological parameters – each subject was taking part at the same period of each day.

During the first week all machines were investigated with six subjects (P1–P6); during the second week two machines (Nr.: 3^a and 3^b) were investigated with all subjects (P1–P12). During the third week all machines were investigated again with six subjects (P7–P12). The sequence of the machines offered to a subject was at random.

Preceded by a period of resting, the test people were offered test conditions of 30, 40, 50 and 60 signals per minute; this contains 1,58, 2,00, 2,30 and 2,58 bits per second respectively.

b. Treatment

For each test the steering accuracy and the heart rate were registered. Immediately after the test the subjective findings were recorded.

The steering accuracy (in %) and the work load (in W/R) were used as inputs for the analysis of variance. The computations were facilitated by the cooperation of the Mathematical Department of the Agricultural University.

The results of these studies are listed in table 35, they are shown in figure 24 and 25.

TABLE 35. Steering accuracy (in %) and load (in W/R) in simulating the operation of combines

Machines – Nr. –	30		40		50		60	
	%	W/R	%	W/R	%	W/R	%	W/R
2	71,4	1,17	69,7	1,21	62,7	1,25	55,2	1,29
3[a]	78,1	1,13	75,1	1,16	69,5	1,19	61,3	1,22
3[b]	78,7	1,09	73,4	1,12	65,8	1,16	60,3	1,17
4	72,9	1,11	67,0	1,14	62,1	1,17	54,3	1,18
Average	76,3 (100)	1,12 (100)	72,3 (95)	1,15 (103)	66,3 (87)	1,19 (106)	58,8 (77)	1,21 (108)

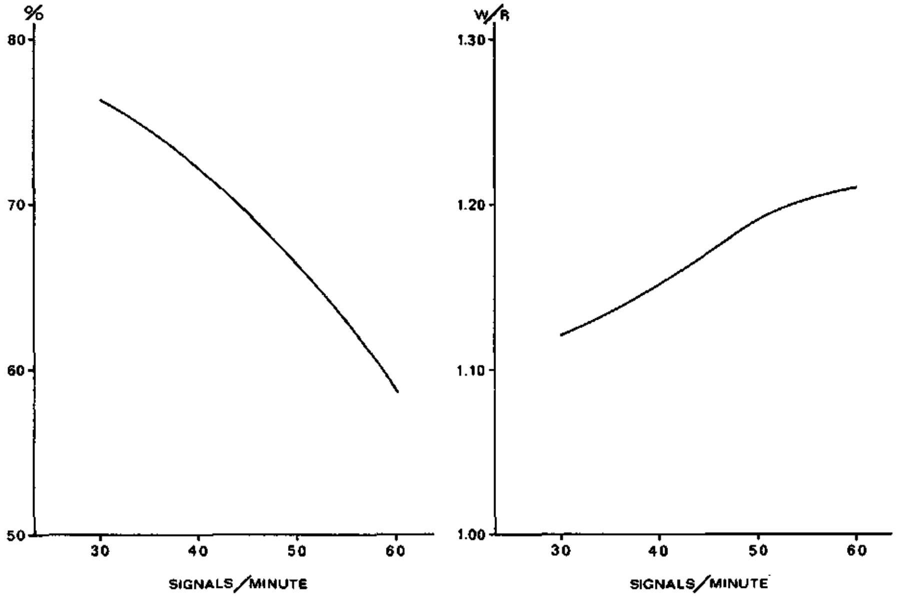


FIG. 24. Steering accuracy (in %) and load (in W/R) in relation to the rate of experimental distraction, in simulating the operation of combines (average).

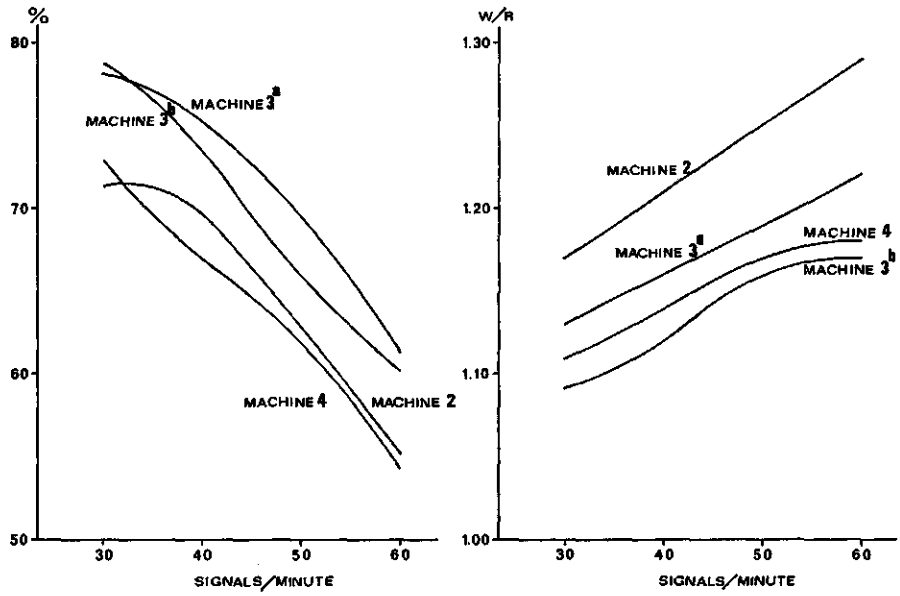


FIG. 25. Steering accuracy (in %) and load (in W/R) in relation to the rate of experimental distraction, in simulating the operation of combines (per machine).

Under experimental distraction the steering accuracy (in %) detiorates as a function of the number of signals per minute in the secondary task (fig. 24); for this test it resulted in a decrease of the steering accuracy with 23% maximal. There is a significant difference between the machines; in favour of machine 3^a and 3^b and unfavourable for machine 2 and 4. This difference is not more significant as the experimental distraction increases (fig. 25).

Under experimental distraction the load (in W/R) increases as a function of the number of signals per minute in the secondary task (fig. 24); for this test it means an increase of the load by 8%. There is a significant difference between the machines; in favour of machine 3^b and 4, unfavourable for machine 2. This difference is more significant as the experimental distraction increases (fig. 25), which implies that under more unfavourable conditions the difference between machine 3^b and 4 on the one side and machine 3^a on the other will increase.

Off all subjects eleven were in favour of machine 3^b; one subject preferred machine 4. All subjects disqualified machine 2.

Summarizing, the conclusion can be made that in simulating the operation of a combine harvester the load and the performance depend upon the experimental distraction and the anthropometric qualities of the work-space lay-out. Under experimental distraction the performance detiorates as a function of the number of signals per minute in the secondary task; the load increases as a function of the rate of signals.

Based upon the results of the M.T.M.-analysis we know, that fingertip control – header height, reel position and ground speed control grouped together within the normal area – leads to a favourable change in the operating time. The results of the indoor experiments are endorsed by the results of the anthropometric studies, for there is a significant difference between the machines under experimental distraction; in favour of machine 3^b (controls grouped together within the normal area) and unfavourable for machine 2 (a more difficult switching pattern with one knob for the six positions). The differences between the various machines are more significant as the experimental distraction increases; these conclusions correspond with the subjective findings.

From the analysis of variance it also appears, that a modification of the work-space lay-out of a certain make of machine (Nr.: 3^a and 3^b) clearly has consequences. The ergonomic quality of machine 3^b not only is significantly better than that of machine 3^a, but we can expect that for a higher information speed – as a result of an increased capacity in the field – the difference between the two types will increase.

4.4.23. Effect of learning

When repeating a task the time needed per cycle and the load will change; with an increasing number of cycles the time is declining – at first fairly quickly – to become almost constant. To the man's load an analogous situation develops, on the understanding that – when repeating many times – the load is increasing again (DE JONG, 1959; CLIFFORD and HANCOCK, 1964; WILTSHIRE, 1968). Moreover, an individual is more familiar with one machine than with another, which causes a more efficient performance, as well as a slighter chance of making mistakes. This will lead, indirectly, to a better output of the whole man-task system.

To study the effect of learning in simulating the operation of combines, experiments were carried out with (RIEMERSMA; 1969):

(i) Different series of information

In 1969 measurements were carried out to study to what extent the appearance of a learning curve would be disturbed by different series of information in the experiment. Besides we determined to what extent this effect varies for two machines (Nr.: 3^a and 3^b).

a. Method

The tests were carried out with eight subjects, the experimental design was chosen in such a way that – to eliminate a possible effect of the daily rhythm of the physiological parameters – each subject was taking part at the same period of each day.

During the first week machine 3^b was investigated with four subjects (P1–P4) with two series of information and one repetition; during the second week machine 3^a was investigated with four subjects (P5–P8) with two series of information and one repetition.

The subjects were offered two series of information (I), namely:

	(1)	(2)	(3)	(4)	(5)	(6)	
I 1	30	50	0	30	40	50	signals/minute;
I 2	50	30	50	40	30	0	signals/minute.

Grouping in this way makes it possible to give statements in respect of the learning effect within the series.

b. Treatment

For each test the steering accuracy and the heart rate were registered; these data were used as inputs for the analysis of variance. The results of this study are listed in table 36.

TABLE 36. Learning effect in operating combines under different series of information.

Machine – Nr. –	30		50		0		30		40		50	
	%	W/R	%	W/R	%	W/R	%	W/R	%	W/R	%	W/R
3^a	98,1	1,16	96,4	1,21	99,0	1,07	97,8	1,13	97,0	1,15	97,0	1,17
3^b	89,2	1,02	86,4	1,04	94,1	0,96	90,0	0,99	89,3	1,00	89,9	1,01

Machine – Nr. –	50		30		50		40		30		0	
	%	W/R	%	W/R	%	W/R	%	W/R	%	W/R	%	W/R
3^a	92,0	1,20	98,4	1,16	94,8	1,19	95,4	1,17	95,7	1,16	96,3	1,05
3^b	89,3	1,05	91,3	1,02	87,6	1,03	90,3	1,01	92,4	1,00	94,2	1,00

Based upon the steering accuracy (in %) and the load (in W/R) neither a learning effect, nor an effect of the previous test, can be proved significantly for one of the subjects. The appearance of a learning curve is disturbed by the series selected in the experiment; this conclusion is in agreement with statements in literature (CLIFFORD and HANCOCK, 1964; WILTSHIRE, 1967).

There is a significant difference between the machines, in favour of machine 3^b.

(ii) Identical series of information

To avoid the disturbance of the learning curve an experiment was set up with an identical series of information. Besides we determined to what extent this effect varies for two machines (Nr.: 3^a and 3^b).

a. Method

The tests were carried out with two skilled operators of combine harvesters (P9 and P10); they had only a little bit of experience with the simulator. The experimental design was chosen in such a way, that – to eliminate a possible effect of the daily rhythm of the physiological parameters – each subject was taking part at the same period of each day.

During the first day the machines 3^a and 3^b were investigated with the subjects P9 and P10 respectively, presenting them a series of identical tasks; during the second day the machines 3^b and 3^a were investigated with the subjects P9 and P10 respectively, presenting them the same test conditions.

The subjects were offered the following series of information (I):

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	
I	0	40	40	40	40	40	40	40	40	40	40	signals/minute

b. Treatment

For each test the steering accuracy and the heart rate were registered; immediately after the test the subjective findings were recorded.

The steering accuracy (in %) and work load (in W/R) were used as inputs for the analysis of variance; the results of this study are listed in table 37, they are shown in figure 26 and 27.

TABLE 37. Learning effect in operating combines under identical series of information.

	Nr. 3[a]		Nr. 3[b]	
Cycle	%	W/R	%	W/R
1	97,2	1,13	89,1	1,14
2	61,8	1,29	39,0	1,19
3	68,5	1,21	67,2	1,15
4	67,6	1,20	75,8	1,14
5	67,4	1,17	83,3	1,14
6	76,6	1,14	85,3	1,12
7	74,0	1,13	86,5	1,11
8	75,3	1,12	86,4	1,07
9	68,5	1,12	86,1	1,07
10	73,9	1,10	85,0	1,06
11	75,8	1,10	78,6	1,05

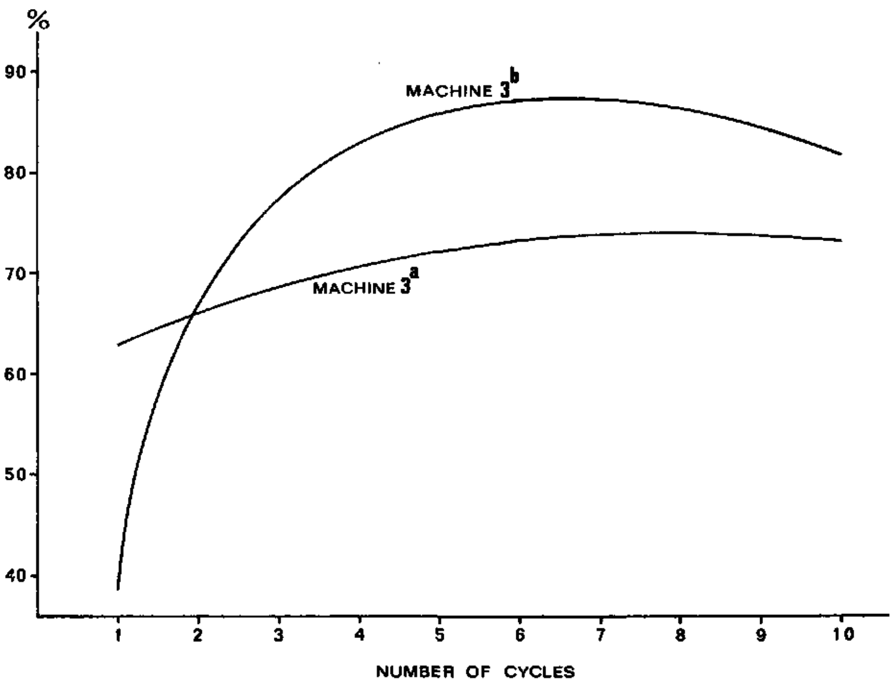


FIG. 26. Learning effect (steering accuracy in %) in simulating the operation of combines.

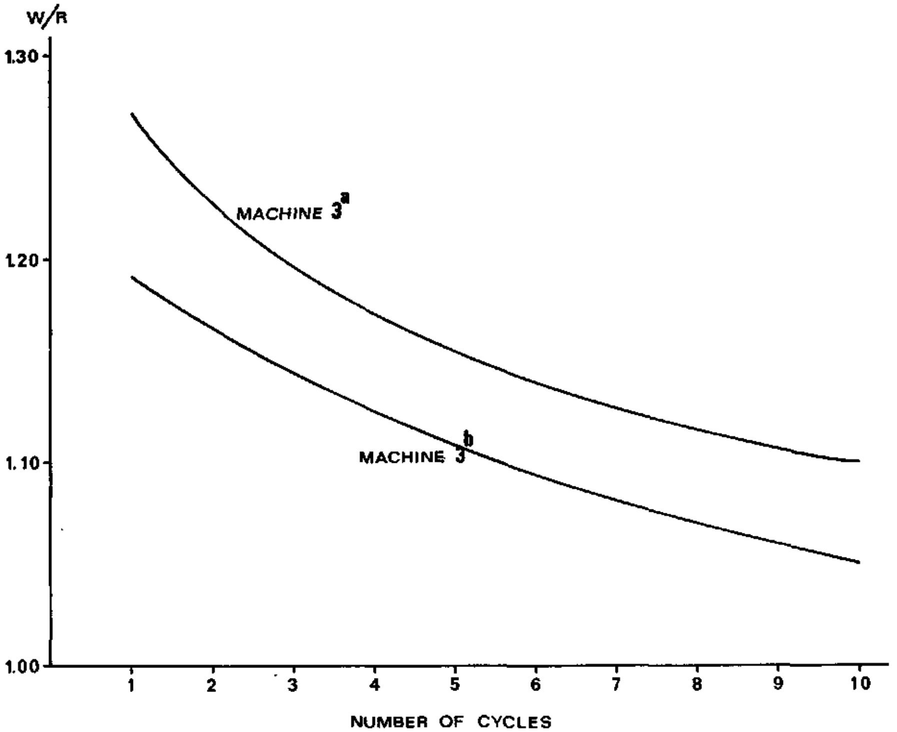


FIG. 27. Learning effect (load in W/R) in simulating the operation of combines.

Based upon the steering accuracy (in %) and the load (in W/R) a learning effect can be proved significantly in simulating the operation of a combine harvester. By executing an identical series of information a learning curve appears; the steering accuracy increases and the load decreases as a function of the number of cycles.

There is a significant difference between the machines, in favour of machine 3^b; this conclusion corresponds with the subjective findings.

Summarizing the experiments on learning, the conclusion can be made, that in simulating the operation of a combine harvester the performance and the load depend upon the number of cycles and the anthropometric qualities of the work-space lay-out.

The results of the experiments on learning are endorsed by the results of previous studies (table 16 and 35); there is not only the significant difference in ergonomic quality between the machines, but the subjects are more quickly familiar with one machine (Nr.: 3^b) than with another (Nr.: 3^a), which causes a more efficient performance. The conclusion can be made that the performance and the load are primarily determined by the work-space lay-out. The designer of a combine harvester must try to reduce the mental load by providing a work-space lay-out in the direction of machine 3^b, in particular: the frequently used, fingertip controls grouped together within the normal area.

4.5. Summary

The transport of data from the stimulated sense organs to the effectors is not simply and solely transport; the data are processed, from the various possibilities the right answer is chosen and transformed into action. In task performance the number of directed switches from input to output determines information processing and mental load, because all signals make use of 'a single channel decision mechanism' with a limited (2 to 3 bits per second) capacity.

For the assessment of mental load a well-functioning parameter is not yet available; most can be expected of the method with dual tasks and the heart rate.

Indoor experiments

For studying a man-task system under controlled conditions and to obtain information regarding the ergonomic qualities of the work-space lay-out of a certain machine, a simulator is built.

The studies led to the following conclusions:

(i) In simulating the operation of a combine harvester the performance and the load depend upon the experimental distraction and the anthropometric qualities of the work-space lay-out. The steering accuracy detiorates and the load increases as a function of the number of signals per minute in the secondary task.

There is a significant difference between the machines, which increases as the experimental distraction increases.

(ii) By executing an identical series of information a learning curve appears; the performance increases and the load decreases as a function of the number of cycles. The appearance of the learning curve is disturbed by different series of information in an experiment.

There is a significant difference between the machines.

(iii) The performance and the load depend upon the experimental distraction (the number of signals per minute in the secondary task and the series of information in an experiment) and the anthropometric qualities of the work-space lay-out of the machine. The indoor experiments confirm the statement, that subjects are more quickly familiar with one machine than with another, which causes a more efficient performance. The conclusion can be made, that the performance and the load are primarily determined by the work-space lay-out.

Although the mechanization in agriculture has reached a stage of automation, in which many actions are carried out and corrected without human interference, the designer of a combine harvester must try to reduce mental load. This is possible by repelling redundant and non-relevant information – sound, dust and mechanical vibrations – and a work-space lay-out, in which the frequently used, fingertip controls are grouped together within the normal area. By paying attention to these aspects the whole man-task system can contribute to adequate processing of a higher information speed – as a result of an increased capacity – and a favourable operator's load.

5. ACTION

5.1. Introduction

The information from the sense organs is transported to the central nervous system, where the data are processed and from various possibilities the right answer is chosen. By signals the choice is transported to the effectors and transformed into voluntary muscle movements, which are necessary for the operation.

This process is called action and leads to the physical load of the man; through the action a change takes place in the man-task system resulting in a performance.

5.2. Theory

The performance is done by the muscles, which costs energy. In the human body chemical energy – supplied in the shape of food – is converted into mechanical energy and heat; heat is partly needed to keep the body temperature steady. The oxygen, needed for this oxidation process, is withdrawn from the air by breathing and is – together with the fuel – transported to the effectors by the blood. For prolonged activities the oxygen supply of the muscles must keep step with the oxygen demand; anaerobic metabolism has to be avoided as much as possible.

If work is heavier, the energy production has to be increased; the respiration volume (higher oxygen uptake), the heart rate (bigger oxygen transport by the blood) and the perspiration (carry off the heat developed) increase (Jongbloed, 1954; Lehmann, 1962; Grandjean, 1963).

The working capacity of an individual is limited and primarily determined by the capability of supplying sufficient oxygen and taking sufficient food. An energy consumption of 20 kJ (= 4,8 kcal) per minute, including a basal metabolic rate of about 4,2 kJ (= 1 kcal) per minute, is the maximum consistent level, that an adult man should be expected to expend; rest pauses should be included, if the average level exceeds this level (Lehmann, 1962; Grandjean, 1963; Anon, 1966). This value corresponds to the consumption of 1 liter oxygen per minute. During the working period 11,3 MJ (= 2700 kcal) are used daily, whilst about 6,3 MJ (= 1500 kcal) are used also for the basal metabolic rate, which depends upon sex, age, length and weight of the body (Benedict and Harris; 1919), as well as off-duty activities (level: 2,5 MJ or 600 kcal). The total metabolism amounts to 17,6 MJ (= 4200 kcal) daily.

The mechanical efficiency of human labour (η = external load/functional load, both expressed in kJ per minute) (CARGO; 1965) can vary from 0–20% (GRANDJEAN, 1963; CARGO, 1965). As certain muscles or groups of muscles are permanently loaded unfavourably, the maximum effect is seldom realizable. The best effect can be obtained with rhythmic motions, whereby the muscles are contracted and relaxed alternately, whilst the motions – becoming more simple and more automatic – are flowing from one to the other without interruption (BURGER and DE JONG; 1962). When the situation of contraction is continued – static muscular activity –, the blood flow is stagnated with a quick fatique as a result.

If a man works under unfavourable climate, we cannot expect the same kind of performance we can when the environment is optimal (EICHNA, 1945; MACKWORTH, 1946; BURTON and EDHOLM, 1955; PEPLER, 1958). The comfort of man depends upon the relative humidity, temperature and velocity of the air. The subjective judgement of the climate is determined by the heat balance of the human body (LEHMANN; 1962). The heat transfer between man and his environment, in which the skin is the most important medium, can take place by conduction, convection, radiation and secretion of sweat (LEHMANN, 1962; GRANDJEAN, 1963). Physiological reactions on heat stress are mostly an increase of the heart rate, body temperature and recovery time, as well as an increased sweat secretion (WENZEL; 1961). The general trend of all studies of the working environment is clear: atmospheric conditions interfering with normal or constant body temperature reduce mental and physical working capacity (CHAPANIS; 1963). It has been assumed that the capacity is strongly slackened at temperatures above 35°C as a result of heat accumulation (LEHMANN; 1962); the data for a comfortable climate are listed in table 38.

Protection against climatic conditions is by technical means (cabin, air-curtain and air-conditioning) or personal means (clothing, rest pauses and properly adjustment of the standards of performance).

TABLE 38. Data for a comfortable climate.

Features	Criteria
Air humidity	30–70%
Air temperature[1]	
· brain-work, sitting	20–21°C
· light work, sitting	19°C
· light work, standing	18°C
· heavy work, standing	17°C
· very heavy work	15–16°C
Air velocity	
· maximum	25 cm/sec
· optimum	10–20 cm/sec
Radiant temperature	equal to or higher (2–3°C) than the air temperature

[1] Air humidity: 50%.

5.3. Assessment of physical load

The assessment of physical load is based on measuring one of the following, physiological parameters (Brouha, 1960; Lehmann, 1962; Mellerowicz, 1962; Cargo, 1965; Anon, 1966; Tomlinson, 1970):

5.3.1. *Energy consumption*

The conversion of carbohydrate, fat and protein into energy is an oxidation process so that from oxygen consumption (i.e. differences between inhaled and expired air samples) the caloric equivalent can be calculated. From the oxygen consumed and the volume of air expired, the energy consumption can be calculated; diminution of this value by the basal metabolism gives the net energy consumption per activity.

The measurement of energy consumption is an accurate assessment of physical load; its main disadvantage is the size of the measuring equipment. It can prohibit easy movements and also contribute significantly to the level of work load, as well as the resistance to breathing, which some subjects find unpleasant. A further disadvantage of respirometry is, that – for accurate analysis of the expended air – a sample must be collected over several minutes.

5.3.2. *Ventilation rate and frequency*

Many physiologists have found the gas analyses associated with oxygen consumption measurements to be disadvantageous because of the time taken. Ventilation frequency is likely to be less accurate since variations in the volume of inhaled air per cycle are excluded (Suggs and Splinter; 1958). A more satisfactory alternative to the face mask technique is the use of strain gauge measures on the chest wall; variations in the size of the chest wall are sufficiently large for accurate measurements to be obtained. The peak-to-peak amplitude of the signals being a measure of the depth of respiration which is related to the volume of air breathed. The validation of this technique might be extremely useful (Tomlinson; 1970).

5.3.3. *Heart rate*

Since the body fuels are carried to the muscles by the bloodstream, an increase in energy expenditure is accompanied by an increase in heart rate; a clear relationship between heart rate and energy expenditure usually exists. A high heart rate associated with relatively low oxygen consumption is especially indicative of muscle fatigue, particularly due to static work (Lehmann; 1962).

The equipment, developed for measuring the heart rate, is based upon one of the following signals: The action potentials of the heart muscle (electrocardiographic measurement) or the bloodfilling of the ear-lap (plethysmographic measurement). The first measurement, frequently used, is based upon the electrocardiogram, which can be obtained by means of three electrodes on the chest. After amplifying and filtering a millivoltage remains of the same moment of the heart cycle (R-peak); the time between consecutive peaks, which are counted, can be converted into a heart rate per unit of time.

Both measurements are usable for determining the heart rate during actions; in all kind of tasks, and even over a long period of time, these measurements give – hindrance for the subject being small, but worthy of mention – a faultless registration.

Measurement of energy consumption, ventilation rate and heart rate should be carried out while the subject is in a steady state; furthermore the measurements have to be continued for some time after finishing the action.

5.3.4. *Body temperature*

A maximum of 20% of the caloric equivalent appears as mechanical energy, the larger part being dissipated as heat. Body temperature is a reliable indication of the heaviness of work, adaptation normally occuring after about one hour's work at a level dependent upon the work load. At high environmental temperatures, body temperature increases disproportionately to oxygen consumption and becomes a specific indication of heat stress (SUGGS and SPLINTER; 1961). Aural and oral temperatures respond more quickly than rectal temperature to changes in deep body temperature (TOMLINSON; 1970).

Only a limited amount of heat can be accumulated in the body; heat production above this increases sweating and can be measured (LEBLANC; 1957).

5.3.5. *Summary*

Based upon the frequently found, relationships between the physiological parameters, the scaling of physical load is listed in table 39 (BROUHA, 1960; SPITZER and HETTINGER, 1964; CARGO, 1965).

As soon as an action continuously demands much energy, the total period of working has to be reduced. Based upon an energy consumption of 20 kJ (= 4,8 kcal) per minute formulas have been developed for rest allowances. In periods of resting the total duration is important; frequent short rest pauses are better for recovery than less frequent, but longer rest pauses (SPITZER, 1951; ROHMERT, 1960[a], 1960[b]).

TABLE 39. Scaling of physical load.

Grade of work	Energy consumption		Heart rate	Body temperature
	– O_2 l/min –	– kJ/min –	– beats/min –	– °C –
very light	<0,5	<10	< 75	37,5
light	0,5–1,0	10–20	75–100	37,5
moderately heavy	1,0–1,5	20–30	100–125	37,5–38,0
heavy	1,5–2,0	30–40	125–150	38,0–38,5
very heavy	2,0–2,5	40–50	150–175	38,5–39,0
unduly heavy	>2,5	>50	>175	>39,0

5.4.1. *Literature*

Based upon the information from crop, terrain and machine the operator has to decide on such an adjustment of the machine, which results in a process with a maximum capacity. This is possible by a high ground speed and/or working width, which, however, involves a higher information speed and many actions for operating per time unit.

In preliminary studies in winterwheat it was ascertained, that on plots with a standing crop the heart rate increases 23 to 29 %, in comparison with rest. When the crop is moderately lodged, the heart rate increases 33 to 42 % and on the end of the plot – making the turnings – the heart rate increases with 43 to 50 % above rest level (ZANDER; 1967).

To determine the work load during combining (working width: 205 cm), measurements have been carried out with the heart rate as a parameter (GLASOW and DUPUIS; 1960). This German study showed, that the scale of work is – even under unfavourable circumstances – light to moderately heavy.

To show the fluctuations in work load on a mechanized farm, harvesting with a self-propelled combine (working width: 180 cm) is chosen as an example of heavy work (KARIMI; 1967). In this German study only time studies have been made, whilst the energy consumption was estimated (SPITZER and HETTINGER; 1964). Based upon the results reported a work load of 24,4 kJ (= 5,8 kcal) per minute is calculable; interpretation of this value is impossible, since the working conditions have not been mentioned.

5.4.2. *Field experiments*

Although, in literature very little is reported about the ergonomic aspects of self-propelled combine harvesters, it is possible to indicate a number of factors, affecting the output of the system. For collecting data about the character and extent of loading components, as well as the influence they have on the output, field experiments were carried out.

The following factors, directly affecting the output in operating self-propelled combine harvesters, were investigated:

- Operator's platform (M)
- Stubble-height (S)
- Ground speed (V)
- Working width (W)
- Header height control (H)
- Crop (C)

In studying these factors the following parameters are recorded (GLASOW and DUPUIS, 1960; WIENEKE, 1967):

(i) Performance

By an observer on the machine a time study is made during harvesting, in particular the operation frequency of the header height, reel position and ground speed control is registered. The observer also controls the required adjustment regarding the ground speed and the stubble-height. The time study is used for calculating the time spent in harvesting (code: 1), turning and moving on the end of the plot (code: 2), unloading the grain tank (code: 3) and solving disturbances (code: 4).

The average operation frequency per test (in n/min) – during harvesting (code 1) – is used as input for the analysis of variance.

(ii) Load

For the assessment of the work load of a subject during a test (W), the heart rate is used. For this registration a cardiotachometer (make: CNR; type: 104) is used; the number of heart beats is registered exactly per 25 cmin. Before each test the heart rate during resting (R) is determined; during this registration the subject has taken a completely relaxed posture. The treatment of the data is done by coupling the heart rate data with the time study.

The average work load (W/R) during combining is used as input for the analysis of variance.

(iii) General

Two skilled and all-round operators were put at disposal for the tests by the IJssel Lake polders Development Authority (R.IJ.P.). Both subjects (P1 and P2), who cooperated in all field experiments, were instructed on the scope of the study and the test procedure. The necessary preparations of the subjects – in particular: instruction, medical examination and preliminary study – were taken into account. Before starting the experiments each machine was adjusted by the operator, according to the instructions of the manufacturer.

The field experiments were carried out in O.-Flevoland on plots of the R.IJ.P. In selecting the plots special attention was paid to the homogenity of the crop and the soil; before the experiments the condition of the soil and the crop was registered. The weather conditions during the experiments – in particular: temperature, humidity and air pressure – were registered by means of a meteorograph (make: THIES-GÖTTINGEN).

The computations were facilitated by the cooperation of the Mathematical Department of the Agricultural University.

(i) Effect of M, S and V

By means of field experiments the effects of machine (Nr.: 2 and 3[a]), stubble-height (S 1: 20 cm; S 2: 40 cm) and ground speed (V 1: 4,0 km/h; V 2: 5,5 km/h) during combining have been studied on plots with winterwheat.

a. Equipment and method

The plots (condition: 100% standing, no undercrop) were harvested at a humidity of 19,0%; the yields of kernel and straw – reduced to a humidity of 17,0% – amounted to 6285 kg/ha and 4345 kg/ha respectively.

During a test the required stubble-height had to be as accurate as possible (tolerance: ± 5 cm). For each test the ground speed was adjusted as accurate as possible (tolerance: ± 0,25 km/h); during the test the operator had to leave the ground speed control undisturbed.

During all experiments the weather conditions were constant and very favourable for combining; the soil was hard and dry.

b. Treatment

For each test the operation frequency and the heart rate were registered.

The operation frequency (in n/min) and the work load (in W/R) were used as inputs for the analysis of variance.

The results of this study are listed in table 40.

TABLE 40. Operation frequency (in n/min) and load (in W/R) during combining at different stubble-heights (S) and ground speeds (V).

	Stubble-height				Ground speed				Average	
	S 1		S 2		V 1		V 2			
Machine – Nr. –	n/min	W/R	n/min	W/R	n/min	W/R	n/min	W/R	n/min	W/R
2	1,34	1,07	1.01	1,07	0,77	1,04	1,59	1,08	1,18 (100)	1,06 (100)
3[a]	1,71	1,10	1,06	1,08	0,87	1,06	1,90	1,13	1,38 (118)	1,09 (103)
	1,53 (100)	1,08 (100)	1,03 (67)	1,07 (99)	0,82 (100)	1,05 (100)	1,75 (213)	1,10 (105)		

With an increase of the stubble-height the operation frequency and the load decrease; based upon the operation frequency this effect is significant. The effect of ground speed (V) is significant; with an increase of the ground speed the operation frequency and the load increase.

The results of these experiments are endorsed by the results of the anthropometric studies and the indoor experiments, for there is a small difference between the machines, in favour of machine 2.

(ii) Effect of M, V, W, H and C

By means of field experiments the effects of machine (Nr.: 3[a] and 3[b]), ground speed (V 1: 2,5 km/h; V 2: 3,5 km/h; V 3: 4,5 km/h; V 4: 5,5 km/h), working width (W 1: 300 cm; W 2: 390 cm) and automatic header height control (H o: disengaged; H 1: engaged) during combining have been studied on plots with springbarley and winterwheat (MUYS; 1969).

a. Equipment and method

The plots with springbarley (condition: 40% standing, no undercrop) were harvested at a humidity of 18,6%; the yields of kernel and straw – reduced to a humidity of 17,0% – amounted to 3820 kg/ha and 2840 kg/ha respectively. During the experiments the weather conditions were somewhat fluctuating, but they did not affect the harvesting; the soil was moderately hard and dry.

The plots with winterwheat (condition: 100% standing, no undercrop) were harvested at a humidity of 21,0%; the yields of kernel and straw – reduced to a humidity of 17,0% – amounted to 4420 kg/ha and 3520 kg/ha respectively. During the experiments the weather conditions were constant and favourable for harvesting; the soil was hard and dry.

For each test the ground speed was adjusted as accurate as possible (tolerance: ± 0,25 km/h); during the test the operator had to leave the ground speed control undisturbed. During all tests a normal stubble-height of 20 cm had to be achieved; the stubble-height and the effective working width were controlled frequently.

b. Treatment

For each test the operation frequency and the heart rate were registered.

The operation frequency (in n/min) and the work load (in W/R) were used as inputs for the analysis of variance. The results of this study are listed in table 41 and 42.

TABLE 41. Operation frequency (in n/min) and load (in W/R) during combining at different ground speeds (V), working widths (W) and in different crops (C).

		Ground speed				Working width					
		V 1		V 3		W 1		W 2			
Machine	C	n/min	W/R	n/min	W/R	n/min	W/R	n/min	W/R	n/min	W/R
Nr. 3[a]	a	1,37	1,27	2,38	1,30	1,79	1,27	1,95	1,30	1,87	1,28
										(106)	(107)
	b	1,12	1,23	1,53	1,27	1,30	1,28	1,35	1,21	1,33	1,25
										(97)	(103)
Nr. 3[b]	a	1,25	1,19	2,28	1,21	1,24	1,23	2,30	1,17	1,77	1,20
										(100)	(100)
	b	1,35	1,20	1,39	1,21	0,86	1,23	1,91	1,19	1,37	1,21
										(100)	(100)
	a	1,31	1,23	2,33	1,26	1,52	1,25	2,12	1,23		
		(100)	(100)	(178)	(103)	(100)	(100)	(139)	(98)		
	b	1,23	1,21	1,46	1,24	1,07	1,26	1,63	1,20		
		(100)	(100)	(119)	(103)	(100)	(100)	(152)	(95)		

a – Springbarley; b – Winterwheat

Based upon the results in table 41 it can be proved, that there is a significant difference between the machines (M), in favour of machine 3[b]. The effect of ground speed (V) is significant; with an increase of the ground speed the operation frequency and the load increase. The difference between the machines becomes greater when working at higher ground speeds. The effect of working width (W) is significant; with an increase of the working width the operation frequency increases and the load decreases.

The interaction between subject and machine (P $\times$ M) is significant, in favour of machine 3[b]; moreover, the subjects prefer machine 3[b] because of the fast learning. In winterwheat the interaction between subject and working width (P $\times$ W) is significant, in favour of the greater working width. The interaction between ground speed and working width (V $\times$ W), representing capacity (C), is significant; there is a preference to work at a low ground speed with a greater working width.

The effect of crop (C) is significant; the operation frequency and the load are higher in springbarley than in winterwheat. The various effects (M, V and W) are found in springbarley, as well as in winterwheat.

Based upon the results in table 42 it can be proved, that the effect of header height control (H) exists, in favour of the automatic system; using this automatic system the operation frequency and the load decrease. The effect of ground speed (V) exists; with an increase of the ground speed the operation frequency and the load increase. The advantage of an automatic system becomes greater when working at higher ground speeds. The interaction between subject and header height control (P $\times$ H) exists. The subjects prefer the automatic system, but they hesitate to trust this equipment completely.

TABLE 42. Operation frequency (in n/min) and load (in W/R) during combining – with and without automatic header height control (H) – at different ground speeds (V) and in different crops (C); working width: 390 cm.

		Ground speed							
		V 2		V 3		V 4			
	C	n/min	W/R	n/min	W/R	n/min	W/R	n/min	W/R
H 0	a	2,25	1,12	4,00	1,21	3,47	1,24	3,24 (100)	1,19 (100)
	b	3,22	1,13	2,12	1,13	5,16	1,17	2,66 (100)	1,14 (100)
H 1	a	0,72	1,18	0,98	1,18	0,88	1,16	0,86 (26)	1,17 (98)
	b	0,49	1,10	0,67	1,11	0,62	1,15	0,59 (22)	1,12 (98)
	a	1,48 (100)	1,15 (100)	2,49 (175)	1,20 (104)	2,18 (147)	1,20 (104)		
	b	1,86 (100)	1,11 (100)	1,40 (75)	1,12 (101)	2,89 (155)	1,16 (104)		

a – Springbarley; b – Winterwheat.

The operation frequency and the load are higher in springbarley than in winterwheat. The various effects (H and V) are found in springbarley, as well as in winterwheat.

Summarizing the field experiments, the conclusion can be made, that during the operation of a combine harvester the load depends upon the stubble-height (S), the ground speed (V), the working width (W), the crop (C) and the machine (M), in particular the anthropometric qualities of the work-space lay-out; using an automatic header height control system (H) the load decreases.

The results of the experiments are endorsed completely by the results of previous studies; there is not only the significant difference between the machines, but the subjects are more quickly familiar with one machine (Nr.: 3^b) than with another (Nr.: 3^a). Based upon the results of the indoor experiments we concluded, that the differences between the machines 3^a and 3^b are more significant as the experimental distraction increases. We expected, that for a higher information speed – as a result of an increased capacity by increasing the ground speed and/or the working width – the difference between machine 3^a and 3^b would increase, in favour of machine 3^b. The results of the field experiments confirm these statements; moreover, the conclusion can be repeated, that the load is primarily determined by the work-space lay-out.

(iii) Effect of capacity (V × W)

By means of field experiments the effect of capacity (C 1: 7 ton/h; C 2: 11 ton/h) during combining has been studied with one machine (Nr.: 3^a) on plots with winterwheat. Besides, the most favourable combination of ground speed (V 1: 2,40 km/h; V 2: 3,50 km/h; V 3: 3,90 km/h; V 4: 4,90 km/h) and working width (W 1: 450 cm; W 2: 570 cm) – at a given level of capacity – has been determined (VAN OOSTEN; 1970).

a. Equipment and method

The plots (condition: 100% standing, some reed) were harvested at a humidity of 17,8%; the yields of kernel and straw – reduced to a humidity of 17,0% – amounted to 7000 kg/ha and 5313 kg/ha respectively. During the experiments the weather conditions were constant and favourable for harvesting; the soil was hard and dry.

For each test the ground speed was adjusted as accurate as possible (tolerance: ± 0,25 km/h); during the test the operator had to leave the ground speed control undisturbed. During all tests a normal stubble-height of 20 cm had to be achieved; the stubble-height and the effective working width were controlled frequently.

b. Treatment

For each test the operation frequency and the heart rate were registered.

The operation frequency (in n/min) and the work load (in W/R) were used as inputs for the analysis of variance. The results of this study are listed in table 43.

TABLE 43. Operation frequency (in n/min) and load (in W/R) during combining at different capacities (C) and with different working widths (W).

	Working width					
	W 1		W 2			
	n/min	W/R	n/min	W/R	n/min	W/R
C 1	1,84	1,12	1,94	1,09	1,89 (100)	1,10 (100)
C 2	2,41	1,16	3,07	1,13	2,74 (145)	1,15 (105)
	2,13 (100)	1,14 (100)	2,50 (117)	1,11 (97)		

Based upon the operation frequency and the load it can be proved, that there is a significant difference between the working widths (W), in favour of the greater working width. With an increase of the working width the operation frequency increases and the load decreases. The effect of ground speed (V) is significant; with an increase of the ground speed the operation frequency and the load increase.

The effect of capacity is significant; with an increase of the capacity the operation frequency and the load increase. Realizing a certain level of capacity, it is preferable to work at a low ground speed combined with a greater working width.

5.5. SUMMARY

The decision of the central nervous system is transported to the effectors and transformed into voluntary muscle movements, which are necessary for the output or performance of a man – task system. The muscle movements demand energy and this leads to the physical load of man, whose working capacity is limited. An energy consumption of 20 kJ (= 4,8 kcal) per minute, including a basal metabolic rate of about 4,2 kJ (= 1 kcal) per minute, has been accepted as the maximum consistent level, that an adult man should be expected to expend.

For the assessment of physical load well-functioning parameters are available. In all kinds of tasks, and even over a long period of time, the heart rate can be faultlessly registered. Based upon the various physiological parameters the physical load can be scaled.

Field experiments

For collecting data about the character and extent of loading components during combining, as well as the influence they have on the output of the system, field experiments have been carried out.

The studies led to the following conclusions:

(i) During the operation of a combine harvester the performance and the load depend upon the machine – in particular: the operator's platform –, the stubble-height, the ground speed, the working width and the crop.

(ii) There is a significant difference between the operator's platforms, which increases as the ground speed increases. The interaction between ground speed and working width, representing capacity, is significant; realizing a certain level of capacity, it is preferable to work at a low ground speed combined with a greater working width.

Using an automatic header height control system the operation frequency and the load decrease; the advantage of an automatic system becomes greater when working at higher ground speeds.

(iii) The results of the field experiments endorse completely the results of the anthropometric studies and the indoor experiments. There are differences between the machines; at an increasing information speed – indoor: increasing experimental distraction; field: increasing ground speed – the differences between the machines become greater.

The conclusion can be repeated, that the performance and the load are primarily determined by the work-space lay-out.

The working capacity of man is limited, besides the mechanical efficiency of human labour is only slight. Only to a small extent the maximum muscular stıength can be exerted for a longer period of time, where the pattern and the speed of the motions play an important role.

To increase the capacity it is necessary, that the designer of a combine harvester pays attention to an adequate processing of the increasing information speed and the operator's load. This is primarily possible by using machines with optimum work-space lay-out, which promote fast learning, as well as the introduction of automation, as shown by the experiments with an automatic header height control system.

6. IDEAL CONCEPT

6.1. INTRODUCTION

By means of principles, parameters, procedures and criteria from various disciplines the ergonomic factors, influencing the performance and the work load of a man-task system, have been studied. Integrating the results of the anthropometric studies, of the indoor and of the field experiments the conclusion can be made, that the performance and the load are primarily determined by the work-space lay-out.

Based upon the results of these studies, the recommendations for the ideal concept of the operator's platform for the self-propelled combine harvester can be formulated.

6.2. RECOMMENDATIONS

The ideal concept is realizable by designing machines with an optimum work-space lay-out (Anthropometry), as well as by eliminating redundant and non-relevant information (Perception).

6.2.1. *Anthropometry*

Based upon the relevant measurements and motions of the human body, as well as the results of the M.T.M.-analysis, the data for an optimum work-space lay-out for the combine harvester can be formulated:

1. Seat

When operating a machine in a sitting position the way of working is strongly governed by the work-space. The seat must be adjustable in horizontal and vertical directions, in order to accomodate a reasonable range (usually: 5^{th} to 95^{th} percentiles) of individuals.

2. Lay-out

The location and displacement of the header height, the reel position and the ground speed control deserve priority in designing the lay-out of controls, for these controls are the most important ones and frequently used. Since a development in the direction of fingertip control leads to an important reduction of the operating element time it is evident, that fingertip control is necessary.

The 'fingertipped' controls for the header height, the reel position and the ground speed have to be located close to each other and within the optimum area, where the motions of the hand are the most favourable.

The steering wheel has to be located within the optimum areas for hand-operated controls. The clutch and the brake-pedal have to be located within the optimum areas for foot-operated controls.

6.2.2. *Perception*

Since machines, performing functions of perception, do not exist or are very rare, the attainments of the investigations regarding perception must be taken into account. For the combine harvester this means primarily an adequate presentation of the relevant information – in particular: the visibility –, as well as the elimination of the redundant and non-relevant information.

6.2.21. Visibility

A good visibility is obtained, when the information becomes visible under the optimum conditions, namely at a view angle of 30° for the vertical plane and a direct distance of 3.000 mm (vertically: 1.500 mm; horizontally: 2.600 mm) between the eye and the object. In the horizontal plane it is necessary, that the information becomes visible within the stationary field.

For combine harvesters it is necessary to obtain information from the feed table auger in front of the conveyor chain and of the separation from the previously cut swath. In comparison with the combines examined, the visibility can be improved considerably by reduction of the view angle and the vertical distance; the operator's platform must be brought closer to the field. This construction gives some difficulties, because of the location of the operator's platform – just above the conveyor chain – on present machines; the motions of the conveyor chain are reduced, since more dust is circulating around the operator. An eccentric location of the operator's platform offers more favourable possibilities, since the platform can be located next to the conveyor chain and closer to the field; the data for an optimum visibility are shown in fig. 28 and 29.

6.2.22. Redundant and non-relevant information

An adequate presentation of the relevant information is primarily promoted by eliminating the redundant and non-relevant information. This complex of variables in a man-task system may be broken down into the major areas of:

1. Sound

A sound pressure level exceeding the limit of 80 dB_A and lasting for more than five hours daily might have damaging effects on the hearing in the long run.

Protection against sound is primarily possible by technical means: machines making less sound and isolation of the sound source, as well as reduction of sound transmission and application of acoustic interference. The most common method is the enclosure of the source, as well as the application of an enclosed cabin to reduce the sound pressure level to bearable levels. In designing a cabin attention must be paid to the attachment, in particular sound transmission has to be avoided.

2. Dust

A dust concentration of 15 mg/m^3 of air is thought to be the permissible limit.

Protection against dust in the air around the operator of a combine is possible by ventilation: blowing away or sucking off the particles. The ideal concept is

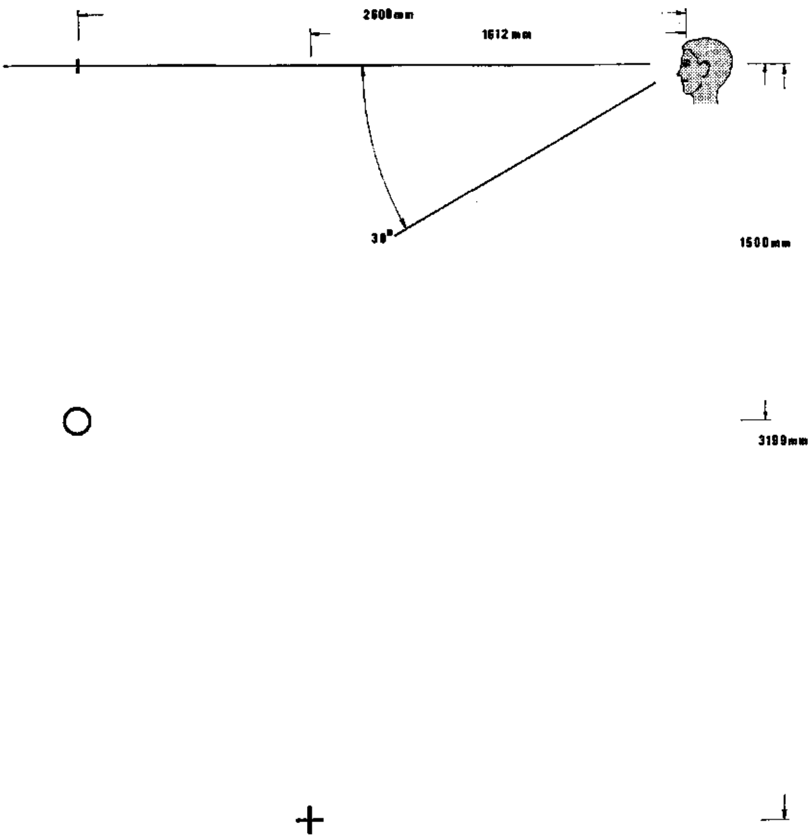


FIG. 28. Optimum visibility of the cutterbar for the self-propelled combine harvester (vertical plane).
○ – optimum position
+ – present position

the enclosure of the operator in a cabin with a small overpressure, so the particles cannot penetrate into the work-space.

3. Vibrations

Mechanical vibrations within the frequency range of 2 Hz to 6 Hz have to be avoided, since the human body is most sensitive to this type of vibrations; the natural frequency of the work-space has to be less than 2 Hz. Moreover, it is necessary, that the value K = 4 is not exceeded, whilst only movements in the vertical direction are permitted.

Protection against mechanical vibrations is of a technical nature (reduction and isolation of the vibrations, as well as reduction of vibration transmission) or of a personal nature (suspension seat or suspended cabin). The most obvious way

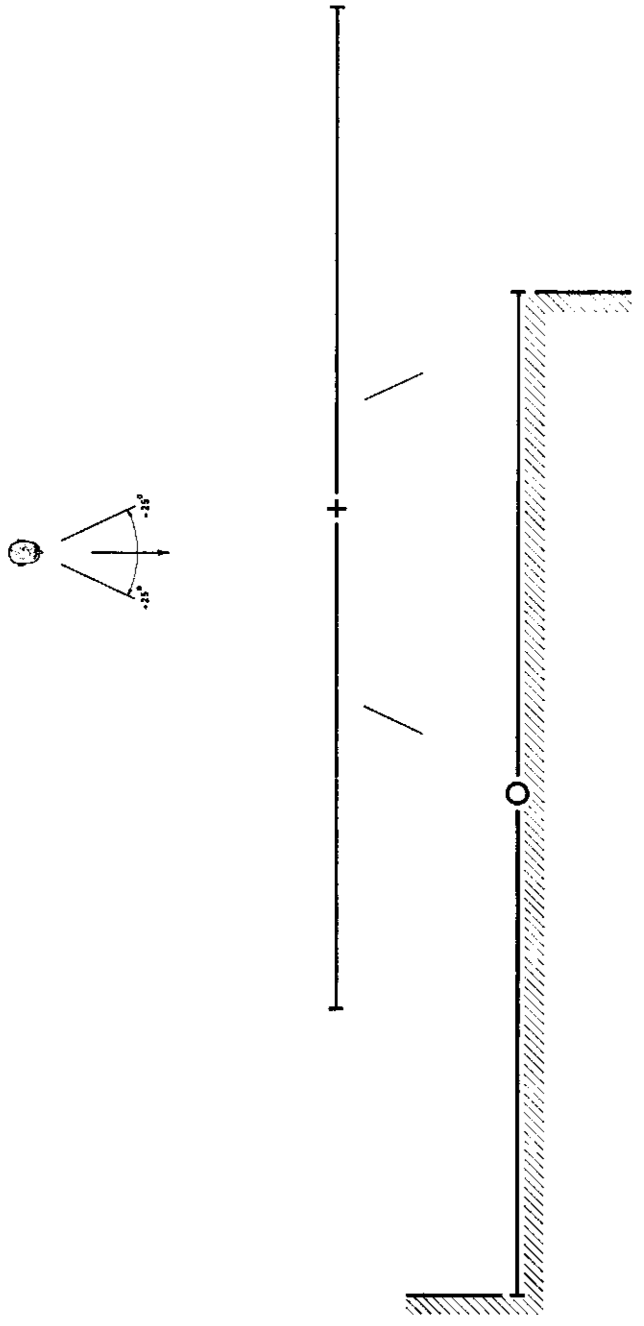


FIG. 29. Optimum visibility of the cutterbar for the self-propelled combine harvester (horizontal plane).
○ – optimum position
+ – present position

is to fit a suspended cabin – in which the seat, the controls and the operator move simultaneously –, equipped with an active system to destroy the vertical vibrational input.

4. Climate

Atmospheric conditions interfering with normal or constant body temperature reduce mental and physical working capacity. By maintaining optimum climatic conditions (air humidity: 50 %; air temperature: 20–21 °C; air velocity: 10–20 cm/sec) a favourable climate can be obtained. From an economical point of view, as well as the objective judgement of the climate, it is preferable to use less stringent data for the air temperature (range: 18–22 °C).

Protection against climatic conditions is primarily possible by technical means: air-curtain or cabin with air-conditioning. The most obvious way is to use an enclosed cabin with air-conditioning.

Summarizing, the ideal concept for the combine harvester is an enclosed suspended cabin – in which the seat, the controls and the operator move simultaneously and only in the vertical direction –, which combines the need for considerably improving ride vibration with greater protection against sound and dust, as well as climatic influences.

The recommendations for an optimum work-space lay-out of the self-propelled combine harvester have been formulated in Appendix A.

6.3. Summary

Supplying the requirements for an increase of capacity it is necessary, that in designing the self-propelled combine harvester attention is paid to an adequate processing of the increasing information speed. This is primarily possible by using machines with an optimum work-space lay-out, an adequate presentation of relevant information and the introduction of automation.

For the combine harvester this means primarily an optimum work-space layout (frequently used, fingertip controls located close to each other and within the optimum area) and an improved visibility by an eccentric and lowered location of the operator's work-space. The enclosed suspended cabin is the ideal concept, which combines the need for considerably improving ride vibration with greater protection against sound and dust, as well as climatic influences.

7. SUMMARY AND CONCLUSIONS

7.1. Introduction

Mechanization not only changes the character and structure of labour in agriculture and industry, but also influences the nature of the work load. Instead of delivering energy, the main issue now is the perception and processing of information, as well as controlling and regulating the work being done by machines. More and more the accent is shifting to tasks which appeal to the capacity of man to process information.

Supplying the requirements for increased capacity is possible by increasing the ground speed and/or the working width, which, however, involves higher information speed, more actions for operation per time unit and a higher operator's work load. Human beings should not adapt themselves to the machine and – as a consequence of too high a load – will hazard occupational diseases and reduced performance.

By means of principles, parameters, procedures and criteria from various disciplines – anthropometry, perception, selection and action – ergonomics can contribute to an optimum man – task system with a high capacity and a favourable operator's load.

This study deals with the ergonomic system-analysis of the operation of a self-propelled combine harvester. The operator of this machine regulates the movement – direction and speed –, the mowing and threshing, the separation of kernel and straw, as well as the delivery of the product. Based upon the information obtained from crop, terrain, plot and machine the operator has to decide on such an adjustment of the machine, which results in a process with a high capacity and a high quality of work.

7.2. Anthropometry

The characteristics of the human body determine the location and displacement of the operating controls, as well as the forces to be exerted, the nature and frequency of movements. Based upon the relevant measurements and motions of the human body, the anthropometric data are given for designing an optimum work-space lay-out of a combine harvester.

1. Lay-out studies

To determine the location and displacement of the controls, as well as the forces to be exerted, and the location of the foot-board and cutterbar, special measuring equipment and methods have been developed.

The work-space lay-out – specific for each machine – appeared to differ considerably. It is recommendable, that frequently used controls are located close to each other and within the normal area.

The forces needed for steering are very low, because of the application of power steering. The forces needed for operating the clutch and the brake-pedal are too high for the older machines; for the newer combines they meet the requirements.

2. Frequency

The frequency with which different operations and movements have to be carried out, determines mainly the operator's work load. The data, collected in measuring the operation frequency, indicate the priority in the lay-out of controls.

The studies show, that the header height, reel position and ground speed control are most important. The location and displacement of these controls deserve priority in the design of the work-space lay-out.

The movements of the steering wheel only have a correcting character.

3. M.T.M.-analysis

Based upon the results of the lay-out studies and the frequency-analysis, the operating element time has been calculated by means of M.T.M.; these time-values can be used to obtain reliable data of the ergonomic quality of the lay-out of a certain work-space.

The study shows, that there are great differences between the various machines; a small modification in the work-space lay-out leads to a favourable change in the operating element time. A development in the direction of finger-tip control – i.e. header height, reel position and ground speed control grouped together – is desirable.

7.3. Perception

The perception of information, that a worker receives from work-space and environment, takes place via the senses, which are sensitive to specific impulses. The reaction to the information depends upon the sense organ that is stimulated, the strength of the stimulus and the place where the stimulus arrives.

1. Sight

The perception of visual information depends upon the object, the environment and the distance between the eye and the object.

For combining it is necessary to obtain information from the feed table auger just in front of the conveyor chain and of the separation from the previously cut swath. On the machines examined the visual angle, as well as the horizontal distance between the eye and the cutterbar, are favourable in the horizontal plane. In the vertical plane the view angle is extremely unfavourable; besides, the distance between the eye and the cutterbar is too long, which is caused by the large vertical distance.

Improvement of the visibility is possible by reduction of the view angle and the vertical distance. The operator's platform must be brought closer to the field. An eccentric location of the operator's platform offers favourable possibilities, since the platform can be located next to the conveyor chain.

2. Hearing

Hearing ensures mutual communication between man, machine and environment. Depending on frequency, sound pressure level and duration of the exposure, sound has an annoying or a damaging effect.

By the functioning of the engine and other parts of the machine, in particular: the threshing mechanism, the operators of combines are submitted to sound. Measured at the operator's ear, the sound pressure levels of the machines examined are too high, whilst the presence of a cabin does not lead to an important decline of the sound pressure level. Moreover, the ground speed during combining does not affect the sound pressure level.

The most common method of solving the sound problem is the enclosure of the source to reduce the sound pressure level to bearable levels.

3. Scent and taste

From an ergonomic point of view scent and taste are less important, because only a small number of actions appeals specifically to these senses. Attention must be paid to the dust in the air around an operator of a combine.

The dust concentration in the air around operators of the machines examined is too high; with respect to the duration of the harvesting period the possibility of developing silicosis must be considered to be low. On a machine without cabin the dust concentration is considerably higher than on a machine with cabin; during harvesting barley less dust is circulating around the operator than during harvesting wheat.

Protection of the operator of a combine against dust is possible by ventilation (blowing away or sucking off the particles) and personal protective equipment. The ideal concept is the enclosure of the operator in a cabin with a small overpressure, so that particles cannot penetrate into the work-space.

4. Feeling

By uneveness of terrain and road surface, the profile of the tyres and the functioning of the engine and other parts of the machine, the operators of machinery are submitted to mechanical vibrations, which adversely affect their health and performance. The effect and impact of vibrations varies with the frequency, as the human body is most sensitive to mechanical vibrations within the frequency range from 2 Hz to 6 Hz. It is necessary, that the curve $K = 4$ of the VDI-Recommendation is not exceeded in designing the work-space of farm machinery.

The intensity of mechanical vibrations on combine harvesters is low, whilst the movements in the vertical direction are more numerous than in the other directions. Combining at different ground speeds appears to affect hardly the intensity; with greater working width the intensity is slightly smaller. When driving on the road with increasing ground speeds there appears an increasing intensity, which is lower than during combining. The spectral distribution indicates the existence of specific frequency ranges, which are explicable from the machine.

At present, the most obvious way to reduce ride vibration is to fit a correctly designed suspension seat. The benefit of a good suspension seat is limited by the increasing movements between the operator and the controls; to eliminate this the vibrations of the whole vehicle or the whole of the operator's work-space should be reduced. A suspended enclosed cabin – in which controls, seat and operator move simultaneously – is an approach, which combines the need for improving ride with greater protection from sound and dust.

Since machines, performing functions of perception, do not exist or are very rare, the designer of a man-task system must take into account the attainments of the investigations regarding perception. For the combine this means primarily an adequate presentation of the relevant information; by improving the visibility of the cutterbar (reduction of the view angle and the vertical distance) this can be realized. Besides, the redundant and non-relevant information – sound, dust and mechanical vibrations – has to be eliminated; the suspended cabin – in which the controls, the seat and the operator move simultaneously – is an approach, which combines the need for improving ride with greater protection from sound and dust.

7.4. Selection

The transport of data from the stimulated sense organs ('input') to the effectors ('output') is not simply and solely transport. The data are processed, from the various possibilities the right answer is chosen ('choice') and transformed into action.

1. Theory

In task performance the number of directed switches from input to output determines information processing and mental load, because all signals make use of 'a single channel decision mechanism' with a limited capacity. Generally, a value of two to three bits per second is assumed to be the limit for adequate information processing.

For the assessment of mental load a well-functioning parameter is not yet available; most can be expected of the method with dual tasks and the heart rate.

2. Indoor experiments

For studying a man-task system under controlled conditions and to obtain information regarding the ergonomic qualities of the work-space lay-out of a certain machine, a simulator is built.

The studies led to the following conclusions:

a. In simulating the operation of a combine harvester the performance and the load depend upon the experimental distraction and the anthropometric qualities of the work-space lay-out. The steering accuracy detiorates and the load increases as a function of the number of signals per minute in the secondary task. There is a significant difference between the machines, which increases as the experimental distraction increases.

b. By executing an identical series of information a learning curve appears; the performance increases and the load decreases as a function of the number of cycles. The appearance of the learning curve is disturbed by different series of information in an experiment. There is a significant difference between the machines.

In simulating the operation of a combine harvester, the performance and the load depend upon the experimental distraction (the number of signals per minute in the secondary task and the series of information in an experiment) and the anthropometric qualities of the work-space lay-out of the machine. The results of the indoor experiments confirm the statements – endorsed completely by the results of the M.T.M.-analysis –, that subjects are more quickly familiar with one machine than with another, which causes a more efficient performance.

The conclusion can be made, that the performance and the load are primarily determined by the work-space lay-out.

7.5. Action

The choice of the decision mechanism is transported to the effectors and transformed into voluntary muscle movements, which are necessary for the output or performance of a man – task system.

1. Theory

The muscle movements demand energy and this leads to the physical load of man, whose working capacity is limited. Besides, the mechanical effect of human labour is very slight. An energy consumption of 20 kJ (= 4,8 kcal) per minute, including a basal metabolic rate of about 4,2 kJ (= 1 kcal) per minute, has been accepted as the maximum consistent level, that an adult man should be expected to expend.

For the assessment of physical load well-functioning parameters are available. In all kinds of tasks, even over a long period of time, the heart rate can be faultlessly registered.

2. Field experiments

For collecting data about the character and extent of loading components during combining, as well as the influence they have on the output of the system, field experiments have been carried out.

The studies led to the following conclusions:

a. During the operation of a combine harvester the performance and the load depend upon the machine – in particular: the operator's platform –, the stubble-height, the ground speed, the working width and the crop. There is a significant difference between the operator's platforms, which increases as the ground speed increases. The interaction between ground speed and working width, representing capacity, is significant; realizing a certain level of capacity, it is preferable to work at a low ground speed combined with a greater working width.

b. Using an automatic header height control system the operation frequency and the load decrease. The advantage of an automatic system becomes greater when working at higher ground speeds.

The results of the field experiments endorse completely the results of the anthropometric studies and the indoor experiments. There are differences between the machines; at an increasing information speed – indoor: increasing experimental distraction; field: increasing ground speed – the differences between the machines become greater.

The conclusion can be repeated, that the performance and the load are primarily determined by the work-space lay-out.

7.6. Discussion

Human beings should not adapt themselves to the machine and – as a consequence of too high a load – will hazard occupational diseases and reduced performance. By means of principles, parameters, procedures and criteria from various disciplines – Anthropometry (Chapter 2), Perception (Chapter 3), Selection (Chapter 4) and Action (Chapter 5) – the ergonomic factors, influencing the output or performance in operating a self-propelled combine harvester, have been studied by means of lay-out studies, indoor and field experiments. Based upon the results of these studies the conclusion can be made, that the performance and the load in a man-task system are primarily determined by the work-space lay-out. Recommendations for the ideal concept of the operator's platform of the self-propelled combine harvester are given (Chapter 6).

Supplying the requirements for an increase of capacity it is necessary, that the designer of a self-propelled combine harvester pays attention to an adequate processing of the increasing information speed. This is possible by using machines with an optimum work-space lay-out and eliminating of redundant and non-relevant information. Moreover, the introduction of automation, in which many processes – combine: moving, mowing, threshing, cleaning and maintenance – are executed and corrected without human interference, offers favourable advantages.

In the near future the 'supervisor of harvesting' has to settle – based upon the conditions of crop, terrain and climate – the norm and the tolerance of the whole process. Next to it, the supervisor has to control – sitting at home, in front of a correctly designed console – the processes and, if necessary, has to re-adjust by means of remote-control.

SAMENVATTING

INLEIDING

De mechanisatie verandert niet alleen het karakter en de structuur van de arbeid in landbouw en industrie, maar beinvloedt eveneens de aard van de arbeidsbelasting. In plaats van het leveren van energie wordt momenteel het accent gelegd op het waarnemen en verwerken van informatie, alsmede het controleren en het reguleren van werkzaamheden, die door machines worden verricht. Het accent verschuift meer en meer naar taken, die een beroep doen op het informatieverwerkend vermogen van de mens.

Aan de eis tot verhoogde capaciteit kan worden voldaan door toename van de rijsnelheid en/of de werkbreedte, hetgeen echter gepaard gaat met een hogere informatiesnelheid, meer besturingshandelingen per tijdseenheid en een hogere belasting van de bestuurder. De mens dient zich niet aan te passen aan de machine en – tengevolge van een te hoge belasting – beroepsziekten en gereduceerde prestaties te riskeren.

Door middel van principes, parameters, procedures en criteria vanuit verschillende disciplines – anthropometrie, perceptie, selectie en actie – kan de ergonomie bijdragen tot een optimaal mens–taaksysteem met een hoge capaciteit en een gunstige arbeidsbelasting.

Deze studie is gewijd aan de ergonomische systeem-analyse van de bediening van de zelfrijdende maaidorser. De bestuurder van deze machine regelt de voortbeweging – richting en snelheid –, het maaien en dorsen, het scheiden van korrel en stro, alsmede het afvoeren van het product. Op grond van de informatie, die wordt verkregen van het gewas, het terrein en de machine, moet de bestuurder besluiten tot die instelling van de machine, welke resulteert in een proces met een hoge capaciteit en een hoge kwaliteit.

ANTHROPOMETRIE

De eigenschappen van het menselijk lichaam bepalen de gegevens inzake de plaats en de verplaatsing van de bedieningsmiddelen, alsmede de uit te oefenen krachten, de aard en de frequentie van de bewegingen. Op grond van de relevante afmetingen en bewegingen van het menselijk lichaam, kunnen de anthropometrische gegevens voor het ontwerpen van een optimale werkplekinrichting worden geformuleerd.

1. Lay-out studies

Om de plaats en de verplaatsing van bedieningsmiddelen, alsmede de uit te oefenen krachten, en de plaats van de voetplaat en het maaibord vast te leggen, is speciale meetapparatuur – met bijbehorende procedure – ontwikkeld.

De gegevens omtrent de werkplekinrichting – specifiek voor iedere machine – blijken aanzienlijk te verschillen voor een aantal maaidorsers. Het verdient aanbeveling bedieningsmiddelen, die frequent worden gebruikt, dicht bij elkaar te plaatsen binnen het normale gebied van de mens.

Door de toepassing van stuurbekrachtiging zijn de stuurkrachten gering. De krachten voor het bedienen van de koppeling en de voetrem zijn te hoog bij de oudere machines; bij de nieuwere machines voldoen deze krachten beter aan de gestelde eisen.

2. Frequentie

De frequentie, waarmee de verschillende handelingen en bewegingen moeten worden verricht, bepalen in hoofdzaak de arbeidsbelasting. De gegevens, die zijn verzameld door het meten van de bedieningsfrequentie, geven de prioriteit aan bij het plaatsen van bedieningsmiddelen.

De experimenten wijzen uit, dat de bedieningsmiddelen voor de hoogte van het maaibord, de positie van de haspel en de rijsnelheid het belangrijkst zijn. Aan de plaats en de verplaatsing van deze bedieningsmiddelen dient prioriteit te worden gegeven bij het ontwerpen van een werkplek.

De bewegingen van het stuurwiel hebben slechts een corrigerend karakter.

3. M.T.M.-analyses

Op grond van de resultaten van de lay-out studies en de gevonden bedieningsfrequentie is met behulp van M.T.M. de effectieve bedieningstijd berekend. Deze waarden kunnen worden gebruikt voor het verkrijgen van betrouwbare gegevens inzake de ergonomische kwaliteit van de inrichting van een bepaalde werkplek.

Het onderzoek wijst uit, dat tussen de verschillende machines grote verschillen bestaan; een kleine wijziging in de werkplekinrichting leidt tot een gunstige verandering van de bedieningstijd. Een ontwikkeling in de richting van 'fingertip control' – de bedieningsmiddelen voor maaibord, haspel en rijsnelheid in een groep bij elkaar geplaatst – is gewenst.

Perceptie

Het waarnemen van de informatie, die de werkende mens ontvangt van werkplek en omgeving, geschiedt door de zintuigen, die gevoelig zijn voor specifieke impulsen. De reactie op de informatie is afhankelijk van het gestimuleerde zintuig, de sterkte van de stimulus en de plaats waar de stimulus wordt aangeboden.

1. Gezicht

De perceptie van visuele informatie is afhankelijk van het object, de omgeving en de afstand tussen het oog en het object.

Bij het maaidorsen is het noodzakelijk, dat informatie wordt verkregen van de invoervijzel – precies vóór de opvoerketting – en de scheiding met het vorige zwad. Bij de onderzochte maaidorsers zijn de gezichtshoek, alsmede de horizontale afstand tussen het oog en het maaibord, gunstig in het horizontale vlak. In het verticale vlak is de gezichtshoek bijzonder ongunstig; bovendien is de afstand tussen het oog en het maaibord te groot, hetgeen wordt veroorzaakt door de grote verticale afstand.

Een betere zichtbaarheid is te verkrijgen door het verminderen van de gezichtshoek en de verticale afstand. Het bedieningsplatform dient dichter bij het maaiveld gebracht te worden. Een excentrische plaatsing van het bedieningsplatform biedt gunstige mogelijkheden, aangezien het platform dan naast de opvoerketting kan worden geplaatst.

2. Gehoor

Het gehoor verzorgt de onderlinge communicatie tussen mens, machine en omgeving. Afhankelijk van frequentie, geluidsdrukniveau en expositieduur heeft geluid een hinderlijk of een schadelijk effect.

Door het werken van de motor en andere delen van de maaidorser – in het bijzonder het dorsmechanisme –, worden de bestuurders blootgesteld aan geluid. Gemeten op oorhoogte zijn de geluidsdrukniveaus van de onderzochte machines te hoog, terwijl de aanwezigheid van een cabine niet leidt tot een belangrijke daling van het geluidsdrukniveau. Bovendien is de rijsnelheid gedurende het maaidorsen niet van invloed op het geluidsdrukniveau.

De meest geschikte methode om het geluidsprobleem op te lossen is het insluiten van de bron teneinde het geluidsdrukniveau tot draaglijke niveaus terug te brengen.

3. Reuk en smaak

Vanuit ergonomisch gezichtspunt zijn de reuk en de smaak van gering belang, omdat slechts een gering aantal taken een beroep doet op deze zintuigen. Wel dient aandacht besteed te worden aan het stof in de lucht rond de bestuurder van een maaidorser.

Bij de onderzochte machines is de stofconcentratie te hoog; gezien de duur van de oogstperiode moet de kans op het krijgen van silicosis gering worden geacht. Op een maaidorser zonder cabine is de stofconcentratie aanzienlijk hoger dan op een maaidorser met cabine. Tijdens het maaidorsen van gerst circuleert minder stof in de lucht rond de bestuurder dan tijdens het maaidorsen van tarwe.

De bestuurder van een maaidorser kan tegen stof worden beschermd door ventilatie (wegblazen of afzuigen van de deeltjes) en persoonlijke beschermingsmiddelen. De beste oplossing is het insluiten van de bestuurder in een cabine met een kleine overdruk, zodat de deeltjes niet kunnen binnendringen in de werkruimte.

4. Gevoel

Door oneffenheden van het terrein en het wegdek, het profiel van de banden en het functioneren van de motor en andere delen van de machine, worden de bestuurders van voertuigen onderworpen aan mechanische trillingen, die de gezondheid en de prestatie ongunstig kunnen beinvloeden. Het effect en de inwerking van trillingen varieert met de frequentie, waarbij het menselijk lichaam het meest gevoelig is voor trillingen in het frequentiegebied van 2 Hz tot 6 Hz. Bij het ontwerpen van de werkplek van een landbouwwerktuig is het noodzakelijk, dat de VDI-grenslijn K = 4 niet wordt overschreden.

De intensiteit van de mechanische trillingen bij zelfrijdende maaidorsers is gering, terwijl de bewegingen in de verticale richting veelvuldiger voorkomen dan die in de horizontale richtingen. Maaidorsen op verschillende grondsoorten en bij verschillende rijsnelheden is nauwelijks van invloed; de intensiteit bij een grotere werkbreedte is enigszins geringer. Indien op de weg met toenemende snelheden wordt gereden stijgt de intensiteit, die echter lager is dan gedurende het maaidorsen. De spectrale verdeling duidt op het bestaan van specifieke frequentiegebieden, die verklaarbaar zijn vanuit de machine.

Om de inwerking van trillingen te reduceren is het aanbrengen van een goede, afgeveerde zitting momenteel de meest voor de hand liggende oplossing. Het voordeel van een goede zitting wordt echter beperkt door de toegenomen, relatieve bewegingen tussen de bestuurder en de bedieningsmiddelen; om dit te voorkomen moeten de trillingen van het voertuig of het gehele bedieningsplatform verminderd worden. Een afgeveerde, gesloten cabine – waarin bedieningsmiddelen, zitting en bestuurder gelijktijdig bewegen – is een constructie, die de behoefte aan het verminderen van de trillingsinvloed combineert met een grotere bescherming tegen geluid en stof.

Aangezien werktuigen, die zelf perceptieve functies uitvoeren, niet of nauwelijks bestaan, zullen de ontwerpers van een mens-taaksysteem terdege rekening moeten houden met de verworvenheden van het onderzoek inzake de perceptie. Voor de maaidorser betekent dit allereerst een adequate aanbieding van de relevante informatie; door de zichtbaarheid van het maaibord (verminderen van de gezichtshoek en de verticale afstand) te verbeteren kan dit worden bereikt. Daarnaast moet overtollige en non-relevante informatie – met name: geluid, stof en mechanische trillingen – worden uitgeschakeld; de afgeveerde cabine – waarin de bedieningsmiddelen, de zitting en de bestuurder gelijktijdig bewegen – is een constructie, die de behoefte aan het verminderen van de trillingsinvloed combineert met een grotere bescherming tegen geluid en stof.

Selectie

Het transport van de gegevens van de gestimuleerde zintuigen ('input') naar de effectoren ('output') is geen transmissie zonder meer. De gegevens worden verwerkt, uit de verscheidene mogelijkheden wordt het juiste antwoord gekozen ('choice') en omgezet in actie.

1. Theorie

Bij de uitvoering van een taak bepaalt het aantal gerichte overschakelingen van input naar output de informatieverwerking en de mentale belasting, omdat alle signalen gebruik moeten maken van 'a single channel decision mechanism' met een beperkte capaciteit. In het algemeen wordt een waarde van twee tot drie bits per seconde aangehouden als de grens voor adequate informatieverwerking.

Een goed functionerende parameter voor het vaststellen van de mentale belasting is nog niet beschikbaar; het meeste is te verwachten van de methode met de duale taken en de hartslagfrequentie.

2. Laboratoriumexperimenten

Voor het bestuderen van een mens-taaksysteem onder controleerbare omstandigheden, alsmede het verkrijgen van informatie inzake de ergonomische kwaliteiten van de werkplekinrichting van een bepaalde machine, is een simulator gebouwd.

De onderzoekingen leidden tot de volgende conclusies:

a. Bij de gesimuleerde bediening van een maaidorser zijn de prestatie en de belasting afhankelijk van de experimentele afleiding en de anthropometrische kwaliteiten van de werkplekinrichting. De stuurnauwkeurigheid daalt en de belasting stijgt als functie van het aantal signalen per minuut in de tweede taak. Tussen de machines bestaan significante verschillen, die toenemen bij een stijging van de experimentele afleiding.

b. Bij het uitvoeren van een serie identieke taken ontstaat een leercurve; de prestatie stijgt en de belasting daalt als functie van het aantal cycli. Het ontstaan van de leercurve wordt verstoord door het uitvoeren van een serie met wisselende informatie in een experiment. Tussen de machines bestaat een significant verschil.

Bij het simuleren van de bediening van een maaidorser zijn de prestatie en de belasting afhankelijk van de experimentele afleiding (het aantal signalen per minuut in de tweede taak en de opeenvolging van de taken in een experiment) en de anthropometrische kwaliteiten van de werkplekinrichting van de machine. De resultaten van de laboratoriumexperimenten bevestigen de uitspraken – volledig ondersteund door de resultaten van de M.T.M.-analyses –, dat mensen sneller wennen bij de ene machine dan bij een ander, hetgeen een efficiëntere prestatie oplevert.

De conclusie kan worden getrokken, dat de prestatie en de belasting primair worden bepaald door de werkplekinrichting.

Actie

De keuze van het centrale keuzemechanisme wordt overgebracht naar de effectoren en omgezet in vrijwillige spierbewegingen, die noodzakelijk zijn voor de output of prestatie van een mens-taaksysteem.

1. Theorie

De spierbewegingen kosten energie en dit leidt tot fysieke belasting van de mens, wiens belastbaarheid beperkt is. Bovendien is het rendement van de menselijke arbeid zeer gering. Een energieverbruik van 20 kJ (= 4,8 kcal) per minuut, inclusief een basaal metabolisme van ongeveer 4,2 kJ (= 1 kcal) per minuut, wordt algemeen aanvaard als het maximum voor een volwassen man.

Voor het vaststellen van de fysieke belasting zijn goed functionerende parameters beschikbaar. Onder alle omstandigheden kan, zelfs over langere perioden, de hartslagfrequentie foutloos worden geregistreerd.

2. Veldexperimenten

Voor het verzamelen van gegevens omtrent de aard en de omvang van belastende componenten bij het bedienen van maaidorsers, alsmede de invloed van deze componenten op de output van het systeem, zijn veldexperimenten uitgevoerd.

De onderzoekingen leidden tot de volgende conclusies:

a. Bij het bedienen van een maaidorser zijn de prestatie en de belasting afhankelijk van de machine – met name: het bedieningsplatform –, de stoppelhoogte, de rijsnelheid, de werkbreedte en het gewas. Tussen de bedieningsplatforms bestaat een significant verschil, dat groter wordt bij toenemende rijsnelheden. De interactie tussen rijsnelheid en werkbreedte, hetgeen de capaciteit voorstelt, is significant; teneinde een bepaald capaciteitsniveau te verkrijgen verdient het aanbeveling te werken met een lage rijsnelheid en een grotere werkbreedte.

b. Bij het gebruik van een systeem met automatische hoogteregeling van het maaibord dalen de bedieningsfrequentie en de belasting. Het voordeel van een geautomatiseerd systeem wordt groter naarmate de rijsnelheid toeneemt.

De resultaten van de veldexperimenten bevestigen volledig de resultaten van de anthropometrische studies en de laboratoriumexperimenten. Tussen de machines bestaan verschillen; bij een toename van de informatiesnelheid – laboratorium: stijging van de experimentele afleiding; veld: toename van de rijsnelheid – worden de verschillen tussen de machines groter.

De conclusie kan worden herhaald, dat de prestatie en de belasting primair worden bepaald door de werkplekinrichting.

Discussie

Het is niet gewenst, dat de mens zich dient aan te passen aan de machine en – tengevolge van een te hoge belasting – beroepsziekten en gereduceerde prestaties dient te riskeren. Door middel van principes, parameters, procedures en criteria vanuit verschillende disciplines – Anthropometrie (Hoofdstuk 2), Perceptie (Hoofdstuk 3), Selectie (Hoofdstuk 4) en Actie (Hoofdstuk 5) – zijn de ergonomische factoren, die de output of prestatie bij het bedienen van een zelfrijdende maaidorser beinvloeden, bestudeerd door middel van lay-out studies, laboratorium- en veldexperimenten. Op grond van de resultaten van deze studies kan worden vastgesteld, dat de prestatie en de belasting in een mens-taak systeem primair worden bepaald door de inrichting van de werkplek. Aanbevelingen worden gedaan voor de ideale inrichting van het bedieningsplatform van de zelfrijdende maaidorser (Hoofdstuk 6).

Om aan de eisen tot verhoging van de capaciteit te kunnen voldoen is het noodzakelijk, dat de ontwerper van een zelfrijdende maaidorser aandacht besteed aan een adequate verwerking van de toenemende informatiesnelheid. Dit is mogelijk door machines te gebruiken met een optimale inrichting van de werkplek, alsmede het elimineren van overtollige en non-relevante informatie. Bovendien biedt het invoeren van automatisering, waarbij vele processen – maaidorser: voortbeweging, maaien, dorsen, schonen en onderhoud – worden uitgevoerd en gecorrigeerd zonder tussenkomst van de mens, gunstige voordelen.

In de naaste toekomst zal de 'supervisor of harvesting' de norm en de tolerantie van het gehele proces moeten vaststellen op grond van de condities, van gewas, terrein en klimaat. Daarnaast moet deze opzichter, die thuis zit voor een ergonomisch verantwoorde console, de processen controleren en, indien noodzakelijk, wederom instellen door middel van afstandsbediening.

REFERENCES

ANONYMUS. Onderzoek naar de functionele belasting in de bedrijfsgeneeskundige praktijk. M.F.I.-T.N.O.; Utrecht, 1966.

ANONYMUS. Universal symbols for operator controls. A.S.A.E.-Recomm.; New York, 1967[a].

ANONYMUS. Groepsbeproeving maaidorsers. I.L.R.-Publ. 110; Wageningen, 1967[b].

ANREP, G. V. Respiratory variations of the heart rate. Proc. Royal Soc. London **CXIX** (1936): 191–230.

ATTNEAVE, F. Applications of information theory to psychology. New York, 1959.

BARNES, R. M. Motion and Time Study. New York, 1958.

BARTENWERFER, H. Herzrhythmikmerkmale als Indikatoren psychischer Anspannung. Psychol. Beiträge **IV** (1960): 7–25.

BARTENWERFER, H. Untersuchungen und Beurteilung der psychischen Beanspruchung. Zbl. f. Arbeitsw. **14** (1960) 12: 231–234.

BARTENWERFER, H. Neuere Ergebnisse zum Problem psychischer Beanspruchung und Ermüdung. Zbl. f. Arbeitsw. **15** (1961) 8/9: 121–148.

BENEDICT, F. C. and J. A. HARRIS. Biometric study of basal metabolism. Washington, 1919.

BENSON, A. J. A Psychophysiological study of compensatory tracking on a digital display. Human Factors **7** (1965): 457–472.

BERTELSON, P. L'évaluation de la capacité résiduelle par la méthode de la tâche ajoutée. Brussel, 1966.

BERTHOZ, A. Vibrations de basses fréquences subies par l'homme. Paris, 1966.

BEVAN, W. Perception: Evoluation of a concept. Psychol. Rev. **65** (1958): 34.

BJERNINGER, S. Vibrations of Tractor Driver. Acta Polytechn. Scand. No. 23; Stockholm, 1966.

BOER, K. De ergonomische taakanalyse in een bedrijfsgeneeskundige praktijk. Eindhoven, 1967.

BORNEMANN, E. Untersuchungen über den Grad der geistigen Beanspruchung. Arbeitsphysiol. **12** (1943): 142–192.

BREDFELDT, R. T. Automatic header height control for self-propelled combines. Agr. Eng. **49** (1968) 11: 666–667.

BROADBENT, D. E. Some effects of noise in visual performance. Quart. Journ. Exp. Psychol. **6** (1954): 1–5.

BROADBENT, D. E. Perception and communication. London, 1958.

BROUHA, L. Physiology in industry. Oxford-Paris, 1960.

BROWN, I. D. Studies of component movements, consistency and spare capacity of car drivers. Ann. Occup. Hyg. **5** (1962): 131–143.

BROWN, I. D. Measurement of control skills, vigilance, and performance on a subsidiary task during 12 hours of car driving. Ergonomics **10** (1967) 6: 665–673.

BROWN, I. D. and E. C. POULTON. Measuring the 'spare mental capacity' of car drivers by a subsidiary task. Ergonomics **4** (1961) 1: 35–40.

BRUNET, Y. and L. LAVIEUVILLE. Pourquoi et comment améliorer le poste conduite des tracteurs agricoles. Etudes d. C.N.E.E.M.A. 293 (1966): 1–61.

Burger, G. C. E. and J. R. DE JONG. Aspects of ergonomics job analysis. Ergonomics **5** (1962) 1: 185–201.

BURTON, A. C. and O. G. EDHOLM. Man in a cold environment. London, 1955.

CARGO, Fysiologische methoden voor het vaststellen van belasting en belastbaarheid. Assen, 1965.

CATE, W. TEN. Human reaction to shipboard vibration. N.S.R.C.-Med. 14 S; Delft, 1966.

CHAPANIS, A., et. al. Applied experimental psychology. New York, 1963.

CHRIST, W. and H. DUPUIS. Aufbaustörungen der Wirbelsäule bei den in der Landwirtschaft tätigen Jugendlichen im Hinblick auf das Schlepperfahren. Grundl. d. Landt. **16** (1963): 13–15.

CHRIST, W. and H. DUPUIS. Über die Beanspruchung der Wirbelsäule unter dem Einfluss sinusförmiger und stochastischer Schwingungen. Intern. Z. angew. Physiol. **22** (1966): 258–278.

CLIFFORD, R. R. and W. M. HANCOCK. An industrial study of learning. Journ. of M.T.M. **9** (1964) 3: 12–27.

COERMANN, R. The mechanical impedance of the human body in sitting and standing position at low frequencies. In: Human Vibration Research. New York, 1963.

COERMANN, R. Physiologische Schwingungsprobleme in Fahrzeugen. Zbl. Luft- und Raumfahrt Med. **11** (1965) 3: 17.

COERMANN, R. and W. O. LANGE. Visual acuity under vibration. Human Factors **4** (1962): 291–300.

COERMANN, R., et. al. Vegetative Reaktionen des Menschen bei niederfrequenter Schwingungsbelastung. Intern. Z. angew. Physiol. **21** (1965): 150–168.

CROSSMAN, E. R. F. W. The information-capacity of the human motorsystem in pursuit tracking. Quart. J. Exp. Psychol. **12** (1960): 1–16.

DAMON, A., et. al. The human body in equipment design. Cambridge/Mass., 1966.

DIECKMANN, D. Einfluss vertikaler mechanischer Schwingungen auf den Menschen. Intern. Z. angew. Physiol. **16** (1957): 519–564.

DIECKMANN, D. Einfluss horizontaler mechanischer Schwingungen auf den Menschen. Intern. Z. angew. Physiol. **17** (1958): 83–100.

DIECKMANN, D. Über die Einwirkung mechanischer Schwingungen auf den Menschen. Arbeit und Leistung **17** (1963) 12: F29–F40.

DRAZIN, D. H. The effects of vibration on vision. Ann. Conf. E.R.S.; Cambridge, 1960.

DRAZIN, D. H. Factors affecting vision during vibration. Research **15** (1962): 275–280.

DREYFUSS, H. The measure of man. New York, 1960.

DUPUIS, H. Untersuchungen an mechanischen Lenkungen und Hilfskraftlenkungen bei einem 35-PS-Schlepper. Landt. Forschung **11** (1961) 1: 1–19.

DUPUIS, H. Bewertung der Schwingbeanspruchung bei Fahrern von Ackerschleppern und Landmaschinen in praktischen Einsatz. Landt. Forschung **14** (1964) 5: 145–149.

DUPUIS, H. Freie Fahrt für bessere Schleppersitze. Landt. **22** (1967) 23: 731–734.

DUPUIS, H. Zur physiologischen Beanspruchung des Menschen durch mechanischen Schwingungen. Fortschr. Ber. V.D.I.-Z.; Düsseldorf, 1969.

DUPUIS, H., et. al. Zweckmässige Gestaltung des Schlepperführerstandes. Bad Kreuznach, 1955.

DUPUIS, H. and W. CHRIST. Über das Schwingverhalten des Magens unter dem Einfluss sinusförmiger und stochastischer Schwingungen. Intern. Z. angew. Physiol. **22** (1966): 149–166.

DUPUIS, H. and W. CHRIST. Untersuchungen der Möglichkeiten von Gesundheitsschäden im Bereich der Wirbelsäule bei Schlepperfahren. Bad Kreuznach, 1968.

DUPUIS, H. and E. HARTUNG. Schleppersitz-Untersuchungen mit Hilfe eines servohydraulischen Schwingungssimulators. Landt. Forschung **16** (1966) 5: 163–171.

EICHNA, L. W., et. al. The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments. J. Ind. Hyg. & Tox. **27** (1945): 59–84.

EIMER, M. Stand der Regelungstechnik beim Mähdrescher. Grundl. Landt. **16** (1966) 2: 41–50.

ETTEMA, J. H. Arbeidsfysiologische aspecten van mentale belasting. Assen, 1967.

FIER, F. R. and V. O. MCCONVILLE. Filtration system for cab ventilation. A.S.A.E.-Paper 66–627; Chicago, 1966.

FISHBEIN, W. L. and L. C. SALTER. The relationship between truck and tractor driving and disorders of the spine and support structures. Ind. Med. & Surgery **19** (1950) 9: 444–445.

FITTS, P. M. S-R Compatibility: Spatial characteristics of stimulus and response code. Journ. Exp. Psychol. **46** (1953): 199–210.

FRANKMANN, J. P. and J. A. ADAMS. Theories of vigilance. Psychol. Bull. **59** (1962): 257–272.

FRAZER, T. M., et. al. Tracking performance during low frequency vibration. J. Aerospace Med. **32** (1961): 829–835.

FREUNDORFER, A. Ist Traktorfahren für Töchter gesundheitsschädlich? Der Traktor **14** (1964): 922.

FRIESEN, O. H. and G. C. ZOERB. Automatic for combines: Controlling feedrates automatically. Agr. Eng. **47** (1966) 8: 434–435.

GAGNÉ, R. M. Psychological principles in system development. New York, 1962.

GARNER, W. R. Uncertainty and structure as physiological concepts. New York, 1962.

GILLESPIE, R. D. The relative influence of mental and muscular work on the pulse-rate and blood-pressure. J. of Physiol. **LVII** (1924): 425–432.

GLASOW, W. and H. DUPUIS. Wird der Mähdrescherfahrer überfordert? Mitt.D.L.G. **49** (1960): 1451–1454.

GOLDMAN, D. E. and H. E. VON GIERKE. Effects of shock and vibration on man. In: Shock and Vibration Handbook. New York, 1961.

GRAF, O. Nervöse Belastung bei industrieller Arbeit unter Zeitdruck. Forschungsber. d. Landes N. Rh.-Westf. 1425; Köln, 1965.

GRANDJEAN, E. Physiologische Arbeitsgestaltung. Thun-München, 1963.

GRUNER, W. Probleme der Mess-, Steuerungs- und Regelungstechnik in der Landwirtschaft. D. Ak. d. Landw., Berlin **17** (1967) 11: 522–524.

GUIGNARD, J. C. Physiological effects of mechanical vibration. Proc. Royal Soc. Med. **53** (1960): 92–96.

HAAS, T. Loading statistics as basis of structural and mechanical design. Darmstadt, 1962.

HAIDER, M. Experimentelle Untersuchungen über geistige Beanspruchung durch Arbeitsleistungen. Arbeitsphysiol. **19** (1962): 241–251.

HARTOG, J. P. DEN. Mechanical vibrations. New York, 1956.

HERMAN, L. M. Study of the single channel hypothesis and input regulation within a continuous simultaneous task situation. Quart. J. Exp. Psychol. **17** (1965): 37–46.

HICK, W. E. On the rate of gain of information. Quart. J. Exp. Psychol. **4** (1952): 11–26.

HILGENDORF, L. Information input and response time. Ergonomics **9** (1966) 1: 31–37.

HOCHBERG, J. E. Perception. Englewood Cliffs, 1964.

HORNICK, R. J. The effect of low-frequency high amplitude, whole body longitudinal and transverse vibration upon human performance. Milwaukee, 1961.

HORNICK, R. J. Effects of whole-body vibration in three directions upon human performance. J. Eng. Psychol. **1** (1962) 3: 93–101.

HUANG, B. K. and Y. R. CHEN. Tractor noise control. VII. C.I.G.R.-Congr.; Baden-Baden, 1969.

I.E.C. Recommendations for sound level meters. I.E.C.-Recomm. 123, 1961.

I.L.O. International Labour Office Review; 83, 1960: 1.

I.S.O. Noise Rating in general. I.S.O.-Recomm. 235, 1961.

I.S.O. Measurements of noise emitted by vehicles. I.S.O.-Recomm. 362, 1964.

I.S.O. Evoluation exposure of humans to whole body vibrations. T. C. 108/WG 7, February 1967.

I.S.O. Thresholds of mechanical vibration and shock acceptance to man. T.C. 108/WG 7, August 1968.

JANSEN, G. Ergebnisse der medizinische Lärmwirkungen. Zbl. f. Arbeitsw. **16** (1962): F1–F12.

JONG, J. R. DE. Bekwaamheid, seriegrootte en benodigde tijd. Amsterdam, 1959.

JONGBLOED, J. Overzicht van de physiologie van de mens. Utrecht, 1954.

KALSBEEK, J. W. H. On the measurement of detioration in performance caused by distraction stress. Ergonomics **7** (1964) 2: 187–195.

KALSBEEK, J. W. H. Mentale Belasting. Assen, 1967.

KAMINSKY, T. L. and G. C. ZOERB. Automatic header height control for grain crops. Trans. A.S.A.E. **8** (1965) 2: 284–287.

KARIMI, N. Untersuchungen über die zeitliche und energetische Belastung der arbeitenden Menschen in einem weitgehend mechanisierten bäuerlichen Betrieb. Giessen, 1967.

KEIDEL, W. D. Vibrationsrezeption. Erlanger Forsch. Reihe B, 1956.

KELLERMANN, F., et. al. Vademecum Ergonomie voor de industrie. Eindhoven, 1965.

KUBICK, S. Gesundheitliche Schäden bei Traktorsitzen. XV. Intern. Congr. f. Arbeitsmed.; Wien, 1966.
KÜHN, G. Gründe und Möglichkeiten für die Anwendung der Regelungstechnik an Mähdreschern. D. Agrart. **18** (1968) 6: 280–285.
KÜHN, G. Zur Durchsatzregelung bei Mähdreschern. D. Agrart. **19** (1969) 8: 353–359.
LASSER, M. Ergebnis der im Jahre 1966 durchgeführten Vergleichsprüfung von Traktorfahrersitzen. B.V.P.A.-Wieselburg/Erl.; **12** (1966) 4: 1–14.
LAVAULT, PH. Quelques aspects de la pathologie du rachis chez le conducteur agricole. I. Congr. Intern. d. Méd. Agr.; Tours, 1961.
LAZET, A. Gids voor technische menskunde. Assen, 1967.
LEBLANC, J. A. Use of heart rate as an index of work output. J. Appl. Physiol. **10** (1957): 275–280.
LEHMANN, G. Praktische Arbeitsphysiologie. Stuttgart, 1962.
LEHMANN, G. Die physiologische und psychologische Wirkung des Lärms auf den arbeitenden Menschen. De Ingenieur **48** (1967): G61–G71.
LUND, M. Human engineering guide for equipment design. New York, 1963.
MACWORTH, N. H. Effects of heat on wireless telegraphy operators during hearing and recording morse messages. Brit. J. Ind. Med. 3 (1946): 143–158.
MAGID, E. B., et. al. Human tolerance to whole body sinusoidal vibrations. J. Aerospace Med. **31** (1960) 11: 915–924.
MATTHEWS, J. Ride comfort for tractor operators. J. Agr. Eng. Res. **9** (1964) 1: 3–31.
MATTHEWS, J. Progress in the application of ergonomics to agricultural engineering. I.A.E.-Symposium; Silsoe, 1967.
MAYNARD, H. B., et. al. Methods-Time-Measurement. New York, 1948.
MCCORMICK, E. J. Human factors engineering. New York, 1964.
MCFARLAND, R. A. Human factors in air transportation. New York, 1953.
MCGRATH, J. J. Irrelevant stimulation and vigilance performance. New York, 1963.
MEISTER, F. J. Die physiologische Wertung von Erschütterungsmessungen. Akust. Zeitschr. **2** (1935): 1–15.
MELLEROWICZ, H. Ergometrie. München-Berlin, 1962.
MICHON, J. A. A note on the measurement of perceptual motor load. Ergonomics **7** (1964) 4: 461–463.
MICHON, J. A. Tapping regularity as a measure of perceptual motor load. Ergonomics **9** (1966) 5: 401–412.
MICHON, J. A. Timing in temporal tracking. Assen, 1967.
MILLER, G. A. The magical number seven plus or minus two. Psychol. Rev. **63** (1956): 81–97.
MORGAN, C. T., et. al. Human engineering guide for equipment design. New York, 1963.
MURRELL, K. F. H. Ergonomics. London, 1965.
MUYS, C. G. M. Ergonomisch onderzoek zelfrijdende maaidorser. Scriptie Afd. Landb. t.; Wageningen, 1969.
OOSTEN, J. A. VAN. Een man-machine systeem in de graanoogst. Scriptie Afd. Landb. t.; Wageningen, 1970.
PARIN, V. V. Heart and circulation under space conditions. Acta Cardiol. XX (1965): 105–129.
PEPLER, R. D. Warmth and performance: An investigation in the tropics. Ergonomics **2** (1958) 1: 63–88.
PLOMP, R. Het gehoororgaan als frequentie-analysator. Ned. Tijdschr. Nat. **31**(1965): 229–241.
POFFENBERGER, A. T. The effect of continuous work upon output and feelings. American J. of Psychol. **39** (1927): 283–296.
REIHER, H. and F. J. MEISTER. Die Empfindlichkeit des Menschen gegen Erschütterungen. Forsch. Geb. Ing. Wes. **2** (1931) 11: 381–386.
RIEMERSMA, S. B. F. Een onderzoek naar de leerkarakteristiek. Scriptie Afd. Landb. t.; Wageningen, 1969.
RITSMA, R. J. Het gehoororgaan als periode-analysator. Ned. Tijdschr. Nat. **31** (1965): 242–253.

ROHMERT, W. Ermittlung von Erholungspausen für statische Arbeit des Menschen. Int. Z. Angew. Physiol. **18** (1960) 2: 123–164.

ROHMERT, W. Zur Theorie der Erholungspausen bei dynamischer Arbeit. Int. Z. angew. Physiol. **18** (1960) 3: 191–212.

ROSEGGER, R. and S. ROSEGGER. Arbeitsmedizinische Erkenntnisse beim Schlepperfahren Arch. f. Landt. **2** (1960) 1: 3–65.

RUTENFRANZ, J. Über das Verhalten des Pulsfrequenz bei Arbeit unter Zeitdruck. Int. Z. angew. Physiol. **18** (1960): 264–279.

SANDERS, A. F. The selective process in the functional visual field. I.Z.F.-T.N.O.; Soesterberg, 1963.

SANDERS, A. F. De psychologie van de informatieverwerking. Arnhem, 1967.

SANTEN, G. W. VAN. Inleiding tot het gebied der mechanische trillingen. Amsterdam, 1950.

SCHILLING, E. Der Einfluss Konstruktionsdaten auf die Aufbaubeschleunigung landwirtschaftlicher Fahrzeuge und die sich daraus ergebende günstige Sitzlage. Grundl. Landt. **15** (1965) 3: 81–86.

SCHMITZ, M. A. and A. K. SIMONS. The effect of low frequency, high amplitude whole body vertical vibration on human performance. Milwaukee, 1959.

SCHMITZ, M. A. and A. K. SIMONS. Man's response to low frequency vibration. Milwaukee, 1961.

SCHOUTEN, J. F., et. al. On the evaluation of perceptual and mental load. Ergonomics **5** (1962) 1: 251–260.

SCHRENK, L. P. Aiding the decision maker – A decision process model. Ergonomics **12** (1969) 4: 543–557.

SHANNON, C. E. A mathematical theory of communication. Bell Syst. Techn. J. **27**(1948): 379–423, 623–656.

SHANNON, C. E. and W. WEAVER. The mathematical theory of communication. Urbana, 1949.

SINAIKO, H. W. Selected papers on human factors in the design and use of control systems. New York, 1961.

SJØFLOT, L. and H. DUPUIS. Frequenzspektren der auf den Fahrer einwirkenden mechanischen Schwingungen bei Ackerschleppern und Mähdreschern. Grundl. Landt. **18**(1968)6: 227–233.

SMITH, R. C. Vigilance Research: Its application to industrial problems. Human Factors **11** (1969) 2: 149–156.

SOLIMAN, J. I. A scale for the degrees of vibration perceptibility and annoyance. Ergonomics **11** (1968) 6: 101–122.

SPERLING, E. and CH. BETZHOLD. Beitrag zur Beurteilung des Fahrkomforts in Schienenfahrzeugen. Glasers Annalen **80** (1956): 314–317.

SPITZER, F. Physiologische Grundlagen für den Erholungszuschlag bei Schwerarbeit. REFA-Nachr., Heft 2; 1951.

SPITZER, F. and T. HETTINGER. Tafeln für den Kalorienumsatz bei körperlicher Arbeit. Darmstadt, 1964.

STIER, F. Die Geschwindigkeit von Armbewegungen. Intern. Z. angew. Physiol. **18** (1959) 1: 82–100.

SUGGS, C. W. and W. E. SPLINTER. Time and energy analysis of agricultural tasks. Trans. A.S.A.E. **1** (1958) 1: 50–52.

SUGGS, C. W. and W. E. SPLINTER. Effects of environment on the allowable work load of man. Trans.A.S.A.E. **4** (1961) 1: 48–51.

SUGGS, C. W. and L. F. STIKELEATHER. The attenuation of terrain induced vibration by means of active control principles. VII. C.I.G.R.-Congr.; Baden-Baden, 1969.

TOMLINSON, R. W. The assessment of work load in agricultural tasks. Proc. of Inst. Agr. Eng. **25** (1970) 1: 18–29.

UZ, E. Auf den Fahrer einwirkende Vertikalschwingungen bei Schleppern und Landmaschinen. Giessen, 1964.

V.D.I. Beurteilung der Einwirkung mechanischer Schwingungen auf den Menschen. V.D.I.-Richtl. 2057; Dortmund, 1963.

WELFORD, A. T. Evidence of a single channel decision mechanism limiting performance in a serial reaction task. Quart. J. Exp. Psychol. **11** (1959): 193–210.

WELY, P. A. VAN and P. J. WILLEMS. Ergonomie. Utrecht, 1966.

WENZEL, H. G. Messungen der körperlichen Leistungsfähigkeit bei Hitzearbeit. Zbl. f. Arbeitsw. **1** (1961) 2: 17–28.

WESTHOFF, J. M. Op zoek naar een maat voor de perceptieve belasting. Philips Techn. Tijdschr. **24** (1962) 11/12: 362–371.

WIENEKE, F. Lehre und Forschung der Landtechnik an der Landbaufakultät Göttingen. Landt. Forschung **17** (1967) 2: 33–41.

WIERSMA, E. D. Bewustzijnstoestanden en polscurven. Psych. en Neurol. Bladen XV (1911): 449–522.

WIERSMA, E. D. Der Einfluss von Bewustseinszustanden auf den Puls und auf die Atmung. Z. ges. Neurol. und Psychiatrie **19** (1913): 1–24.

WILTSHIRE, H. C. The variation of cycle times with repetition for manual tasks. Ergonomics **10** (1968) 3: 331–347.

WOODSON, W. E. Human engineering guide for equipment designers. Berkeley, 1960.

WOODWORTH, R. S. Experimental Psychology. New York, 1938.

WOODWORTH, R. S. Experimental Psychology. New York, 1954.

YOUNG, L. R. On adaptive manual control. Ergonomics **12** (1969) 4: 635–675.

ZANDER, J. Ergonomie. Landbouwmech. **16** (1965): 271–273, 397–401, 525–528, 639–645.

ZANDER, J. Some studies of operating combine harvesters. R.A.S.E./E.R.S.-Conf.; Nottingham, 1967.

ZANDER, J. Studies of combine harvester operation. Proc. of Inst. Agr. Eng. **25** (1970) 1: 30–35.

ZANDER, J. and F. C. VAN DER HORST. Is comfort meetbaar? Landbouwmech. **18** (1967): 143–145, 251–255.

ZELLER, W. Masseinheiten für Schwingungsstärke und Schwingungsempfindungsstärke. A.T.Z. **51** (1949): 95–97.

ZIMMERMAN, G. Gesundheitliche Schädigungen bei Traktorfahren mit besonderer Berücksichtigung der Wirbelsäule. XV. Intern. Congr. f. Arbeitsmedizin; Wien, 1966.

APPENDIX A

RECOMMENDATIONS FOR THE SELF-PROPELLED COMBINE HARVESTER

1. ANTHROPOMETRY

The recommendations for an optimum work-space lay-out may be broken down into the major areas of:

1.1. SEAT

The seat must be adjustable in horizontal (range: + 75 and — 75 mm) and vertical (range: + 50 and — 50 mm) directions, in order to accomodate a reasonable range of individuals.

The data for the seat are listed in table 1.

TABLE 1. Data for the seat.

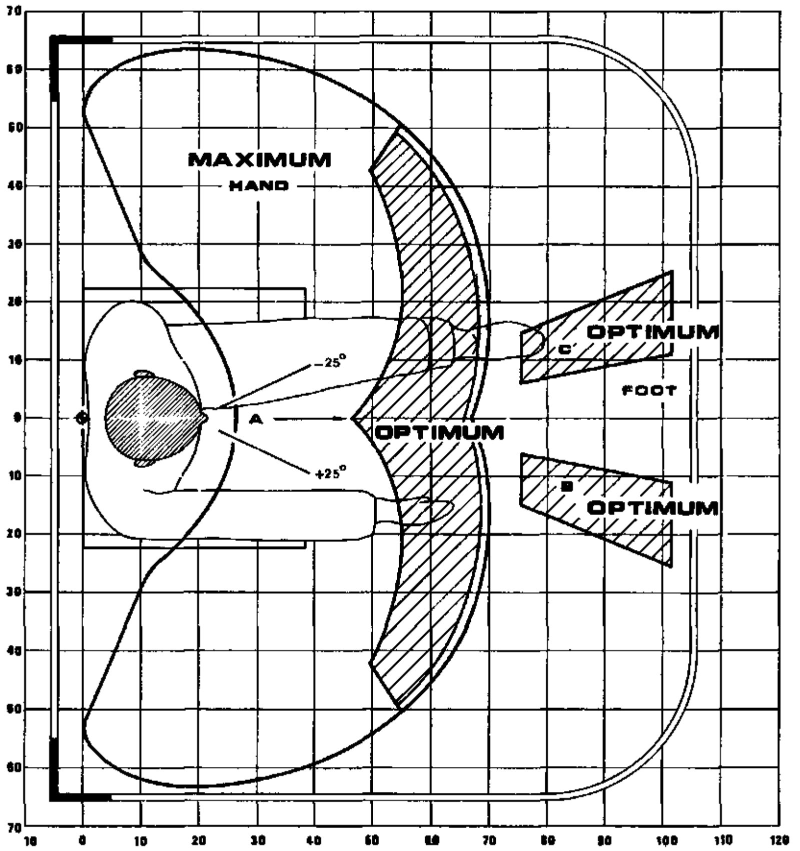
Code	Features	Criteria
1.01	Shape	rectangular, rounded
1.02	Dimensions (mm)	
	· length	380
	· width	450
1.03	Force (N)	-
1.04	Displacement (mm)	+ 50 and — 50 (minimum)
1.05	Location	see fig. A.1 and A.2
1.06	Motion	only vertical
1.07	Inclination	
	· direction	backwards
	· angle	3–5°
1.08	Material	warmth-isolating, ventilating
1.09	Surface	waterproof cover, profiled
1.10	Adjustment (mm)	
	· horizontal	+ 75 and − 75
	· vertical	+ 50 and − 50
1.11	Support	
	· sidewards	150 mm above seat (maximum)
	· backwards	240 mm above seat (minimum) 400 mm above seat (maximum)
1.12	Miscellaneous	
	· seat height (mm)	400

1.2. Lay-out

The data for an optimum work-space lay-out have been shown in fig. A.1 and A.2; using these figures the following points must be kept in mind:

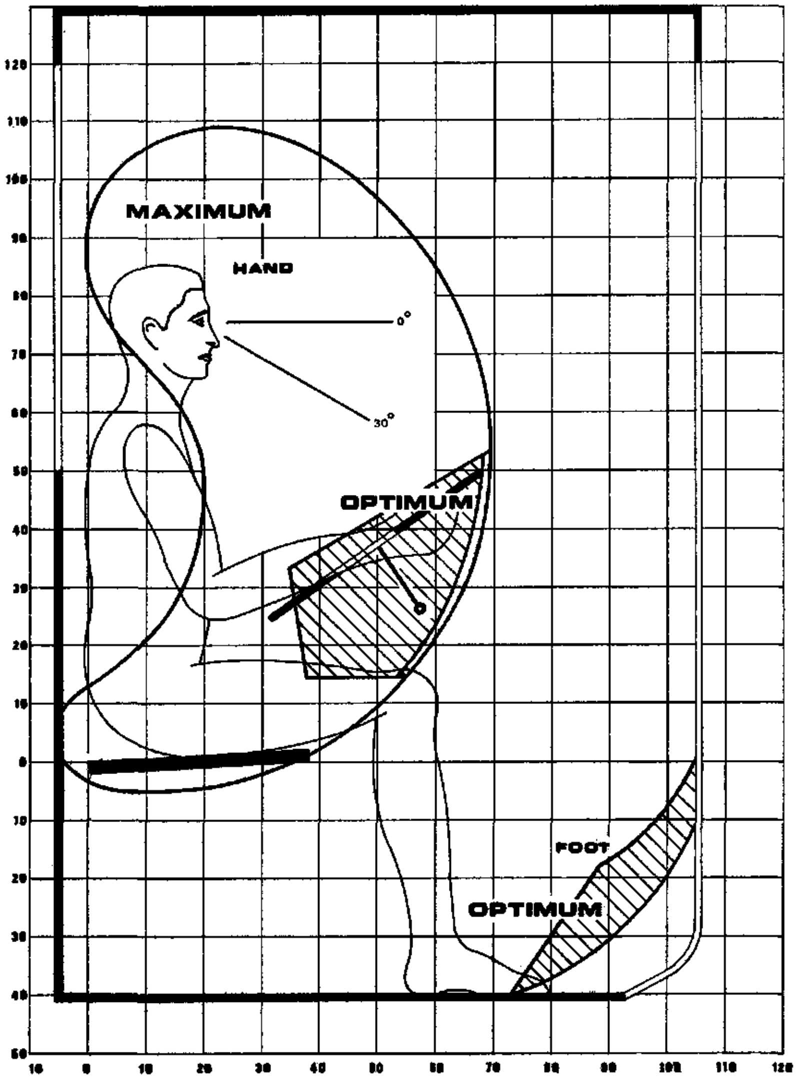
1. Frequency

The frequency with which different operations and movements have to be carried out, indicate the priority in the lay-out of controls.



A.1. Optimum work-space lay-out for the self-propelled combine harvester (horizontal plane); 18 cm above seat-reference point (SRP).

A – stationary field
B – brake pedal
C – clutch pedal
■□ – minimum dimensions of the cabin



A.2. Optimum work-space lay-out for the self-propelled combine harvester (vertical plane).
■□ – minimum dimensions of the cabin.

2. Maximum area

This area is suitable for hand-operated controls, which require much force. No operating controls should be located outside the maximum area, unless the operation frequency is extremely low.

3. Optimum area

Within this area the motions of hands and feet are the most comfortable. Frequently used controls have to be located within this area.

1.2.1. *Steering wheel*

The steering wheel has to be located within the optimum areas for the hands; the data for the steering wheel are listed in table 2.

TABLE 2. Data for the steering wheel.

Code	Features	Criteria
2.01	Shape	round
2.02	Dimensions (mm)	
	· steering wheel	400–500
	· rim	20– 50
2.03	Force (N)	10– 50
2.04	Displacement (maximum)	to the right: 1½ turn to the left : 1½ turn
2.05	Location	in the optimum area
2.06	Motion	clockwise = right
2.07	Inclination	sitting : 45° standing: 90°
2.08	Material	warmth-isolating
2.09	Surface	profiled and shaped to the hand, space for the fingers in the lower side
2.10	Adjustment	telescopic
2.11	Support	not wanted
2.12	Miscellaneous	none

1.2.2. *Hand-operated controls*

The location and displacement of the header height, the reel position and the ground speed control deserve priority in designing the lay-out of controls, for they are the most important and frequently used controls.

The fingertip controls for the header height, the reel position and the ground speed have to be located close to each other and within the optimum area; the data for the fingertip controls are listed in table 3.

The other hand-operated controls have to be located, dependent on the frequency, more or less in the optimum area, but within the maximum area; the data for the hand-operated controls are listed in table 4.

1.2.3. *Foot-operated controls*

The clutch and the brake-pedal have to be located within the optimum areas for foot-operated controls; the data for the clutch and the brake pedal are listed in table 5.

TABLE 3. Data for the fingertip controls.

Code	Features	Criteria
3.01	Shape	square, rounded
3.02	Dimensions (mm)	
	· length	12
	· width	12
3.03	Force (N)	
	· optimum	5–8
3.04	Displacement (mm)	10
3.05	Location	in the optimum area
3.06	Motion	only vertical
3.07	Inclination	not required, pressing surface horizontal
3.08	Material	warmth-isolating
3.09	Surface	smooth, bent
3.10	Adjustment	–
3.11	Support	–
3.12	Miscellaneous	–

TABLE 4. Data for the hand-operated controls.

Code	Features	Criteria	
		levers	knobs
4.01	Shape	round, rounded	bulb-shaped, round, rounded
4.02	Dimensions (mm)		
	· diameter	25–45	25–45
	· length	$\geqslant$ 75	
4.03	Force (N)		
	· hand	$<$100	$<$100
	· finger	$<$ 20	$<$ 20
4.04	Displacement (mm)	$\leqslant$200	$\leqslant$200
4.05	Location	dependent on the frequency, more or less in the optimum area	
4.06	Motion	· rearward or toward the operator for stopping · forward or downward to lower	
4.07	Inclination	preferably vertical to the forearm (not applicable with knobs)	
4.08	Material	warmth-isolating	
4.09	Surface	smooth	
4.10	Adjustment	–	
4.11	Support	–	
4.12	Miscellaneous	accurate setting, stepless or in small steps	

TABLE 5. Data for the foot-operated controls.

Code	Features	Criteria	
		clutch	brake
5.01	Shape	rectangular	rectangular
5.02	Dimensions (mm)		
	· length	50– 75	50– 75
	· width	100–120	100–120
5.03	Force (N)		
	· optimum	100–200	100–200
5.04	Displacement (mm)	80–100	80–100
5.05	Location	left-foot operated, in the optimum area	right-foot operated, in the optimum area
5.06	Motion	forward and/or downward for disengagement	forward and/or downward for stopping
5.07	Inclination	70°	70°
5.08	Material	solid	solid
5.09	Surface	non-slipping	non-slipping
5.10	Adjustment	–	–
5.11	Support	Bent-up at the side	Bent-up at the side
5.12	Miscellaneous	–	–

2. PERCEPTION

The perception is primarily promoted by an adequate presentation of the relevant information – particularly: the visibility (1) –, as well as the elimination of the redundant and non-relevant information (2).

1. Visibility

An optimum condition is achieved, when the information – particularly: the feed table auger in front of the conveyor chain and of the separation from the previously cut swath – becomes visible at a view angle of 30° for the vertical plane and a direct distance of 3000 mm between the eye and the object. In the horizontal plane it is necessary, that the information becomes visible within the stationary field; the data for an optimum visual field have been shown in fig.1 and 2.

An eccentric and low location of the operator's work-space is favourable, since the work-space can be located next to the conveyor and close to the field.

2. Cabin

The ideal concept to eliminate the redundant and non-relevant information is an enclosed suspended cabin – in which the seat, the controls and the operator

move simultaneously –, which combines the need for improving ride vibration with greater protection against sound and dust, as well as climatic influences.
The data for the enclosed suspended cabin are listed in table 6.

TABLE 6. Data for the enclosed suspended cabin.

Code	Features	Criteria
6.01	Dimensions (mm)[1]	
	· length	1100
	· width	1300
	· height	1750
6.02	Sound	
	· sound pressure level	$< 80\ dB_A$
6.03	Carbon monoxide	
	· concentration	< 0,003 %
6.04	Dust	
	· concentration	< 15 mg/m^3 of air
6.05	Vibrations	
	· direction	only vertical
	· natural frequency	< 2 Hz
	· intensity	K < 4
6.06	Climate	
	· air humidity	50 %
	· air temperature	20–21 °C
	· air velocity	10–20 cm/sec

[1] minimum, interior.

3. SELECTION

3.1. MENTAL LOAD

A value of 2 bits per second is the limit for adequate information processing.

4. ACTION

4.1. PHYSICAL LOAD

An energy consumption of 20 kJ (= 4,8 kcal) per minute, including a basal metabolic rate of about 4,2 kJ (= 1 kcal) per minute, is the maximum consistent level for an adult man.

APPENDIX B

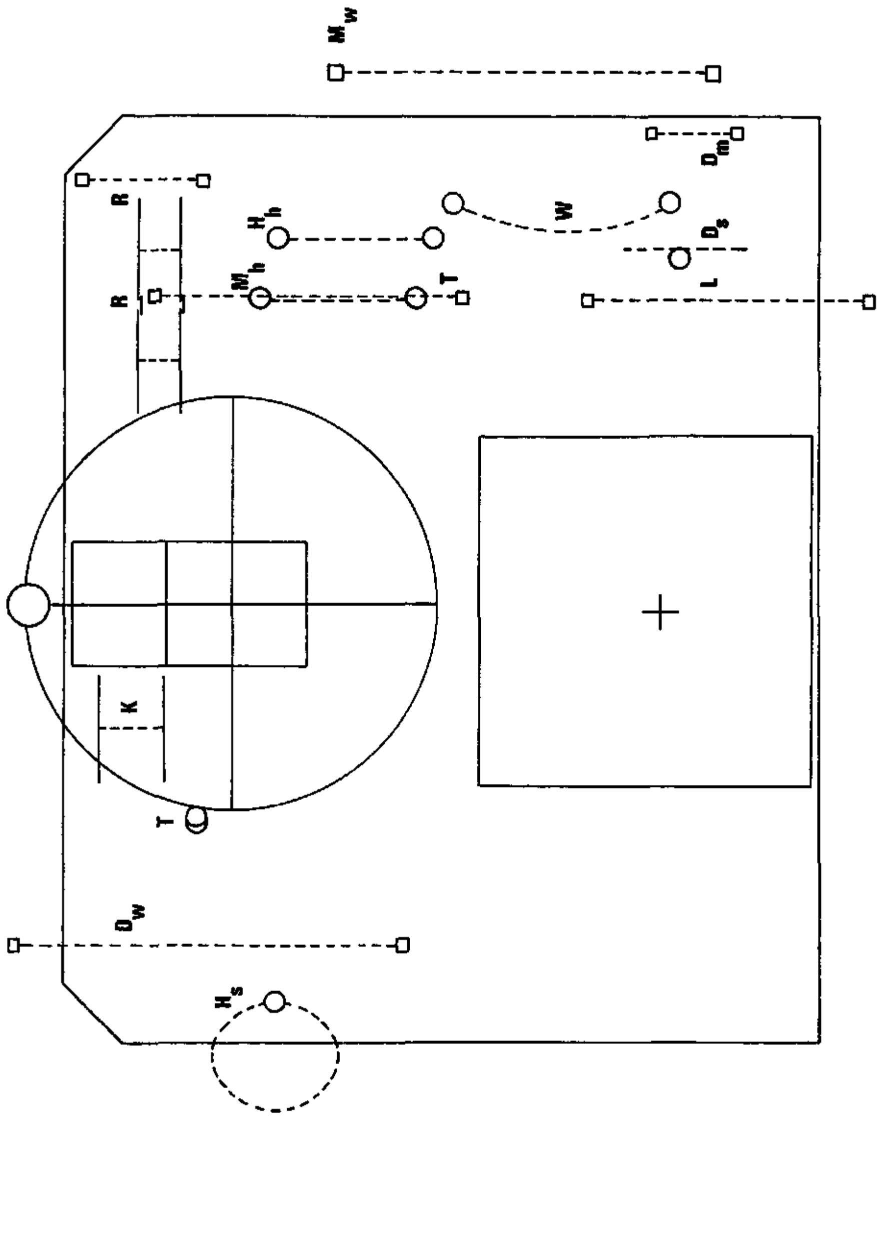
LAY-OUTS OF SELF-PROPELLED COMBINE HARVESTERS

1. CODE

○ = hand-operated control (knob)
□ = hand-operated control (lever)
● = foot -operated control (pedal)
--- = displacement

2. LEGEND

D_m – concave adjustment
D_s – cylinder speed
D_w – threshing engagement
G – throttle
H_h – reel height
H_s – reel speed
H_v – reel position
H_w – reel engagement
K – clutch
L – grain tank unloading
M – cutterbar
M_h – header height
M_w – header engagement
R – brake
S – stop
T – ground speed
W – gear shift



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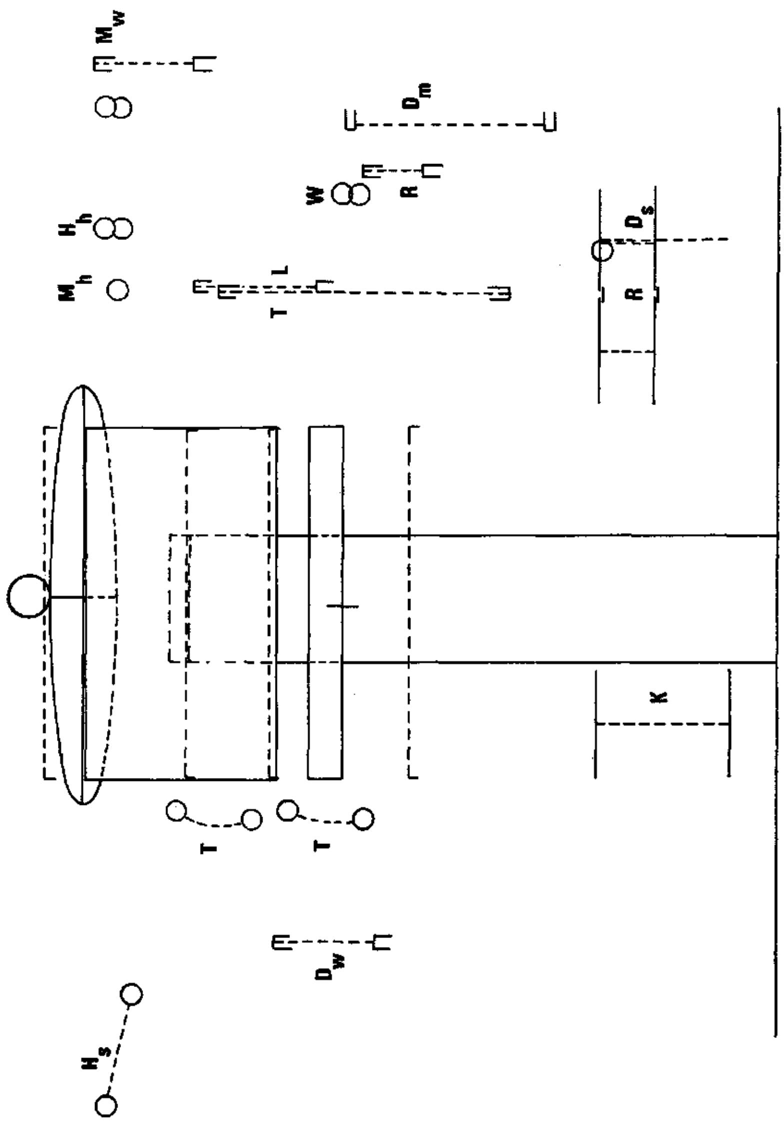

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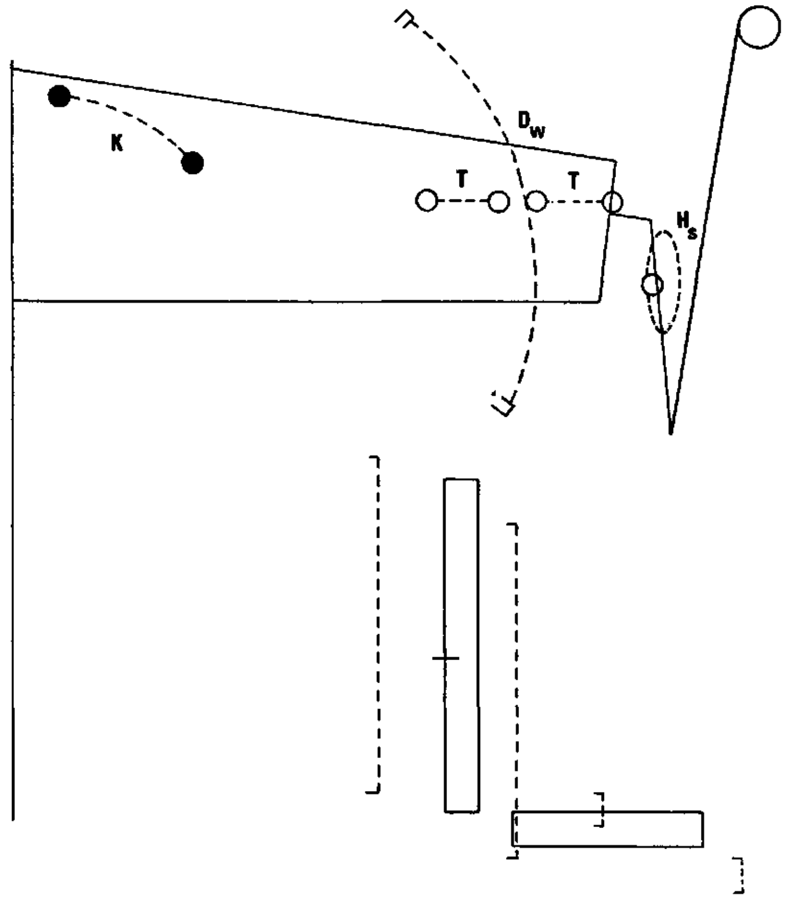

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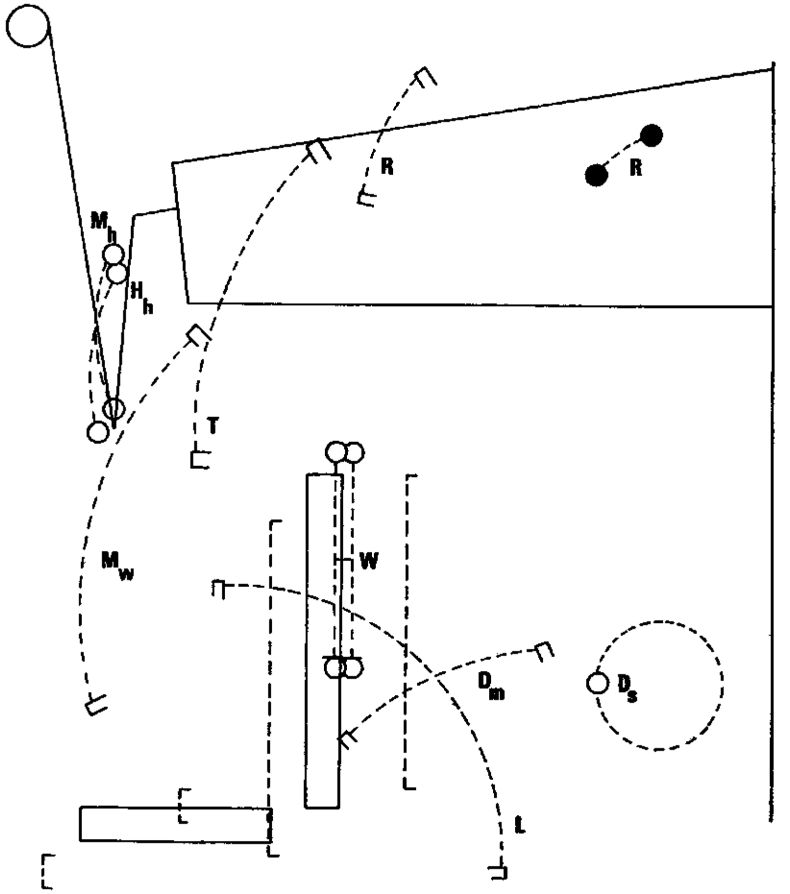

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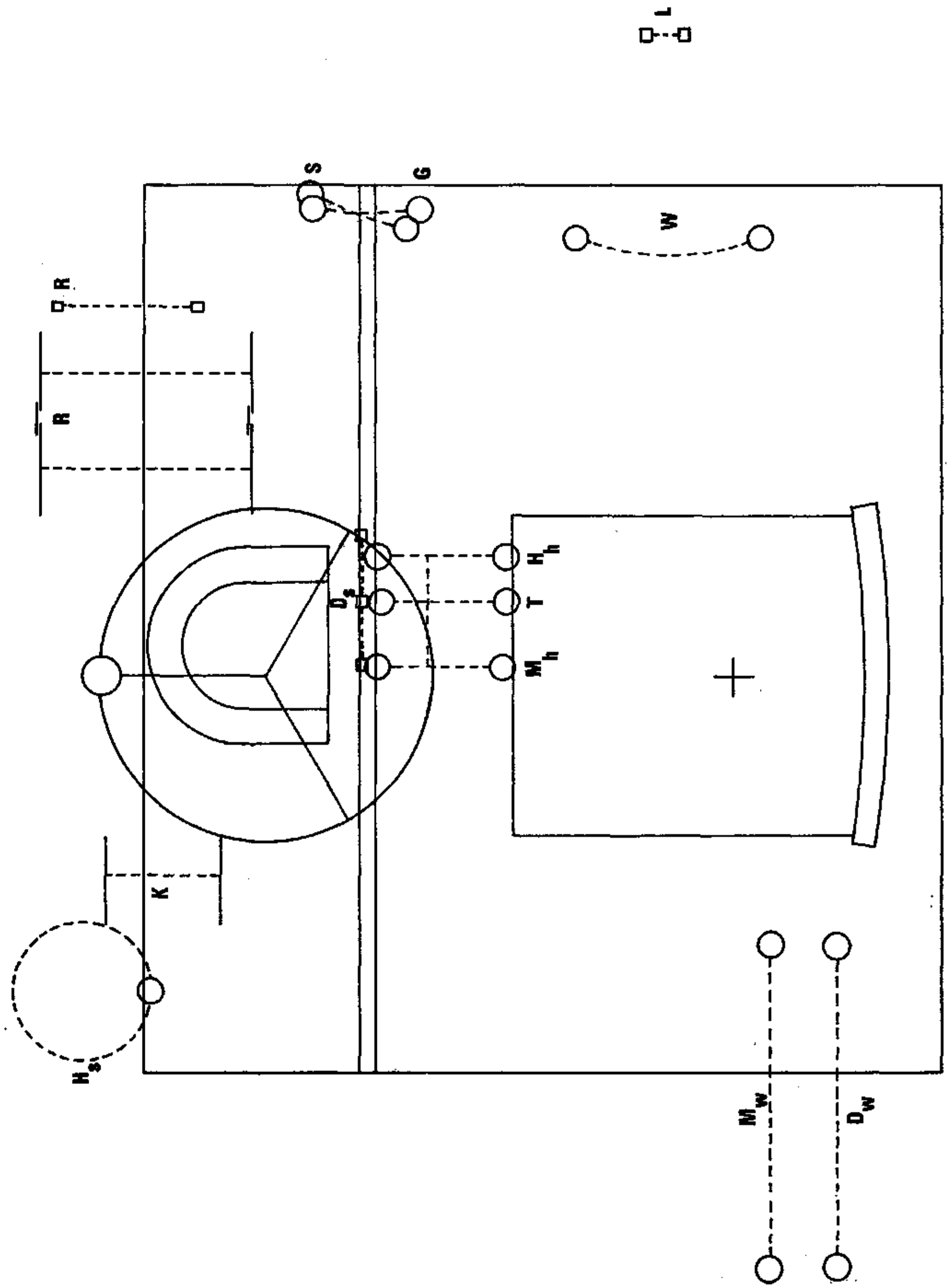

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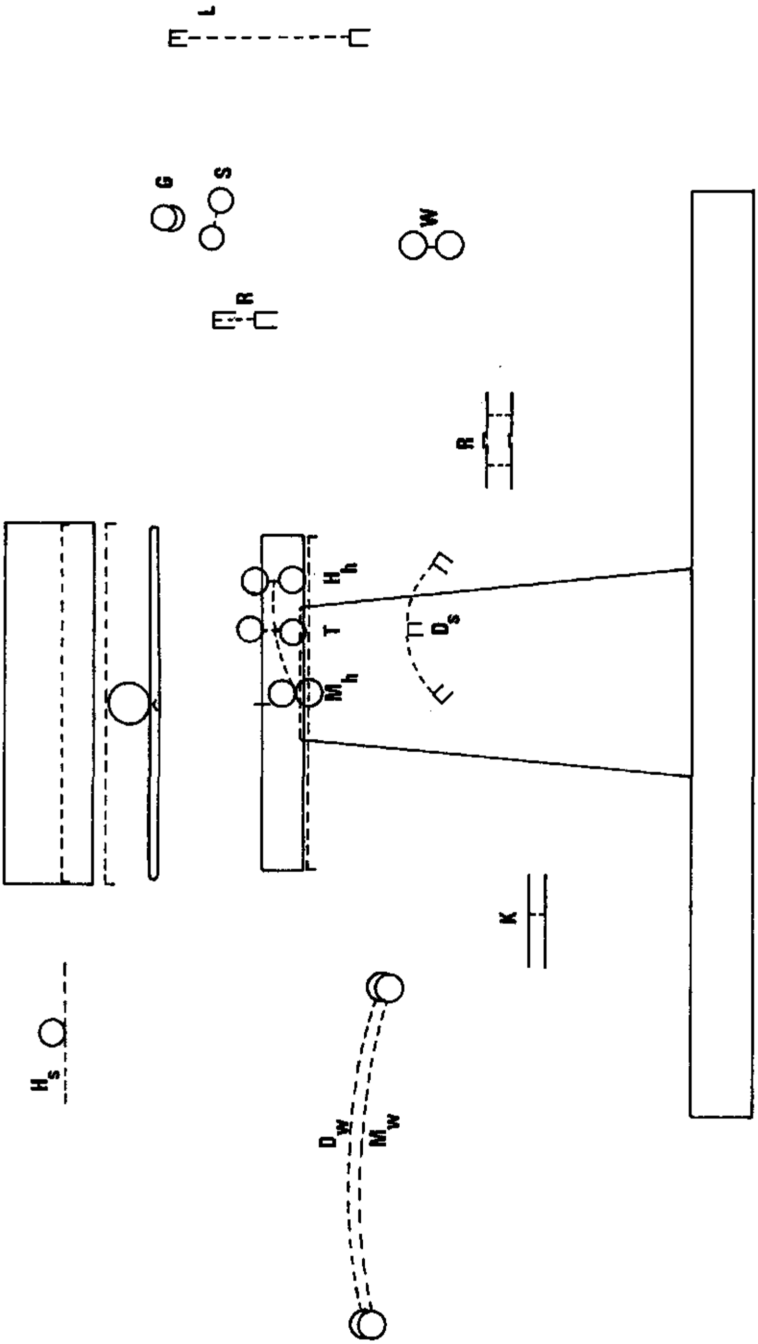

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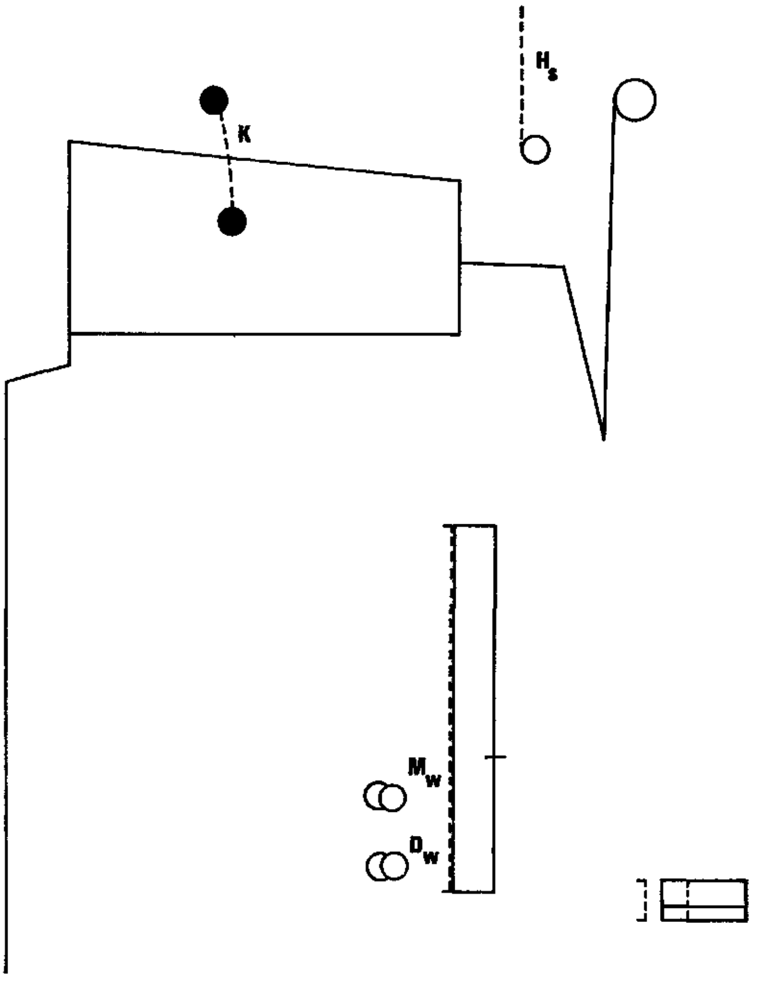

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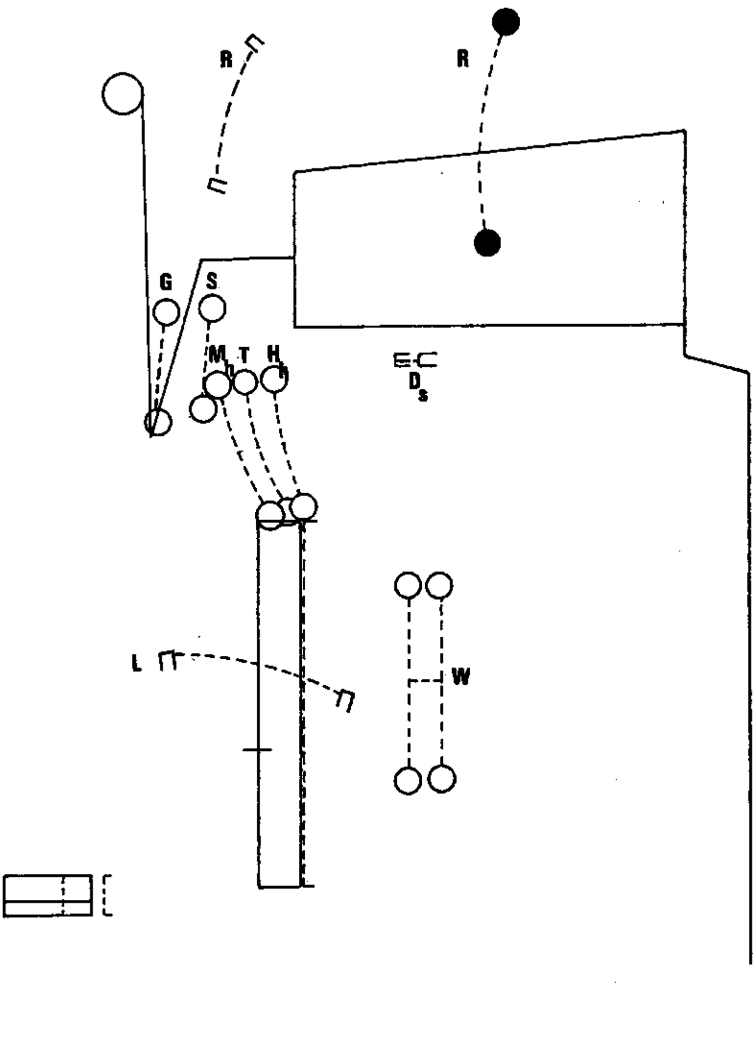

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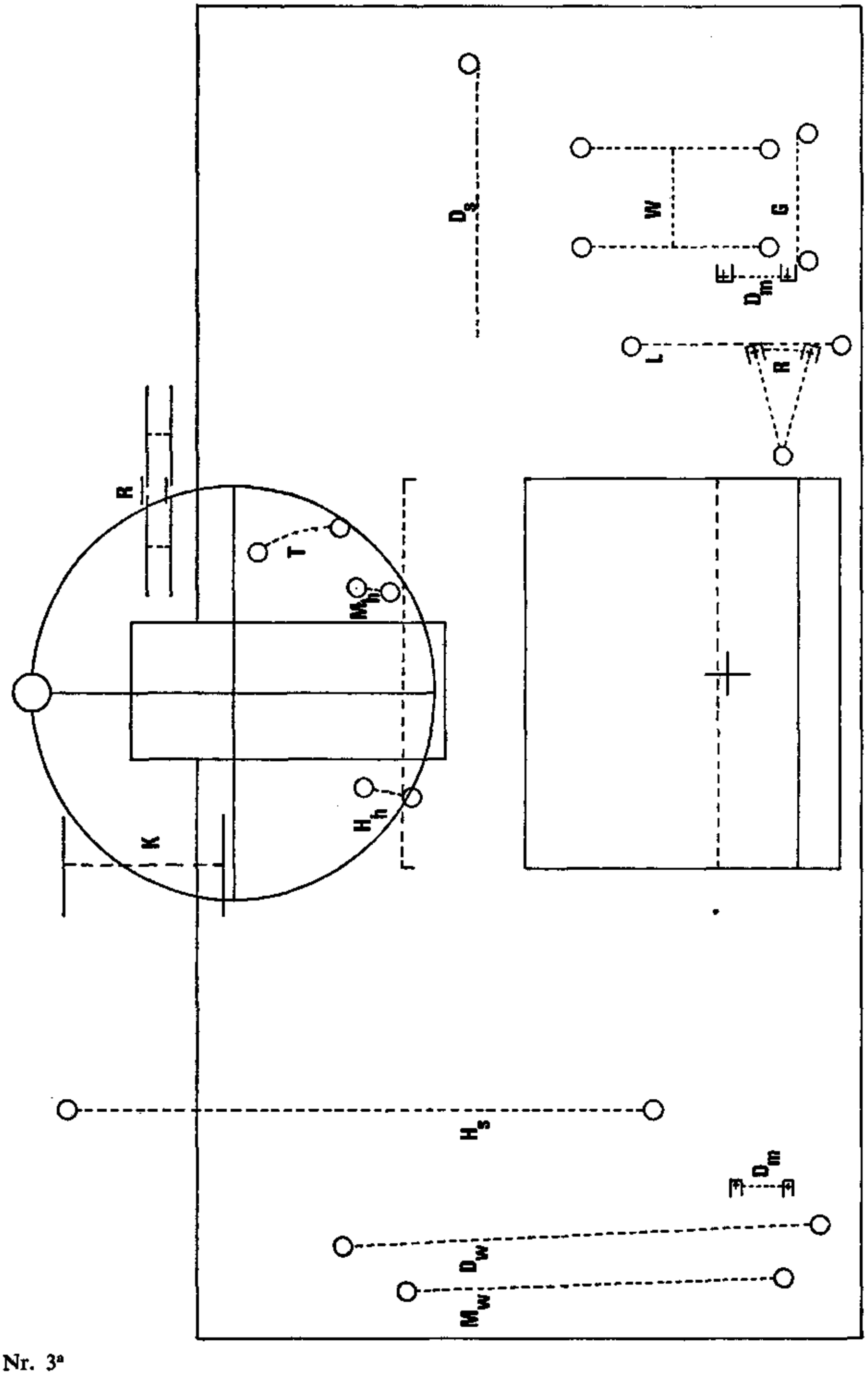

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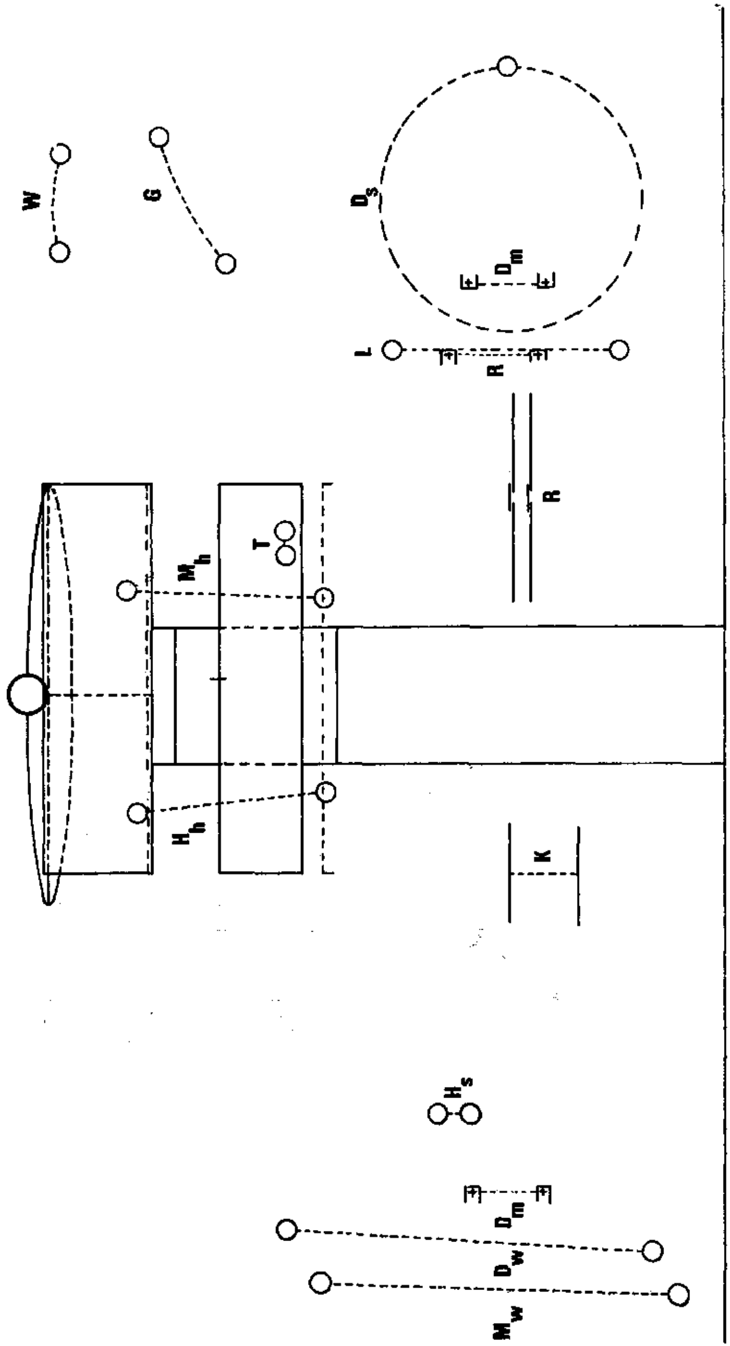

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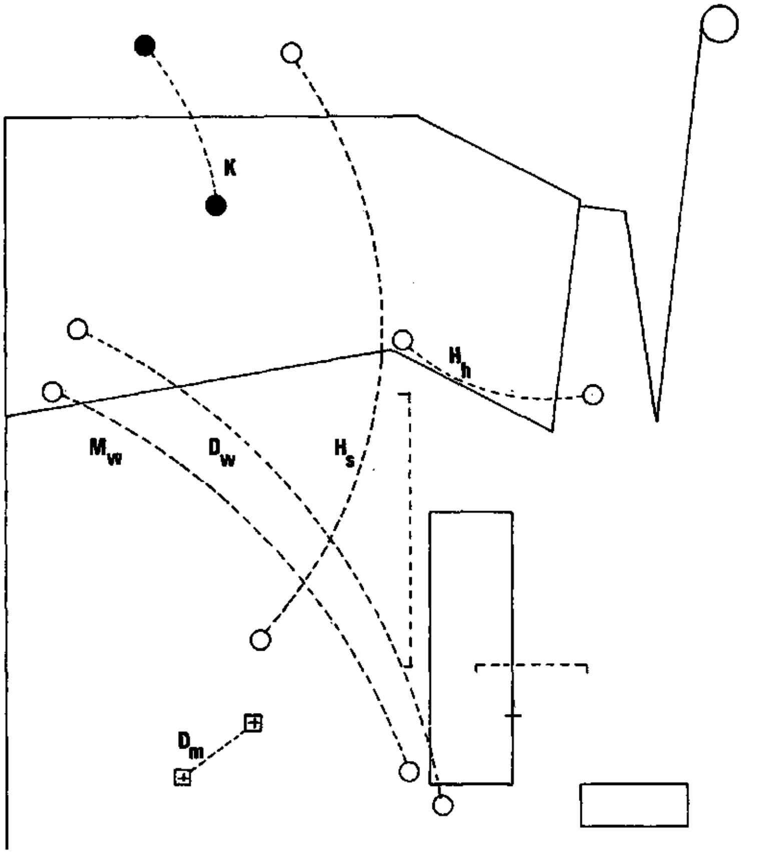

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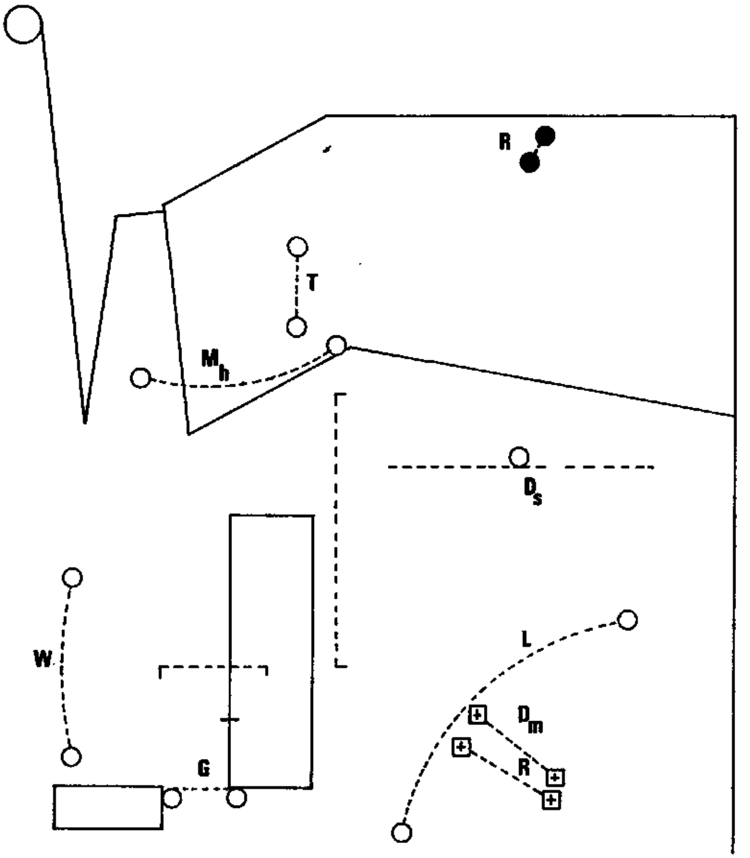

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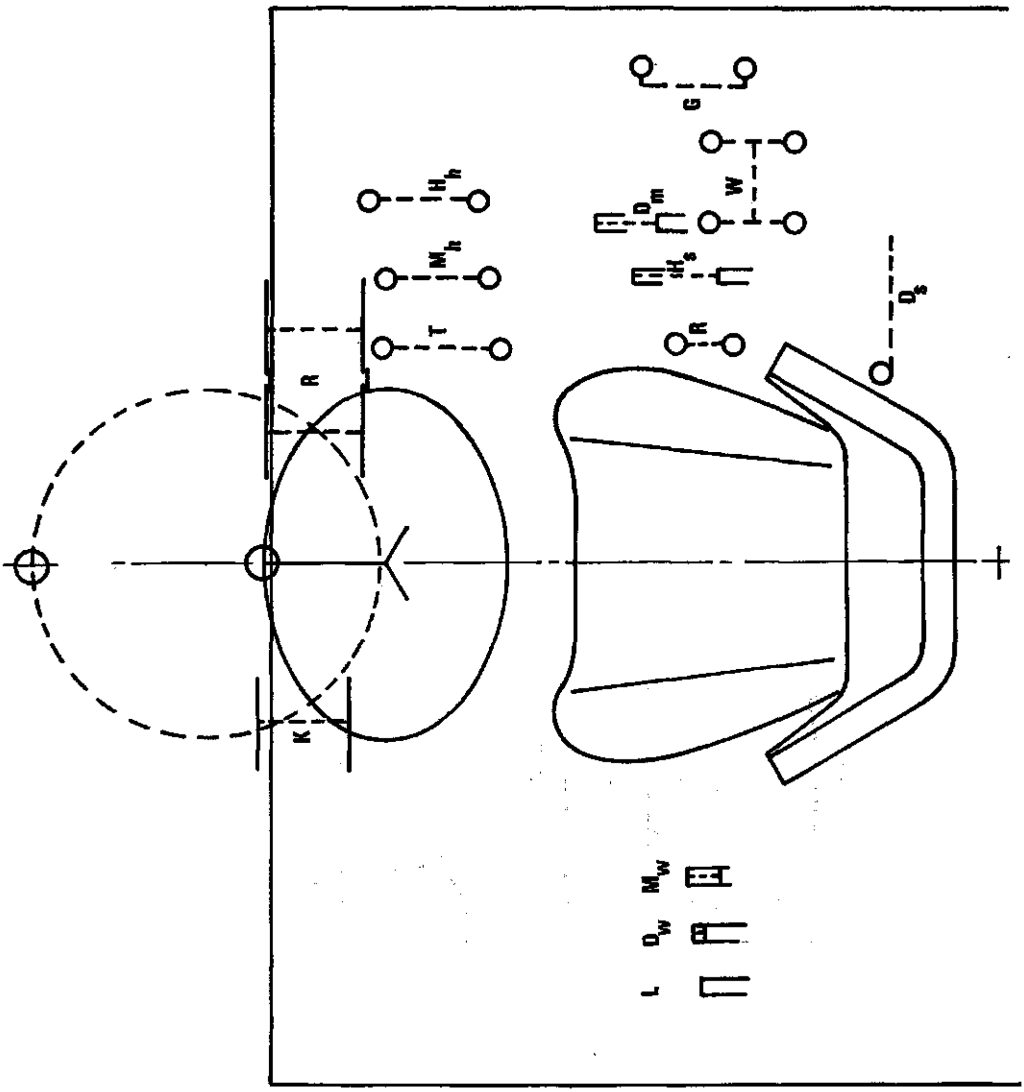

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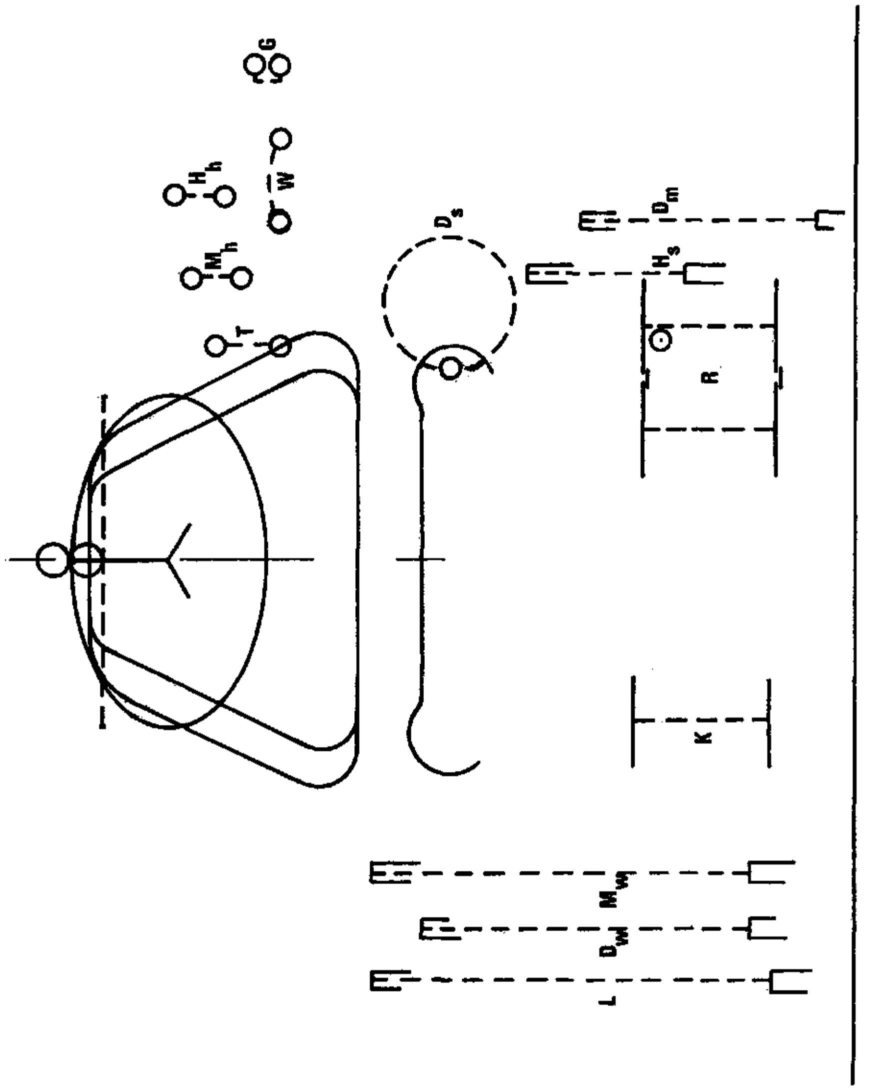

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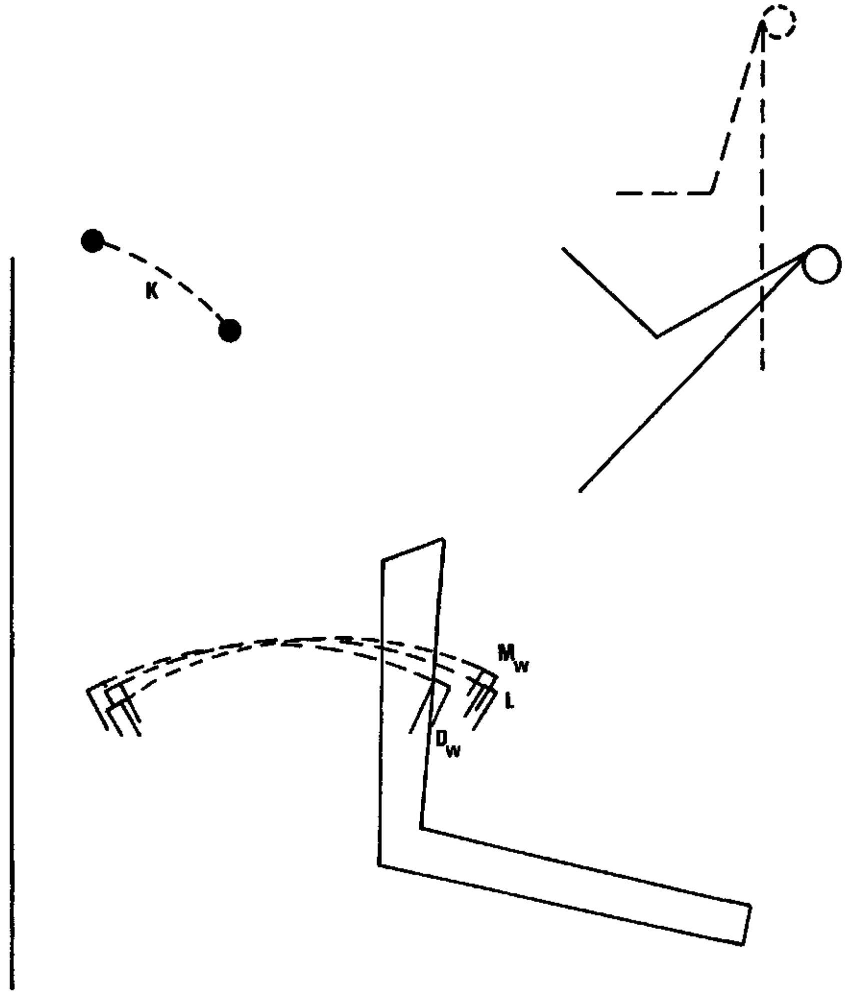

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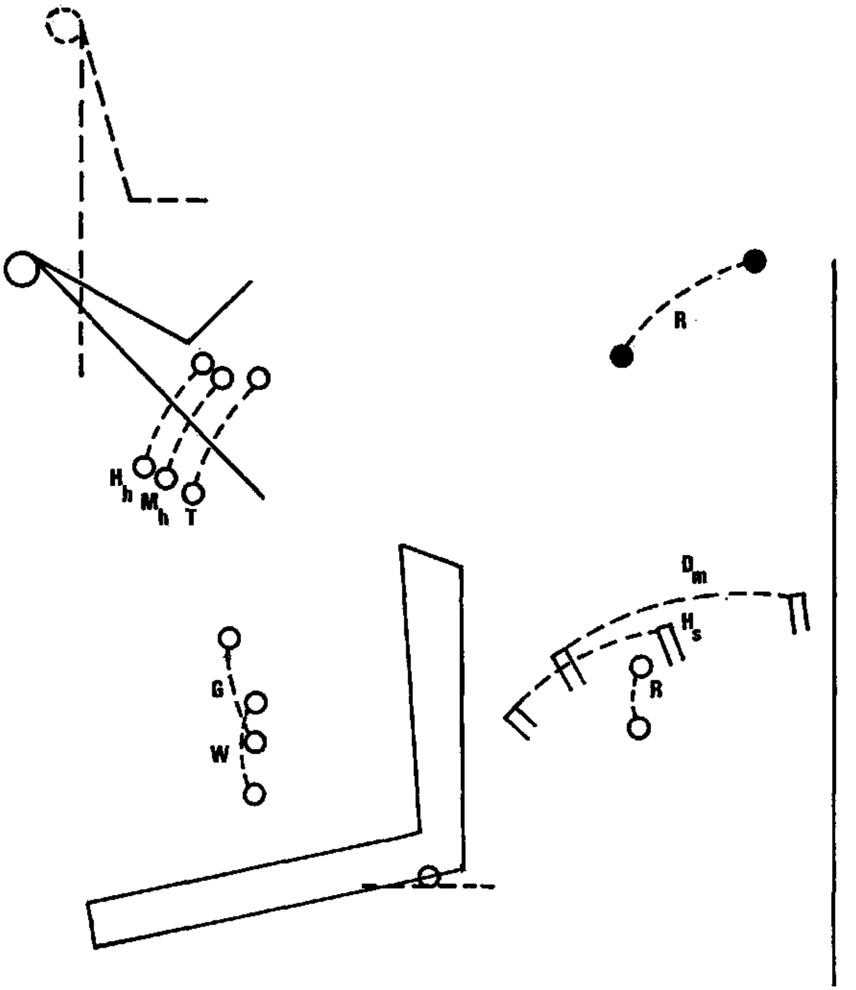

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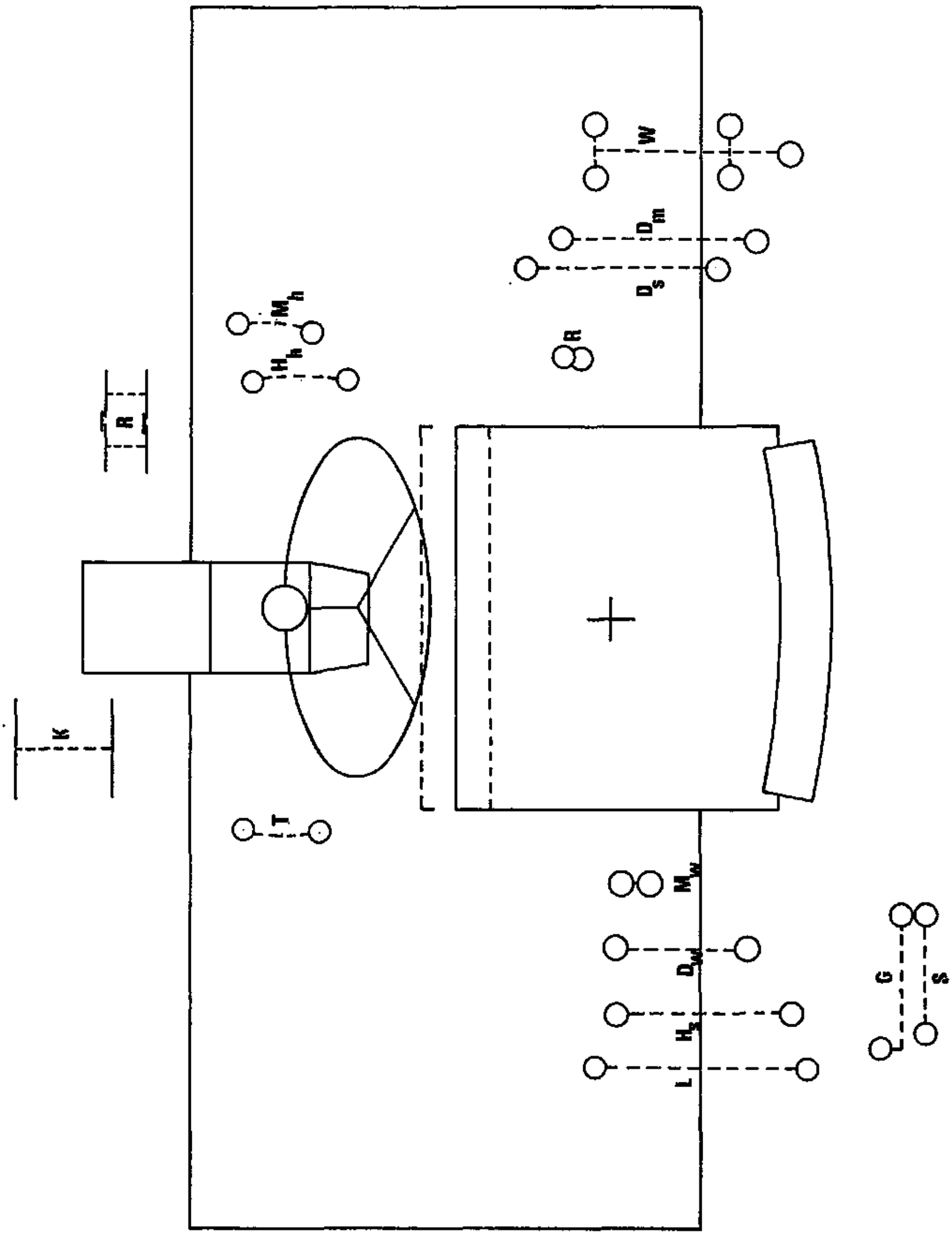

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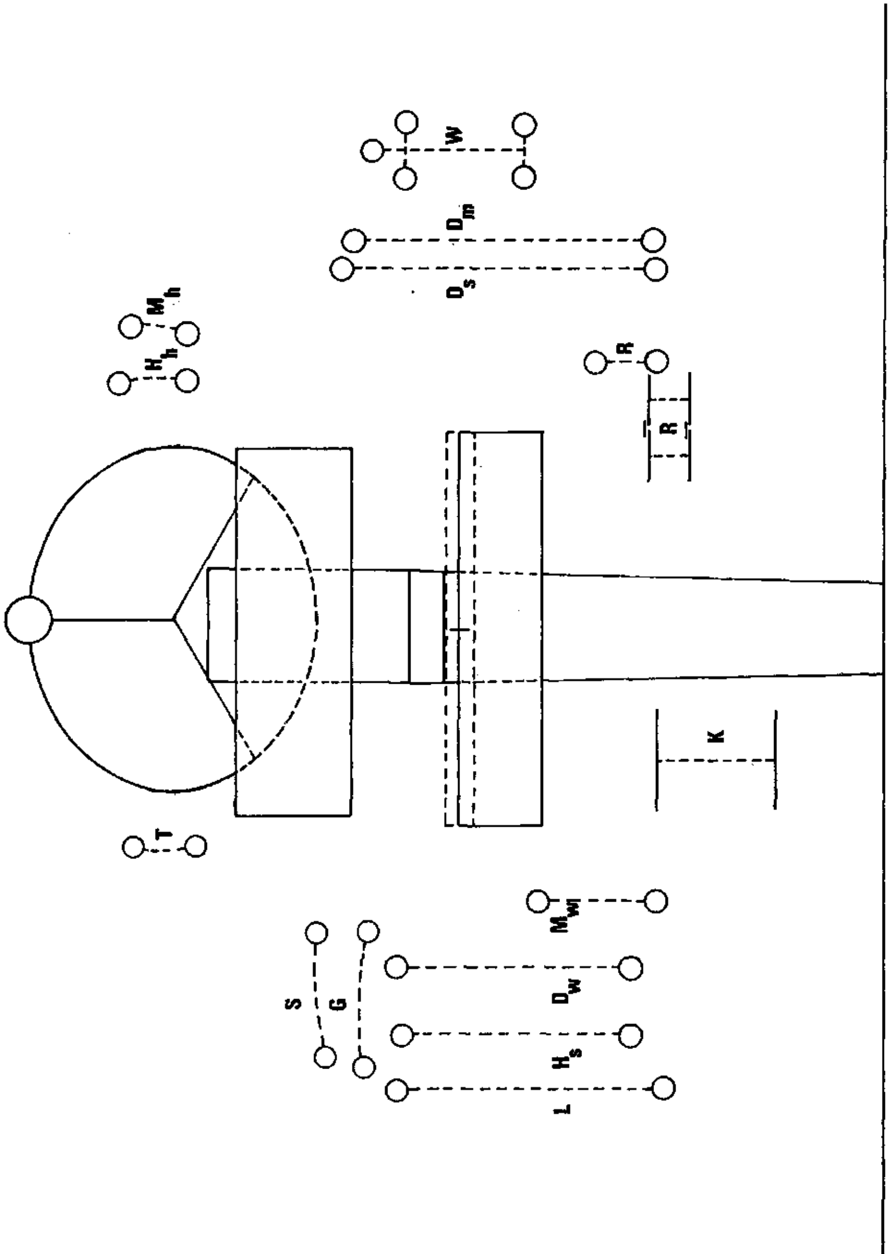

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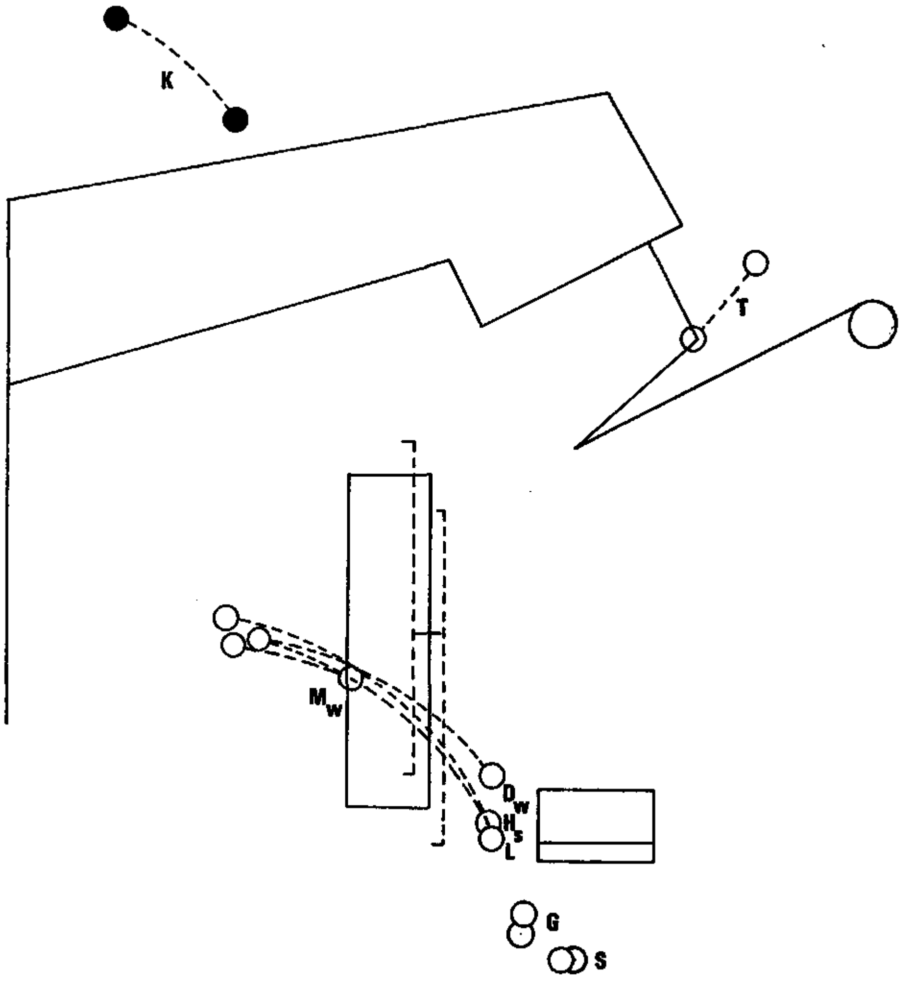

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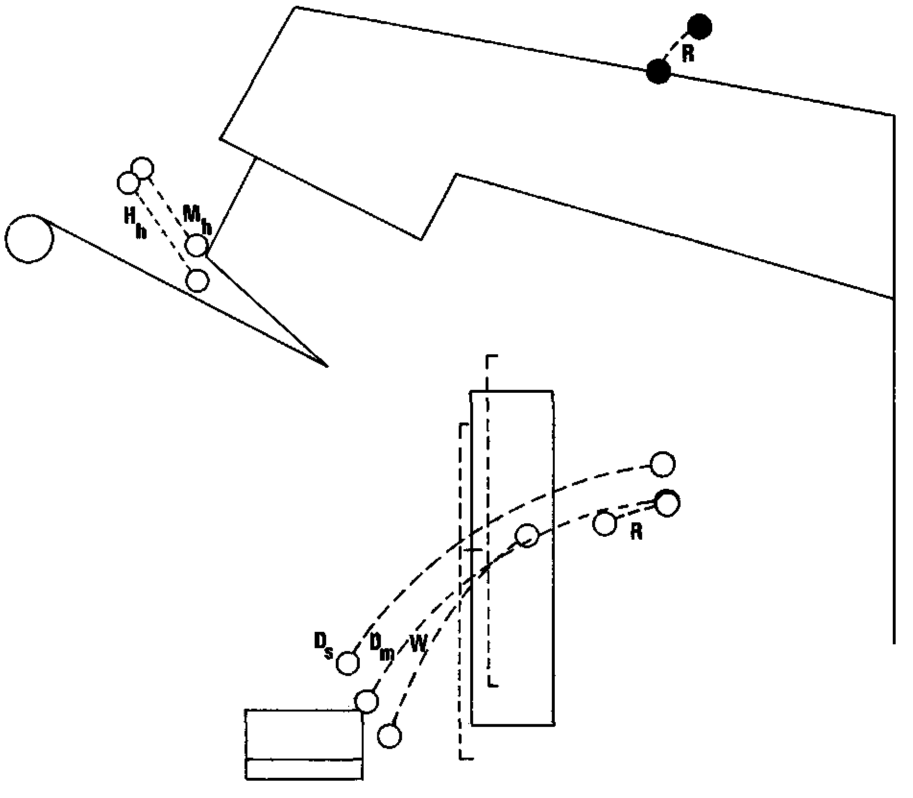

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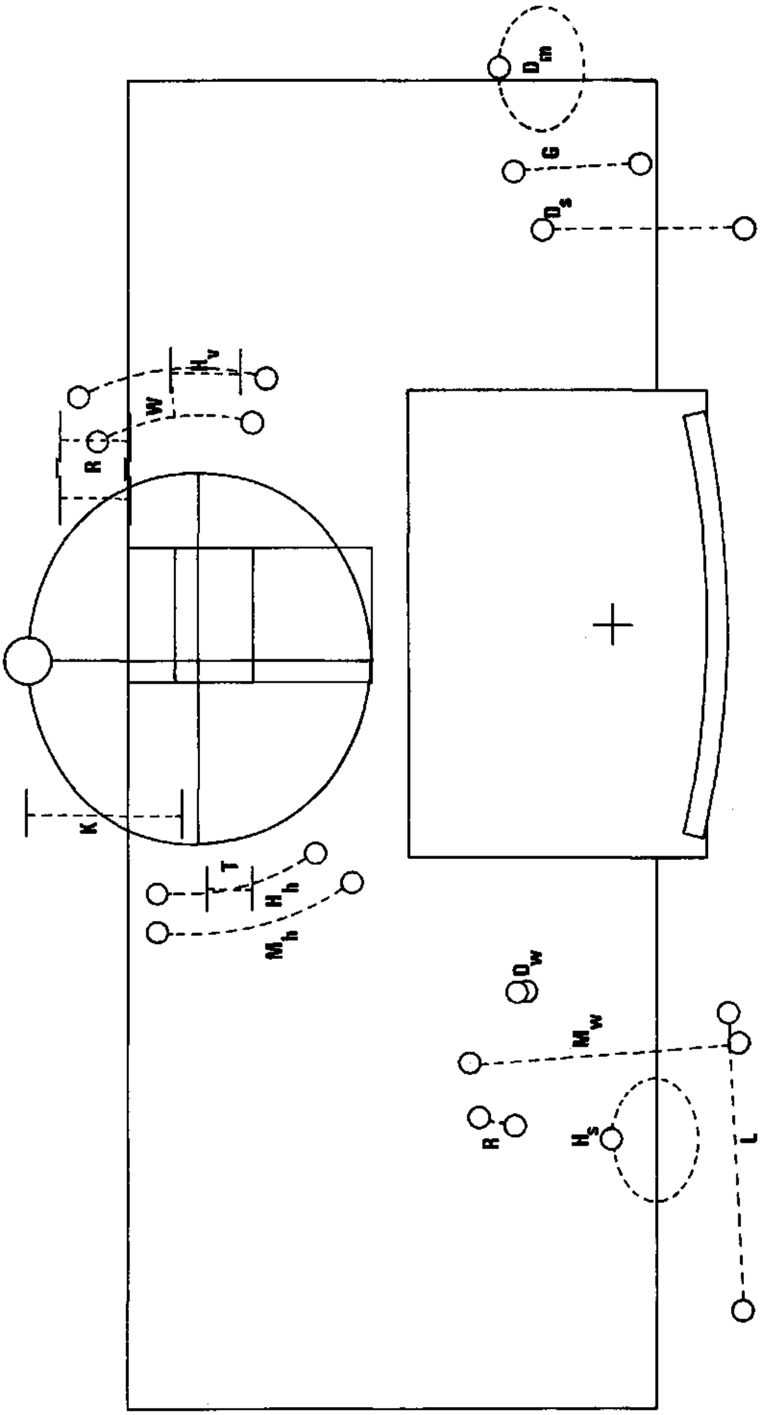

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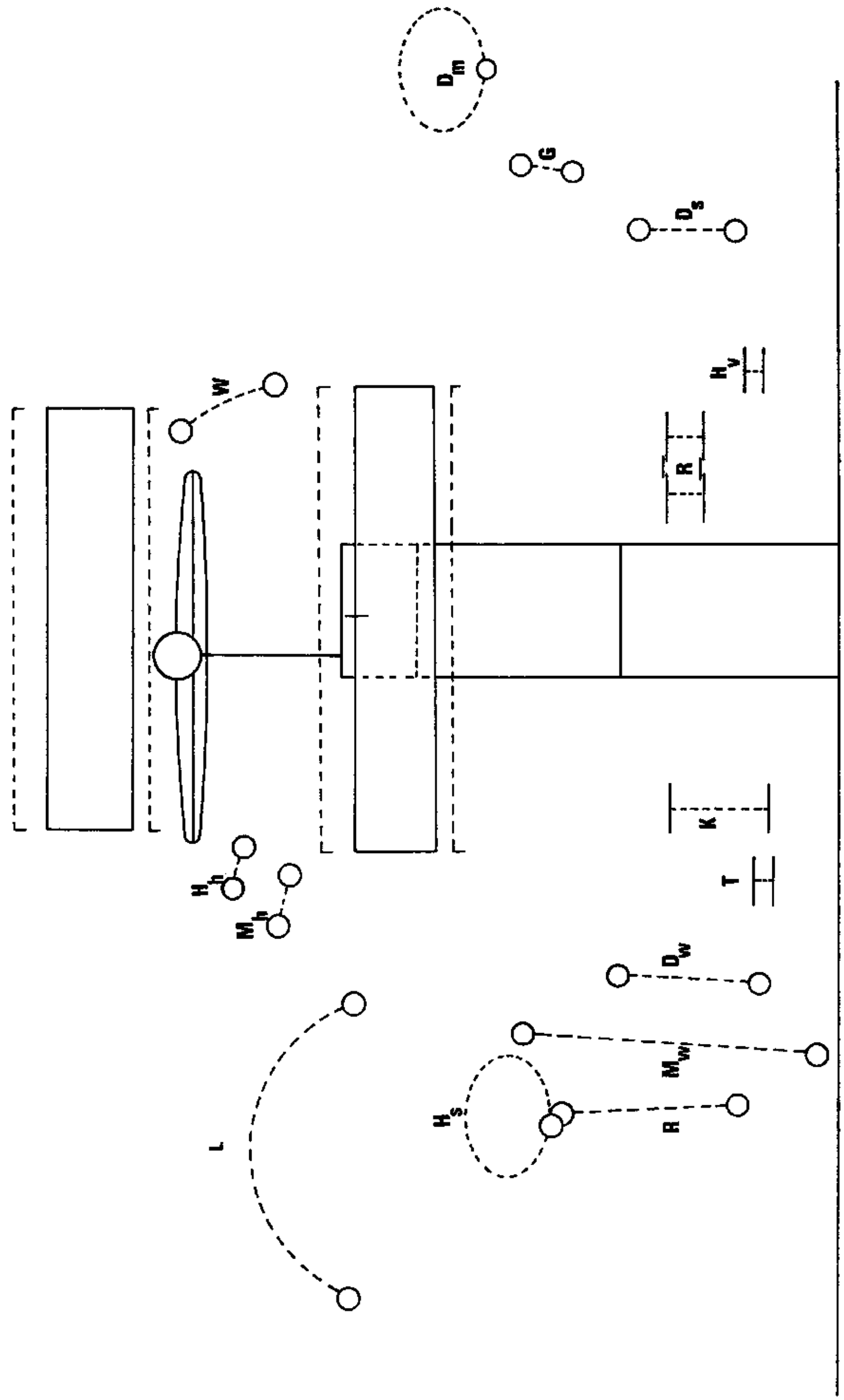

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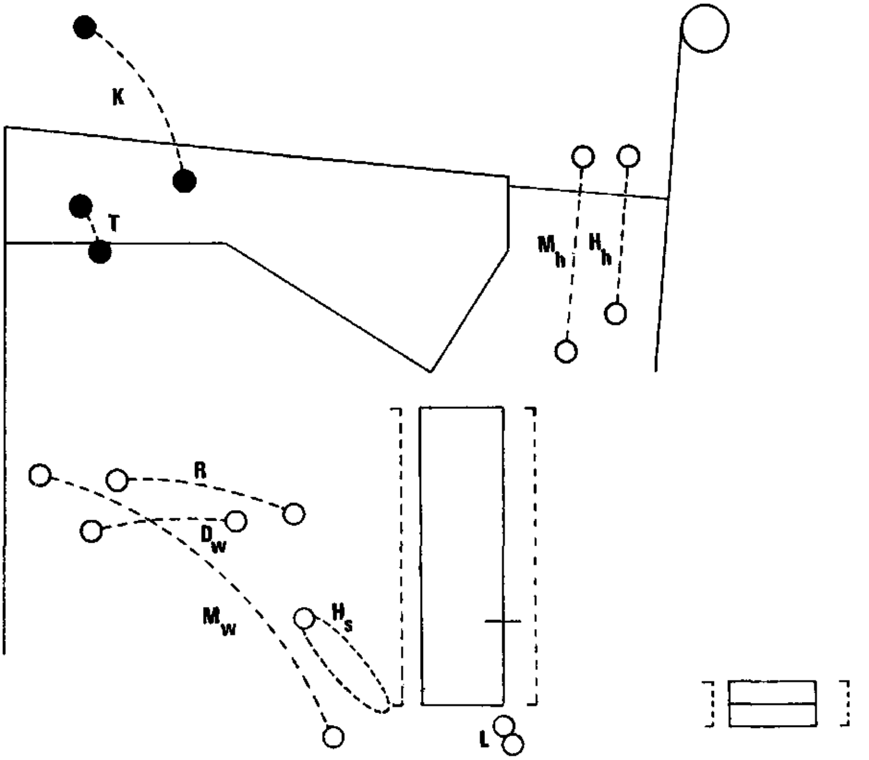

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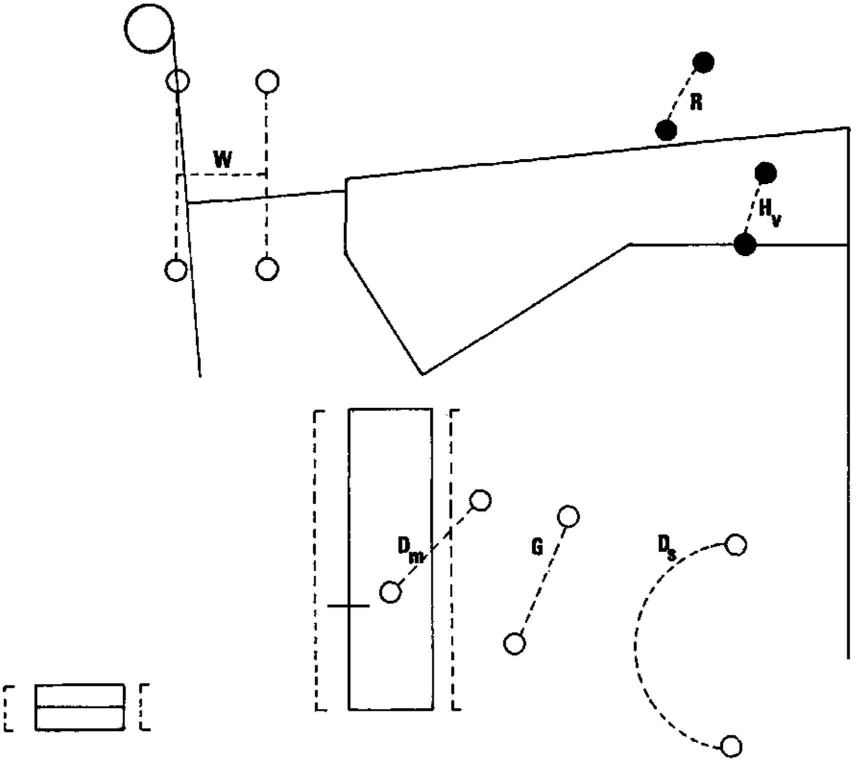

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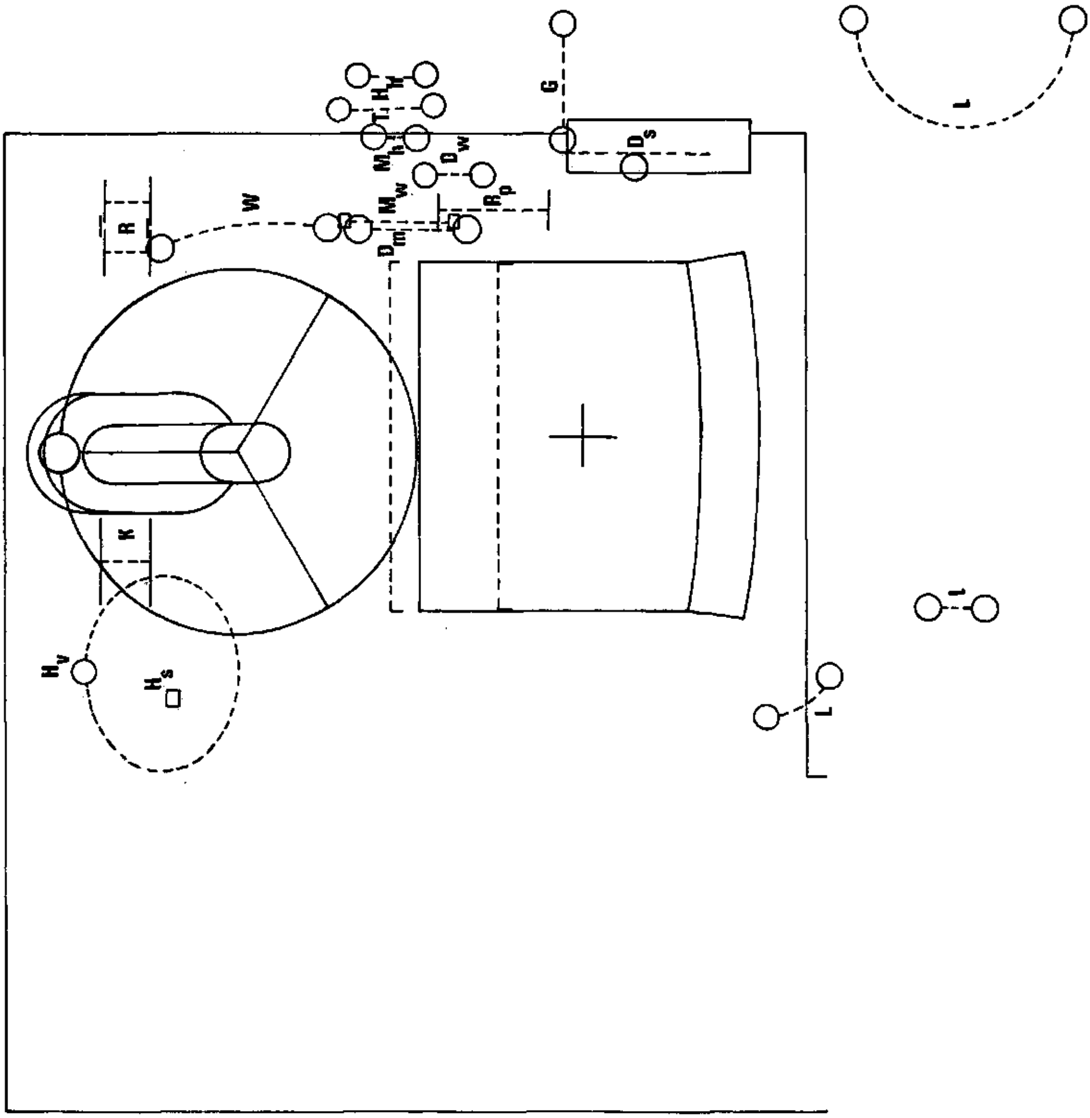

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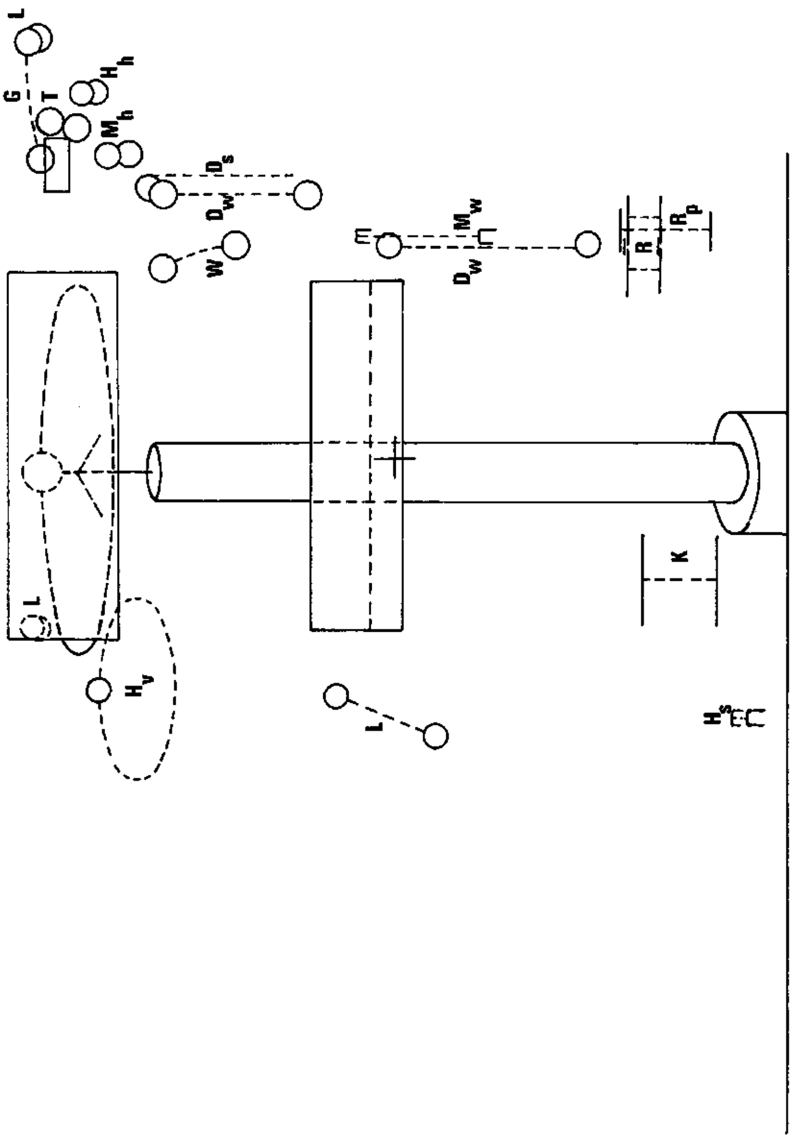
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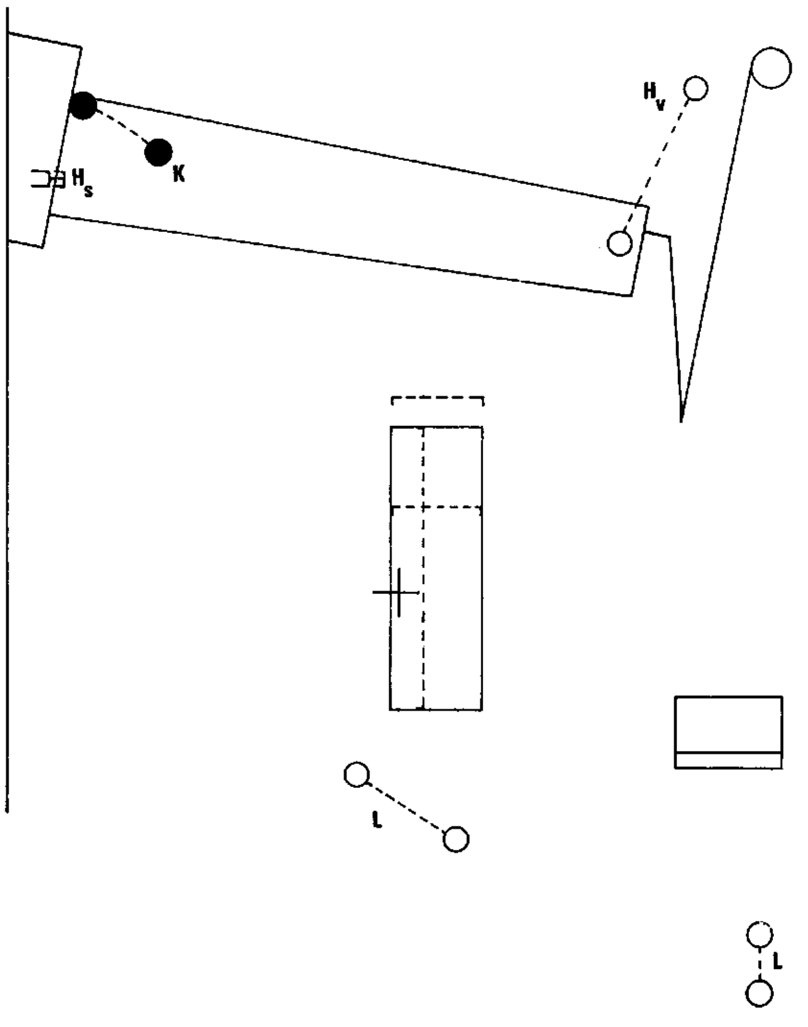

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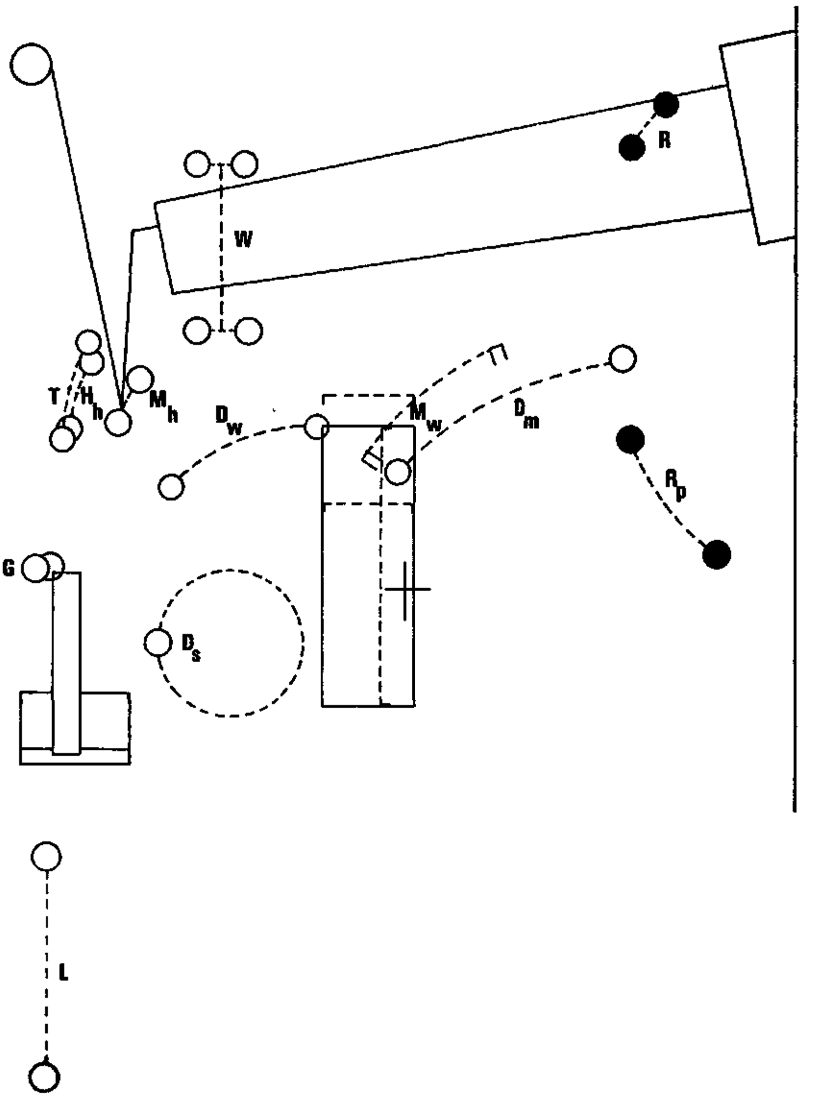

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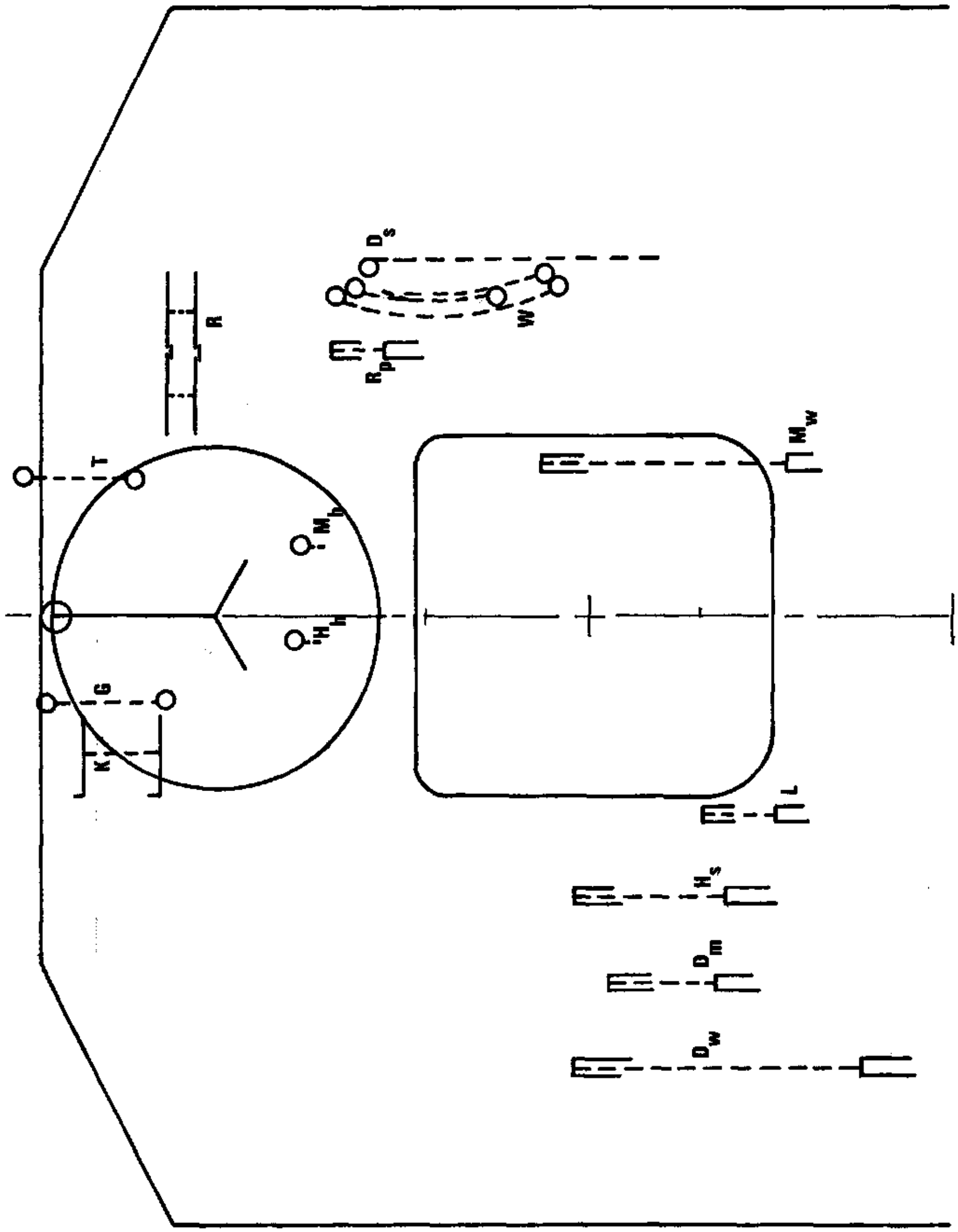

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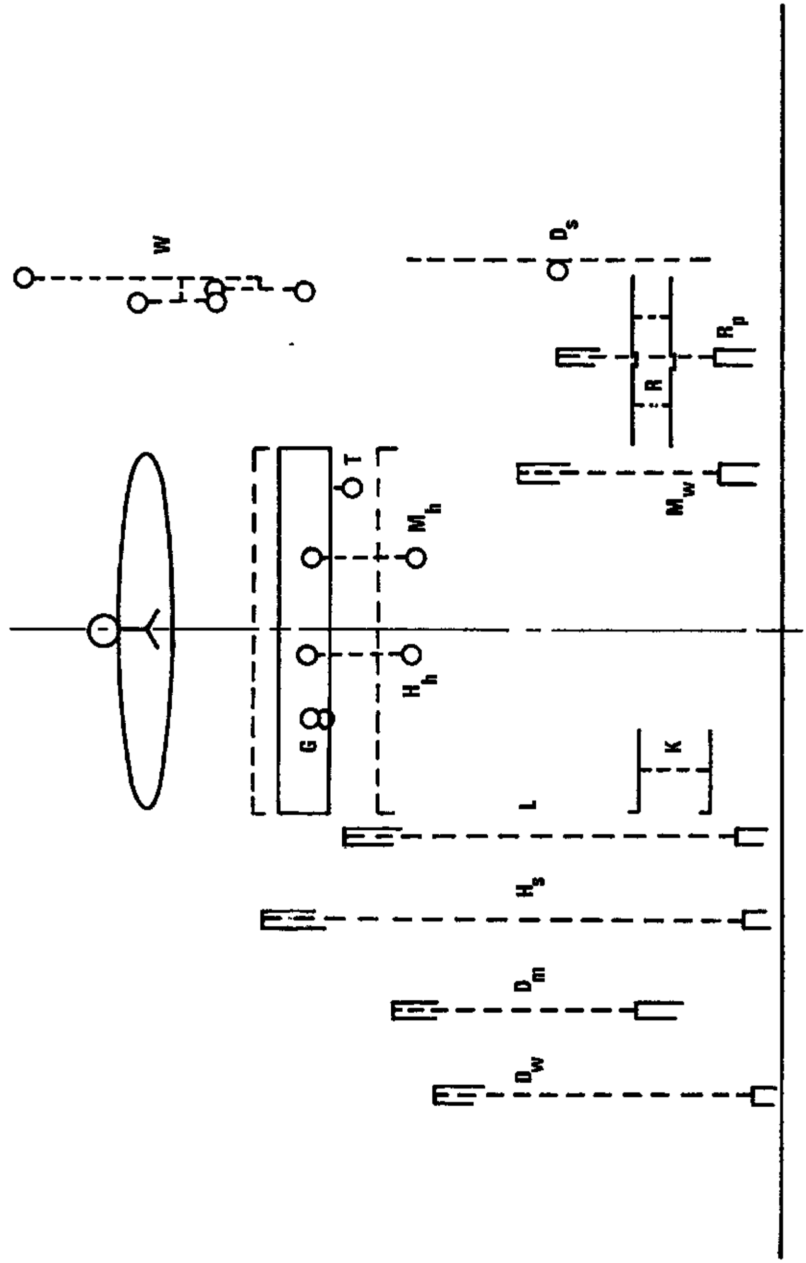

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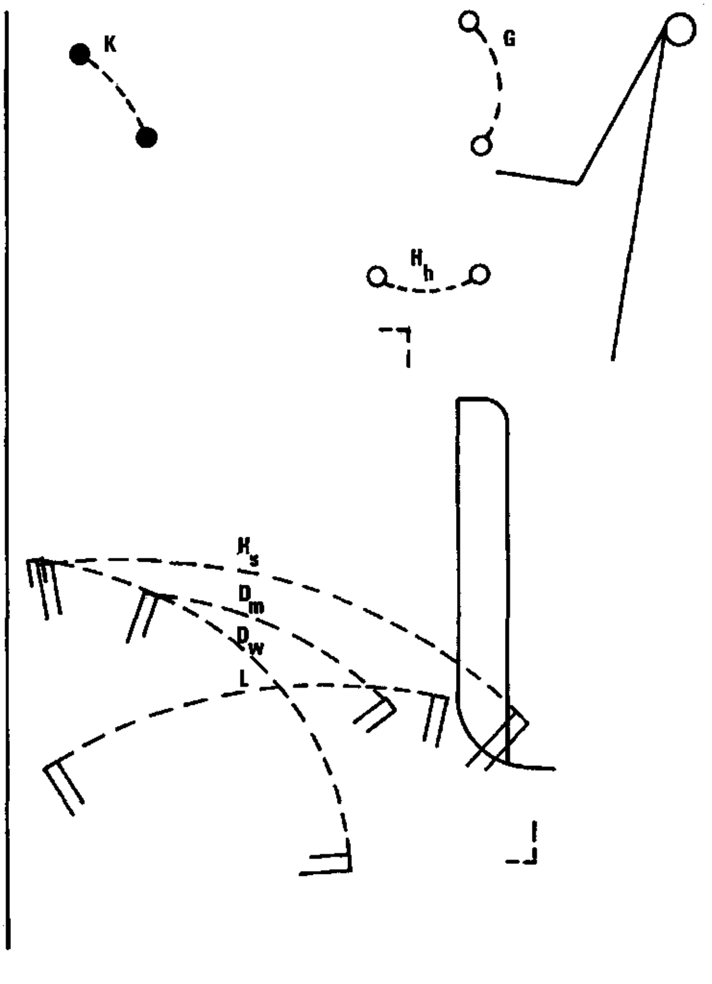

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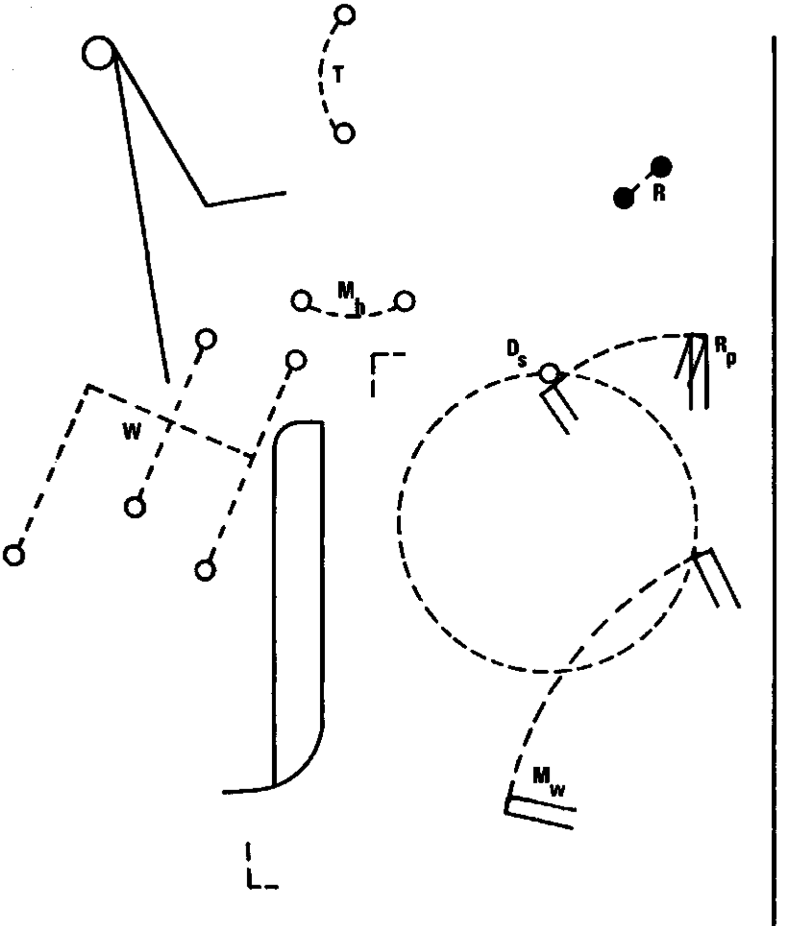

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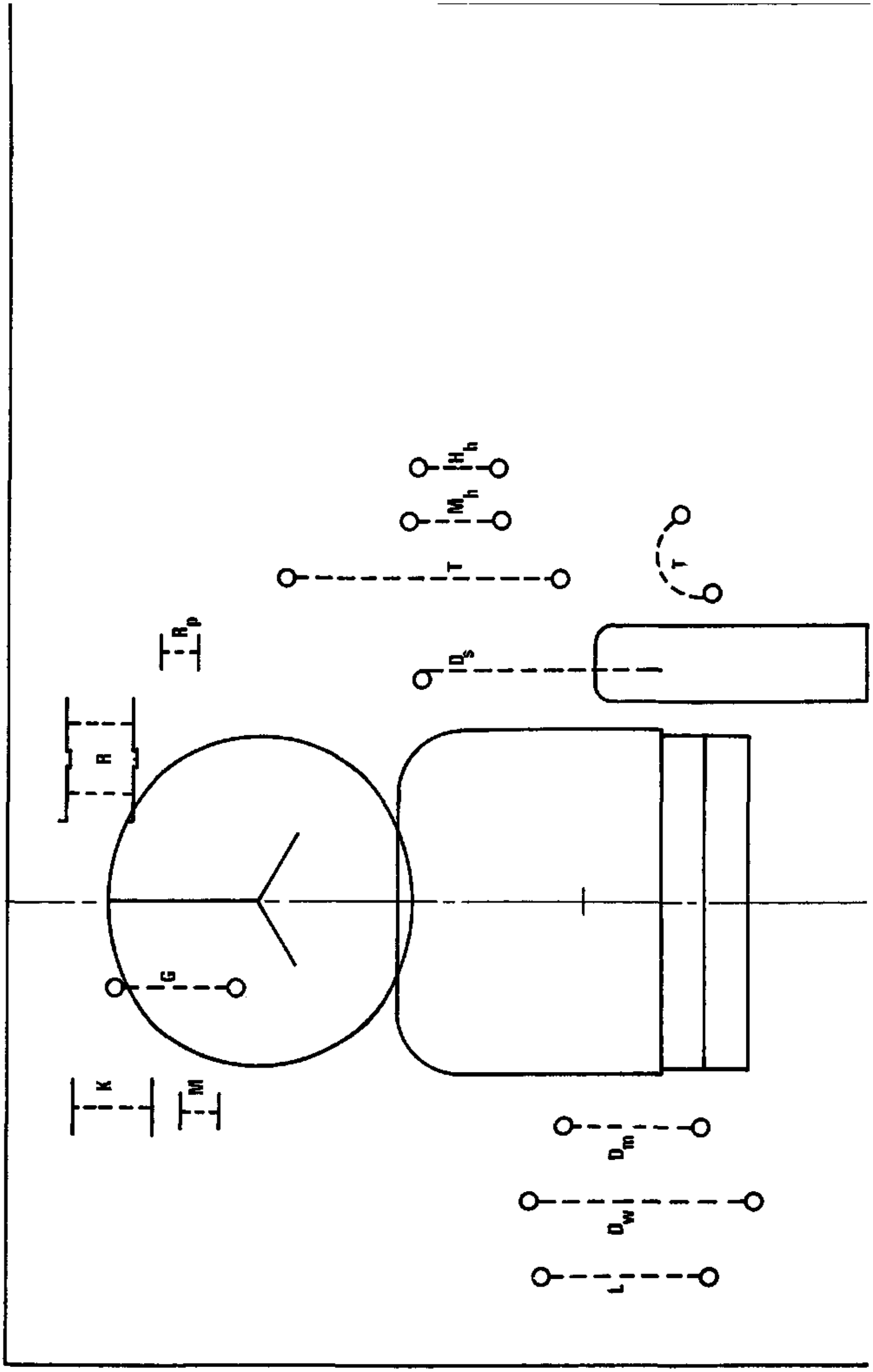

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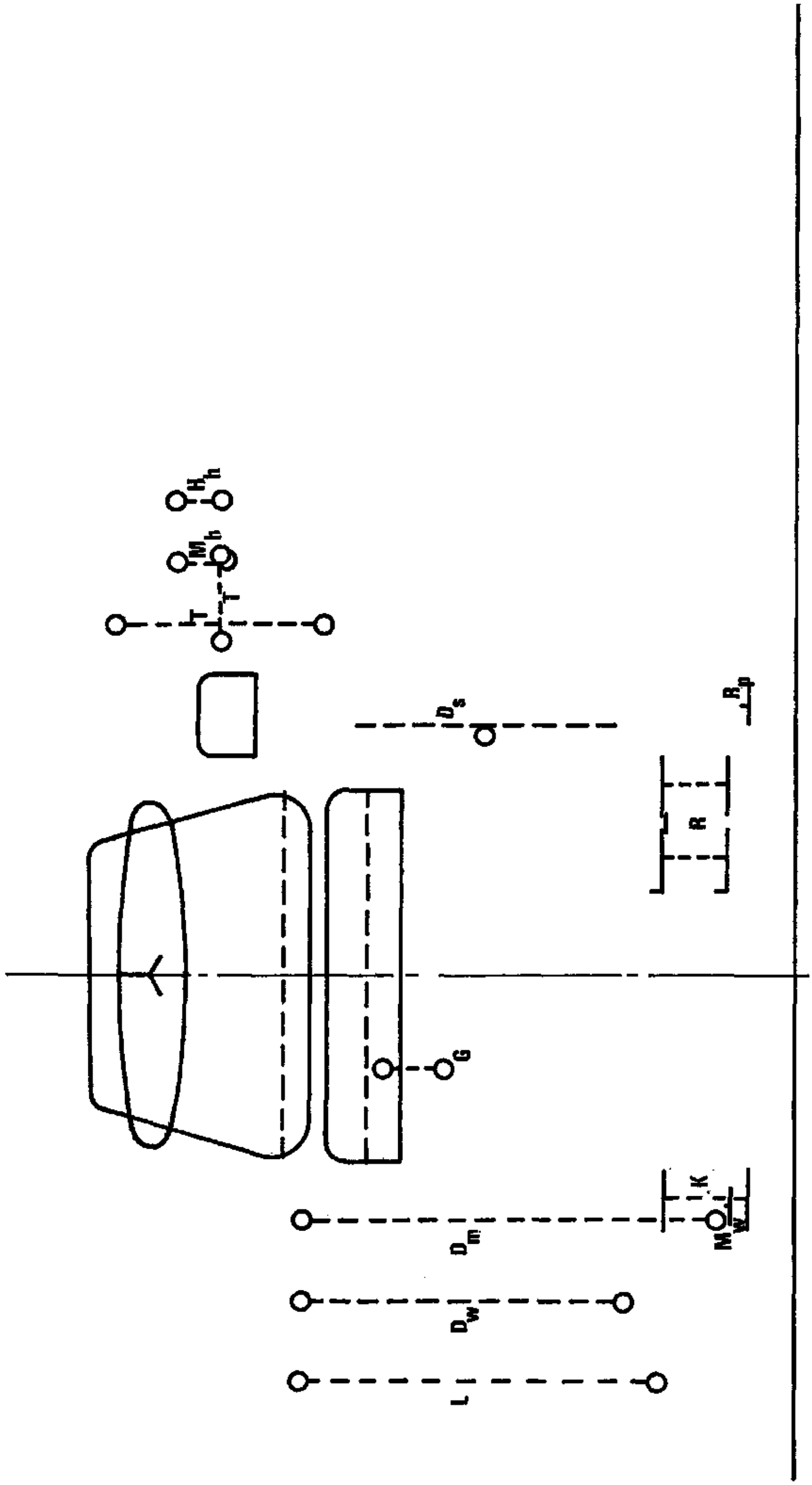

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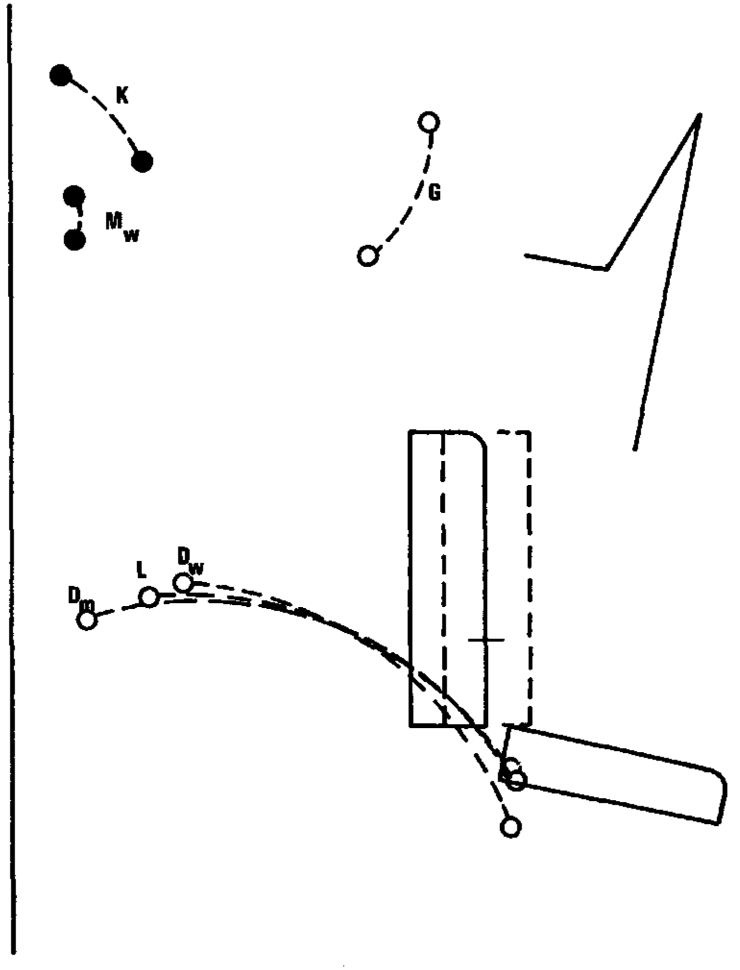

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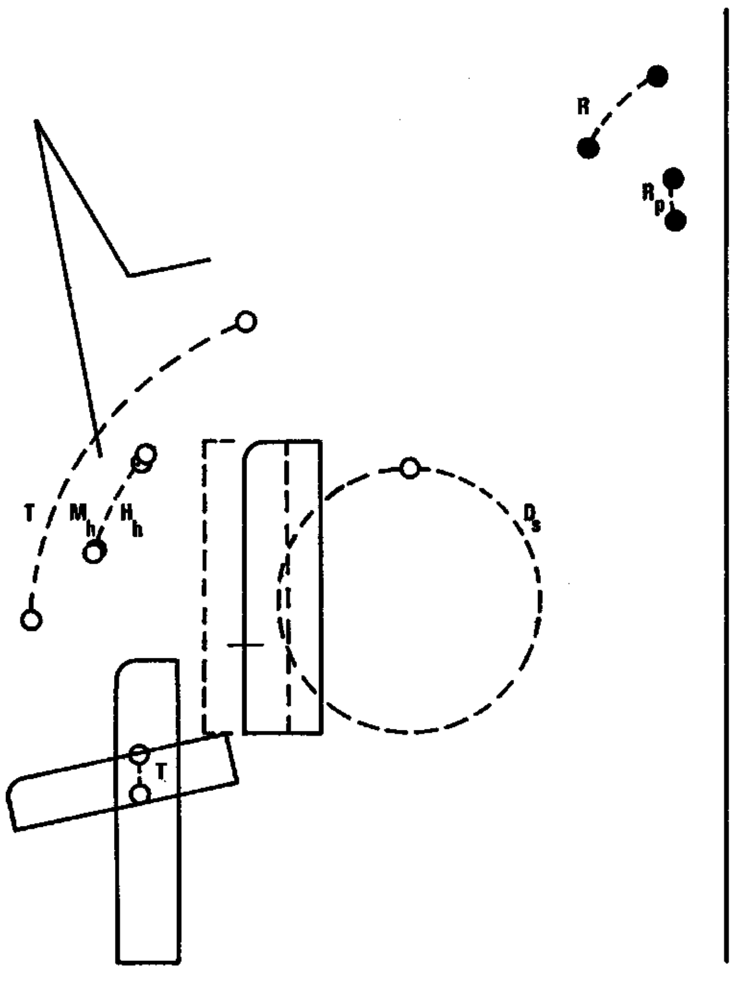

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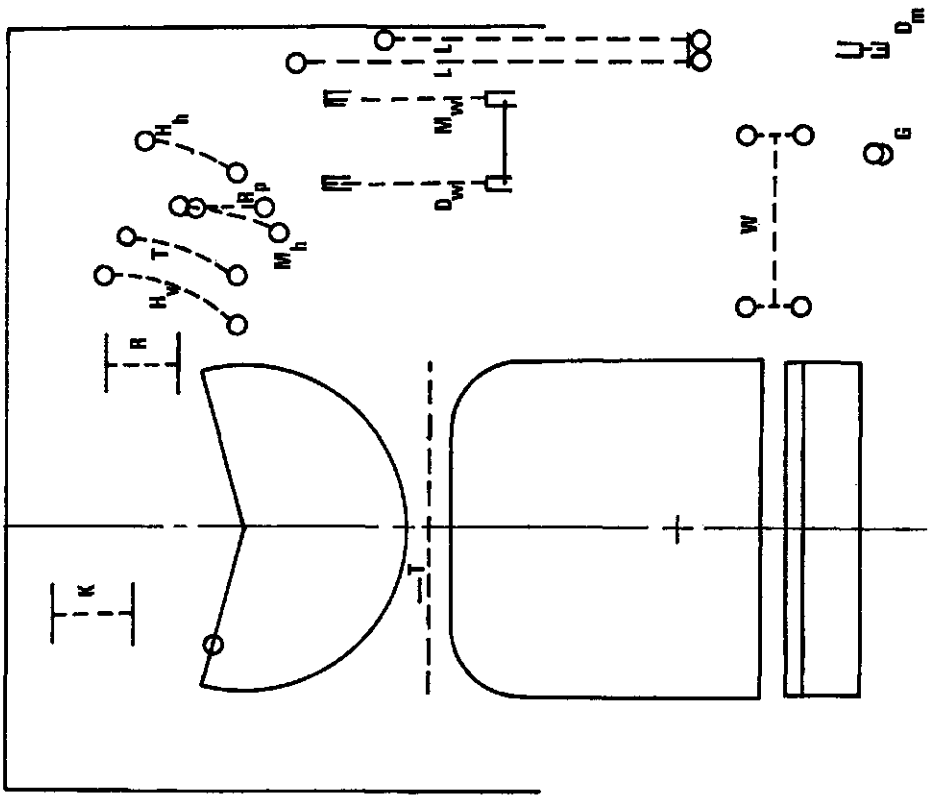

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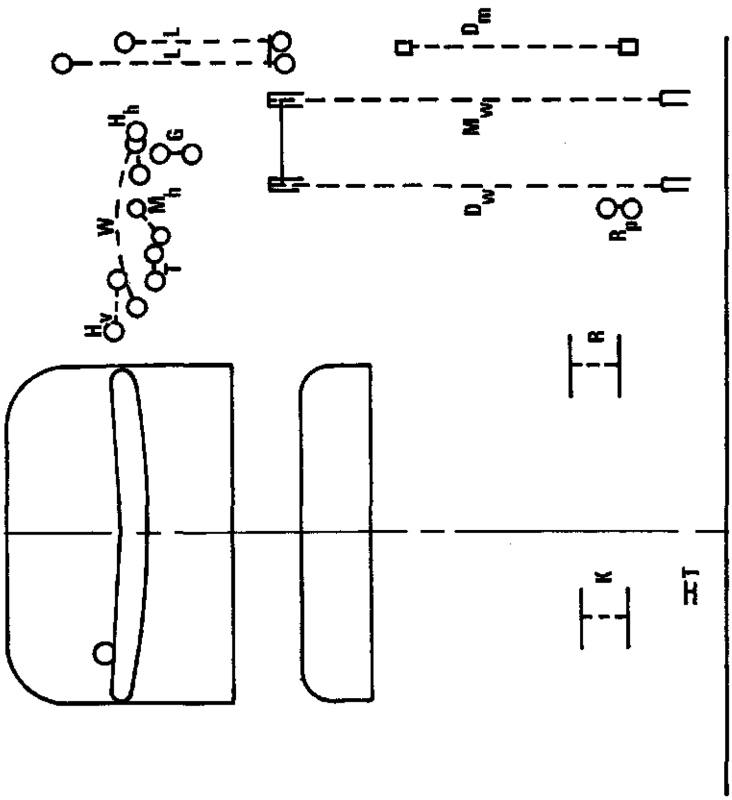

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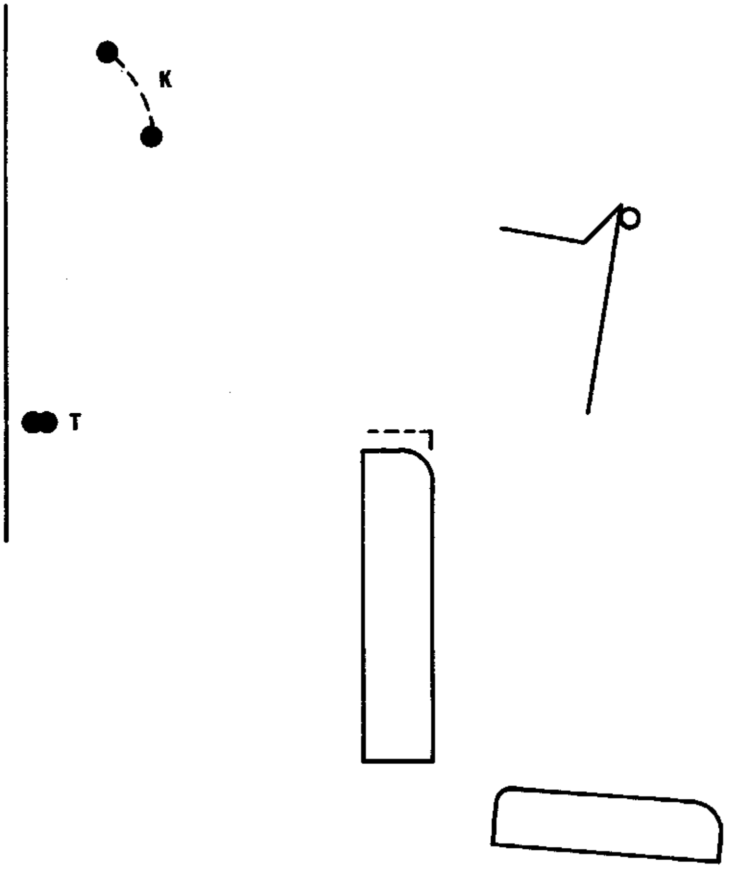

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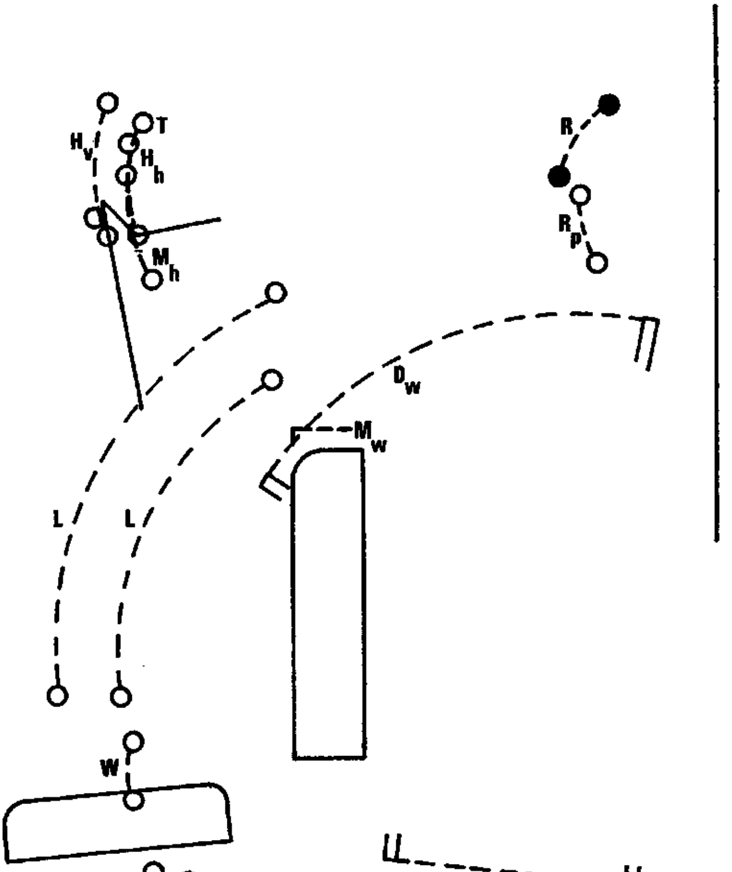

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