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SYMPOSIUM ON HUMAN ENGINEERING ASPECTS OF MAIN BATTLE TANK DESIGN

HELD AT
ROYAL MILITARY COLLEGE OF SCIENCE
SHRIVENHAM

1-2 APRIL 1969

RECORD OF PROCEEDINGS

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INTRODUCTION

The Dean of the Royal Military College of Science, Dr Farley, welcomed the delegates, particularly those from overseas. He outlined briefly the history and purpose of the college and invited those interested in learning more about it to meet the Deputy Commandant, Brigadier A.G. Lewis, later in the day. He regarded this Symposium as a follow-up to the Human Factors Conference held at the college in Autumn 1968.

The Chairman of the opening session, Dr Penton, outlined the scope of the Symposium. He pointed out the need to balance the requirements of users, designers and personnel research workers.

CREW DUTIES - USER ASPECTS

Crew Duties - User Aspects

By

Lt Col D.H. Hawkins, MC, MM, 15/19H
HQ, RAC Centre, Bovington

Introduction

1. Most of us know that significant design advantages would result from any reduction in the volume under armour of a main battle tank. One possibility of realising this is to reduce the crew in number when automation and control equipment engineering have advanced to the stage where this is technically feasible. The user, on the other hand, has considerable reservations on the practicality of such a step and will want a lot of convincing of the tactical validity of any such solution. My task is to explain the crew duties and user aspects in the context of the number needed in the crew.

2. I will approach this in the following way:

a. Taking CHIEFTAIN as a starting point:

(1) Discuss the crew operated Military Characteristics of shooting, moving and communicating.

(2) Show how these are catered for in equipment and crew tasks.

(3) Analyse a Battlefield Day in terms of crew activity.

b. Discuss the factors affecting crew size and see if any changes in the work load could be made.

c. Having assessed a new work load concept, discuss various ways of exploiting it in formulating the requirement.

Military Characteristics

3. It will be appreciated that of all the Military Characteristics of CHIEFTAIN the crew are concerned with:

Shooting

Moving

Communicating, including Command and Control.

4. To this list we might also add house-keeping and self-security, about which you will hear more in Serial 6.

Shooting

5. Shooting is broken down into the following stages:

a. Target acquisition.

b. Ranging.

c. Laying and firing.

d. Loading and ammunition stowage.

e. Maintenance.

6. Target Acquisition (including detection, recognition and identification):

a. This task is mainly the tank commander's. He has an all round vision cupola and a x10 binocular periscope. These aids give him good facilities in daylight. For night work an infra-red searchlight and sight are provided. Being near IR the range at night is reduced and the active system is easily detectable.

b. The gunner has a x8, x1 periscope sight, a x7 telescopic sight and an infra red sight. He uses these for target search and acquisition but his field of view is much less than the commander's, upon whom he relies to a greater or lesser extent for indication.

c. The driver and loader are not used for target acquisition other than in special circumstances. They only have x1 viewing facilities but can be given surveillance tasks within these limitations as necessary.

7. Ranging. The system available in CHIEFTAIN is a RMG effective up to about 1800m range. Up to this range the gunner carries out a drill which could mean firing a total of 15 rounds of .5 in ranging ammunition in bursts of three rounds before firing the main armament. At longer ranges visual range estimation by the commander is used as a preliminary to normal Observation and Correction.

8. Laying and Firing:

a. The gunner is primarily concerned in this. As we have already seen, he has a choice of instruments, each incorporating a ballistic graticule and he has the necessary traversing, elevating and firing controls.

b. The commander has overriding facilities for sighting and laying in his contra-rotating cupola but these are primarily as aids in the transmission of orders and to monitor the gunner's lay. He can fire the guns if necessary but UK practice is to try and avoid him becoming too closely involved with any one particular crew task to the detriment of his overall supervisory role. Once the gunner is laid ON the commander is free to concentrate on the next target.

9. Loading, Ammunition Stowage and Rate of Fire. These items are so interrelated that it is best to deal with them together. The requirement is for rapid fire of 10 rounds per minute and sustained fire of 6 rounds per minute for 4 minutes. Because of the need for ramming the separate ammunition, and the diversity of stowage, much training and physical fitness is required to achieve the required figures.

10. The major part of this task, including the loading and stoppage clearing on RMG & Coax, falls on the loader, who deals with the following natures:

a. Main Armament:

(1) APDS - Qty 19 consisting of:

(a) Projectile - 28 lbs 12 oz in weight. Note the weights

(b) Charge - 28 in long cylinder 27 lbs 8 oz weight. " " "

(2) HESH - Qty 34 comprising:

(a) Projectile - 46 lbs in weight. " " "

(b) Cartridge - 26 in long half cylinder 10 lbs 12 oz weight. " " "

b. RMG - 6 boxes, 34 lbs per box of 100 rounds.

c. MG 7.62 mm - 30 boxes, 2 for commander's MG, 16 lbs per box of 200 rds.

d. Vent Tubes Electric and Magazines - 60 in six 10 round magazines. 18 round magazines will be issued in the near future.

e. Other Natures. Responsibility shared between commander and loader:

(1) Smoke Grenades - Qty 24, 12 loaded in dischargers.

(2) No 36 Grenades - Qty 6.

(3) Signal Cartridges - Qty 12 for 9 mm SMG - Qty 6 magazines.

11. Ammunition is stowed at various places which can only be reached at certain positions of the turret, but design is such that there are sufficient ready rounds available for immediate use in any position of the turret. Loading the main armament comprises:

a. Selecting projectile and removing from stowage.

b. Chambering and ramming projectile.

c. Selecting appropriate charge and removing from stowage. Care is necessary to ensure correct selection.

d. Ramming the charge and closing the breech.

e. Ensuring the vent tube magazine contains sufficient vent tubes for the coming engagement.

f. Unlocking the safety switch and informing the gunner when all is ready for firing.

12. Gun Controls. Both commander and gunner have duplex power controls to lay the gun, the commander's overriding the gunner's primarily to aid him in indicating targets, transmitting orders and monitoring their compliance. When the vehicle is moving the stabilising gear provides the gunner with a steady gun, but his sight is

moving in relation to his head. Little physical effort is required to effect the gun lay and for any normally co-ordinated man the skills required to lay and fire on the move are not too complex. Hand traverse and hand elevation are provided for the gunner but the physical effort required, particularly for the former, precludes its use except for short periods.

13. Weapons Maintenance. Servicing before, during and after firing is carried out by the loader, the only task requiring the gunner's assistance being the removal and replacement of the obturators after 60 rounds.

Moving and Vehicle Maintenance

14. Driving. The driver, under the commander's direction, is completely involved in this task and has all the controls for driving the vehicle. Normally, once given his direction he picks his route aided by his knowledge of ground appreciation, but at night he needs considerably more assistance from the commander. The loader usually assists the commander during movement with radio watch, map reading, traffic control etc.

15. Maintenance. The driver is responsible to the commander for vehicle maintenance and fuel replenishment, but cannot carry out all the tasks himself. He requires physical help because of the effort required to lift engine decks and maintain tracks. The commander supervises all maintenance.

Communication

16. Gun tanks are equipped with comprehensive communication equipment for their command and control based on a two set radio installation operated by the loader, who is trained in R/T procedures, and an inter-communicating system linking all crew members. Drills and netting are simple and quick, and periodic attention to set and maintenance minimal. Normally the commander uses the radio but the loader receives and transmits on both sets as necessary; largely because of this the loader is normally the second in command in the tank. The CLANSMAN range of wireless sets is expected to reduce the operator effort in attention although not in traffic.

Battlefield Day and Crew Work Load - CHIEFTAIN

17. The Military Characteristics of CHIEFTAIN did not stipulate the breakdown of a Battlefield Day other than 40% cross-country, 40% idling and 20% road movement. We have therefore assumed a 24 hr Battlefield Day breakdown as follows, based on the schedule for the APRE environmental trials carried out in 1968:

			hrs
a.	Observation and Recce	-	6
b.	Fighting, including movement in contact	-	4
c.	Maintenance and replenishment	-	1
d.	Movement, ie out of contact	-	4
e.	Stand to, listening watch etc	-	4½
f.	Rest	-	4½

18. The chart (figure 1) shows this with an attempt to relate the crew work load

to time, not effort, in each phase, divided as follows:

a. Manual. By which we mean hard work, not just handling switches or power controls.

b. Mental. This includes sensory, whether visual, hearing and tactile. Smell and taste are not included.

19. This is purely a personal estimate based on the environmental trials previously mentioned, modified by experience and memory, and we fully realise it is open to criticism. Nevertheless we believe it is a reasonable estimate and will serve our purpose as a starting point for any discussion.

Work Load

20. Commander. In commanding a tank he is involved completely in observation, reconnaissance, fighting, movement, stand-to and wireless watch. The majority of this work is mental/sensory, very little is manual. In a period of 24 hrs the commander is working for, say, 85% of the time. During maintenance and replenishment he may well be away on recce, 'O' groups etc.

21. Gunner. He is involved completely in fighting, maintenance and replenishment, partially so in observation, reconnaissance and wireless watch and slightly in movement. Except when he has to use hand traverse, and when doing his share of maintenance, his work is not manual.

22. Loader. He is involved completely in fighting, maintenance, replenishment, stand-to and wireless watch, and partially in observation, reconnaissance and movement. Much of the loader's work in fighting maintenance and replenishment is manual, but little manual work is involved in the other tasks.

23. Driver. He is involved completely in movement, maintenance and replenishment, partially in fighting, stand-to, and slightly in observation and reconnaissance. His work in fighting, maintenance, replenishment and movement is manual.

24. You will see that the crew as a whole is not fully employed during any of the Battlefield Day phases. In fact, in some phases only the equivalent of three men are fully employed.

Factors

25. When considering the number in a tank crew there are a number of factors which have to be examined, and we will now discuss these in relation to the work load. The factors are:

a. Type of work.

b. Fatigue.

c. Logistics.

d. Training and morale.

e. Fear.

26. Type of Work:

a. Mental/Sensory:

(1) This can be more tiring than manual work. During the 24 hr period the ordinary commander spends about 75% of the time on mental/sensory work, ie about 18 hrs, in marked contrast to the other crew members. In a MBT, which is what we are considering, he could not therefore absorb any other crew task except possibly the gunner's. But this would conflict with the needs for command and control at all stages of the battle in eg Troop Leaders and above. Are we to change our current philosophy to implement this? Unless we do, and I'm not suggesting we should, I cannot see two man crews as viable.

(2) Of the five senses the eyes are used most, followed by the ears, touch and smell in that order. Taste is not used. The use of one's senses in abnormal conditions can be very tiring, eg observing in bad light will cause eye strain. Noise also affects the use of one's senses, although good attenuation can counter this. So long as adequate aids are provided mental/sensory work should not present much of a work load.

b. Physical. The most tiring work is track maintenance and replenishment because great effort is required to be sustained in both these for a considerable time. With experience much of the other physical work in an AFV can become a matter of knack. The task of loading the main armament occurs in short bursts, and unless one is loading at the maximum rate required by the Military Characteristics the work load is not as great as imagined. It can be eliminated altogether by provision of an automatic loader if design permits. In driving the steering lever pull is about 50 lbs. Drivers soon learn the knack of using these continuously and are not completely exhausted by sustained driving. Nevertheless, because of the 24 hr requirement we would look for a significant decrease in the effort required to drive and service the vehicle. As with mental, the amount of physical work, except during maintenance, could be done by less than three men, but you have already heard why we cannot see a two-man crew as viable.

27. Fatigue. Apart from the kind and amount of work, the other contributory causes of fatigue are environment and crew comfort:

a. Discomfort. Working in a cramped space and possibly an awkward position will reduce the potential work output of a man. Confined space makes any removal and replacement of clothing and access to stowage during the 24 hours an awkward and arduous task. Nothing is provided in CHIEFTAIN for the easy collection and elimination of human biological waste. Crew positions are not conducive to restful sleep. The main effects of discomfort will be to slow down reaction times of the crew and decrease morale.

b. Temperature. Temperature outside certain limits will increase discomfort and fatigue.

c. NBC Conditions. The wearing of respirators and CB clothing, together with the additional fear of chemical agents, will increase fatigue in each member of the crew, and again lessen morale. In certain circumstances decontamination will add a heavy burden to the crew.

28. Logistics:

a. Two possible ways of countering fatigue, other than mutual relief or unit relief as at present, are:

(1) Use of Slip Crews, ie two crews per vehicle relieving each other at intervals. We see this as impracticable for the following reasons:

(a) Uneconomic use of skilled manpower, which is at a premium anyway.

(b) When and how to arrange relief. The logistic problem of holding, briefing and moving complete relief crews, including the command structure, would be nearly as great as unit relief.

(c) Psychological effects on crews being relieved. There are two aspects: first, the effect on a man anticipating relief being ordered into a fresh battle; and second, the effect on the commander who must give this order.

(2) Use of Servicing Teams. The practicability of this is highly questionable as in addition to the problems above the crew would still have to do their daily tasks, including servicing before, during and after firing. Nevertheless, servicing teams could relieve the crew in eg heavy track maintenance and periodic tasks, provided that:

(a) Operational availability or crew rest/sleep are not jeopardised by waiting for team to arrive.

(b) Crew's pride and necessity to retain confidence in their own equipment permit the servicing team to operate unsupervised.

b. Reducing crew numbers while retaining simplicity of operation and training, implies increased complexity of automatic and control equipment. The price is usually less mechanical reliability and the need for highly skilled maintenance and repair backing, except perhaps on electronic equipment. It must be recognised that any demand to simplify equipment on grounds of cost and maintainability is negated by the demand to reduce crew numbers. A balance must be struck between these two mutually exclusive aspects.

c. Messing. At present tank crews are self supporting for messing, receiving rations periodically, and cooking and eating under their own arrangements as circumstances permit and with the aids provided. Reducing their numbers does not decrease the work involved in crew messing but it will increase the individual work load per crewman, eg in the simplest terms the cooking rota is shorter. The Corps has considered the idea of communal messing in the field but armoured flexibility rules it out.

29. Training and Morale. Training is to be discussed by a later speaker. It is enough to say at this point the present RAC trained soldier is able to take his place in a CHIEFTAIN crew under guidance and supervision. Maintenance, crew servicing and repair are also within the capability of RAC and REME trained soldiers. The question is would they be able to cope with any increased complexity of operating or maintaining, and which should carry the added load? You will be better able to consider that position when you have heard about the training problem from Col READE later. All the factors mentioned have a bearing on morale but the well-trained crewman starts with high morale, having confidence in himself, his equipment, and his fellow crewmen. So long as men are fully occupied in combat and can see the point of their efforts, morale will remain high but periods of inactivity reduce it.

30. Fear. Fear is experienced by all men in combat and has to be overcome for the crew to be effective. A man on his own is more likely to give way to fear than when in a crew. On the other hand, time on one's hands is a fermenting ground for fear and a careful balance must be struck between these two when deciding the crew numbers.

Possible Crew Combinations

31. The chart at fig 1 has been compiled from the APRE trials schedule, modified to some extent by individuals' memory and experience, and is meant to average crew tasks as work load in 90% of all cases. Whereas the commander is fully occupied in time, the other three crew members are only working for about half the time. It would therefore seem at first glance that a three man crew is possible by redistributing various tasks, and these we will now consider. Three combinations appear possible given suitable re-design:

a. Driver/Loader.

b. Driver/Gunner.

c. Gunner/Loader.

32. Suppose the driver and loader are combined. The work distribution of these positions will be as follows:

a. Observation, Recce and Movement - No problem.

b. Fighting. The combination would be impracticable unless an automatic loader were provided, and the pros and cons of this would need careful consideration. I think it is rather outside my brief to discuss in detail but there is no doubt that if its disadvantages could be accepted or preferably overcome the advantages it offers are very substantial in terms of rate of fire and ease of stowage. Its reliability must be assured.

c. Maintenance. The existing three man work load will probably be too much for two men to carry out. Don't forget we cannot count on the commander's presence.

33. The crucial factor is probably fatigue as this suggestion combines the two crew members with the most physical work. Provision of automatic loading would still leave a heavy crew servicing load to be reduced or overcome in some way.

34. Gunner/Driver:

a. Observation and Recce - No problem.

b. Fighting. The gunner is fully occupied and the driver partly so but there is no doubt that their duties could be combined and have been in eg 'S' Tank. Fire on the move would have to become the commander's responsibility.

c. Maintenance and Replenishment. The vehicle work would still remain divided as at present between loader and driver, and from this point of view this combination would be acceptable.

d. Movement - No problem.

e. Stand to - As for fighting.

35. Gunner/Loader:

a. Observation, Recce and Stand to - No problem.

b. Fighting. The two duties are not complementary as the guns must be loaded and layed prior to firing, but with suitable aids they could be combined, ie the provision of an automatic loader. Elimination of the gunner and retention of the loader is not feasible as the physical effort required in loading would seriously detract from his ability to lay the guns.

c. Maintenance and Replenishment. There would be no change to the present distribution of physical work if the loader were retained at the expense of the gunner. On the other hand, a large proportion of physical work, ie loading, would be eliminated altogether by the provision of an automatic loader.

d. Movement - No problem. Both are largely unoccupied in this phase.

Exploitation and the Future

36. We see that with the provision of the necessary aids the present crew can be reduced to three men provided the fatigue factor is accepted or overcome. We do not see reduction to two men as practicable in a MBT without substantial re-appraisal of our doctrine and methods in tank warfare. The involvement of the commander in any one particular task detracts unacceptably from his command and control capability. This is especially so in sub unit commanders. The provision of the necessary aids even for three men implies increased complexity of control equipment needing highly skilled manpower for adjustment and maintenance,

and this may well be the limiting factor, especially if no increase in training is permissible.

37. Although there is little or no reduction of mental or sensory work foreseeable, the manual work load per crewman can be reduced for driver and loader by introducing automation:

a. **Driver.** The manual work here is in pulling the steering levers and the average pull for each application of the lever is found to be 50 lbs. This could be reduced to a small tiller requiring no more than 1 lb effort. Hydraulic track tensioners would help reduce the track maintenance load.

b. **Loader.** His major work load, and he with it, could be replaced by an automatic loader. The advantages and disadvantages are well known and provided the latter can be overcome this is a practical solution. Its reliability must be beyond question as any failure during an engagement amounts to an 'F' kill.

38. In conclusion we see three possible concepts as worth considering, all for three men:

a. Rotating Turret:

(1) To include the driver. This allows all three options of combinations and permits fire on the move with a stabilised gun, but many design problems have to be overcome.

(2) Driver in hull, ie combining gunner and loader. It implies automatic loading. Stabilised fire on the move is still possible but, again, many design problems can be foreseen.

b. Turretless, eg Swedish 'S' Tank. All crew combinations can be considered but there are many limitations to this concept, including not being able to fire on the move.

FIGURE 1 - BATTLEFIELD DAY - DISTRIBUTION OF CREW WORK LOADS

	Observation & Recce 6 hours	Fighting 4 hours	Maint & Replen 1 hour	Movement 4 hours	Stand to & W/T Watch 4.5 hours	Rest etc: 4.5 hours	Approximate time working in 24 hr Battlefield Day
Commander	..............-----	..........--	'O' Gp etc	.........---	....	..--	85%
Gunner	.......----	..........--	.---	.--	.......---	..--	55%
Loader	.........--	.......----	.---	....	....	..--	65%
Driver	.--	..----	.---	..----------	..-----	..--	45%

Mental/Sensory ....

Manual ----

Discussion

Mr BAYLY PIKE opened the discussion by stating that it appeared from the paper that the critical time was the period of maintenance and servicing. He asked if the designers could make the need for vehicle maintenance less frequent and whether the system for refuelling could be simplified.

Lt Col HAWKINS replied that the requirement for every new vehicle included the need to ease maintenance but it must be borne in mind that Armoured fighting vehicles (AFV) operate under high mechanical stresses. Regarding refuelling several alternative methods of refuelling in the field had been studied. It had been found that the carrying of jerricans had proved the most practical answer as it was adaptable to all conditions.

Mr MONGER pointed out that, unlike motor cars, tanks were designed for a comparatively short life. The design accepted many components being highly stressed. However much more could and would be done to reduce maintenance.

Colonel READE stated that current trials on bulk refuelling indicate an easing of the replenishment problem but on 25% of occasions it would still be necessary to use jerricans. He also drew attention to the physical effort demanded when replenishing ammunition.

Brigadier SIMPKIN raised the problem of fatigue induced by monitoring visual electronic displays such as near infra-red, radar and image intensifiers. He understood that a drop in efficiency occurred after 30 minutes and became serious after 45 minutes.

Major LINAKER stated that from his experience track maintenance was the worst chore. He added that on most exercises only the essential items in the maintenance schedule were undertaken. As regards weapon maintenance he said that the most awkward item was the machine gun and the accessibility of this was an important factor.

SUSTAINED OPERATION AND THE NEED FOR SLEEP

Implications of periods of sustained operation and the need for sleep

By D.W.J. Corcoran

Medical Research Council, Applied Psychology Research Unit, Cambridge

Under operational conditions the serviceman may find himself (a) without any sleep at all for very long periods (b) with much reduced sleep over very long periods or (c) suddenly awakened to perform a complex operation a few minutes after awakening. This paper summarises the results of conditions like (a), (b), and (c), upon measures of performance. It does not seem worthwhile at this stage to consider any physiological effects of sleep deprivation 1. because there are virtually no changes which have been consistently reported in the literature and 2. because even when changes occur they do not have consistent effects upon performance. On the other hand not all measures of performacne show changes, but it can now be predicted with fair reliability which kinds of work are affected by the fatigue resulting from loss of sleep.

First a few general words about sleepiness. It would be most convenient experimentally if the amount of sleepiness experienced were monotonically related to hours of sleep deprivation, but in practice this is not so. Recent work by Colquhoun, Blake and Edwards (1968) confirms much earlier and less adequate findings that during the normal working day performance undergoes changes. Using tasks such as vigilance (in which unpredictable signals of low intensity occur at irregular intervals), additions, letter cancellation (which involves searching through prose crossing out all the letters "e") and sorting playing cards, it was shown that performance was at its best about 14 hours after awakening, ie at about 8-10 pm in the evening. It was poorest at 4 am, even when sleep was allowed during the day. These normal diurnal changes overlie the effects of sleep-loss. The speaker has observed subjects hardly able to keep awake, and in states which at times resemble psychosis after as little as 42-46 hours without sleep, yet eighteen hours later, behaving normally and showing improved performance. This phenomenon occurs presumably because after 42-46 hours without sleep the time happens to be 1-5 am, when the circadian rhythm is at its lowest ebb. I should add that body temperature is a good index of performance efficiency, during the diurnal cycle, and so is also a good measure of efficiency after loss of sleep - Williams, Lubin and Goodnow (1959). Thus loss of sleep is probably simply a more accentuated change in the same underlying mechanisms which causes smaller changes in sleepiness during the normal working day.

Of the three states in which the operator may find himself, by far the greatest amount of research effort has been concerned with total sleep deprivation. Indeed very little work has been done with partial sleep deprivation or sudden awakening, despite their obvious practical importance.

Total Sleep Deprivation

The factors in the task itself which influence the effects of loss of sleep are as follows:

1. Time on Task

Tasks of relatively short duration are much less likely to show an effect of sleeplessness than those of long duration. After one night awake, reliable decrements can be observed after about 15 minutes, and after two nights without sleep, this figure probably drops to about 10 minutes (Wilkinson, 1958). These figures apply to tasks which are sensitive. Insensitive tasks may be prolonged up to 2 hours without showing a deterioration even during the early hours of the third day without sleep (Wilkinson, 1964). Figure 1 is taken from Wilkinson (1958) which shows the interaction between time on task and loss of sleep on a very sensitive watch-keeping task. Notice that as the time on task increases so the effect of loss of sleep increases. This data was obtained after one night only without sleep. This same task when used after two nights without sleep showed such a deterioration that most of the subjects failed to detect a single signal during the last 15 minutes.

Under normal conditions task length itself tends to deteriorate performance; when loss of sleep is added the deterioration is accentuated.

2. Signal Frequency

Figure 2 taken from Corcoran (1963) shows how another feature of the task influences the extent to which performance deteriorates after loss of sleep. This is the rate at which signals are presented in a detection task. In this task the subjects were presented visually with a series of digits. They had to report when three successive odd digits occured in a sequence. In the slow condition the digits were presented at a rate of 1 per sec; in the fast condition at a rate of 2 per sec. Under normal sleep conditions there is little to choose between the mean levels of performance on three successive days. The four points on Day 1 show performance of 4 groups under identical conditions. (The lowest point spoils the picture somewhat; this group happened to be a little poorer than the others.) The point to note is that the EXP/Slow group showed a greater day to day drop in performance than the EXP/Fast group. Starting with a 20% superiority over the Fast group on Day 1, the Slow group ended up about 10% worse.

3. Effects of repeated testing (Practice)

Figure 3 taken from Wilkinson (1961) shows the effects of having subjects repeat a standard uninteresting task almost daily for six weeks. Each fortnight formed a complete latin square design in which each subject was tested having lost a night's sleep once each week.

The task was a standard one used for effects of stress at APRU, called the "5-choice". The subject is seated before a pentagonal display of bulbs and a horizontal board with a similar lay-out of metal discs. Each light corresponds to a disc on the board and the subject's job is to tap the disc corresponding to the light which is on. When he does this the light moves to another randomly selected position. Three measures of performance can be taken. Speed, the number of correctly tapped discs in unit time, Accuracy, the number of incorrectly tapped discs and "Gaps" the number of times the response time has exceeded $1\frac{1}{2}$ seconds. The latter measure was assumed to represent lapses of attention.

These graphs show the effects of loss of sleep on the 3 measures of performance. Notice that the effect becomes greater as a function of the number of times the task is repeated. In the normal working environment, the repetitious nature of the job is likely to produce effects of sleeplessness far in excess of those reported here.

4. Complexity and Interest

It was previously thought that the extent to which a task was affected by loss of sleep was a function of its simplicity. All the tasks we have examined thus far have been sensitive to the effects of loss of sleep and all have been simple in nature. But a characteristic of simple tasks is that they are also usually uninteresting, whereas complex tasks tend on the whole also to be interesting. It therefore needs to be questioned whether it is the interest or the complexity of the task which affects its susceptibility to loss of sleep. This has never been resolved with any certainty.

It is true that the Battle Game taken from Wilkinson (1964) shows no effects of loss of sleep whatsoever. In this task four lower films move upwards at a constant rate. The films contain symbols C, S, D and B representing four different kinds of ship. Four upper films move downwards at speeds controlled by the operator. He is given four rules:

B or S can intercept C successfully

A or D can intercept S successfully

B or C can intercept D successfully

and A or S can intercept B successfully

The subject's job is to control the speed of the four upper films in order to make them reach the mid point at the same time as that ship which the upper symbol can successfully intercept. Subjects loved this task, and it never showed any effect of loss of sleep even when prolonged for 2 hours after nearly 60 hours of deprivation.

Tasks which seem equally complex, but not too exciting do show effects however. But when one specifically increases the amount of information to be processed eg by increasing the signal rate, this aids sleep deprived performance. Also practice at a task as well as making it less interesting also makes it less complex by increasing the ease with which it is performed and practice has deleterious effects. Interest is certainly a factor, but complexity we know little about at present.

5. Effects of Motivation

If we refer to Figure 4, we see the effects of another variable upon performance after loss of sleep. In this design, a procedure was incorporated which it was hoped raised the subjects level of motivation. At intervals throughout the task subjects were told how many responses they had made, how many errors, and how many gaps. This "knowledge of results", reduced the effect of loss of sleep on performance. Under normal sleep conditions, this procedure has little effect, but when subjects are deprived of sleep its effect is enhanced.

Incidentally, on the basis of a personality scale of introversion-extroversion, we can predict with fair accuracy, which subjects will be affected by Knowledge of Results and which will not. Extroverts only are affected by this procedure under normal sleep conditions, but both types are improved under sleepless conditions. Figure 5 shows how important personality variables are. It shows how extroverts deteriorate relative to introverts during a 3-day sleep deprivation.

Another form of incentive used has been to punish subjects with loud blasts of noise when they make errors. This procedure is also effective.

6. Effects of Loud Continuous Noise

Figure 6 taken from Corcoran (1962) shows levels of performance on the 5-choice in terms of gaps, when subjects are with and without a night's sleep, and are subject to about 100dB of white noise whilst the task is in progress. The graphs show the changes from the 1st to the 2nd half of the test. Notice that loss of sleep is associated with the greater within-session deterioration. When noise is incorporated however, this deterioration is reduced. In many tasks noise increases the within-session decrement, as does loss of sleep, so that one might expect that by combining both stresses one would obtain an even greater decrement. This is not so, the two stresses in this case cancel one another out. Noise therefore has the same effect as incentive and high signal rate in opposing the effects of sleeplessness.

Measures of Performance

A considerable amount of interest has centred around the actual measure of performance which is affected by sleeplessness. In general four kinds of measure have been examined. Speed in unpaced tasks (ie those in which the subject can go at any rate he likes), the "commissive errors" made when people go at speed, missed signals in a detection task, (this is a paced task, because the experimenter determines when signals are put in) and gaps or lapses of attention, (Figure 4).

Probably the best summary is given in Williams, Lubin and Goodnow (1959). Speed is affected by loss of sleep, Gaps are affected, and Detections are affected, but commissive errors are not. In other words the sleepless man will be less likely to "do what he ought not to do", than to "not do what he ought to do".

Behavioural Effects

When loss of sleep is extended into 40 or more hours, effects cannot be as easily classified or explained as the ones we have examined up to this stage.

The "psychosis" of sleep deprivation has been described many times. In the 60 hour deprivations run at APRU there were many occasions in which hallucinations were related, many misperceptions, a case of apparent deafness, irritability and so on.

These effects disappear after sleep and are of little consequence except that they affect performance whilst the man is in the state he is in. Performance at the 5-choice was impaired in a man who claimed he saw a chess pawn on one of the discs. He did not want to remove it, so failed to hit this disc when the appropriate light came on. The hallucinations are relatively long lasting and can affect decisions. One Rating for example claimed that one of the supervisors was dressed in German uniform and he became temporarily difficult to control. Similar cases of paranoia are reported in the literature. Whereas one can predict with reasonable accuracy what will happen to performance when the man is simply sleepy, one cannot predict what he is going to do when he is temporarily in a psychotic-like state.

However, one fact stands out clearly from the studies we have examined here. It is that sleepiness can be at least for a while reversed, by extra stimulation from the task and environment. Whereas the loud radio may affect the alert driver deleteriously, it will be more likely to improve his performance when he is sleepy. A French radio station has a programme especially for long distance lorry drivers on night work. As well as playing their requests it also turns up the amplitude of its output occasionally to waken any driver who is drifting off into sleep. What the sleeping operator needs is stimulation. I find that even eating a sweet helps a little on a long drive. Some such measure might be used when operators are in an hallucinatory or other state.

Performance under reduced sleep

The only recorded adequate study is by Wilkinson (1968). People worked at long periods of watch-keeping and calculation after losing one hour up to $7\frac{1}{2}$ hours of sleep. This was achieved by preventing the subjects going to bed for the requisite amount of time. The results are shown on Figure 7. It was found that about 3 hours loss of sleep reduced vigilance performance and about 5 were sufficient to cause a deterioration in performance in calculation. When kept with reduced sleep for two nights, the effects were greater.

This kind of procedure is a realistic one. On operations it is more likely that a few hours sleep will be taken when the opportunity arises than that men will stay permanently awake.

Performance on Sudden Awakening

Langdon and Hartman (1961) in a number of studies have asked whether the performance of people is seriously impaired when they are wakened from sleep and required to work within a few minutes. Using a fairly complex display involving switching to many light sources the data show impairment relative to normal performance. However, the practical question of importance is whether it is better to keep people awake continuously if they are likely to be required for an operation, rather than allowing them to sleep. In other words the levels of performance attained after sudden awakening should be compared with the levels achieved at the same times by people who have been kept awake all through the night. Work is in progress at APRU on this topic, but no data is at present available.

Conclusions

1. Sleepiness caused by sleep deprivation is a reversible process. Measures can be taken to prevent a serious decline in performance. These are a. Use of incentives where possible. This is likely to be present to a high degree in a battle situation, so that performance on exercises may not adequately reflect the levels which may be achieved under real stress. b. Wherever possible the length of time spent on a task should be reduced eg by changing the jobs amongst the operators. c. Attempts to reduce noise should not be made. Indeed use of radios etc should be encouraged after sleepiness, but choose your programme well. d. It may be useful where feasible to introduce artificial signals. e. Work output is the most likely to be affected, but particular attention should be paid to tasks in which short lapses of attention might be serious. f. Although not mentioned specifically in the body of this report, there is evidence (eg Tyler, 1947) that amphetamine will reduce the effects of sleepiness.

2. Tasks which will be likely to show lowered efficiency with loss of sleep are those with the following characteristics. Long, uninteresting, well practised, with low "signal" frequency (ie requiring relatively few operations other than sustained attention) and in which no external incentive is available.

3. All the effects are likely to be present when the man is working under partial sleep deprivation and when he is suddenly awakened.

4. Measurements of body temperature may give the commander warning of an impending disability. Finally many serious errors of decision can be made when sleeplessness is severe, due to "sleep psychosis". Several years ago a trawler skipper ordered his vessel to be put on a suicidal course, after 60-80 hours without sleep. The mate took command. This contingency should be covered by appropriate regulations.

DIAGRAMS

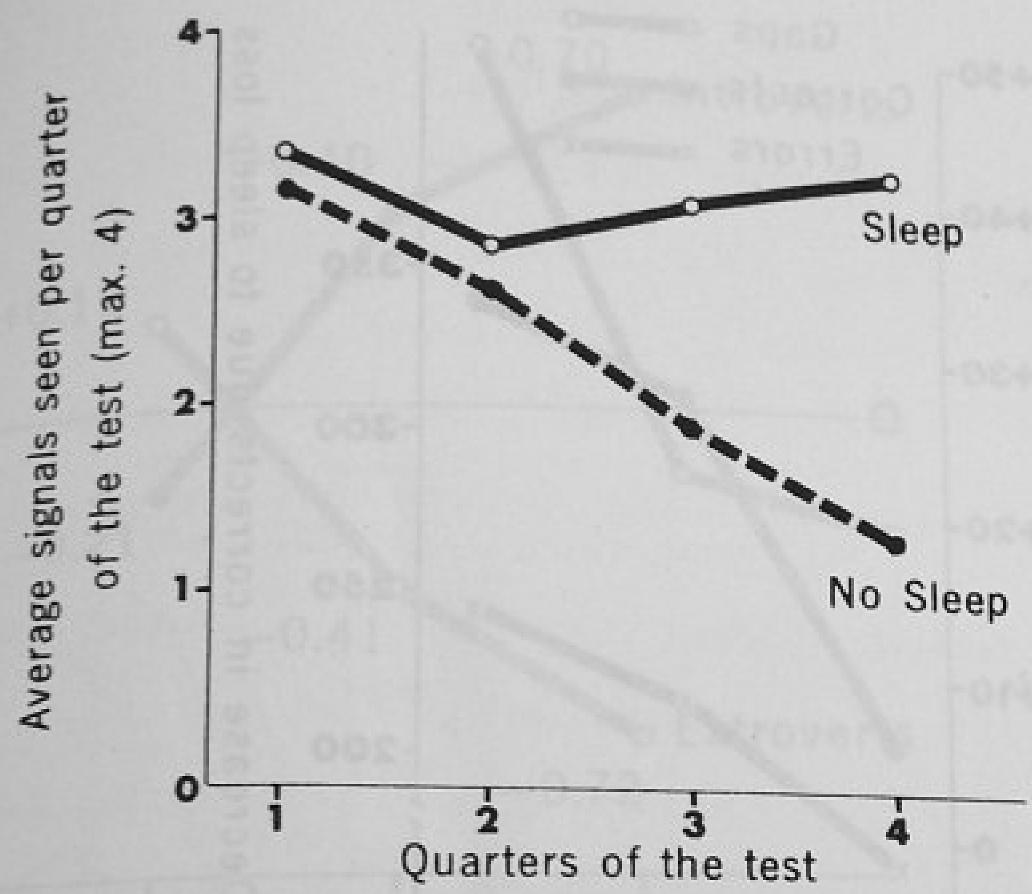

Fig. 1 Effect of lack of sleep on number of signals seen during a sensitive watch keeping task.

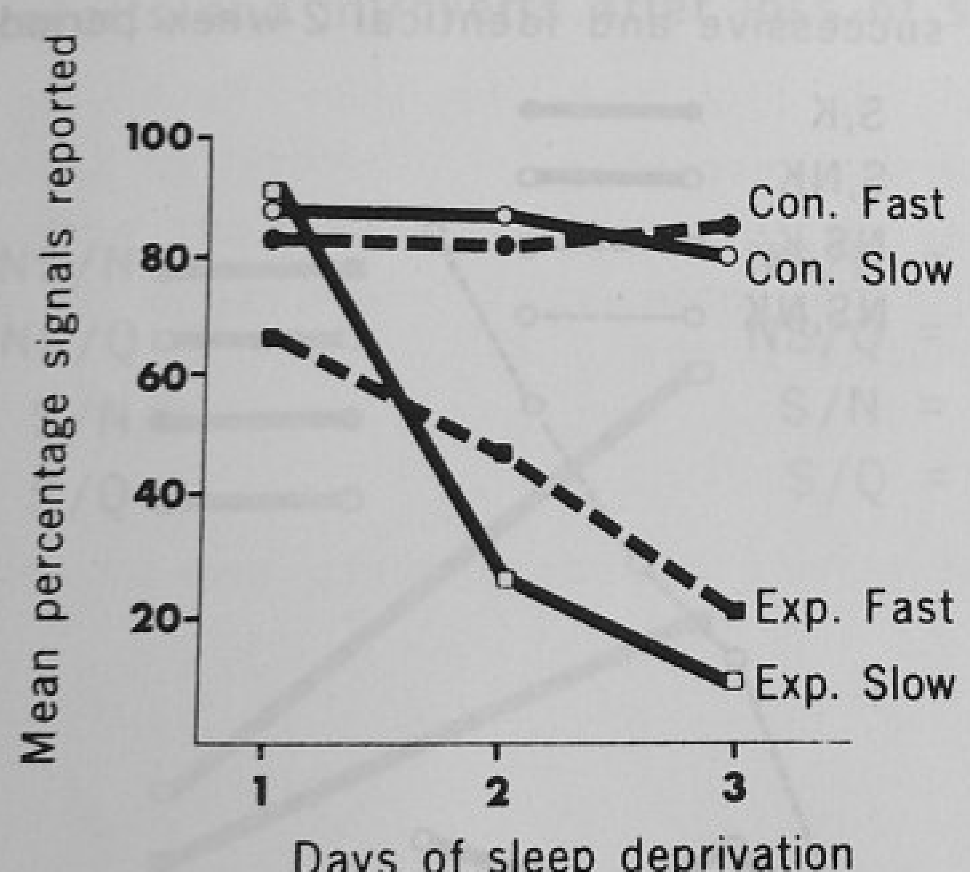

Fig. 2 Mean percentage of signals in 3 consecutive days. Effect of signal frequency after loss of sleep.

Note: 'Con' refers to control group i.e. normal sleep
'Exp' refers to experimental group i.e. subjects who lost sleep.

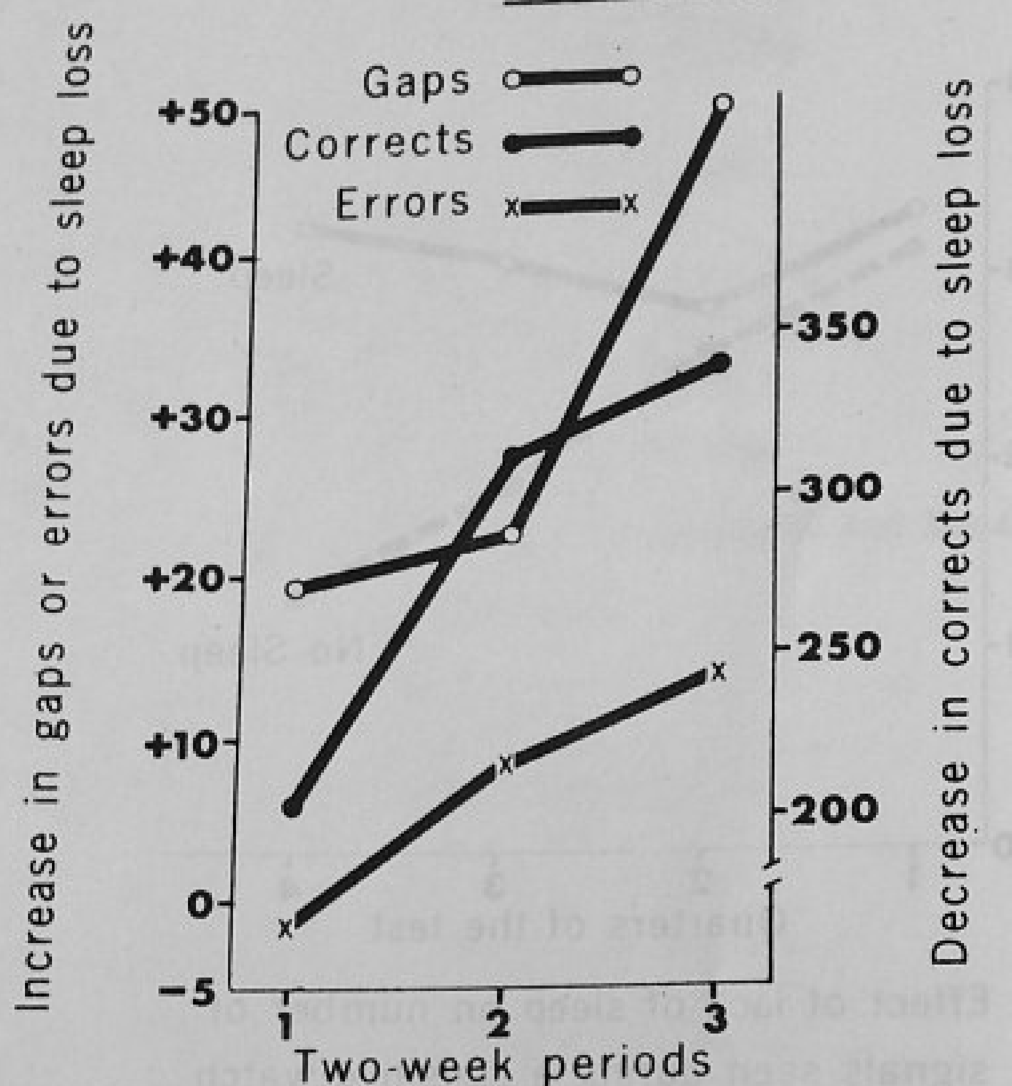

Fig. 3 Change in the impairment of performance due to lack of sleep over three successive and identical 2-week periods.

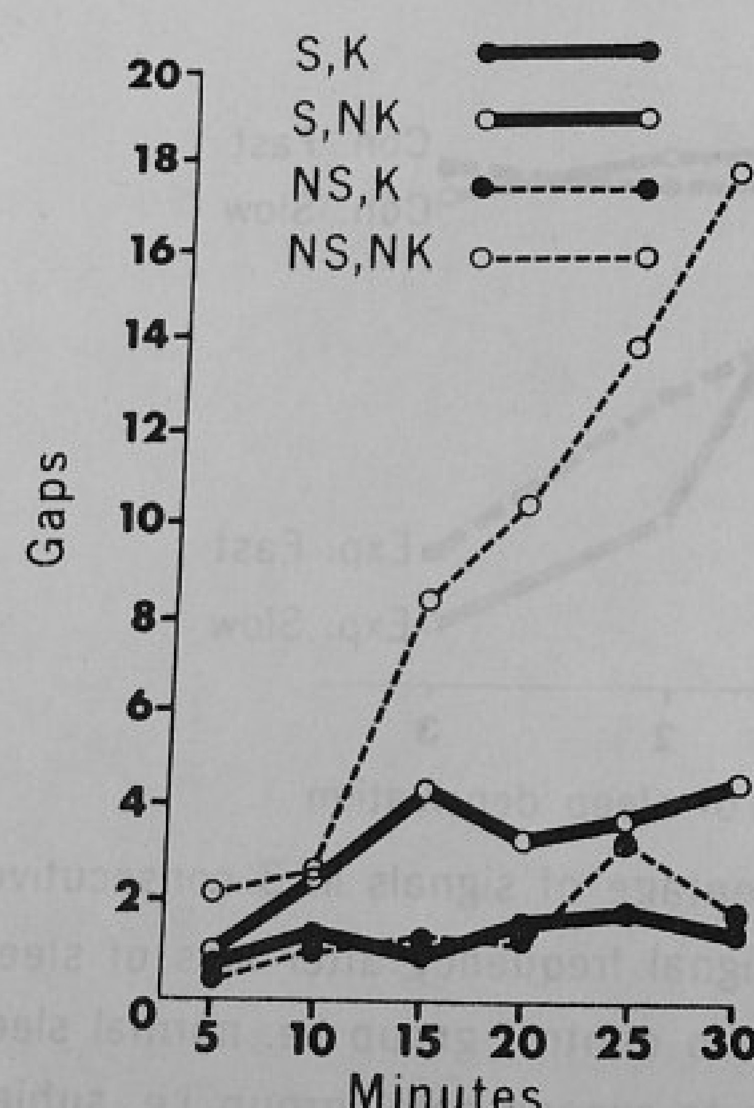

Fig. 4 Effect of one night's loss of sleep on gaps (reaction times over 1½ seconds) under 'knowledge' (K) and 'no-knowledge' (NK) condititions (S=sleep NS=no sleep)

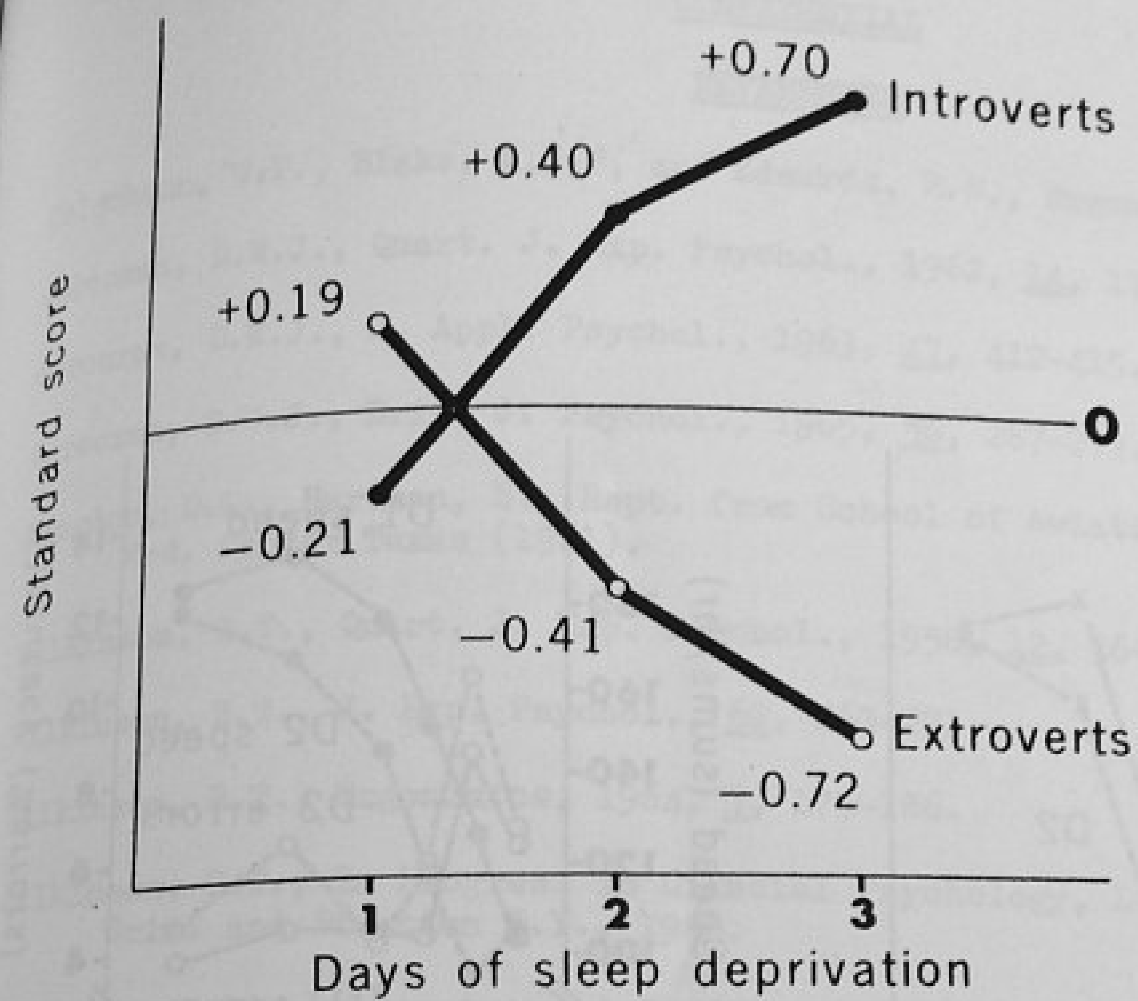

Fig. 5 Relative deterioration in performance of extroverts and introverts after loss of sleep.

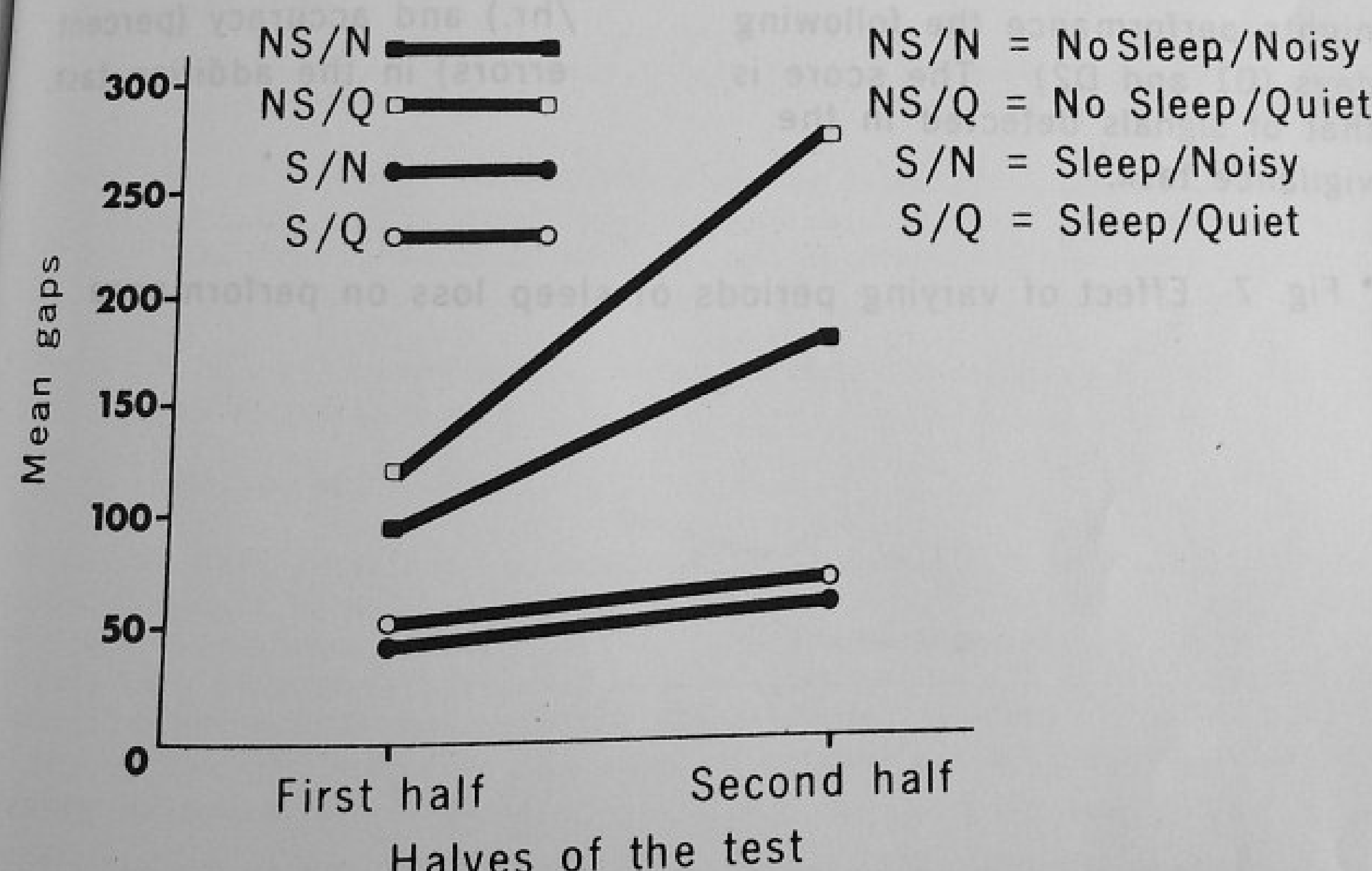

Fig. 6 Effect of noise on performance after loss of sleep.

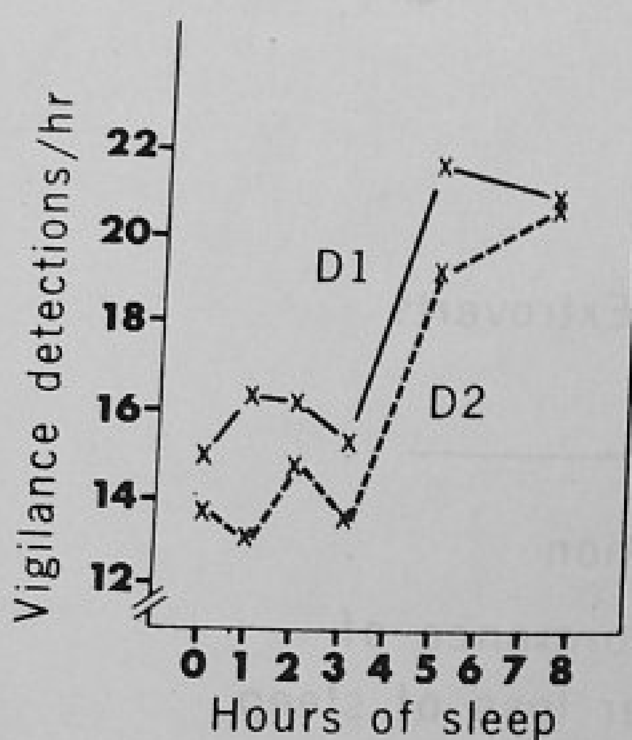

Fig. 7A The effect of 0, 1, 2, 3, 5, or 7½ hr. sleep on two successive nights performance the following days (D1 and D2) The score is that of signals detected in the vigilance task.

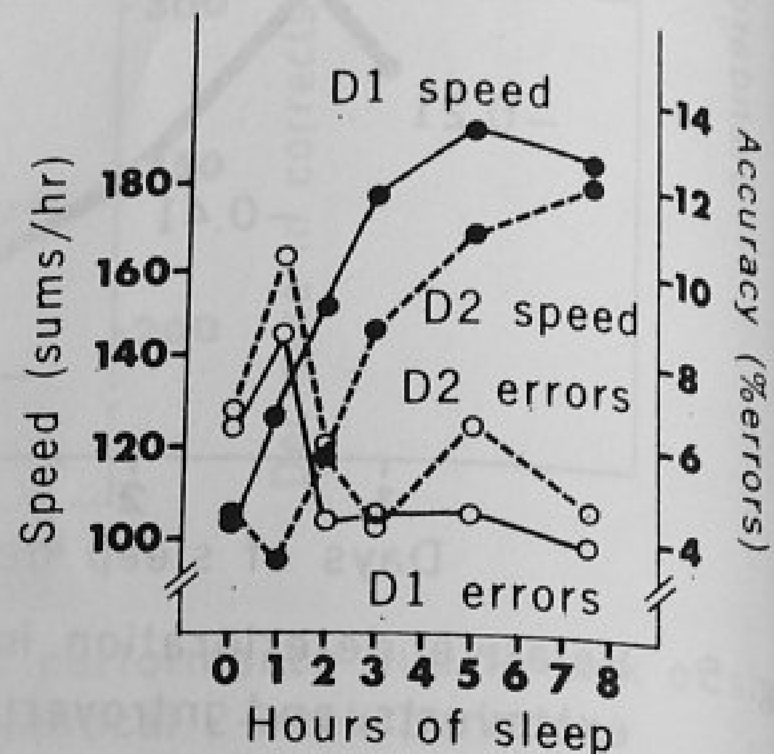

Fig. 7B As for Fig. 7A but with scores of speed (sums done /hr.) and accuracy (percent errors) in the addition task.

* Fig. 7 Effect of varying periods of sleep loss on performance

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Discussion

The discussion on Dr Corcoran's paper took place after the next paper on Multiple Task Performance by Mr Rolfe.

SIMULTANEOUS TASKS

Multiple Task Performance

by

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The object of this paper is to consider some of the problems which arise when the human operator is required to perform in a work situation which demands that he must control simultaneously the behaviour of more than one task. The problem is one which arises from the perceptual and motor limitations of the human operator when performing continous tasks. It has gained greater prominance as the military work situation has changed from one where the demands imposed upon man are primarily physical to one where the burden is more mental, demanding more covert than overt activity on the part of the operator. This condition has been aggravated by increased vehicle performance capability and the reduction in the number of participating crew members. In consequence, whilst recognition must still be given to human limitations imposed by the senses, used for gaining information, and the limbs, used for implementing decisions, the emphasis of the load has shifted to those central mechanisms which are responsible for organising information and decision making.

The human operator may be considered as a communication path (figure 1) with the following components:-

1. The peripheral recepters, whose function is to receive visual, auditory, tactile or pressure stimuli and convert them into nerve impulses.

2. Peripheral sensory nerves, which transmit the above impulses to the central nervous system.

3. Central nervous system, which may be loosely considered as the data processing unit which receives the incoming impulses, translates them into patterns of meaning, and determines the correct pattern of response related to the impulses.

4. Peripheral motor nerves, which conduct the decision bearing impulses to the muscles.

5. Muscles, which execute the response.

In the task situation, as Longton (1965) puts it, "the controller receives a random stream of data or pieces of information about the state of each item of equipment through one or more senses. There are, therefore, a number of sources of data each emitting a stream of bits of information and several senses of the controller may each be transmitting simultaneously a stream of stimuli to the brain. At any one moment, therefore, a number of sources and a number of senses are bombarding the brain with signals".

A multitude of stimuli from the environment are therefore continually impinging upon the operator. All these stimuli are potentially conscious but in fact:-

1. Many stimuli do not cross the threshold of consciousness. Some predetermined criteria imposed by the operator determines the value of the information and allows only that which is relevant into consciousness.

2. Accepting that certain categories of information are relevant there is no guarantee that the operator will be able to handle all this information in the form in which it is presented.

An example of the first category is the exclusion from consciousness of certain basic physiological functions which are deemed in the task situation to be totally irrelevant and therefore not required to be monitored, for example awareness of the current state of the right big toe. In the second category is the appreciation that in certain complex task situations, where a variety of information bearing imputs are present, there is no guarantee that despite the appreciation that they convey information, the operator will be able to accept and handle all the information sources at one time.

Interest in the problem of multiple task performance has therefore arisen because of the recognition that the operator can be over loaded with the result that performance undergoes a deterioration. Fitts (1961) lists this aspect of the task situation as one of the eight factors which can have an adverse effect upon skilled performance. The factors are:-

1. Information overload occurring with the necessity to respond simultaneously to information from multiple sources.

2. Danger or other conditions which result in fear, anxiety or other emotional responses.

3. Extreme environmental conditions such as cold, heat, vibration, intense noise and glare.

4. Noxious substances, including radiation effects.

5. Restriction of movement and lack of sufficient variation in sensory imputs.

6. Physical deprivations arising from restriction of food, water or air intakes.

7. Long periods of intense work without adequate rest cycles (fatigue etc).

8. Inability to practice a skill under the conditions necessary for maintaining adequate proficiency.

Whilst these above factors were originally set out with regard to the space environment the relevancy to the current military environment of this symposium will, no doubt, be appreciated. It is therefore to be stressed that this paper sets out only to consider one of eight possible factors which affect the quality of the human operator's response in complicated and demanding task situations.

In relation to the human operator's performance in complex task situations where overload may be present, Miller (1961) has listed eight fundamental mechanisms which are related to the effect of the stresses arising from an excess of information. The mechanisms are:-

a. Omission, simply not processing information.

b. Error, processing information incorrectly and then not making the necessary adjustment.

c. Queueing, delaying responses during peak load periods and then catching up during lulls.

d. Filtering, the systematic omission of certain categories of information, according to some sort of priority scheme.

e. Approximation, producing a less precise or accurate response because there is no time to be precise.

f. Multiple channels, synchronising responses to more than one task so that comparable responses can be made at the same time.

g. Decentralisation, which is a special case of multiple channels.

h. Escape, leaving a situation entirely or taking any other steps that effectively cut off the flow of information.

Similarly, Longton (1965) has argued that in operational research the indication that the total system is suffering from information overload can be diagnosed from the occurrence of:-

1. Delays in dealing with incoming information.

2. Distortion in the transmission of the information.

3. Loss of information.

The work of the experimental psychologist has provided a body of evidence to suggest that the nervous system acts, to a large extent, as a single communication channel. It has also been argued that this single channel is of limited capacity and that once one piece of information has entered the channel it remains closed for further transmission until that information has been processed and cleared via the effect or organs. The period of closure is looked upon as having a minimum duration of about 0.5 of a second (Welford, 1967). Adams (1966) has examined in some detail the mechanisms of motor responding and concludes that the single channel mechanism is not a true description of the limiting capability of the human operator to perform more than one task at the same time in all situations. In his view the limit shows itself where the tasks involved possess event uncertainty and the central mechanism is defined as a decision centre whose function is the resolution of choices. It appears to be the case that simultaneous task performance will be at its worst where both tasks demand the subjects attention because they both possess sufficient uncertainty in the occurrence of stimuli to prohibit the operator being able to anticipate the requirements of the task or build up some pattern of automatic response which does not depend entirely upon the cues obtained from external stimuli.

That the degree of impairment is related on the degree of uncertainty inherent in the stimulus situation was demonstrated by an experiment conducted by Bahrick and Shelley (1958). In the experiment concurrent performance of a visual and an auditory serial reaction task was measured at three stages of practice. There were four versions of the visual task, differing in the degree of predictability of the stimulus sequence. The degree of predictability had no effect on performance when the task was practised alone. But on those occasions when the secondary auditory task was introduced the greatest decrement in performance took place on the random version and progressively reduced through the lower redundant version and higher redundant version to the lowest decrement taking place on the repetitive version of the task (figure 2). The authors' concluded that the above results supported the hypothesis that the redundancy of stimulus sequences permitted a change from extra-ceptive control responses to proprioceptive control and that performance in time sharing situations was able to demonstrate the degree by which a task could become automatised.

What effect does learning have on the ability to handle multiple tasks? Bahrick, Noble and Fitts (1954) conducted an experiment to investigate the value of a second task as a measure of learning a primary task. Subjects were trained in either a repetitive or random version of a motor task and concurrent performance on an extra task in the form of an auditory arithmetical subtraction task was required either early or late in practice on both versions of the motor task. The results showed that arithmetic performance was comparable for the random and repetitive groups if the secondary task occurred early in practice. However, arithmetic scores were superior for the repetitive group when the second task was added late in practice. Scores on the motor task remain comparable whether the secondary task was added early or late.

Can a situation be attained where through repeated practice, it is possible to perform two tasks simultaneously without any deterioration taking place on either task? Baker, Wylie and Gagne (1951) examined the interference of one task on another after varying degrees of practice on the first. The task studied was a complex co-ordination task which involved learning a motor skill. The second task consisted of the appropriate forward or backward movements of a control lever in response to the occurrence of a light. The experiment involved six matched groups of male subjects and was divided into six stages. One group had the interfering task from stage one onwards, another group from stage two and so on. The results (figure 3) showed that the interfering task produced an increase in the time necessary to make control movements on the primary task. At each stage there was an initial sharp increase in the time score when the interfering task was introduced for the first time. Although performance on the primary task improved as practice with both tasks present continued it never reached the level of the performance of those subjects who were not given the interfering task.

To summarise, it would appear that when simultaneous tasks are to be performed, intereference between them must be expected and a deterioration in the quality of each task performance is likely to occur. The degree of intereference appears to be related to such factors as the level of learning achieved on the task and the extent to which the task can be performed automatically. The evidence available would indicate that even in the later stages of learning interference still takes place between tasks if both demand the operator's attention in order to resolve the uncertainties inherent in the tasks.

Merely to say that a task demands attention is an inadequate analysis of the potential load it will impose upon the operator. Few tasks, if any, demand that the operator must pay continuous and undivided attention to them. In many the task demands some sort of sampling sequence; the rate of which depends to a large extent upon the degree of predictability which is inherent in the task situation, the ease with which the response is capable of being performed in a fairly automatic manner and the two components of speed and load as related to the flow of information in the system. These latter two factors demand some additional consideration, for the implication is that the work stress imposed upon the operator is dependent upon, not only the degree of uncertainty existing in the stimulus information, ie the load in terms of the possible number of stimuli, but also the frequency with which the information is occurring. Cumming (1964) considered human performance in multiple choice response time situations and as response time rose as a function of the number of possible alternatives, demonstrated that a measure of the number of decisions which can be handled per unit time could be taken as an inverse function of the reaction time. Thus a marked fall in decision rate per second occurs as the number of possible alternatives in each decision rises (figure 4). The indication of this result is that in a situation calling for a high rate of decision making if the demands of that situation are to be met each decision must have as limited a number of alternative choices as possible. On the other hand if decisions do not have to be made under the pressure of speed the operator is able to handle situations in which greater uncertainty is present.

A further point to bear in mind in this context is the recognition of Poulton's (1958) proposition that "the absence of overt action does not necessarily indicate that a man's capacities are not being fully employed". The overt response in a task situation must be considered as the culmination of a series of covert activities which form the intervening action which succeeds the occurrence of a stimulus. Related to vehicle management by the human operator this final response must be looked at as the control component of the operator's task which is preceded by the more intellectual aspect of guidance. Carel (1965) argued that the operator's role in vehicle guidance implies the following activities:-

1. The selection of a goal (for example, the choice of a target or destination).

2. The measurement of the position of the vehicle relative to the goal.

3. The selection of a path to goal consistent with vehicle restraints.

4. The measurement of path error or the computation of predicted error at the goal, given present vehicle position and performance.

5. The selection and use of sensing and control mechanisms to realise physically the required path to goal.

Of the above factors it will be appreciated that four of the five are covert. The decisions related to the measurement of position relative to goal and the determination of an optimum path to achieve the goal must be arrived at before the operator is able to make any adequate control imput to the system. Interference between simultaneous tasks will occur, not only when the operator is actually controlling one or other of the tasks, but also when his attention is taken up in the resolution of the uncertainties involved in the decisions related to the achievement of task goal. As an example of the above situation the author undertook a series of experiments in the laboratory in which subjects were required to perform a simulated height changing task. At the same time subjects were required to perform a two choice response task. Analysis of response times on the second task showed that they underwent a deterioration in the speed of response, not only when the subject was actually levelling out at the required value but also in the period up to five seconds before the point where the subject initiated any levelling response. In that time it was argued that whilst no overt change in the subject's control response was apparent, the subject was involved in the decision making process related to the final levelling at the required goal. In the experimental context it is of interest to note that the same pattern of secondary task response was found irrespective of whether the task was presented visually or auditorially. This finding is taken as providing supporting evidence for the contention that the locus of the interference between the competing attention demanding tasks was at a central level in the operator's information handling mechanism rather than at a peripheral level.

A second aspect of interference between simultaneous tasks during the covert phases of the operation is in relation to the limitations of the human operator's short term memory. Current thinking about the mechanisms of remembering indicate that remembering has two stages. The first, known as short term, may be likened to a buffer store in a computer which holds the information for short period use. Later if the material has been found to be relevant and has lasting value, it may be transferred to a long term store where active rehearsal of it is no longer needed for instant retention. It has been shown that short term memory has a limited capacity and material in it soon fades unless reinforced by rehearsal or by its use in some other activity, we will be aware of this fact when given a new telephone number and finding that unless it is used or written down very quickly the number is not retained. Fading of information in short term memory also appears to be brought about by an interposed task, and it would appear that perception shares some of the brain mechanisms used in short term memory (Murdoch 1965). Thus, if an operator is trying to hold something in short term store, for example a new radio frequency and at the same time monitoring a CRT, it may well be the case that the operator will miss a signal on the display. Alternatively if he detects the signal and proceeds to identify it he may well forget the radio frequency he had stored in short term memory only moments before. It therefore seems best to design the task situation so that minimal reliance is placed upon short term memory, the operator being provided with more permanent aide memoirs wherever the task requires.

The design of the equipment can have an effect on the operator's ability to perform simultaneous tasks. Olson (1963) studied the effect of different arrangements of eighteen instrument displays not only on performance of the instrument task but also on the performance of a second task involving the subject in performing a simulated driving task while monitoring the visual displays. He demonstrated that not only did the different display arrangements affect performance on an instrument monitoring task but it also affected performance on the independent pursuit tracking task (figure 5). The author noted that his results indicated that the more data sources using the same sensory channel, the less information the operator could be expected to handle.

Combining a variety of information from a variety of sources onto one display may improve the quality of response. Regan (1959) compared performance of subjects when using individual or a combined display to perform two-dimensional tracking. He showed that, in both compensatory and pursuit tracking conditions, the combined display produced lower errors than the separate displays. Similarly with regard to controls the same experiment examined the effect of using individual controls for each axis of tracking or a two-dimensional joystick. Again it was found that the joy-stick control gave improved performance over the individual display. This experiment and that of Olson sited above lends credance to the principle that multiple types of information can be more adequately received and "processed" if presented through a limited number of channels. Similarly, if the method of response can be combined into one co-ordinated response device the demands imposed upon the subject appear to be reduced.

To summarise this paper it has been suggested that the human operator's ability to perform simultaneous operations is at its least effective when the tasks demand the resolution of uncertainty and where the speed of required response and the number of alternative probable solutions are high. It has been argued that the operator tends to act as a single channel mechanism and this mechanism is involved in the gathering of information and the making of decisions based upon that information.

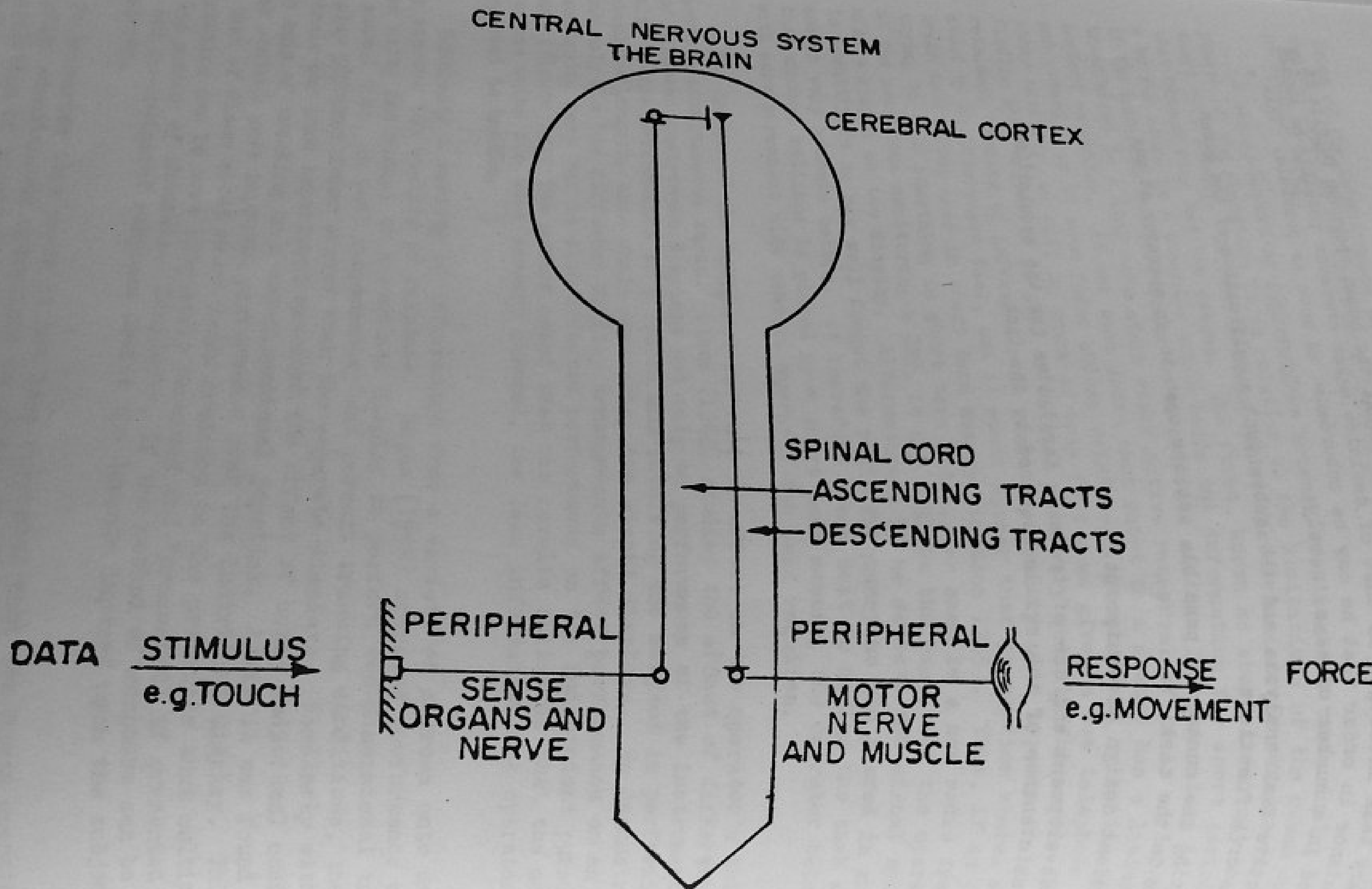
Whilst it is accepted that one of the major functions the human operator fulfils in the contemporary task situation is that of decision maker wherever possible he should be given assistance in order that he may be unburdened as much as possible. This can be achieved in a number of ways, namely:-

1. Effective task analysis and the subsequent specification of the human operator's functions.

2. Limiting the number of possible actions open to an operator at any stage in the task.

3. Efficient design of equipment.

4. The development and use of training facilities for the acquisition and maintenance of the skills required by the task.



The human controller.

Figure 1. Schematic model of the human controller (from Longton 1965)

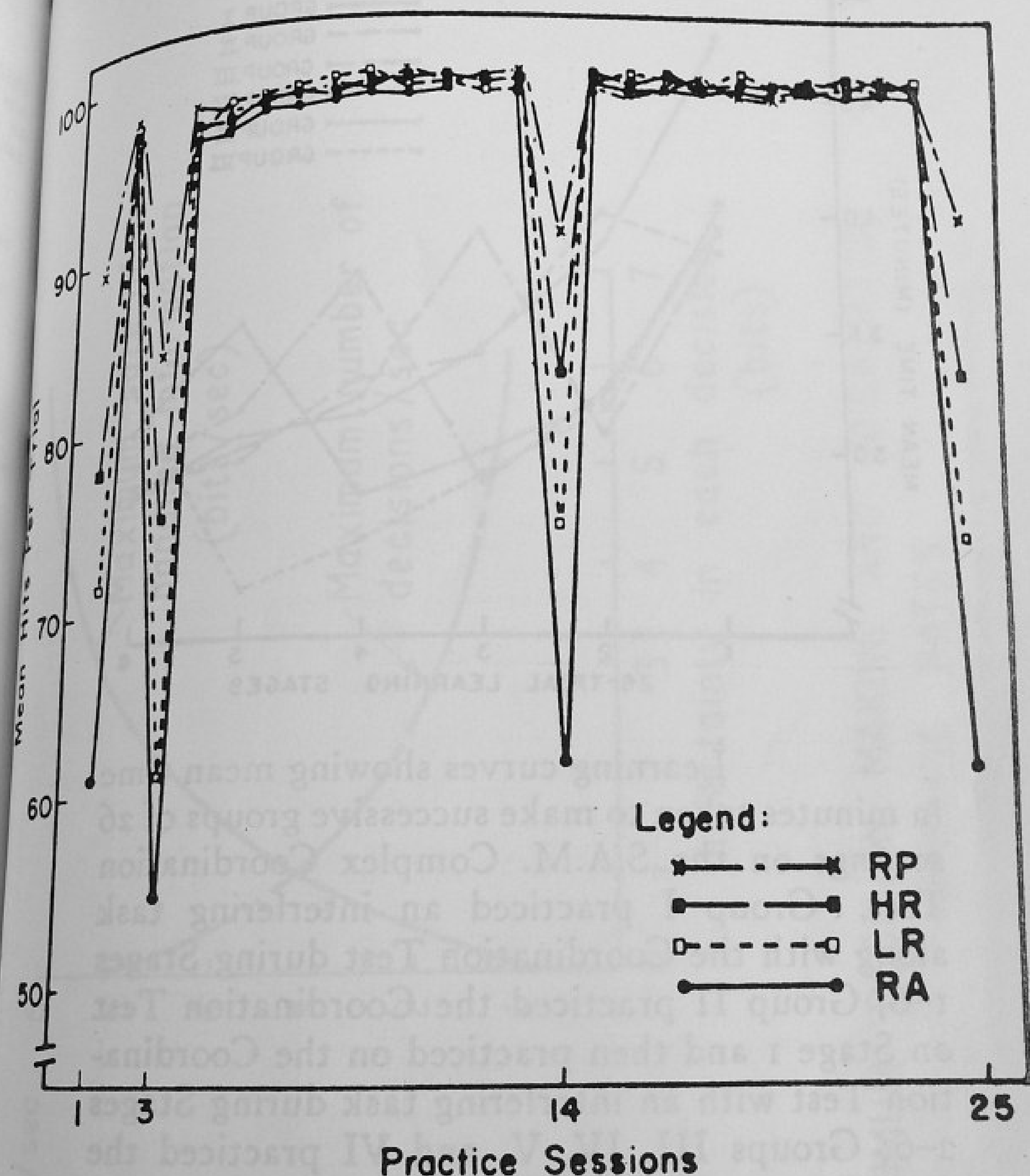
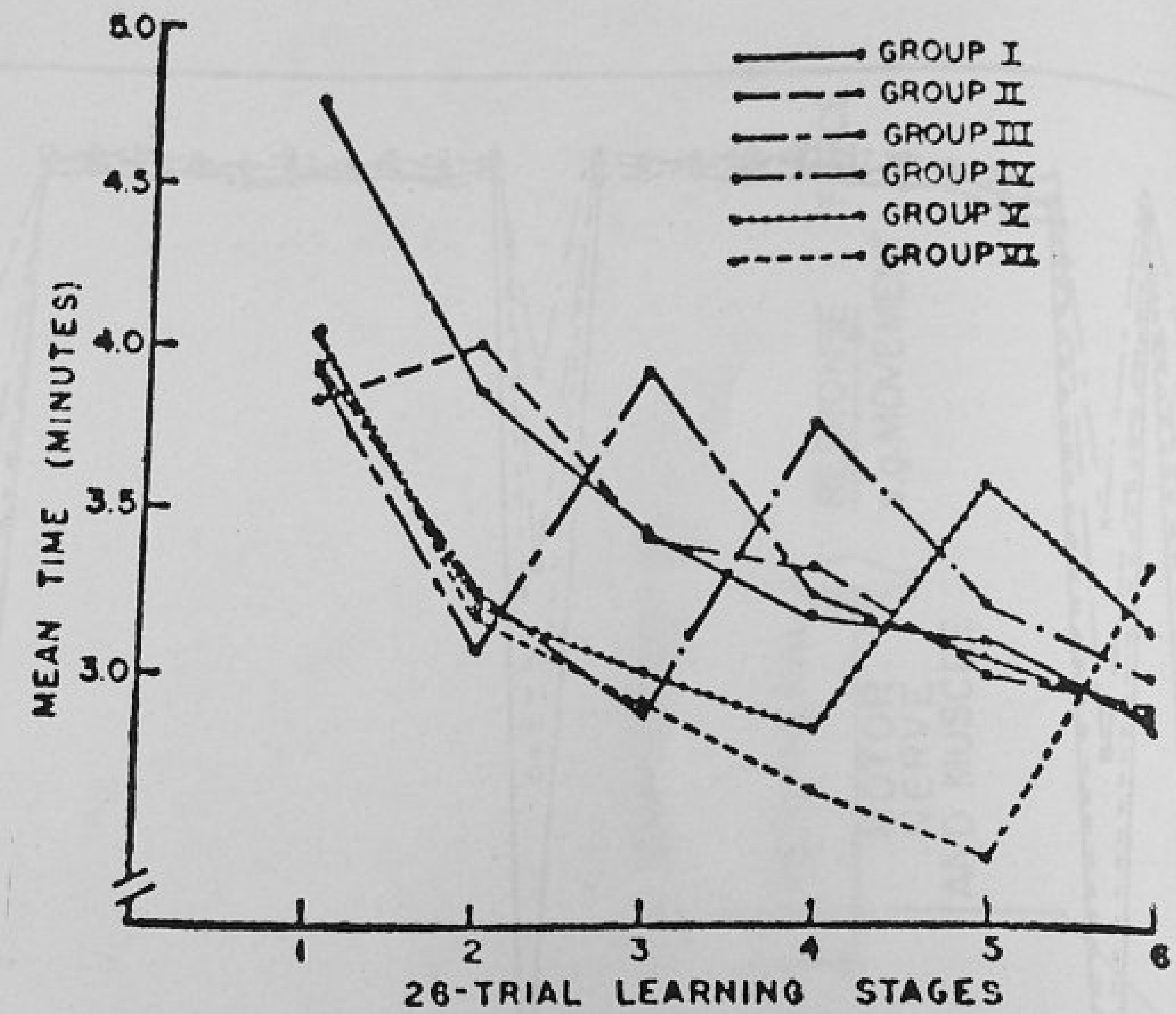
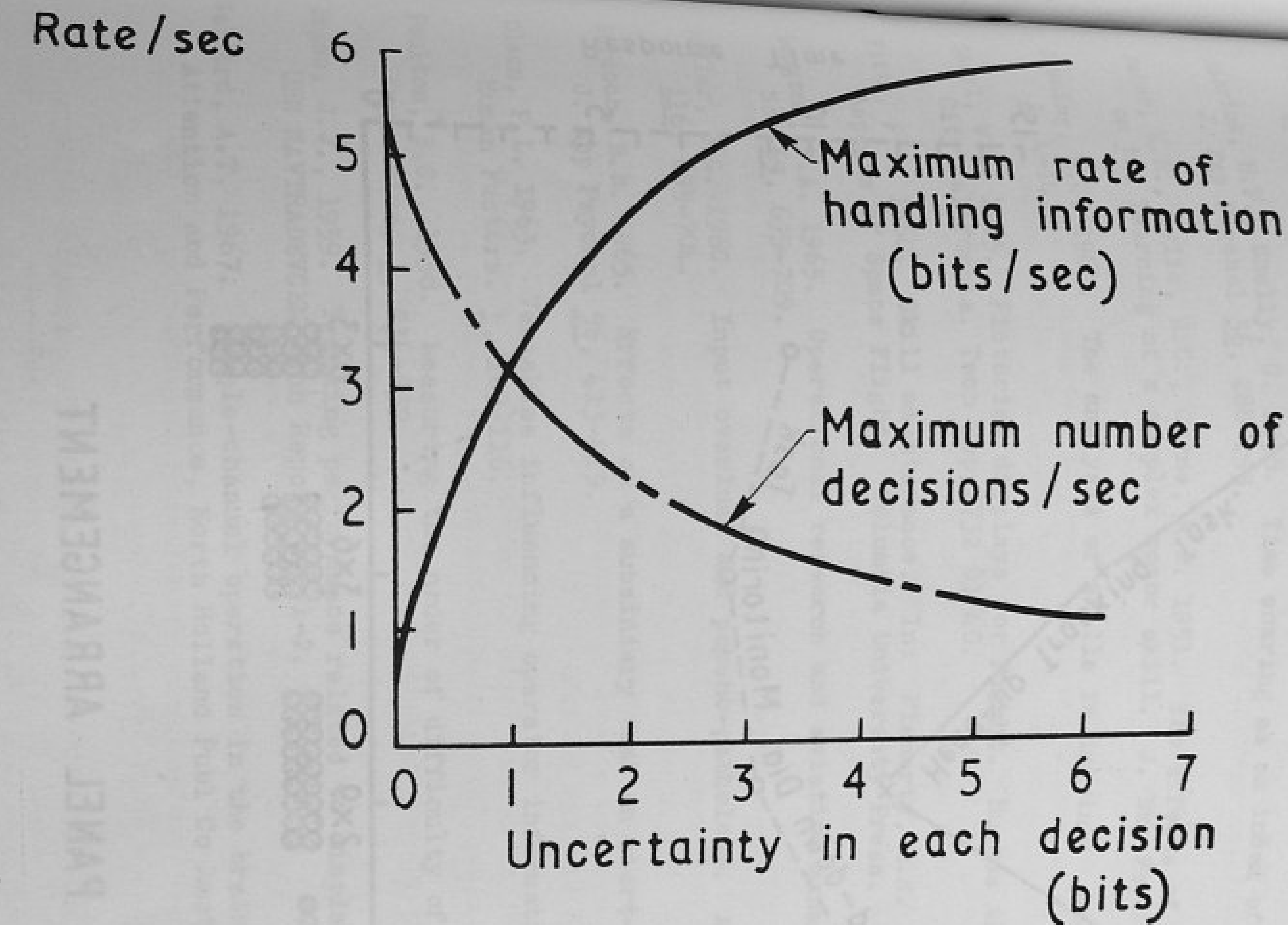


Figure 2. Results from the experiment of Bahrick and Shelly (1958)
Key to legend RP = Repetitive task
HR = High redundancy task
LR = Low redundancy task
RA = Random task.



Learning curves showing mean time in minutes taken to make successive groups of 26 settings on the S.A.M. Complex Coordination Test. Group I practiced an interfering task along with the Coordination Test during Stages 1–6; Group II practiced the Coordination Test on Stage 1 and then practiced on the Coordination Test with an interfering task during Stages 2–6; Groups III, IV, V, and VI practiced the Coordination Test during the first 2, 3, 4, and 5 stages, respectively, and then practiced the Coordination Test with an interfering task during the remaining stages.

Figure 3. Results from the experiment of Baker, Wylie and Gagne (1951).



MAXIMUM DECISION MAKING AND INFORMATION HANDLING RATES

Figure 4. Diagram showing the relationship between the speed of decision making and information handling rates (from Cumming 1964).

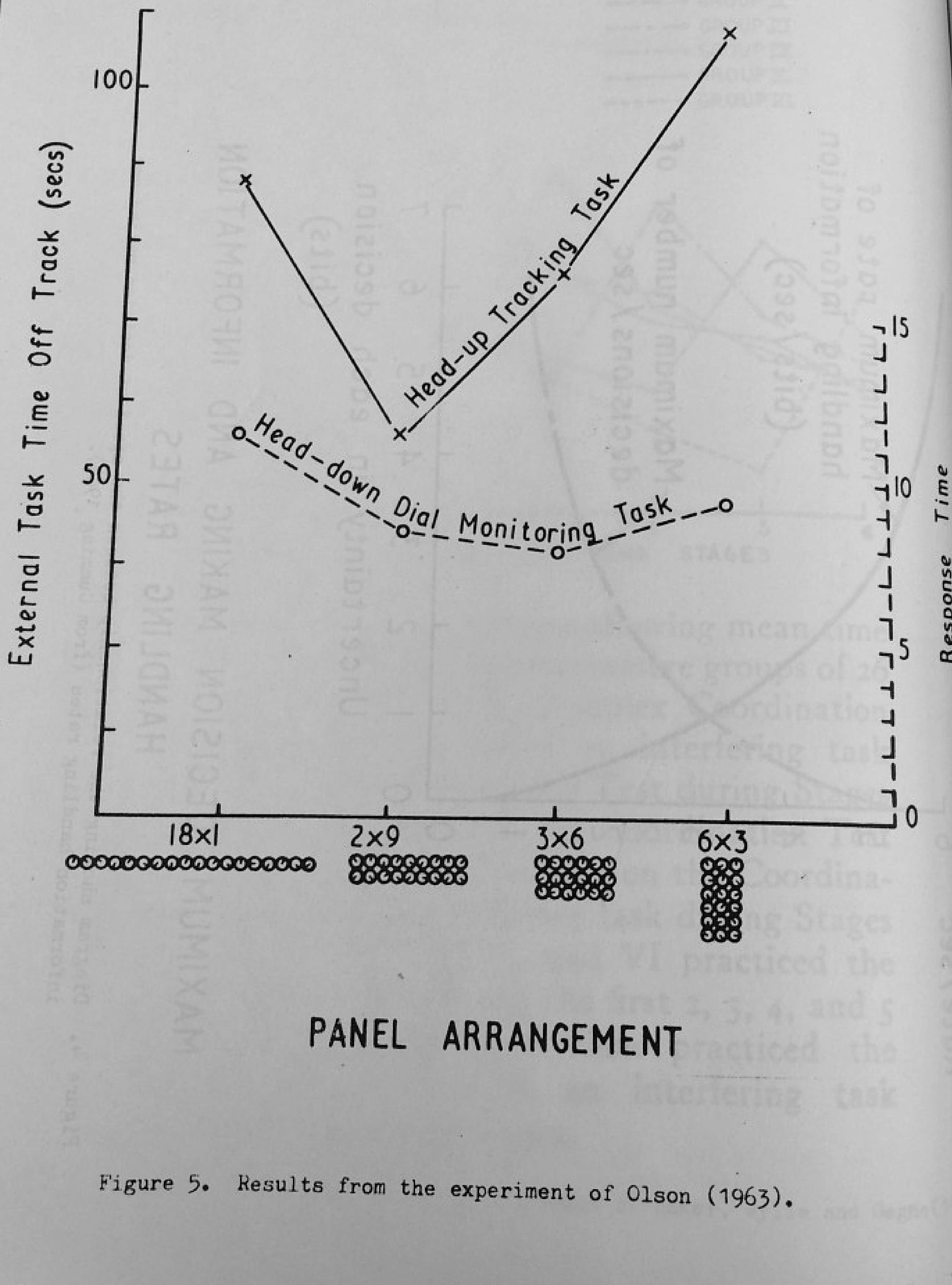


Figure 5. Results from the experiment of Olson (1963).

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Discussion (Two papers)

Sustained operation and the need for sleep; and simultaneous tasks.

The Chairman, Dr PENTON, opened the discussion by stating that a thorough analysis needed to be made by the users in order that a delicate balance might be achieved between the four points that concluded the last paper.

Lt Col BEARDSWORTH asked how many simple automatic tasks could be dealt with in conjunction with a decision making task.

Mr ROLFE replied that this depended on whether the automatic tasks were an output of the decision or whether they were performed at the same time. If the latter they might be subject to delay or approximation. In respect of coping with multiple tasks there were two schools of thought among psychologists: those who considered this to be an innate ability placed the emphasis on selection; whereas those who considered it to be an acquired skill placed the emphasis on training. He mentioned the work of Brown at APRU who could predict at an early stage those who were likely to pass a bus driving course from a study of the supplementary tasks that could be carried out in conjunction with driver training. He gave warning against providing the tank commander with too much information. This was supported by the work of Longden at London Airport in relation to ground control that had resulted in information now being provided to the controller on a "need-to-know" basis having been filtered at a lower level.

Gp Capt WHITESIDE expressed surprise that the effect of thermal environment on operator efficiency was not included in the programme. Dr Corcoran had described an improvement in performance in sleep deprived men by the use of a noise stimulus. He (Whiteside) had observed a similar effect when civil aircrew, who may have been deprived of sleep, deliberately lowered the temperature on the flight deck. He wondered if there was a need to control the thermal environment in AFVs in order to bring about a similar effect.

Dr CORCORAN replied that he had found no improvement or impairment of performance had occurred in sleep deprived subjects with an increase in temperature.

The Chairman, Dr PENTON, welcomed Gp Capt Whiteside's comments. APRE had been concerned with control of thermal environment in tanks and he looked forward to closer co-operation with IAM in the future on these problems.

Mr LARGE pointed out that the trouble in many AFVs was over stimulation in the form of heat, cold, noise, vibration and cramp.

Lt Col HAWKINS asked if use of noise stimulation described by Dr Corcoran was valid in an environment with a high level of noise.

Dr CORCORAN replied that in certain circumstances, for example where a "cat-nap" might be beneficial, it might be helpful to reduce the noise level. He added that the benefit or otherwise of "catnaps" had not been studied.

Capt CHESHIRE asked whether any difference in performance had been found between subjects with no sleep and those with interrupted sleep.

Dr CORCORAN replied that no adequate experiments had been carried out on this topic. Experiments were at present being undertaken to study the differences in performance between subjects recently woken up and those kept awake. It seemed likely that the results would be inconclusive and the crucial question was likely to be whether there would be differences between the two groups on the following day.

NOISE

Noise
by

M.A. Elwood, Army Personnel Research Establishment
Farnborough, Hants

Noise has been defined as unwanted sound. Apart from the lack of reasons why noise is undesirable, such a simple definition is confusing when linked with Impulsive Noise produced, for example, by gun fire which to a Physicist is not sound. There are two distinct forms of noise in man-made environments: continuous and impulsive noise. These must be measured by different instrumentation systems, and in spite of a common unit of pressure measurement, quite distinct exposure criteria are appropriate.

The aspects of noise which concern the vehicle designer are firstly the potential risk to health and secondly any effects upon the performance of personnel. The extent to which the noise generated by armoured fighting vehicles is an annoyance to local population must be considered in relation to legislation on this topic in different countries, and will not be considered in this paper. Below this level however there is the noise which may be described as the "signature" of an AFV, which may be very important as a factor in its detectibility by a potential enemy.

It has been stated by Carpenter 1962 with regard to the effects of noise on performance that no effect had so far been proved with noise less than 90dB. Above this noise level in tasks which require continuous attention an increase in errors and in failures to notice unexpected events has been demonstrated experimentally, but it is difficult to make any general statement. The best solution is to study the effects of noise on the performance of the specific tasks under consideration. One task which all crew members of the AFVs undertake is verbal communication. The measured noise levels within tracked AFV indicate that decreased intelligibility of speech may be expected, even though the military situation has the advantage of a fairly restricted vocabulary. Both the effects on performance and interference with speech are expected at and above the levels stipulated for hearing conservation therefore this paper will concentrate on the criteria for acoustic trauma and the associated exposure limits.

Noise Measurement and Damage Risk Criteria

Continuous noise is measured with a sound pressure level meter giving a root-mean-square value for the pressure at a given frequency or frequency band. The film to be shown later will illustrate the techniques used. The exposure limits for the conservation of hearing vary among different authors, but those given by W. Burns (1) are currently used by the Royal Navy and the Army. It is a conservative criterion to protect 95% of the population and indicates the pressure levels within one-third octave bands which are permissible without ear protection for the durations given. Other exposure limits have been published notably in the USA (2) which aim to protect 75% of the population (see fig 1).

It is not appropriate to use the sound pressure level meters described above to record the peak transient pressure levels of impulsive noise. In the last few years the use of condenser microphones with persistent trace oscilloscopes and recording cameras has been widely accepted. Although it is possible to measure the rate of rise with sophisticated instrumentation, for all practical purposes the rise of gun fire pressure pulses is regarded as instantaneous. The important parameters appear to be the peak transient pressure level and the time for that pressure to decay either to the original ambient level in the case of simple pulses, or to one-tenth of the original pressure level (20dB reduction) when there are subsidiary pulses and oscillations (see fig 2).

While it may seem that impulsive noise problems are more the concern of weapon designers rather than vehicle designers, it must be remembered that the Instructor and more particularly the Commander are exposed during tank gunnery training primarily because their vision from within the tank is inadequate. Hence solution of this particular noise problem may rest with the solution of the all round vision problem from tanks and other AFV.

When vehicles are used, perhaps not for the purposes for which they were originally designed, criteria for exposure of personnel to impulsive noise are important for example when infantry support weapons are fired from armoured personnel carriers. In these circumstances one must consider not only the hazard to hearing, but also potential hazard such as ear drum rupture and possibly lung injury. Such blast injury may not seem appropriate under a heading of noise, but should be included in the definition of impulsive noise. The exposure limits for blast injury as far as they are known, refer to single exposures in contrast to the criteria for acoustic trauma for which one hundred rounds per day is anticipated (see fig 3).

In the field of blast injury measurements have often been made with directional blast gauges. Indeed the orientation of microphones for impulsive noise measurement can be important, in parallel with the different susceptibility of the human ear depending on its orientation to the source. Often pressure measurements are required for the indentification or evaluation of potential hazards. It is vitally important that the technique of measurement used in defining any criterion for human safety is the one selected for the evaluation. For lung injury or ear drum rupture measurements have been made with direction sensitive blast gauges in the side-on mode. Microphones have been employed more often in relation to acoustic trauma in the manner already described. Both techniques suffer from difficulties in interpretation when the potential hazards to be studied occur in restricted of confined spaces. Relatively low pressures can be extended in duration by reflections so that it is possible to approach an area of ignorance concerning the threshold of lung injury. This has occurred with some tactical situations during the introduction of new weapons and in the potential use of an infantry support weapon from an APC.

Sensitivity to Noise

Crews of AFV are subjected to mixtures of continuous and impulsive noise which do not form consistent daily patterns over a prolonged period of time. While there have been some attempts to produce a noise dose meter for continuous noise, this has not been entirely satisfactory, and for the moment does not accept impulsive noise inputs. A simple means of monitoring the total exposure of soldiers to noise is needed. In this context it may be appropriate to refer to the wide variation in human sensitivity to noise. Work at APRE has shown that exposure without protection while firing a Self Loading Rifle produces 20dB of temporary hearing loss in 25% of a large sample of soldiers. This amount of temporary hearing change is produced by as few as twenty rounds, while a further quarter of all men required either 60 or 120 rounds to produce such a change.

About one half the population must be regarded as relatively insensitive. A few of the sensitive men showed changes as high as 50dB beyond which the risk of incomplete recovery increases rapidly, leaving a degree of permanent damage (see fig 4).

Men do not remain consistently in these gradings with time but the number who change in one direction to become more sensitive is balanced by the number who change in the reverse direction to become less sensitive. It is estimated that a sample of at least 18 men must be taken to ensure having at least one man from the sensitive (Grade 1) group. A number of estimates have been made of human sensitivity to continuous noise, Glorig 1957 and Leeuwen 1958 both suggest that 20% of the population are sensitive to noise. At the present time it is not certain that those who are sensitive to continuous noise are also sensitive to impulsive noise. Indeed APRE in collaboration with the Institute of Sound and Vibration Research, Southampton University, has been able to collect a little negative evidence on this point. On these grounds therefore, there would seem no future in any attempt to screen out sensitive men from the army, or any of the other services during recruitment. The solution to the problem must lie in making the user aware of the risks and in the provision of adequate ear protection.

Ear Protection

There is a wide variety of ear protection available (see fig 5). For the British armed services an insert ear plug is used under the commercial name "Sonex", which is very similar to the V51R Ear Plug used in the USA. Where greater protection is required an ear muff is used. This was originally developed as the RAF Ear Defender Mk III which did not contain any communication system. Later versions have incorporated ear phones with or without attached microphones for use on aircraft carriers, in ships engine rooms and with the 105mm Self-Propelled Gun, as well as for the RAF applications. The comparative attenuation of these forms of ear defender also indicate that the very low attenuation provided by dry cotton wool should be regarded as an inadequate and dangerous alternative. However where a disposable ear plug is required the use of glassdown ear plugs has proved successful. These give greater attenuation equivalent to the majority of commercial ear plugs. If the cotton wool is impregnated with vasoline or glycerine its attenuation properties are considerably improved, but the preparation time is at least ten minutes and the end result is subjectively very much less acceptable. The communication head set worn by tank crews should if fitted correctly give about the same attenuation as the ear plugs, but as worn it is very often loosely fitted over the ears with very little of its available attenuation actually used.

Use of ear defenders without communication systems necessarily involves a reduction of communication by normal speech as assessed in relatively quiet conditions. It has been shown that as noise increases the intelligibility of speech is actually better while ear plugs are being worn than without ear plugs. This is only in intense noise above 100dB and is a comparative statement (Kryter 1946). It is important to remember that the degree of communication in these circumstances will never be good, and that communication systems are necessary if a high degree of speech intelligibility is required. Such a solution is available in tanks or other AFV carrying a permanent crew where a power source is available. A recent development by the Ministry of Technology, ERDE, has been a battery operated communication system in a muff protector. There are two microphones, mounted externally on the muffs, operating through one-to-one gain transistor amplifiers to ear phones inside the muffs. The amplifiers are peak-limited and will not transmit sounds above 95dB. In principle these protectors are ideal for impulsive noise exposures on ranges remote from power supplies or even for instructors standing on the rear engine decks of a tank controlling range safety and instructing the crew in gunnery. It is known that the hearing ability of gunnery instructors in general deteriorates quite rapidly to the state where they can no longer perform their duties efficiently while wearing muff type protectors without communication aids. In some cases this may be true even with the moderate attenuation of Sonex ear plugs. In principle therefore although the battery operated system developed by ERDE is expensive, about £25 each, this would be a small price to pay for ensuring the efficient instruction of crews and that there was no further deterioration in the hearing capacity of instructors. Provision of such ear protection/communication systems is a fraction of the cost of new weapons or vehicles. This system while it is good for impulsive noise exposure will transmit continuous noise up to its cut off point. In these circumstances it would be better to switch off the communication system and use the protection available in the muffs alone. It may be that such a system could be linked with head sets in new radio communication systems as a third alternative to supplement radio transmission or intercommunication within the vehicle. Whether this is done or not it would appear highly desirable that either a boom microphone or a throat microphone be developed for consideration by the RAC in place of a hand held microphone used at present, which demands the use of a hand throughout the period of transmission.

It is understood that discussions have taken place to ensure compatability between ear defenders, communication, head protection (helmet) and sighting systems in AFV. The position is not so easily solved for those occupants of AFV who may be required to dismount rapidly, for example the infantry section in the next generation of Armoured Personnel Carriers or their equivalents. The dismounted infantryman does not need head set communication, except the specialist radio operator. In general all men will require no covering over their ears, but will be wearing a ballistic protective helmet. While occupying their personnel carrier it would be possible to give sufficient ear protection using Sonex ear plugs, but these will probably not permit adequate speech communication in the noisy environment of the moving vehicle. For the infantry section mounted in its armoured personnel carrier it may be possible to provide ear protection and communication through a flexibly mounted hood to fit over the man's head while wearing the combat helmet he will use when dismounted. Such a hood could remain attached to the vehicle so that the man is not delayed by the need to remove it on the order to dismount. This approach may be evaluated in comparison with other solutions. In designing future armoured personnel carriers it is essential to consider the nature of the infantry task and to decide whether he will be required to fire any or all of his weapons from within the vehicle. Only in this way can we avoid the problems associated with the many modifications carried out to our current FV432 to permit the firing of the infantry support weapons from it. If it is accepted that the infantry section will use weapons from the vehicle and that the Commander must have fire control over them, it is considered essential to have a direct intercommunication system between him and each occupant of the vehicle. It is possible that APRE may conduct some tests to evaluate this situation using current personnel carriers as experimental vehicles.

Unlike anthropometry, where measurements of the human body can be applied to the drawing of a future vehicle and checked for the space available to a man, it is not currently possible to apply knowledge of human exposure limitations to noise or other conditions such as heat cold and vibration to the engineers' drawing. These exposure limits may only be used against measurements from a prototype vehicle. However it is possible to advise engineers and make them aware of the points already discussed in this paper so that an appropriate combination of ear protection and communication is incorporated into future vehicles. If present trends continue, it will be possible to say without much fear of contradiction that future vehicles and weapons are likely to be noisier than the ones in current use. However the prediction of noise, vibration or heat levels in future vehicles from information available on the drawing board, may be possible, since predictions for individual structural components appear possible already. Mercer and Seavy 1967 have proposed a method predicting natural frequencies and normal modes of skin-stringer panel constructions. It is suggested that any available methods of prediction such as these are gradually incorporated into a complex system using computers for the calculations involved, rather than taking the comfortable assumption that it is impossible to apply human factors to engineering design in early stages.

Conclusions and Recommendations

Ear protection is necessary against both impulsive and continuous noise in current armoured fighting vehicles to avoid acoustic trauma and decrements in performance. A simple means of monitoring the total daily exposure of individual men is needed.

Direct communication systems appear necessary to enable the commander of future APC to exercise fire control over the carried infantry section if and when they use their weapons from the vehicle.

The mutual compatibilities of helmets, ear protection, communication systems and AFV sighting systems should be examined and agreed by both the users and also by the designers of the respective items.

A human factors agency may support the design of AFV at three levels, prototype evaluation, advice in detailed design stages, and, possibly, by estimating crew conditions before prototypes are built.

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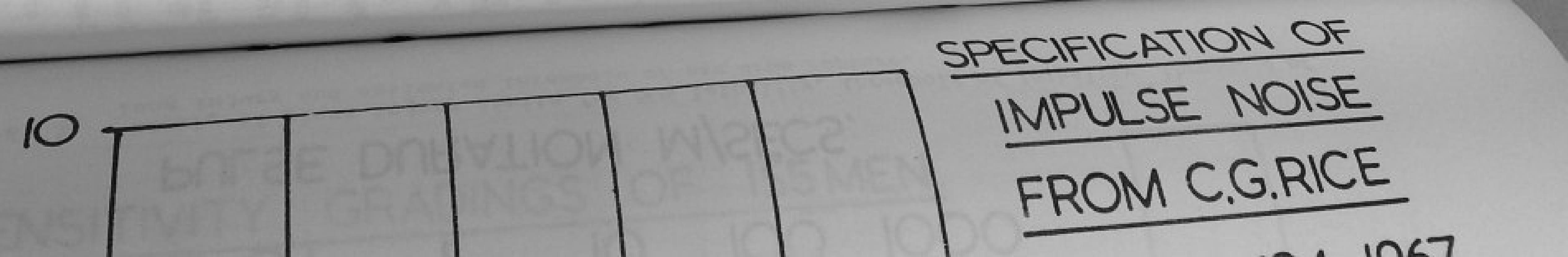
Centre Frequency HZ (C/S)	Sound Pressure Levels at Specified Durations DB						
	7 min	15 min	30 min	1 hr	2 hrs	4 hrs	8 hrs
63	122	116	110	106	103	100	97
125	116	110	104	100	97	94	91
250	112	106	100	96	93	90	87
500	109	103	97	93	90	87	84
1000	107	101	95	91	88	85	82
2000	105	99	93	89	86	83	80
4000	104	98	92	88	85	82	79
8000	103	97	91	87	84	81	78

Fig. 1. Exposure limits for a conversation of hearing in continuous noise (after Burns, 1968).



103	97	91	87	84	81	78
				85	82	79

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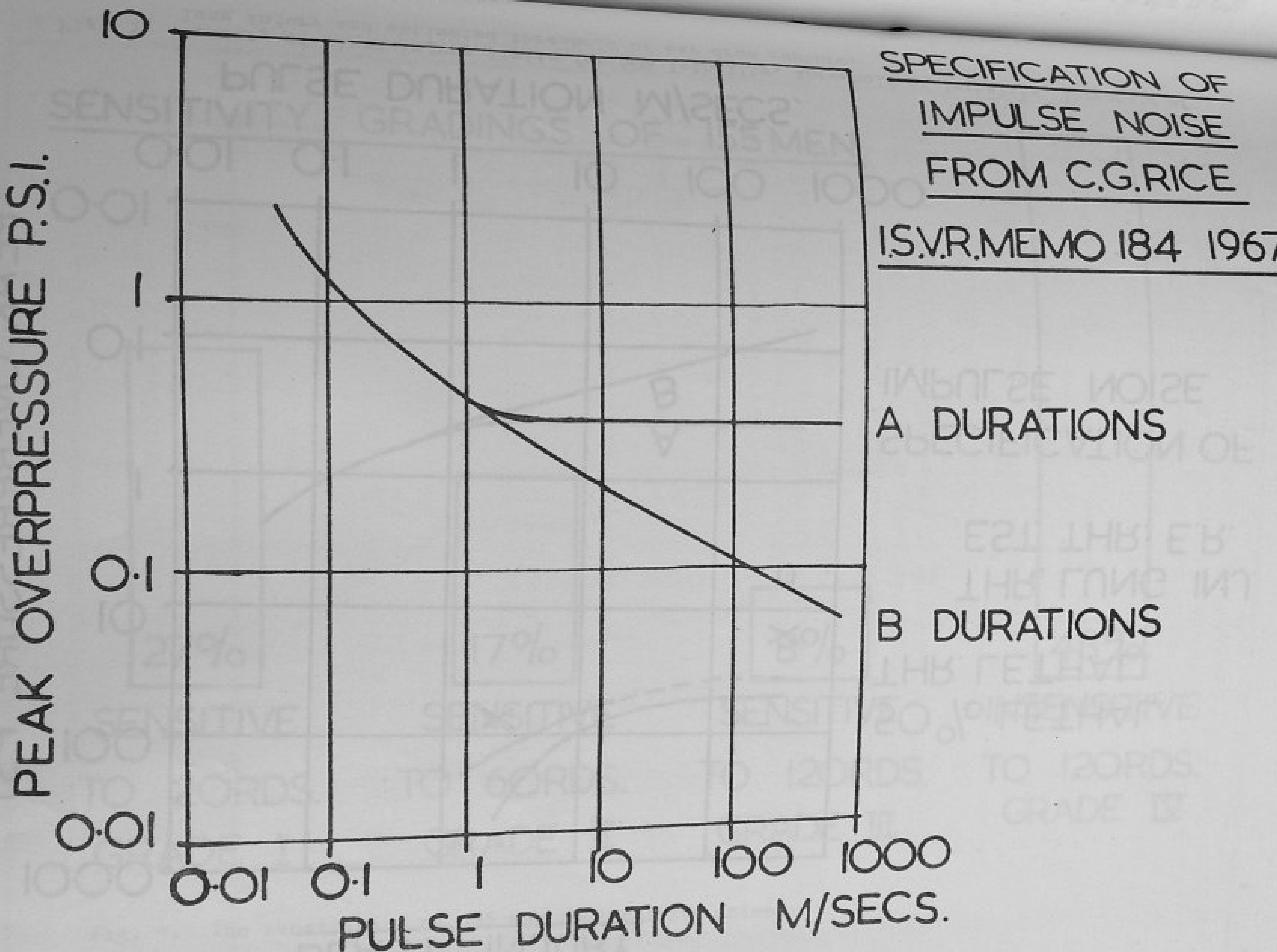

Fig. 2. Damage risk criteria and exposure limits to impulsive noise.

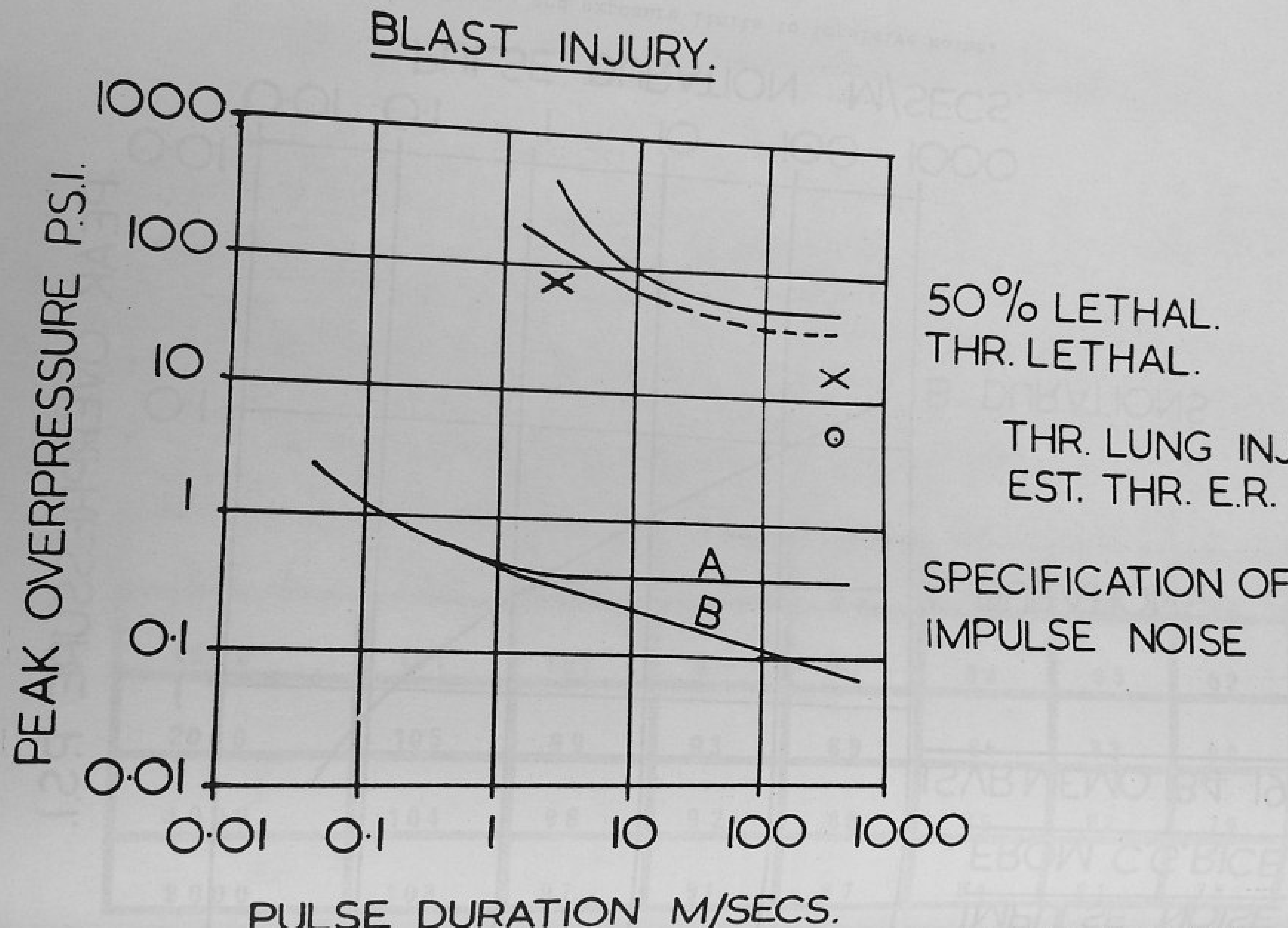

Fig. 3. Summery of blast injury limits for 50% lethality, threshold of lethality, threshold of lung injury and estimated threshold of ear drum rupture.

Fig. 3. Summery of blast injury limits for 50% lethality, threshold of lethality, threshold of lung injury and estimated threshold of ear drum rupture.

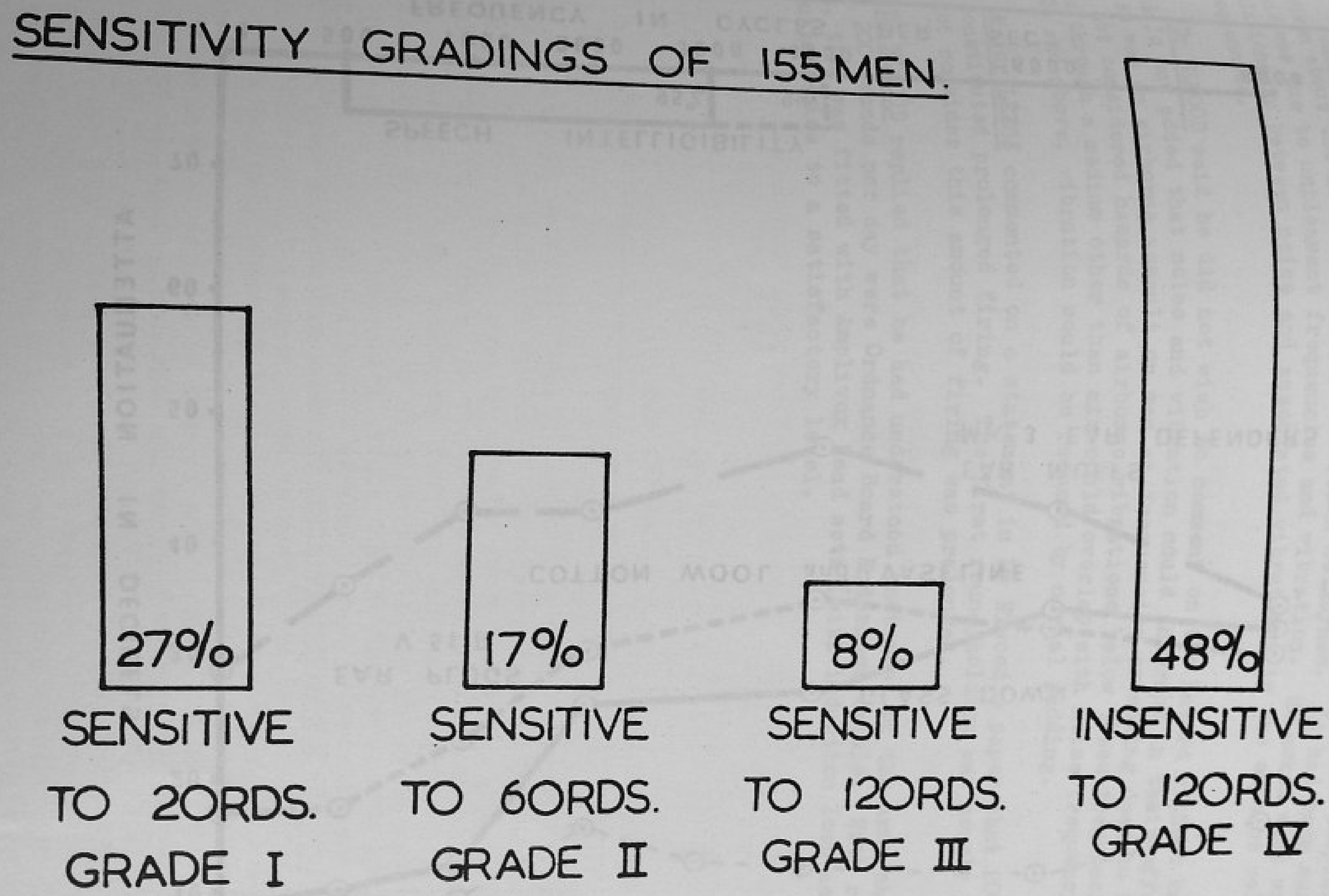

Fig. 4. The sensitivity of 155 men to impulsive noise.

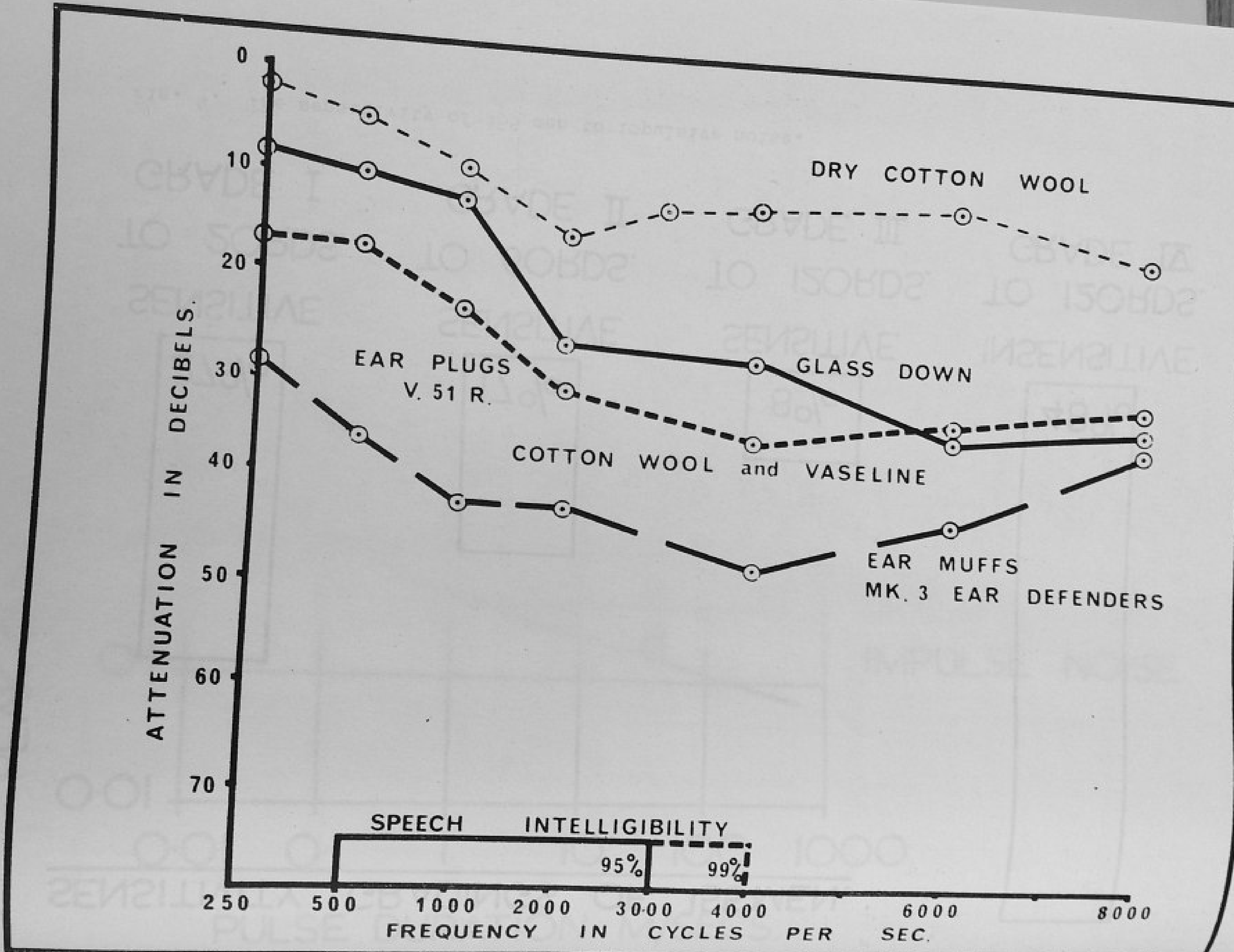

Fig. 5. The attenuation of ear defenders.

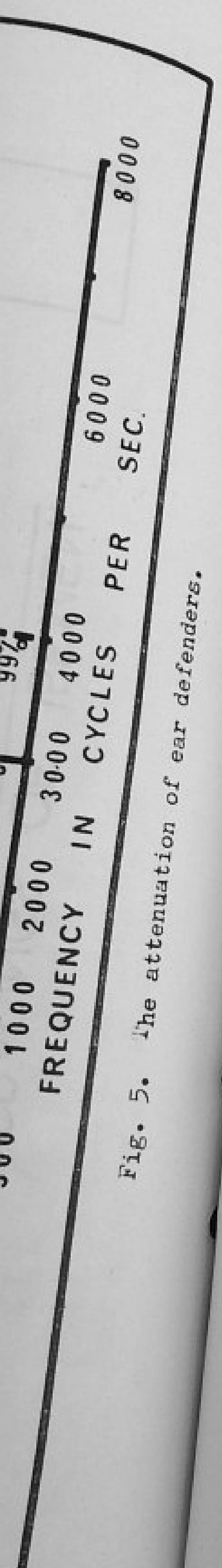

Fig. 5. The attenuation of ear defenders.

Discussion

Brigadier SIMPKIN opened the discussion by mentioning that complaints had arisen about the noise emitted by Chieftain metadynes. It had been suggested that this was due to unpleasant frequencies and vibration. He asked what was the relationship between noise and associated vibrations in the same or related frequencies.

Dr ELWOOD said he did not wish to comment on the hazard without knowing more details but added that noise and vibration could interact in their effect on man. Noise was an airborne assault on man at frequencies extending down to 20 Hz. He had not considered hazards of airborne vibrations below these frequencies. Vibration through a medium other than air could overlap with noise frequency, but at 20 Hz and above, vibration could be reduced by normal padding.

Major LEESE commented on a statement in Dr Elwood's paper that 200 rounds per day constituted prolonged firing. The first round holding was nearly 200 and he did not consider this amount of firing was prolonged.

Dr ELWOOD replied that he had understood that most of the Army shoots of about 200 rounds per day were Ordnance Board Endurance trials. With reference to Abbot, this was fitted with Amplivox head sets (with induction loop aerials) which attenuated noise to a satisfactory level.

SKILL COMBINATIONS AND TRAINING

Skill Combinations and Training

by

Colonel A.H.N. Reade

HQ RAC Centre, Bovington

Gentlemen, the second part of our presentation deals with skill combinations and training. My aim is to direct your thoughts towards the problems of training crewmen to man main battle tank 80 and also to get you to consider what effects the design of that tank will have upon the training necessary for the men who are going to man it. In considering this aim I feel rather like Barbara Hutton's seventh husband who remarked upon the wedding night that he knew what he had to do but he doubted his ability to make it interesting ...... I am going to deal with this subject in four parts. Firstly, we shall examine the requirement; secondly, we will look at the time required to fulfil this requirement; thirdly, we will look at the material available; by that material I mean human material as well as inanimate objects; and finally, we want to have a look at what training aids will be likely to be available for us in the time frame we are considering.

Firstly, what is our requirement? Is it the requirement to train men in peace or in war: clearly we must consider both of these. Here is a Table showing the basic trades we have in the RAC:

DVR AFV III

SIG AFV III

GNR AFV III

There are others such as Guided Weapon Controllers and B Vehicle Drivers, but we are concerned with the BIII AFV Crewman. The peacetime requirement is one that will certainly be with us and must be a major factor in our considerations when we are designing this tank. This, in fact, is what this symposium is all about. It is no use producing the most wonderful tank the world has ever seen if its use means that we either have to train a race of super men to man it, or we have to train men for so long to acquire the necessary skills that it becomes uneconomical or if operating the tank under conditions of wartime proves to be such an exhausting business that your human material is worn out while your fighting vehicle is still operative. These are all hazards which we must avoid, so I consider our first consideration must be the problem of the normal peacetime training of soldiers who are to man the tank. Then we can go on to consider to what extent it is necessary or possible to amend this training in time of war. There is, of course, a common fallacy that you can train a man much quicker in wartime than you can in peace. To a certain extent this is so, in that in time of war people are prepared to work much harder in much less comfortable surroundings and to accept discomforts and exertions that would not be considered reasonable in peacetime. On the other hand there is a limit to the amount of learning which you can cram into a man within a given time, in the same way that while you can work a man to the limit of his endurance that limit does exist, and if you work him to it at the end of it he will require a considerable period of rest before he is back at maximum efficiency again. In peacetime I consider - possibly - your basic training can in fact be less thorough than is necessary in war and in fact could possibly be got through in a shorter time than is necessary in war. The reason for this is that in peacetime a man has got to continue his basic training to complete and apply this knowledge of his job when he gets to his service unit. However, in wartime you must train and turn out your trained soldier ready to take his place in battle and there is no room for any errors or omissions or gaps in his training.

The next factor which comes into this problem is the concept of what the next war is going to be like. Well I think here we have got to take reasonable assumptions based upon the current trend of thinking. As I see it, the most likely type of war we must prepare for is, of course, the type of war that MBT 80 is designed to fight in, namely a major war in Europe or under European conditions; that is really the way the entire national strategy is now directed. Now that war may be purely a limited war; for example you can think of many ways in which the scenario could be written: the East Germans re-establishing a frontier on the Rhine, trying to do it in the same way that the Israelis established a frontier upon the Suez Canal, then sitting back and saying to the rest of the world "We're here, so what?". That is one possibility. There is the possibility of an extension of the area of influence of the Warsaw pact countries to cover a greater part of the continent of Europe. Any of these may well remain a conventional war: by conventional I mean non-nuclear. I think this is likely. I think it's also certain that although they may be non-nuclear, they will be chemical wars. But one must always be prepared for one of these wars, any one of these wars not just necessarily one of them - there may be more than one - to go nuclear at some stage. That stage may be after only 24 hours or it may be after 10 days or even longer. There are people who will say that it is bound to become nuclear at some stage or another; I think this is not necessarily so; I think it may become nuclear but I do not think that it is bound to.

What comes out of all this, though, is that it seems unlikely, not impossible but it seems unlikely, that any future war in Europe will be prolonged to an extent whereby one can train up reinforcements in time for them to take part in the conflict. One may well be wrong on this of course. I'm told that in 1914 people were eager to get in the war because they all thought it would be over by Christmas 1914. Similarly, in 1939 there was a school of thought which considered as soon as war broke out, the mainland of England would be devastated by heavy bombing attacks within the first week, at the same time the gallant British Expeditionary Force would be fighting its way towards the heart of Nazi Germany. As we all know both these events were considerably delayed. However, it is quite clear that we must base our plans upon training in peacetime the soldiers we will need to fight a war. If it does happen that a war is so prolonged that there will be the need and the opportunity to train further recruits from scratch, then that training organisation must be adapted from the peacetime training one, and with such qualifications as are necessary to the syllabus. This does not, of course, mean that this problem cannot be considered in peacetime and even planned in peacetime, and we will have a look at it at the end of this presentation.

At present the RAC crewman spends 15 weeks at the basic training regiment. During this period the man is taught two things. Firstly, he is taught how to be a soldier: he is turned from a civilian into a soldier. The other thing is that he is taught the rudiments of his trade. Now we may think that this 15 weeks is rather a long time in which to carry out two fairly simple and straightforward tasks. A little later on I will deal with a detailed breakdown of this period and we can have a look at it to see what economies could be achieved in the future. However, I think that we must remember the importance of the first half of this training, in other words the General Military Training. Now what do we mean by this GMT, what are we teaching a man? Well, getting his hair cut, teaching him how to wear uniform; teaching him to salute and generally to be a smart soldierly-like sort of chap instead of a long-haired layabout with his hands in his pockets. Well, that's all very fine, but that I think is only the outward and visible sign of what we are doing to the man; we are really making him into a soldier, we are putting into him team-work and loyalty and we are insuring that when he goes into action he will continue to play his part as a member of the team. The natural human reaction in the face of danger is to run away. The soldier must overcome this tendency and continue to stay where he is and continue doing his job and doing it efficiently. Now you can overcome this natural human tendency to fear by various ways; some have been used very successfully in the past. There is a passionate belief in the cause; this may be political. It may be, and often has been in the past, religious. You can brainwash the man, which is much the same thing as inducing a passionate belief in the cause. Of course you can use drugs and you will remember that the assassins of the Middle East were so called because their name derives from Hashish. They consumed such large quantities of Hashish that their powers of reasoning and their natural instincts were both inhibited and they became fanatical and fearless fighters. Well, of course, as you all know, we don't talk about Hashish anymore, it has become respectable and has a respectable name, its called Cannabis. However, I do not suggest that 'pot' should be regarded as a substitute for discipline in encouraging bravery in the British Army. No, what we must do is to install in a soldier discipline, and that discipline must be based upon reason and also upon pride. I am not going into the long question of regimental tradition and so on, though of course I'm a firm believer in it myself; but all I am doing is making the point that you cannot expect to take a man, however conscientious and reliable he may be by nature, straight from civilian life and expect him to be a soldier under the stress of war, so you still need a degree of GMT training. In addition to the moral purpose of GMT training, if I may so put it, one must motivate and teach the man the basic skills which any soldier must have if he is to survive on the battlefield. There are quite a lot of these. For example, he must be able to use his own personal weapon, he must be trained in the use of his anti-chemical warfare protection devices, which is far more complicated than using just a gas-mask. He must be taught to dig holes for his protection; he must be taught how to cook his food. These things are all second nature to the trained soldier and we don't think twice about them, but, of course, they are not second nature to the untrained civilian. So much for GMT ......

Now let us think about the trade training. Immediately one comes to the question of whether this is best done by a central training organisation or whether it should be done within service regiments. At the present time, of course, we have a combination of systems. As I have said, the recruit is taught the rudiments of one trade during his basic training and then when he gets to his regiment he learns the other skills which are necessary to make him a fully fledged and versatile crew member. But with increasing complexity and also of course increasing costs, I think we are seeing and will continue to see, a trend towards centralisation of training. There is one prime example of this in progress at the moment which I think may well be a pointer towards things to come, that is the training of guided weapon controllers in the Royal Armoured Corps. This is all done centrally at the Guided Weapons Wing of the RAC Gunnery School, Lulworth, which I have the honour to command. The main reason for this is that the GW simulator is such a large and expensive piece of equipment that you cannot afford the money or the space to have one in each regiment, or even to build one in each station where regiments are likely to be. So we have to get the soldier from regiments and teach him his basic training at the School before he goes back. Of course guided weapons at the moment are really in a very elementary, if I may say, stage. I think that there is a principle that while the amount of training depends upon the complexity of the skill required, that skill diminishes with the progression of the system for which the skill has to be taught. This may sound rather obscure but let me illustrate it by reference to the changes which many of us have seen in recent years. I will take a very straightforward matter, the question of communications within, for sake of argument, a Cavalry Regiment. Some years ago this was a very simple and straightforward affair. One occasionally used such complex devices as flags, but generally speaking the method of conveying information was by giving a message, written or verbal, to a man mounted on a horse. He had already been taught to ride his horse and it didn't need much skill, in any case, but the additional complexity of carrying a message did not demand any great degree of further training. Of course we must remember this was not always a particularly reliable method of communication as those who've seen the film "The Charge of the Light Brigade" will remember. However, not so very long ago a new method of communication was introduced called 'the wireless set'. Now I can remember when I first joined the Royal Armoured Corps we had a thing called a Number Nine Set. That was a very complicated and large piece of machinery full of little doors, covered with dials, handles which had to be wound round and round and round and to operate it at all, let alone effectively, required a great deal of skill and training. In those days the wireless operator in the tank was selected as being a man with a high, bulging forehead and delicate skilled fingers, whereas his counterpart, the gunner, merely had to have sufficient space between his eyebrows and top hair to fit onto the browpiece of a telescope. All that the wireless operator had to do, so far as loading was concerned, was to slip a 2 pounder round up the breech. However, the situation has now changed. The gunner has the bewildering array of dials and knobs, the wireless operator has to operate a very simple set, from the point of view of making it work he has to do little more than switch it on and set the frequency. He does have to have great quantities of ammunition around, so now your broad-shouldered, beetle-browed man, is the wireless operator. When one comes onto the 'Clansman' range of radio, I think it is only fair to say that operating it will be considerably less complex than operating the ordinary television which every soldier will have grown up with at home. So we have seen the progression between the very early crude wireless set, which required great skill to operate it and the present, very advanced, wireless set which is extremely easy to operate and therefore requires very little training indeed; but of course he still has to learn the correct procedures and the use of codes. I think we may confidently see this process developing in other fields; indeed we already know that driving the Chieftain tank is a much easier matter than earlier models of tanks with which the British Army have been equipped. So, I think, that in future we may confidently expect to have to spend less on teaching a man a basic trade or skill because with more highly developed equipment it will be easier for him to operate it. We may also here be able possibly to combine skills and therefore reduce the number of crewmen.

To apply this principle to GW. As we have seen, at present it requires very expensive and complicated machinery and takes a long time. The skill of flying a missile is only acquired with the expense of much time and effort. However, as we progress to semi-automatic systems, and eventually the fully automatic guidance systems, with a trans or supersonic velocity the task of the controller will become very much easier.

I have spoken for long enough, but before I stop I would like to remind you briefly of the large number of tasks which the tank crew have to perform that were outlined in Serial 2. I will now ask Major Caunter of the AWSG briefly to expand on this theme.

Crew Duties

Presented by: Major J.R.L. Caunter, RTR
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General

1. The skill required by a fully trained AFV Crewman can be divided into three categories:-

a. General Military Training.

b. Specific duties applicable to the crewman's seat in the type of vehicle in which he works.

c. General crew duties as applicable to the type of vehicle.

These three categories are briefly explained below, the subjects included are not meant to be exhaustive, and are in no particular order.

2. General Military Training

Swimming.

First Aid.

Personal protection against and decontamination from CBR agents as may be applicable.

Skill with personal weapons, including grenades.

Duties as a sentry or OP (including aircraft and vehicle recognition, CBR, Radar and Infra-red detection etc).

Lifting mines.

3. Specific Crew Duties

This is the task which the crewman carried out in his allotted position. We have started Job Analyses of the three Chieftain positions, excluding the Commander. I shall return to this subject later, but it is sufficient here to say that each vehicle is quite distinct. You cannot, therefore, do a job analysis of a Driver AFV(T). You must do it of a Chieftain Driver or a Centurion Driver or whatever.

4. General Crew Duties

These are Team tasks which all or part of the crew carry out simultaneously:-

Replenishment of ammunition, fuel, food and water.

Track and vehicle camouflage.

Cooking.

Protection and decontamination of the vehicle from CBR agents.

Protective digging.

Erection of bivouacs, etc.

Preparation for swimming/wading/schnorkelling.

Tasks in the Vehicle

5. I am now going to concentrate on my second heading - specific crew duties. It is imperative, however, to remember the importance of the individual training of our soldiers in or on vehicle duties. It is equally necessary to remember that in addition to his individual tasks in the vehicle the crewman has vital, lengthy and exhausting duties as a member of the team as a whole.

The Individual Tasks in Chieftain

6. Commander. As I have said no job analysis of the Commander's job even in outline, has yet been done. Two facts, however, are quite clear. Firstly he is, under all conditions when in action, the crew member with the most to do. Secondly, his tasks are essentially exterior to the vehicle - looking and listening - and only occasionally operating equipment. From this it follows:-

a. He is the least suitable member of the crew to be given any additional tasks at all.

b. Anything that turns him into an introvert (in vehicle terms) such as loading guns and clearing their stoppages, or fiddling with the wireless set, should be avoided.

7. Operator/Loader. In battle he is probably the crew member with the next most to do, after the Commander. His duties during action may perhaps be summarised as follows:-

a. Loading the main armament. This involves a detailed knowledge of the ammunition stowage and includes replenishment of ready round bins from less accessible positions during lulls in firing. This is extremely hard manual labour and he is the only crew member who has any real physical work to do when mounted.

b. Maintaining the main armament in action. This involves a detailed knowledge of the mechanism.

c. Loading the two machine guns and clearing their stoppages. This again involves a detailed knowledge of their mechanisms.

d. Tuning the wireless sets and changing frequencies as required.

e. Acting as assistant to the Commander. This may involve:-

(1) Keeping listening watch on one or more sets.

(2) Speaking on one set when the Commander is otherwise involved.

(3) Encoding and decoding messages.

f. Carrying out maintenance tasks assigned to him.

8. Gunner

a. Operates the fire control equipment and engages targets with either the main or secondary armament. This will normally be done as part of one of a number of sophisticated drills under the direct supervision of the Commander. The Commander may, however, brief his Gunner to continue engaging a group of targets (or an area target) under less close supervision while he is otherwise involved, eg giving a SITREP on the radio.

b. Carries out maintenance tasks assigned to him.

9. Driver

a. Drives the vehicle under any required condition (ie closed down, cross-country, snow, ice, mud, sand).

b. Carries out maintenance tasks assigned to him and diagnoses and rectifies minor running faults.

Conclusion

10. Finally, I would like to stress again the point I made earlier. Although one can make an ideal distribution of duties for any size of crew from two upwards, the general military tasks and the team tasks of the crew will remain. The smaller the crew the larger share of such tasks will each man have to do, and the quicker will they become exhausted. No matter how technically brilliant a vehicle may be it will be useless if it has a clapped-out crew.

Continuation of paper by Colonel Reade:

Now to my second point, that of the time required to train a man well enough in the basic skills of being a soldier in order to keep him and the rest of his crew alive. There are three main factors which will dictate the length of course the man must undergo. His intelligence and ability to absorb the training, the number of things he must learn, and, lastly, the complexity or otherwise of the equipment he has to operate.

At present, the RAC accepts men down to SSG3M and we have found that it takes 15 weeks, 7½ weeks GMT and 7½ weeks trade training, to achieve the standards we have today. The whole system of selection and grading is under review but whatever they call it in the future we will require a higher SSG than we get now if we are to increase the standard of AFV tradesmen. In a conscript army you will get a higher proportion of the higher SSGs anyway. So this more intelligent man will be able to absorb the training more quickly, but in war one must produce a man fully capable of taking his place in an AFV which is not the case in peacetime. Therefore the overall training time will increase.

You have heard of the large number of diverse subjects the AFV crewman must know about before he can be considered to be basically trained. It is a lot to learn in 15 weeks. Certain subjects could be reduced. For example, Army education could be cut out. Drill on the square and sport, both of which are essential parts of training, could be reduced. But one cannot accept any reduction in the standard of competence of AFV crewmen.

If you reduce the size of your crew to 3 men you will have to increase the training time in order to include the skills of the fourth member of the crew which have been reallocated to the remainder. If future equipment is easier to operate then training time should be reduced, as long as you do not give him extra things to learn to operate, for example, all these surveillance and detection devices. To sum up, you will save time with having a higher IQ recruit and with extra simplicity of operation, but you will require more time to produce a finished product instead of a half finished one: you will require more time if you reduce the size of the crew.

One could introduce various streams of training where you put those with a high IQ into one and those of a lower IQ into other streams. The top streams would cover the same syllabus as the others but more quickly. The RAC training machine as such will cease to exist as the Service Regiment, which does the job at present, is earmarked to become a Forward Delivery Squadron from M-3. There is bound to be a time lag while it is re-established, also, of course, it is not big enough to cope with the numbers envisaged after mobilisation. Therefore extra training regiments will have to be set up. It may interest you to know the length of basic training courses other arms and services undergo.

Gunner RA	13 weeks GMT then specialist training
Private Inf	15 weeks to Grade IV Soldier
Sapper RE	18 weeks to BIII
Ordinary Seaman RN	15 weeks then specialist training
Royal Marine	26 weeks then specialist training.

Please remember that we are only considering the training of Basic Recruits to BIII Standard and not the training of BI or Tank Commanders which is a regimental responsibility, and which produce a large number of problems themselves. Let us now turn to the material we will have available. I will consider it under two headings:-

a. Men.

b. Equipment and leading on into training aids.

With the school leaving age going up to 18 one could expect to get a better educated and more mature man to train. There is no doubt that youngsters are far more technically aware than they were even a decade ago. They are very familiar with a vast range of electrical gadgets. A large number will be able to drive. Talking about teaching machines, spacecraft and computers will not be strange to them so you will be able to subject them to sophisticated training aids and so produce a more polished article in a shorter time. That is on the credit side. You may find that for every moment saved in teaching technical skills you will have to spend twice as long to reawaken the man's natural 'animal cunning' and teach him how to exist in primitive conditions and not only to survive but be aggressive and determined as well.

All the points in fact which we made in Serial 2. We can expect large bonuses on the equipment side. It will undoubtedly become more complex, but it will also become easier to operate. I am not going to enter into the argument on the increased technical backing required for these bits of sophisticated kit or the fact that some new equipments like ZB 298 radar and image intensifier are very tiring to operate. That problem has been dealt with already. If the equipment is easier to operate, it should, therefore, be easier to train on.

My final point concerns training aids. As I said earlier they will become more and more expensive and therefore there could be fewer of them. GW and Driving Simulators are two examples which come to mind at once. Other devices which can and will be adapted for RAC use are speed reading and language laboratory type of instruction, to name only two. These will reduce the time in the classroom and give more time for various practical skills to be learnt.

I do not propose to summarise all I have said even if I could, but in conclusion perhaps you would like to mull over the commander problem.

Every AFV must have a commander and that man could well be a troop leader or even squadron leader as well. If you have a 4 man crew then only 25% of your crewmen need to be trained as commanders. If you have a 2 man crew then the proportion goes up to 50%. In a two man crew all the jobs have to be divided into two, not half but two. A two man vehicle is smaller and more difficult to work in than a four man one. So the smaller the vehicle the more difficult it will be to train your commander who will have so much more to do in a smaller space.

Discussion

The Chairman thanked Colonel Reade and Major Caunter for their presentations but regretted that time did not allow for discussion before the next paper. He suggested that any points should be raised during the final discussion at the end of the Symposium.

CREW NUMBER IN FUTURE ARMOURED FIGHTING VEHICLES

Crew Number in Future Armoured Fighting Vehicles

by

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Some of the points in this paper will be obvious truisms; many have already been excellently covered. Some points are likely to be contentious, some quite deliberately so. If these provoke discussion and argument this is all to the good. I would like to stress that where I quote particular vehicles as examples, I am in fact refering only to the concept embodied in that vehicle and not to the vehicle as a whole.

The tactical environment of a fighting vehicle and what it is expected to do dictate the vehicle's tasks. The vehicle's tasks dictate the crew duties and the crew's duties broadly dictate the crew number. Historically medium and heavy tanks had a higher number of men in their crew than now, early tanks and even those in use up to the end of the last war had more men than the present vehicles. The number of men has been reduced to the number of four in present main battle tanks. In some new vehicles the number has dropped to three, namely the Swedish 'S' tank and the United States of America/Federal Republic of Germany MBT 70.

Reconnaissance vehicles, on the other hand, have for a long time had a crew of three or two men. The tasks of these two types of vehicle might be considered at first glance to be widely different. However, in some respects the tasks are basically similar except that the reconnaissance vehicle does not have a heavy anti-tank role and if it sees a main battle tank approaching it with obviously evil intent it withdraws very rapidly indeed. Neither does it have a heavy fire support role for infantry, but again on the other hand it _is_ expected to engage light targets, soft-skin targets and infantry concentration targets. It is expected to fight sometimes for its information and it might be expected at times to be called up as fire support for dismounted infantry. The task of the vehicle is primarily to obtain information, to go forward cross-country sometimes behind enemy lines, to observe and watch, to report information, to defend itself if need be and to return.

From the actual duties of the crew and the means which they are given to achieve their aims, this is not really so very different from a tank. The crew do not use a heavy gun but the use of the lighter gun that is provided is basically the same as the use of the main armament of a tank. This is perhaps an over-simplification but as so much of the duties are very similar, even if the proportion of times spent doing one duty or another vary between a reconnaissance vehicle and a tank, it is proposed to consider the two types of vehicle as one for the rest of this paper. The third type of vehicle which should be considered is the Armoured Personnel Carrier or, in the future perhaps, Mechanised Infantry Combat Vehicle. In the past these vehicles tended to be either open "taxis" or closed "taxis" carrying troops forward to the area where they have to dismount and they then become true infantry. In the future it is quite probable that the vehicles will be fitted so that the infantry section within the vehicle can fight from the vehicle and the vehicle will thus be literally a Fighting Vehicle. It will itself fight and only at certain times will the infantry dismount and, say, proceed on foot to a target, mop up, take control and then remount. The Russians currently have such a vehicle. This type of vehicle has its own set of special problems which need urgent attention, its duties are different and to this extent its crew number will probably be different. As this symposium is directed primarily to the consideration of crew number in tanks and as time is short the Armoured Personnel Carrier or Mechanised Infantry Combat Vehicle cannot unfortunately be discussed.

An important question to ask is "What is the need to consider the crew number of tanks?". There are many possible answers: to reduce the volume of the vehicle and thus its weight as a direct result of its reduction in volume; to try to reduce the overall height; to try by both these means to reduce the required engine power and the amount of fuel carried under armour; to increase the space for ammunition; to reduce the weight so that the vehicle has a greater range of mobility not only cross country but in terms of bridge strength, air-portability and many other such arguments, and finally to reduce the problems of sufficient trained manpower and the perennial problem of cost. It is possible that there is a general agreement in most countries that it would be desirable to reduce crew number. The big question is, "How few men can satisfactorily carry out the duties that are foreseen for the future?". The problems of the actual crew duties, what they are, what the crew must do, how, when and why, are covered in other papers. The problem now to be considered is how, from the Human Factors viewpoint, the numbers can be reduced and to what number they can be safely reduced for the crew to remain effective and to be able to perform their military tasks to an efficient level for a reasonable and specified length of time.

The generally standardised arrangement of crew within a tank is to have a Commander, a Driver, a Loader/Operator and a Gunner whose tasks are by their titles self-evident, and the majority of tanks are fitted with a turret which rotates and to a great extent dictates this number and type of organisation.

The most important man in the tank is naturally the Commander. He has the overall responsibility for his tank carrying out the mission he has been given, of taking the vehicle to his given location, engaging whatever targets are presented and bringing his vehicle and crew safely back. To do this overall task he has many minor jobs, some of which he can delegate, but most of which he must either supervise or do himself.

The Gunner must lay the gun on a target and he must help the Commander in observation tasks, but beyond that he has, in current vehicles, a very limited fighting job. He is also responsible to the Commander for weapon maintenance.

The Loader, again by definition, must load the main armament (which requires considerable strength and agility to do especially if firing on the move with the tank lurching all over the place) and in between times he can assist the Commander in observation and he can share with the Commander in most vehicles the major part of the task of operating the radios. For this last reason he is usually the Second-in-Command in the vehicle.

The Driver drives and positions the vehicle as required, and is responsible for its mechanical state.

There are two more obvious ways by which crew number could be reduced. The first is by automation: if a task can be performed by a machine then this relieves a man of that particular task. If a major task can be performed by a machine then perhaps a crew member is released, the more obvious instance of this being an automatic loader which would eliminate the need in most circumstances for a man to perform the task. There would be occasions when a man would be involved in perhaps setting fuse on smoke rounds, but for the majority of the time such a device would release a crew member for helping with other tasks or entirely eliminate the need for a crew member.

The second more obvious alternative is to share tasks between two or more men. An instance of this might be the controls provided for the Commander of Chieftain. He can at present, if he wishes, lay the gun using his "Override Control" and thus do most of the Gunner's work in direct fire tasks. This saves time, and saves communication problems with another man. Everything can be lined up for the Gunner for him to make the final fine control adjustments and fire. Now, if a few more of the Gunner's controls were given to the Commander, the Commander could do all the gunnery tasks. This perhaps is an over-simplification but the thought is there. However it would mean in this particular case that the poor Commander, besides all his other tasks, would have the task of firing. This would be unshared with anyone, and there would be occasions, perhaps many occasions, when he would be required to do several more things at once. This is not considered to be a good suggestion.

If automation were brought in to a major extent, despite the weight and cost of such machinery, then perhaps crew number could be further reduced. An example of such a logical sequence is in the Swedish 'S' tank where there is a crew of three: a Commander/Gunner/Driver, a Gunner/Driver, and a rear facing Driver/Loader/Radio Operator. The vehicle has been so designed that for limited operation it could be fought quite satisfactorily with only two men and in extreme cases by one man only. This is carrying both arguments that have been suggested to perhaps their extreme. The proof, though, of such an argument has not to our knowledge been fully attempted. Can a crew of three or can a crew of two (given suitable controls, suitable equipment and suitable mechanical back-up) carry out the fighting task which is required of them?

However, it is not all as simple as that because the type of vehicle chosen, turreted or turretless, will to a great extent dictate the minimum number of men required. The Swedes for example with the 'S' tank have opted for the turretless concept. Their argument I think, though I may be wrong, being that firing on the move even with stabiliser against a pin-point target is unlikely to be very effective; against an area target it is acceptable. They followed this argument by making their tank very highly manoeuvreable so that it can be stopped, swung on to a target, engage that target and move off in a time little different from the time taken by a turreted tank with stabiliser to swing its turret on to that target and engage it. By the 'S' tank becoming stationary its chance of a hit against a target is arguably greater than the chance of a hit even with a stabilised gun control equipment on a turreted tank. The sudden change in speed and direction, with its short time stopped, might give it some added immunity. Having opted, using this argument, for a turretless tank they have been able to bring the Driver back from the front of his vehicle to be with the rest of the crew: they have concentrated their crew in one part of the vehicle and duplicated the controls. In this way the men are able to share the majority of fighting tasks, all men are of the same height above the ground, two men have exactly the same view forward and the tasks are split between the men in such a way that two men, for a limited time perhaps, can successfully fight the vehicle. The Rear Driver/Operator - the third crew member - spends most of his time being a passenger.

With the turreted tank however the Driver is currently normally left forwards on his own, by himself. On many occasions he is unable to communicate directly or physically with the rest of a crew (except through an intercom). This leaves little opportunity for duplication of tasks except that perhaps radio operation could be added to his tasks.

The alternative is to bring him to the turret as is done on the US/FRG MBT70 and put him in a contra-rotating minor turret within the main turret. But again, although he is now physically with the rest of the crew, by being in a small contra-rotating turret it is difficult to see what he can do to assist the others in their tasks of fighting the vehicle and he cannot presumably take part in gunnery procedures at all. Perhaps his only opportunity to share tasks is in the observation role. Both these points mean effectively that the crew must consist of a Driver and others, the others carrying out all the tasks which remain to be done. It would thus seem that the absolute limit of crew reduction with a turreted tank would be a crew of three men or if an auto-loader could be fitted, two men. The same limit of reduction with a turretless tank would be two or perhaps one. If the argument is accepted that to command a vehicle, to observe, to use the radio and codes, to position the vehicle, read a map, to see targets and identify and engage them rapidly, drive, and perhaps control a Troop or a Squadron at the same time cannot all be done by one man, then the ultimate limit for crew reduction from both mechanical means and by sharing of tasks would seem depending on the turreted/turretless concept, to be three or two. The argument to differentiate between those two numbers would seem to lie on the crew's capabilities, the men's capabilities. Can two men operate such a vehicle for the length of time required of them and carry out all their tasks successfully? The usual complement of three men for reconnaissance vehicles shows that a crew of three can and does function efficiently.

So far I have considered only the fighting aspects of a vehicle's duties and no mention has been made of maintainance or replenishment. As was explained by Lt Col Hawkins in his paper 'Crew Duties - User Aspects' it is believed for several reasons that crews must carry out their own maintenance and replenishment. On many or most of the occasions when these tasks are being done the Commander is called away and cannot assist. Even with labour-saving aids like hydraulic track tensioners, many tasks are at least 'two-man' tasks and some, like ammunition replenishment, are lengthy and strenuous even for three men.

This last argument then, if accepted, rules out two-man crews as normal vehicle complements, leaving us with a minimum of three. It is still of interest, however, to consider the actual fighting ability of a crew of two, as it is quite possible to be one man short for some time before a replacement could be obtained. There have been two trials, to our knowledge, which might shed some light on this.

The first (though chronologically second) was a joint APRE/RAC Equipment Trials Wing trial during the RAC assessment of the Swedish 'S' tank. Without going into detail, which I cannot here, a short trial using two 'S' tanks and four crews was undertaken to see if it seemed reasonable or possible for two-man crews to operate efficiently for 24 hours under simulated battlefield conditions. Again without going into detail, there were strong indications that there was little or no decrement in performance of crew or of individual tasks, that crews were not being stressed to anything like their limits (this point will be amplified later), and that for the whole period of their Trial Runs they performed at an acceptable and high level of military efficiency. This only serves to support claims published by the Swedes.

The second trial conducted again by APRE/RAC Equipment Trials Wing was our

"Capsule" Trial, the Final Report of which is in draft. This was not directly concerned with crew number, its aims being broadly to investigate turret crew performance within a very small-space turret mounted experimentally on a tracked load-carrying vehicle. The crews were closed-down for 48 hours, let out for 12 hours and then again closed-down for 48 hours. This involved a crew of three men – Commander, Gunner and Driver – and assumed an auto-loader. We used eight subject turret crews (16 men) for this Trial; the Driver did absolutely nothing to assist the subjects beyond driving the vehicle from point to point as ordered. He was in effect a member of the Trials Directing Staff with whom he spent more time than he did in his vehicle. As we were assuming NBC threat or attack, the crews had to remain closed down for the entire period and all maintenance and replenishment was carried out by "protected" maintenance personnel. Short of actually driving the vehicle and carrying out maintenance, the subjects were effectively two-man crews. There was no sharing of controls, beyond the radios, so that the Gunner/Operator could not in any way assist the Commander/Operator except in some observation and cooking tasks. There will be a short film to illustrate some aspects of this Trial later this evening. The main results indicated that there was some fluctuation of performance levels associated with time of day and that there was a very slight decrement in performance associated with duration of "encapsulation" in only one of the assigned tasks. The main point, though, is that the performance of <u>all</u> tasks was considered to be at a militarily acceptable level throughout.

One aspect of instrumentation used in this Trial might be of interest, and has a bearing on my earlier remarks about the 'S' Tank Trials. It also, as a side issue, has been touched upon by Dr Elwood on "Noise" and might be worth incorporating in future vehicles. All crews used the RAF Flying Helmet (outer and inner) and a permanantly "live" intercom noise-cancelling hands-free microphone system. The crew could converse without having to find and hold a microphone and without being temporarily deafened by vehicle noise, and had to use a switch only when transmitting on a radio. For trials purposes we relayed this live intercom by an extra radio link to our TRIALS DS vehicle where it could be overheard. Besides giving us otherwise unobtainable information on events within the 'Capsule' which might affect measured performance (eg the Gunner had bumped his head), it gave us an insight into the general level of morale and stress within. I am not advocating this <u>relay</u> system for tank use, but I <u>would</u> advocate the 'live' intercom: it makes life that little bit easier.

To revert to the main subject, this system gave clear evidence of a high level of morale and, except at odd brief hectic moments, a relatively low level of stress.

While every effort was made in both Trials to simulate realistic battlefield conditions and tasks, we did not have an effective "enemy" and we could in no way simulate the real fear of being fired on. Presumably no Human Factors trials could ever simulate this, so it will probably never be possible to state firmly that such Trial results will be directly applicable in battle. However, the inference would seem to be that it might be possible for two men for a limited time perhaps to fight effectively.

I have already mentioned automation of tasks and sharing of tasks as a means of reducing crew number. In both cases this really means making life somewhat easier per man. While it is not suggested, both from the points of expense and complexity, besides the traditional British puritanical suspicion of 'comfort', that the inside of Tanks should be luxurious, anything which helps to maintain crew efficiency near its peak is of value. The other side of this line of thought is that as tanks become more complex and sophisticated, with each Chieftain costing in the order I believe of £90,000 and each US/FRG MBT 70 costing I believe in the order of £250,000, it would be foolish not to add fractionally to this cost to save having what could become under some conditions an inert or only partially efficient mass of metal of enormous cost on the battlefield.

The type of 'luxury' I am considering is to have the vehicle air-conditioned between the upper and lower extremes of physiological temperature stress, extremes leading to casualties and accidents; the level of internal noise reaching the crew's ears reduced, either by acoustic insulation of noise sources or by having noise-excluding headsets, so that men on guard duties in leaguer areas can hear the foot-falls of approaching enemy patrols; the provision of bump-protective helmets and harness - perhaps Inertia Reel, so that vehicle cross country speeds may be increased with safety for the crew; the fitting of some means of disposal of biological waste, essential for long term closed down operations; the combining of as many outputs from visual-aid-devices as possible into one display, this becoming even more essential as more types of vision and surveillance devices appear; the combining of controls from their many locations and modes of operation into a common system, centrally located for each man at an optimum position for comfortable operation and with optimum operating loads; the provision from the earliest Feasibility Study/Design Stage of accessible stowage for all the items of equipment for the particular jobs which are likely to find their way into the vehicle (eg Troop/Squadron Commander's Map Board, Slidex pack, etc) and so on.

From all the preceeding arguments and those we have heard earlier, I would very tentatively suggest an approach to the ideal type of vehicle from the Human Factors viewpoint with a minimum number of crew. This vehicle would be a turretless tank with automatic loader, with a small rotating Commander's cupola/seat assembly. There would be a crew of three; (a) Gunner/Driver; (b) Driver/Gunner/Operator; (c) Commander/Gunner/Operator/Rear Driver/"Fused-Round Setter"! I am not suggesting that he should <u>do</u> all these tasks but should have the ability to do so if he wished. By implication from the crew's titles, all controls except those for rear driving and fuse setting are triplicated. The Commander would have a power-operated cupola-seat assembly; with this facing forwards he would have the forward-driving controls in front of him, with it facing rearwards he would have the rear-driving controls and fuse-setting space. There would be a servo system to line up the tank to coincide with the direction of his cupola at the press of a button so that the gun could be rapidly laid. Only the main <u>essential</u> driving and gunnery instrumentation, a single warning system (for danger or malfunction), and the controls themselves would be triplicated, grouped together and comfortably placed for each man. <u>All</u> other minor controls and instrumentation would be placed on a central panel between the Driver/Gunner and Gunner/Driver, needing reference only occasionally or when the single "central warning system" indicated (roughly as on the Swedish 'S' Tank). In all probability it would mean practically all controls and instrumentation would be remote from their source points as indeed most are now. While this will undoubtedly make the designer's task more difficult and maintenance more complex, it will avoid some of the major turret mounting, stabilisation and weight problems and it will most importantly make the crews tasks much easier to carry out. In other words, they should be less fatigued and therefore their acceptable level of efficiency should last longer.

Gentlemen, I said at the beginning that this was likely to be contentious. I think I have now said quite enough.

Discussion

Colonel MASTERS opened the discussion suggesting that future trials to test whether two men could operate without decrement of performance should take place over a seven day period.

Mr LARGE replied that vehicle maintenance was the problem and limiting factor.

Colonel WHEELER considered that the tactical assumptions in the paper were incorrect in that reconnaissance vehicles operated in pairs whereas tanks operated in troops or squadrons and forced their way rather than worked their way through any opposition. The MICV might either fight forward with the crew dismounted to mop up or defend against the enemy with the crew dismounted to dig in. He said tanks were unlikely to be brought back for replenishing as this was done by the crew in the forward area. On the subject of rate of fire and firing on the move he mentioned achievements of a US Army crew firing Chieftain at Aberdeen Proving Ground. These were:-

a. 85% hits at 1500 metres firing 12 rounds APDS in one minute,

b. 85% hits travelling at 15 mph (24 kph) over the worst "bump" course firing 8 rounds APDS in one minute starting from 1500 metres.

Mr BAYLY PIKE, referring to the chart "Distribution of crew work loads" (page 14) shown by Lt Col Hawkins during his presentation, was puzzled by the time allotted to the activities of the gunner when the time of actual firing could be only a very small part of 24 hours.

Colonel MASTERS pointed out that the gunner had a large surveillance task in addition to firing.

Brigadier SIMPKIN added that with all round vision for the Commander, and at the range over which he scanned, the Commander selected the most important sector of this very large area and allotted the less important sector to the gunner. Coverage of the whole area was too much for one man to perform effectively.

Major LINAKER mentioned that guard duties were frequently given to the gunner.

VEHICLE DESIGN ASPECTS

Introduction to the Problems Facing the Vehicle Designer when considering Fitting the Crew into Combat Vehicles

Paper by L.C. Monger

Vehicle Concepts Branch FVRDE

Gentlemen,

My paper is addressed to that body generally referred to as 'the User'. As a designer I see the User as the customer who must decide what he will have for the money he has to spend.

The allocation of space under the heavy armour of a main battle tank is at best a compromise. Every component is likely to be allotted less space than the specialist who is concerned with it would expect to get and this applies equally to the crew. Engines would need less hp for cooling and would be easier to maintain if they could have more space, the radius of action could be better if more space could be allotted to fuel, more engagements could be fought before replenishment if more space could be given up to ammunition and the crew efficiency could be improved if they were never restricted by lack of space, but whilst the loss of efficiency of the various engineering components, which is attributable to space limitations, can be assessed and given finite values, the loss of efficiency of the crew can only be established by comparative trials with men of different physiques and under different conditions. Such trials are likely to result in assessments which are less finite than those with specific components.

Reduction in crew space can be considered under two main headings. It can be achieved by giving less cubic feet per man or by reducing the number of men.

Considering, firstly, the simpler problem, let us think aloud about the space we allot per man and extend the argument to embrace the attitude or position in which the man can be installed in the AFV.

The number of cubic feet a man's body occupies is the same whether he is in the hull or in the turret and whether he is on his head or his heels. That is not to say that his attitude makes no difference for although his body will occupy the same number of cubic feet seated as reclining we have shown in the design of the Chieftain that by reclining the driver the weight of armour could be reduced. This can be simply explained if one realises that when reclined he needed extra length which added weight at the rate of about 100 lb per inch but saved on hull height at a rate of about 500 lb per inch.

One might argue that if the driver were taken out of the hull and put into the turret the maximum saving in both length and height of hull could be made (and perhaps MBT 70 fell into that trap). The arguments against putting the driver into the turret are complex but the more important of them are worth mentioning here. A driver in the turret is likely to increase the area of the turret roof but the area of the turret base is restricted by a number of factors not least of which is the rail gauge. It follows therefore that as the turret roof area approaches that of the base so the turret walls approach nearer to the vertical which leads to a decrease in protection or intolerably thick armour. With our aims for protection in future AFVs, the slope of the armour becomes even more important than it was in the past.

The additional complexity needed for the driver's controls in the turret may not seriously influence the internal space requirements but it will seriously affect cost, maintenance load and reliability.

If the driver is put into the turret the hull can be shortened but only to a limited extent, for a reasonable length to width ratio must be maintained, and with the higher road and cross-country speeds now envisaged a higher aspect ratio is needed rather than a lower one.

It must be obvious to you that the cubic feet of space required for each crew member is that occupied by his body when static (which is surprisingly low at about 5 cubic feet) <u>plus</u> that needed for movement which must include entry and egress space.

The space needed for movement is related to the functions each man is to fulfil so it would be possible by automation to put him into a pod and to a large degree reduce his space requirements by giving him a set of buttons to press.

If the complexity needed to do this was acceptable it might still prove a poor solution for the commander who needed to move more in order to get a better view of the battlefield around him; this must apply particularly when he is a troop or squadron commander.

In any case the increased complexity will be expensive, it will take longer to develop, it will increase the maintenance load and reduce reliability. It is important to realise that the complexity which is possible in an aircraft is more difficult in an AFV which operates in a very different environment and does not return to base for maintenance. It might be shown that during trials and peace time operation a higher degree of complexity than exists in present AFVs could be tolerated but could it be tolerated on the battlefield? How would it stand up to the concussing effect of a heavy projectile which the armour could withstand? Increased complexity is inevitable in future AFV's to improve their chance of hit at longer ranges, to enable them to fight at night and to enable them to move faster off road but can we afford to go any further than that?

The designers must continually strive to achieve the best balance between the conflicting demands of simplicity and battlefield effectiveness, for one expensive and complex vehicle is unlikely to be as good as two at half the cost but a little less effective individually.

Before leaving the problem of space required per man let us not forget that an increase in the REME load for maintenance of the additional complexity might be a high price to pay for saving a few cubic feet of space in the AFV.

Now let us consider the space which might be saved by a reduction in the number of men in the AFV.

Firstly, no designer should put a man in an AFV to be shot at by the enemy unless he is really needed for the battle. You have no doubt heard the argument put forward in the past that four men are needed in a battle-tank so that at the end of the day one goes to the 'O' group, one maintains the weapon, one the vehicle automotive equipment, the other prepares food, refills with fuel, oil etc. Let us hope we have advanced beyond that sort of thinking.

You may already have had some experience of three man tanks. The last was Charioteer in the UK. The driver in Charioteer was in the conventional position and fulfilled the conventional role of a tank driver so the problem was how the duties of the loader, gunner commander and wireless operator should be shared between two men. It is probably fair to say that the problem was never satisfactorily solved. No useful purpose would be served by discussing that problem now because in any future battle-tank designed for less than four men the task of loading the gun is almost certain to be automatic.

A detailed analysis of the duties performed by each member of the crew of a Chieftain during a realistic battle exercise would be of considerable value to the vehicle designers but it must be representative of how you would expect to fight in future and should show the difference between a 48 hr battlefield day in a normal gun tank, a troop leader's tank and a squadron commander's tank. Such an analysis would form a very useful basis for discussions between Users and Designers.

Concept studies over the past few years have shown that the battlefield surveillance problem is seriously influenced by the number of men available to scan the battlefield and to maintain a look-out over long periods especially when radar displays and night vision devices are included.

Let us look at one example of this problem.

Figure 1 shows one of the many concepts which are being examined during a study of future AFVs. It is not a proposed design and it is being shown only to demonstrate to you the problems of reduced crew numbers and battlefield surveillance.

For those who have not seen any of the external gun MBT concepts a short description is needed but this is not the occasion to discuss its pros and cons.

The HV gun as you see is externally mounted and has 360° traverse with a conventional +15° to -10° elevation. Ten rounds of ammunition are carried on the gun and automatically fed into the breech. The gun and its ammunition are enclosed in small arms and splinter proof armour.

The replenishment ammunition is carried in the rear compartment of the hull. When the gun is to be replenished it must be brought to 12 o'clock and elevated. The feed from the hull will then be automatic.

Now to discuss the crew. The driver as you see is beside the engine but since the rest of the crew are in the hull the driver is no longer remote from them as he is in today's tanks. Hence you might be able to allot to him other duties but if firing on the move is required he cannot be expected to do much else except drive.

In the picture two men are shown under the gun - let us call them the commander and gunner although with some increase in complexity it would be possible for each to have the same facilities for gunning and commanding. They rotate with the gun so this must be borne in mind when considering whether the driver could share any of their duties.

It is envisaged that in addition to the main armament there will be an Anti-APC weapon, a GPMG and smoke dischargers so when considering one man under the gun his responsibility for all the weapons as well as commanding must be appreciated.

It must also be realised that the MBT may have to carry its own IFF, compass and detector systems.

The gun sight is envisaged with the object glass at gun trunnion height. Vision would be by means of a long periscope with its object glass in a rotating and elevating head above the gun <u>and</u> a ring of X1 periscopes would be provided around the men.

If the commander has the long periscope he has, in a sense, 360° vision. He also has a large arc of vision through his X1 periscopes but, of course, he cannot see through them to the side occupied by the gunner. You may, however, like to consider the case for accepting such a limitation because by a limited movement in azimuth of the gun he can see the full 360°.

If, however, you believed the vehicle could be effectively fought with only two men, ie a driver and a gunner/commander the man under the gun could have a full X1 360° vision.

The vehicle designers job would be easier if you could operate with a two man crew, for as you see, now that the turret has gone, the wireless, the small arms ammunition and a lot of other stowage must be packed into the hull. Realising the limited space available you will see that with two men under the gun, as the development proceeds some ammunition from the rear compartment may have to be traded off for other essential stowage items.

When, later, the General Staff are presented with a large number of concepts to consider, the choice will be difficult but it will be that much easier if you have spent the intervening period in a careful analysis of the present duties of the crew and how you will visualise them being changed in future.

MAIN BATTLE TANK on M.I.C.V. COMPONENTS

Front Engine

Three-man crew

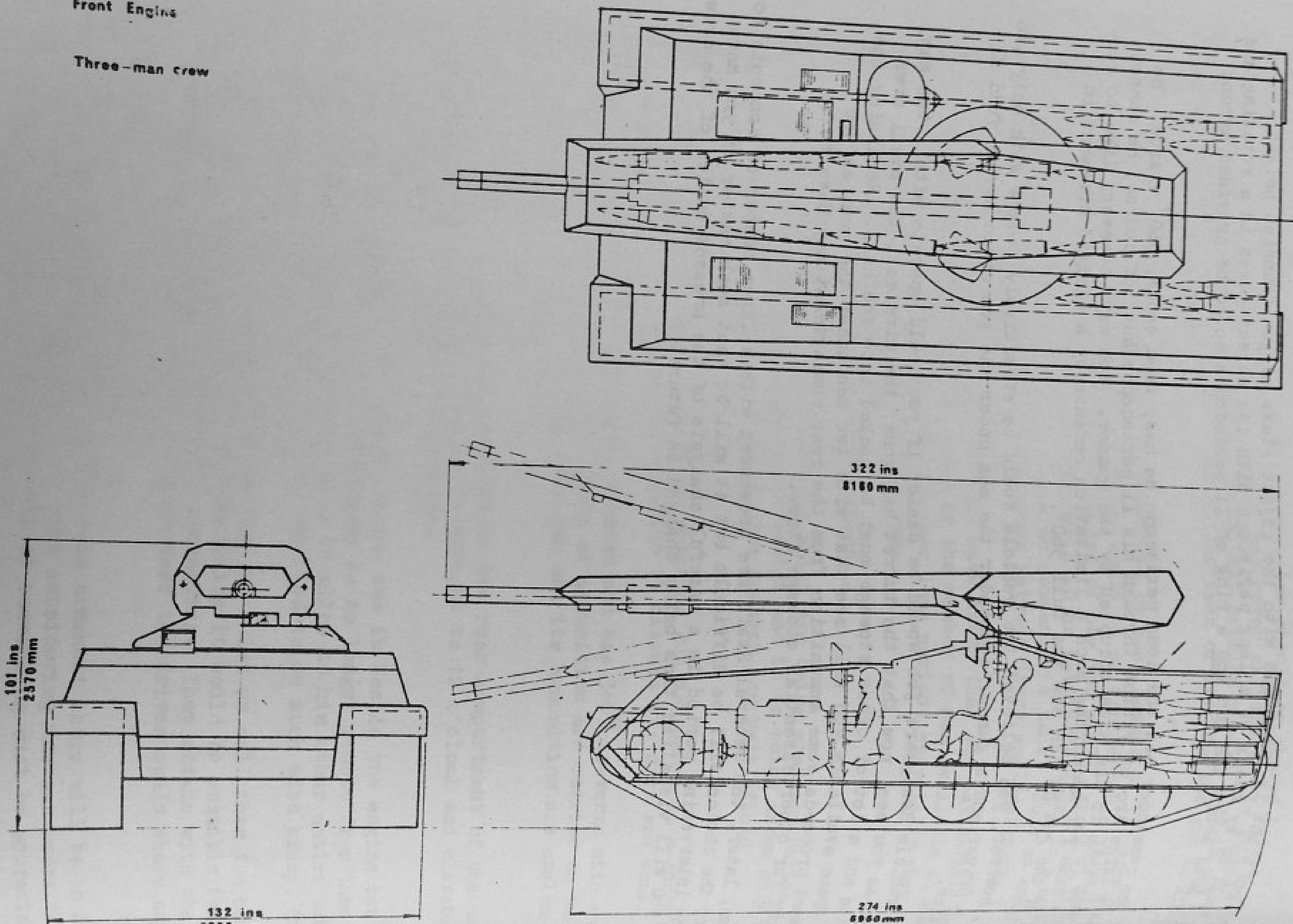
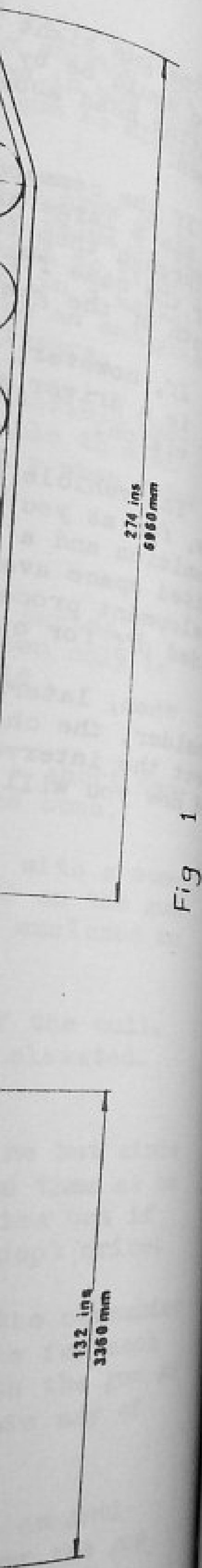


Fig 1



Discussion

Mr MONGER opened the discussion himself by stating that from previous papers he was no longer certain whether the designer should provide more comfort to allow the crew to sleep or less to keep them awake. He considered it important to know the value of "catnaps".

Mr WILSON pointed out that British tanks now have better vision for Commanders than any other tanks. He raised the question of closed-down operation: in this context would the tank shown in figure 1 by Mr Monger, in which the Commander's vision was limited, be acceptable?

Major EVELEGH envisaged that in the 1980s a fundamental tactical problem would be to absorb the enemy's first rush which would have a much superior weight of armour. New developments had enabled tanks to fight at night; it was important, therefore, that tanks should be capable of operating continuously for ten days in order to establish a defence in depth. This would be feasible if crews could operate efficiently over this period with only "catnaps" for sleep.

Professor WOODALL was of the opinion that intensive research on the value of "catnaps" should be undertaken.

Dr CORCORAN added that if the period was ten days then research should be directed towards the use of drugs.

Brigadier SIMPKIN then raised the possibility of impairment of judgment after using drugs for ten days.

Group Captain WHITESIDE stated that in normal sleep the depth is greatest at first. With "catnaps" there might therefore be too great a proportion of non-REM sleep and this could adversely affect performance.

Dr CORCORAN agreed that with little sleep one would go straight into stage 4 sleep, but stage 4 was required as well as REM sleep. "Catnaps" therefore might be of some benefit.

Major EVELEGH said that if a military commander knew how long men could operate under various conditions he could plan accordingly.

Mr ROLFE pointed out that in research it was not acceptable to test men to their limits.

Major WALLERSTEIN suggested that the problem might be overcome by providing one extra man in the crew and space to sleep.

Mr WILSON mentioned a recent trial during which the crew were kept awake all night. At the subsequent debriefing all, except one who was accustomed to little sleep, admitted to being in poor shape afterwards.

Dr ELWOOD referred to the relationship between "catnaps" and a reasonable period of sleep (five or six hours). It had been stated earlier in the day that impairment of performance occurred immediately after being aroused from sleep. He thought that frequent awakenings should therefore be avoided but that the views of the users should be sought.

Mr MONGER stated that results of studies on "catnaps" could have an important effect on design such as provision of more comfortable seats and dual controls. If "catnaps" were accepted a minimum of three men would be required in the crew.

CROSS COUNTRY SPEEDS

The Chairman Mr BAYLY PIKE opened the session by remarking that the papers of the previous day had dealt with the number of crewmen, its effect upon vehicle size and hence vulnerability to enemy fire. The papers today would consider aspects of the cross country speed of the vehicle.

Cross Country Speeds and Agility

by

Colonel J.D. Masters GS(OR)17 MOD(A)

Purpose

1. The purpose of this paper is to set down the various factors relative to the needs of tank speed against which the problems of human engineering may be discussed.

Need for Speed

2. A tank requires speed of movement for two purposes:

a. in order to carry out positioning manoeuvre expeditiously, probably out of direct contact,

and b. to render the tank less likely to be hit when moving.

Positioning Manoeuvre

3. A commander uses the mobility of his forces to achieve a supremacy in numbers and firepower over the enemy at some particular place and time. One of the essential requirements necessary to do this is that the movement must be achieved before the enemy is able, by a corresponding move, to cancel out the superiority intended.

4. The possible tactical situation, initially at least, in which we may have to carry out a mobile defence in the face of superior numbers puts a premium upon our ability to redeploy rapidly in order to cover a developing threat. Redeployment may be possible using roads but may also need to be made across the grain of the ground in the face of a threat developing with the grain, probably based upon roads. Thus an ability to move rapidly across country as well as on roads is essential.

5. Though velocity can be regarded as providing useful measures of mobility, care must be taken to ensure that they are not also taken to indicate the value of the mobility. Thus, for example, a vehicle which can move at twice the speed of another will only be of more value if use can be made of its extra speed over a significant part of the distance to be covered and, in any case, is unlikely to be exactly twice the value.

6. The average speed achieved during a movement by road will depend on factors such as the number of vehicles involved, the presence of bottlenecks, the incidence of hazards, traffic control and so on, just as much as the inherent speed of the vehicle. The greater the latter the more restrictive to the attainment of high average speed the former becomes.

7. The same principle applies in the case of cross country movement. A vehicle capable of high cross country speed will, dependent on the nature of the ground, be brought down to a safe speed by the commander/driver as a possible obstacle appears in their vision. In desert conditions this may be

infrequent, but in Western Europe each hedgerow may mask a sunken road or quarry. Experience so far is that this effect, combined with the less good going across country, has resulted in average speeds being about half that along roads. Even if suspension systems are vastly improved it is likely that average speeds along roads will still be higher than across country because the former usually contains less obstacles and gradients. Thus if we achieve what we want across country, the resultant road capability is likely to satisfy.

8. These considerations, in addition to pointing out the relationship of speed attainable to the resultant incidence of possible hazard, emphasises the need for what has become known as "agility" in the requirement for tank mobility, meaning rapid acceleration and deceleration.

9. In considering the inherent speed needed in a future MBT we must not only bear the technological problems in mind, but must also consider the above or else much unusable high speed may be put in to the design. This would seem to apply particularly to a tank designed for Western Europe.

10. Having weighed the factors, the two following illustrations may assist in making an intuitive decision on what speed is needed in a main battle tank to satisfy the requirements for positioning manoeuvre.

11. Figure 1 considers the requirement to redeploy 10 kms across country and shows the time taken at a number of different average speeds. It may be considered from this that whereas the gain from 30 minutes (the present situation) to 15 mins or 10 mins is likely to be a cost effective advantage, the subsequent time advantages at 65 kph and 83 kph are not. A very good return is achieved up to 50 kph but diminishes rapidly thereafter.

12. Figure 2 is extracted from a FVRDE report of some years ago but is still relevant. Even if we assume that modern suspension design can lift the cross country curve to that of the road, we see that a maximum design speed of 68 kph decreases to an average speed of 46 kph, and that the curve is flattening out.

13. Taking these together, it is considered that, in order to satisfy the requirement for positioning manoeuvrability, a new tank need not possess a maximum design speed greater than that which will permit an average speed of 40-43 kph across country and along roads, assuming the same incidence of obstacles and possible obstacles on each.

Decrease of hit chance

14. Although theoretically it may not be true, it is likely that the majority would accept, until faced by a homing missile, that the chance of being hit whilst on the move will decrease with speed, either because of the increased difficulty of the gunner to lay or track accurately or the possibility of reaching cover before the projectile arrives. The former applies in the case of both gun and missile attack. The latter to the missile only in terms of first round hit but possibly includes the gun also for subsequent rounds.

15. When in contact, tanks attempt to move between bounds, covered by other tanks. However, when in close proximity to the enemy but not directly engaged, unexpected contact may result when local repositioning manoeuvre is taking place. In this case tanks may not be covering each other and bounds may be much longer.

16. A bound is a position upon which protection may be obtained to at least the hull, by the nature of the ground from the most likely area of attack ie the forward arc. Hence the concentration on this arc in terms of armour and protection. Movement between bounds will make use of covered approach if possible. The covering tanks should be in positions from which they can engage weapons which engage the tanks covered - this is often difficult. This tactical method will be used when possible. The degree to which it can be will depend upon the configuration of the ground, which is never constant. This will also affect the length of bounds. At troop level, 500-750 m, is about the aim, though often it may have to be of greater distance.

17. Thus in terms of speed we need three things in order to decrease both the chance of hit and the exposure time one is subject to attack:

a. high acceleration

b. high speed

c. an ability to stop quickly.

18. Over shorter bounds a and c are proportionately more important than high speed, which gains in importance as the length of the bound increases. However, as the top speed capability increases so must the ability to stop quickly.

19. The exposure time will clearly vary according to the nature of the ground. In the desert exposure time may be very long even if high speed is achieved. In certain parts of Western Europe the broken nature of the ground will have the opposite effect. It is against a background of Europe that this problem should be considered and it is the varied nature of the ground which makes a mathematical solution difficult to achieve. However mathematical data can assist in pointing the right direction.

20. Figure 3 shows the 50 per cent chance of first round hit using current methods at various target velocities and angles of attack.

21. If the 10 degree angle of attack is ignored (virtually head on and therefore may be considered close to a stationary target), the table shows that considerable advantage obtains in the other cases, particularly the real crossers (60° and 90°) as speed increases; in fact a doubling of speed from the present 21 kph to 42 kph halves the range at which a 50 per cent chance applies.

22. This represents the situation in terms of current tank gunnery techniques and control equipment. In the future it is possible that the first round hit probability against crossing targets will be greatly increased if a computer is introduced into the system. Theoretically, in this event, the speed of the target will cease to be a factor; an ability to hit with the first round being simply the product of range - the probability being about 100 per cent at 750 m, falling in a nearly straight curve to 45 per cent at 3000 m.

23. If we accept this, speed in the context of hit avoidance will be relevant mainly in its effect upon lessening the exposure time to attack.

24. During movement in contact tanks are unlikely to follow a straight line as the tank commanders are trained to take advantage of cover. The amount

of cover available will vary with different types of terrain. In the case of open flat country, tank movement may be much faster than in closer country. The tank may be expected to resort to evasive action as counter measures to long periods of exposure.

25. When operating in closer country tank average speed may be much slower between bounds and advantage is obtained from the use of cover when the attitude, range and speed of the tank may be different on two successive occasions of exposure. Such conditions are not likely to be to the advantage of the anti tank weapon unless it is equipped with a system capable of achieving a very high chance of hit with the first round in a short time. This is because the probability of achieving a success, based on a multi round engagement when the first round does not hit, will be dependant on the time that the tank is exposed and this may not be of sufficient duration for such an engagement.

26. As part of a study on these problems, a programme of trials was arranged in order to obtain information on times of exposure and their frequency using tanks moving tactically over five different representative courses. The courses varied in length from 730 m to 2500 m. The enemy position was manned by another tank which gave the commander advantage of height. The attacking tank was manned by a commander, gunner and driver who was asked to drive at the speed which he could best maintain. The tank was timed over each of 45 runs distributed over the five courses, thus the average speed for each run on each course was obtainable.

27. The observer at the enemy position was equipped with a multi-channel electro-magnetic oscillograph using ultra-violet techniques and from the records, the times of exposure were deduced both in respect of hull-up and hull-down tanks.

28. Allowing for difficulties experienced by the observer in defining precisely when the turret or the whole tank was exposed, the shorter exposure times and the greater number of occasions on which only the turret was exposed appear to be according to expectation.

29. Using the data obtained plots were made to show the effect of tank speed on duration of exposure. Speeds used varied from 5 kph to 48 kph.

30. Figure 4 shows the mean values for all the courses. An examination of this shows that the time available in which to make an engagement differs very little when tank speed is upwards of 20 kph, when a hit must be achieved inside 10 seconds.

31. This trial deals with only five courses in one location, but indicates that not much advantage may be gained in the avoidance of being hit at tank speeds above 20 kph in this type of terrain. An ability to move across country at an average of 45 kph, which this paper has suggested is the optimum for reasons of positioning manoeuvre, would seem to provide for much more open country than that used in this trial in respect of exposure times.

Conclusion

32. The speed capability of the tank is provided in order:

a. that positioning manoeuvre may be carried out expeditiously

and b. to render the tank less likely to be hit when on the move.

33. An ability to carry out positioning manoeuvre expeditiously depends less upon a high top speed capability than on the incidence of obstacle or possible obstacle at design speeds above about 30 kph.

34. The probable high incidence of obstacles and possible obstacles emphasises the need for "agility" - meaning rapid acceleration and deceleration.

35. Optimum speed capability for positioning manoeuvre is likely to be achieved in a MBT with a design speed which will permit an average speed of 40-45 kph across country.

36. In order to decrease the chance of being hit a tank should have:

a. high acceleration,

b. high speed,

c. an ability to stop quickly.

37. In the face of current gunnery techniques an ability to average 42 kph between bounds (as opposed to the current 21 kph) halves the range at which a 50 per cent chance of hit exists.

38. In the future, improved gunnery control equipment may render speed immaterial in the chance of hit on moving targets. Exposure time will then be the only factor affecting hit chance.

39. In this case, an ability to move across country at an average speed of 40-45 kph appears likely to be greater than the optimum needed to minimise the chance of first round hit in European type terrain.

Time to complete 5 miles cross country movement

Average Speed	Time Taken
17 kph	30 mins
34 kph	15 mins
51 kph	10 mins
68 kph	8 mins
85 kph	6 mins

Figure 1

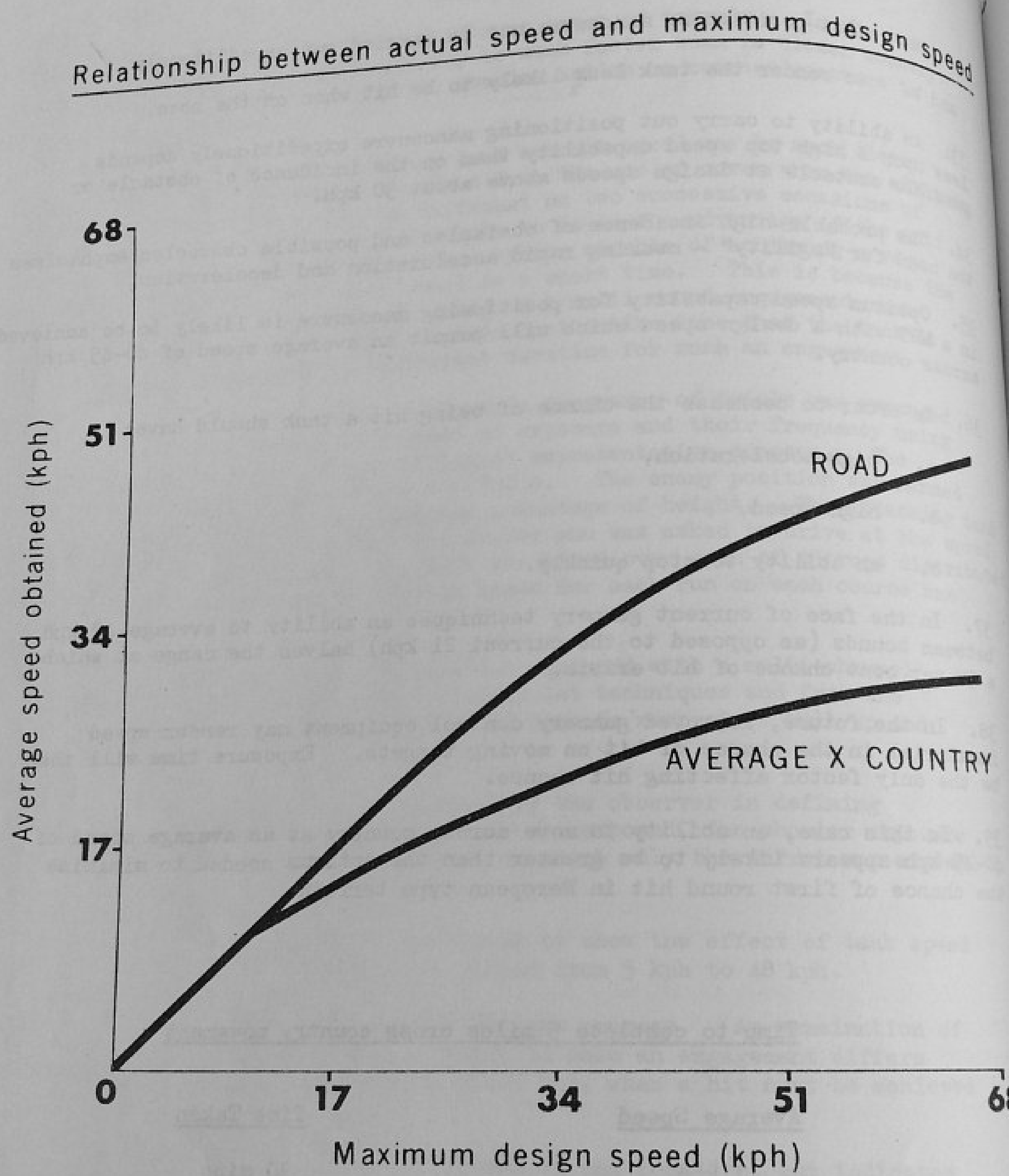

Relationship between actual speed and maximum design speed
68
51
34
17
0
17
34
51
68
Average speed obtained (kph)
Maximum design speed (kph)
ROAD
AVERAGE X COUNTRY

Figure 2

Hit chance - range and velocity for 50 per cent chance of hit (aim at leading edge)

Target Velocity	Angle of Attack			
kph	10°	30°	60°	90°
14	2450m	2550m	2200m	1800m
21	2650m	2150m	1700m	1350m
28	2600m	1800m	1300m	1100m
35	2400m	1500m	1100m	850m
42	2150m	1300m	900m	750m
49	2000m	1150m	800m	650m

Figure 3

MEAN VALUES—ALL COURSES.

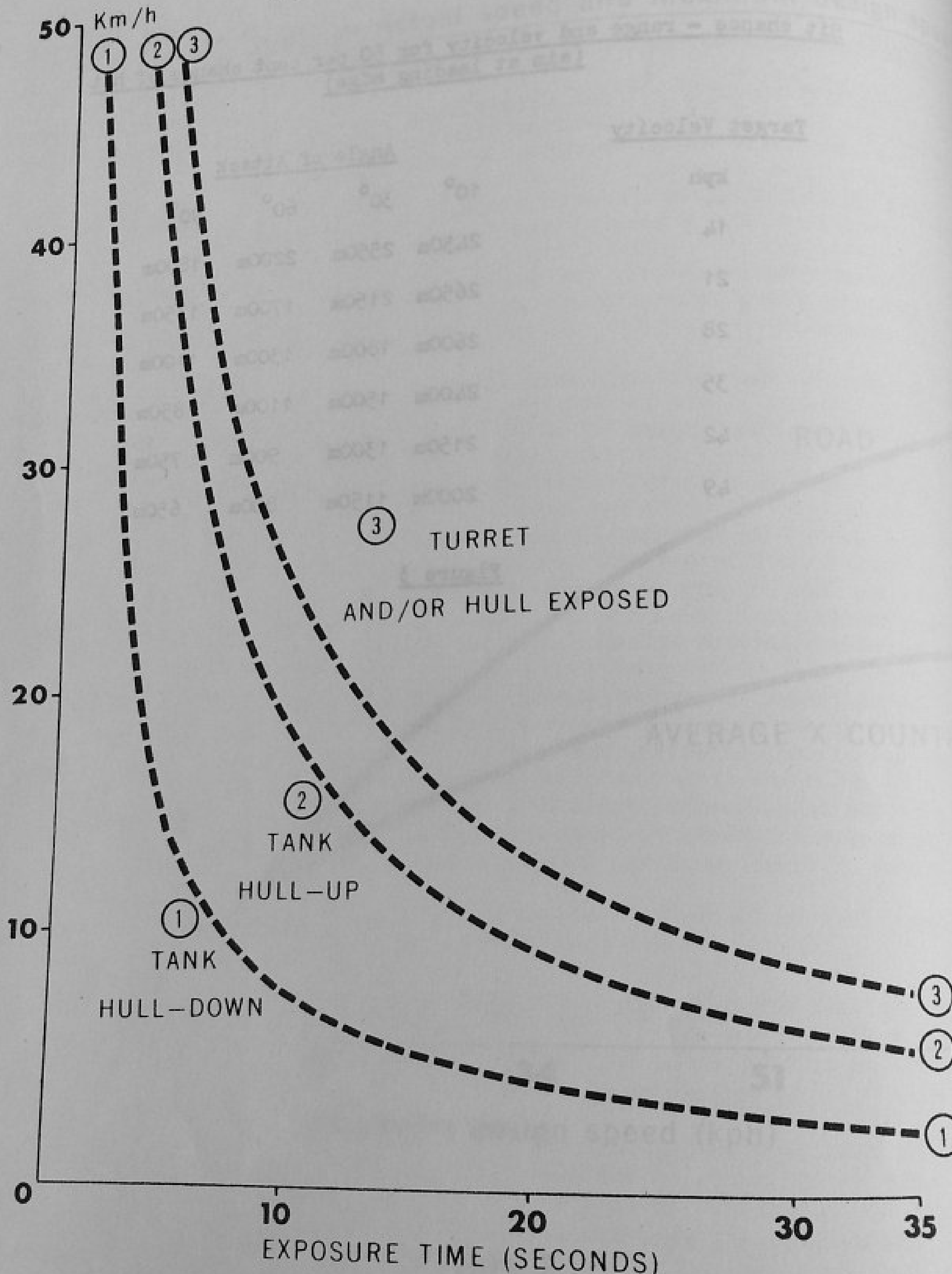


Figure 4

Discussion

Group Captain WHITESIDE asked what was the period between the first appearance of a target and firing a round and what figure had been used in the calculations given in the paper.

Colonel MASTERS replied that the period was of the order 10 to 15 seconds. Below 10 seconds one would not expect to hit the target.

It was agreed to take further discussion after the next paper.

Introducing the next paper the Chairman Mr BAYLY PIKE referred to Colonel Master's figures on cross country speeds where it appeared that the power weight ratio and suspension were adequate to enable the vehicle to attain high speeds. The controlling factor might well be the ability of the crew to withstand the shocks and bumps of the higher speeds. The next paper would deal with a pilot study on this topic by APRE.

Cross-Country Speeds of Armoured Fighting Vehicles: Shocks and Bumps

by

Laurence M. Croton

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Introduction

1. Any increase in average cross-country speed in a modern AFV would be of great advantage. The attainment of high operational speeds may be prevented by design and construction of the vehicle or by the imposition of intolerable shock or vibrational loads upon the AFV crew. In order to study this problem, APRE Project 517 was commenced during 1968.

Object

2. The Terms of Reference for this Project are:-

a. To measure and compare the cross-country speed of a Main Battle Tank with (1) full crew operating under normal RAC regulations and (2) with driver only, who is provided with protection, restraint, and freedom from responsibility for damage to the vehicle.

b. To measure, from the structure of the vehicle, the shock-loading or impact accelerations to which the crew may be exposed, and compare the results obtained when the vehicle is driven under the two different conditions at sub-para a.(1) and a.(2) above.

c. To consider the possible effects of variation in cross-country speed of main battle tanks upon the turret crew members.

Method

3. a. At this time it has only been possible to carry out a 'pilot' trial to examine techniques for the measurement of vehicle speed, and of acceleration forces, and the use of crew questionnaires covering their experiences in the vehicle selected for the 'pilot' trial.

b. In accordance with the Terms of Reference for the Project, an improved pattern seat was installed in the test vehicle and an adequate harness provided. The selected seat was a 'Contour 6' seat based upon a welded tubular steel frame. The cushion was

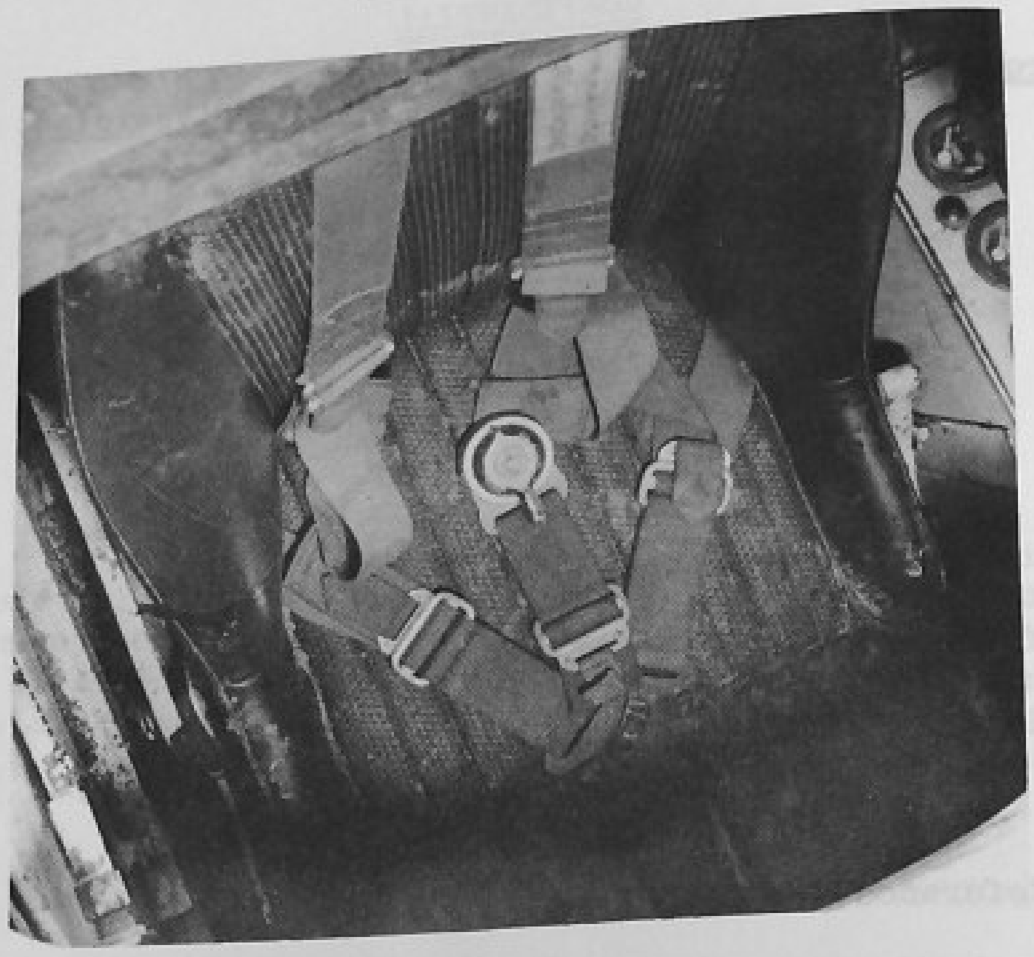

Fig 1 "Contour 6" Seat and Quick Release Harness

polyether foam ($1\frac{1}{2}$-2" thick) supported in the seat frame by a stretched rubber diaphragm. The backrest was substantially curved, or wrapped round the body, to give sideways support to the hips and back. It was constructed of a rigid mounting upon which was a layer of polyether foam. (Fig 1)

Fig 2 shows an experimental subject seated in the "Leopard" tank with the 'quick release' harness adjusted and wearing "bump protection" in the form of an RAF Mk 1 helmet.

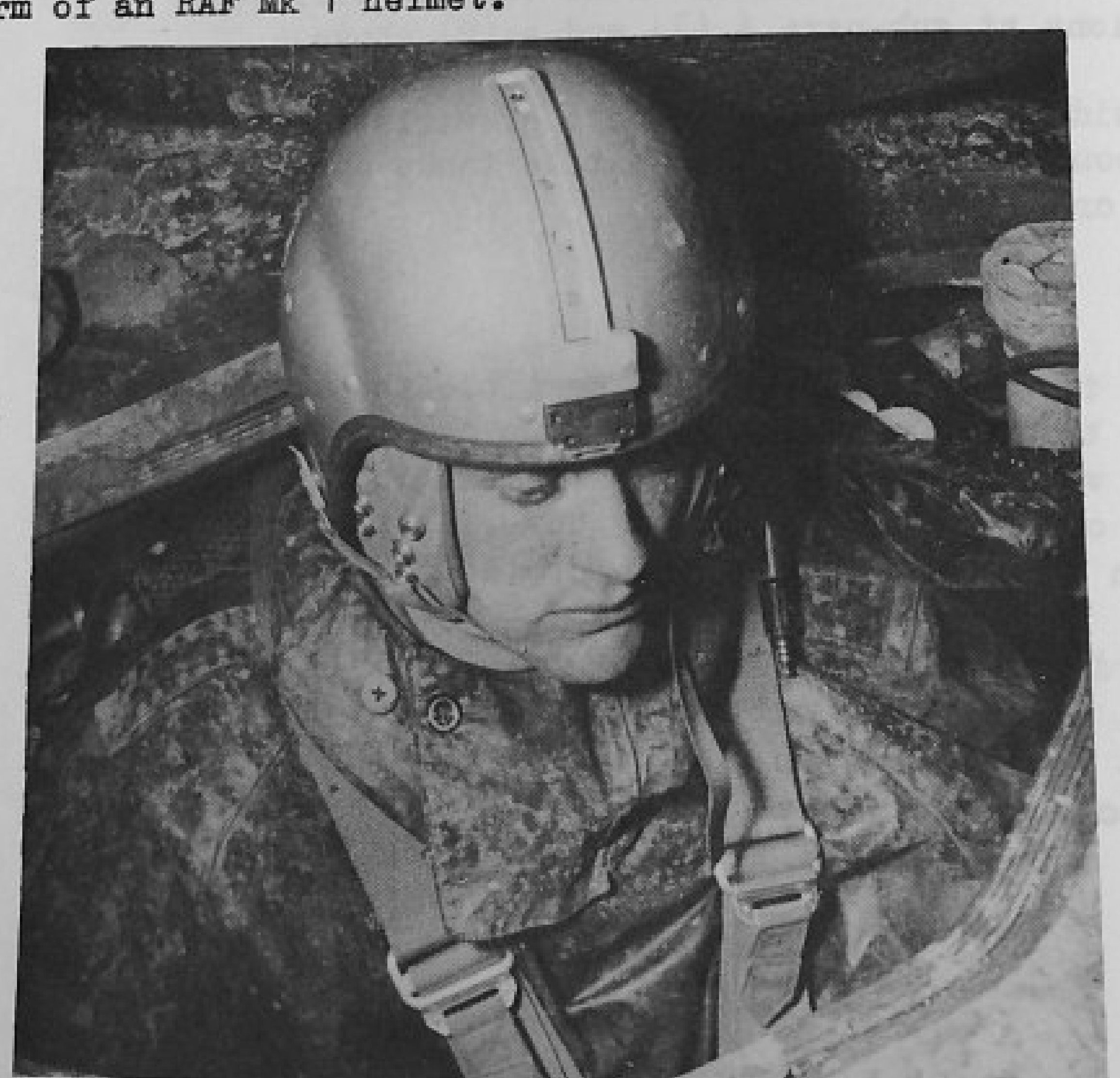

Fig 2 Driver Seated in "Leopard" Tank

Intercommunication was ensured by wearing the RAF type 'skull cap' beneath the protective helmet to which the necessary ear phones were attached.

c. Average speed over three different courses was measured by stop-watch. Several observers timed the vehicle. One or two were stationed at the start line (which the vehicle passed after a flying start) and a further one or two observers timed it as it reached the end of the course.

d. Accelerations were measured by positioning accelerometers on the vehicle hull at chosen crew locations and also near the centre of gravity of the vehicle.

e. At the conclusion of each course, a questionnaire was administered to each crew member individually, or singly to the driver when no other crew were present during the "free speed" runs.

f. The three courses selected were considered against the concept that,

Fig 3 Course No 2 (Alternate Rough, Smooth, Bumpy)

in moving from Point 'A' to Point 'B' (the beginning and end of each course) which were both screened from aerial detection, cover from aerial view could not be secured but, due to varying types of terrain, there were degrees of screening from ground view.

Course No 1 was 2300 ft (700 metres) long with no cover and fairly flat, sandy ground. Figure 3 gives an indication of Course No 2 which was 1800 ft (548 metres) long, with no cover and consisted of alternate rough, smooth and bumpy ground with many hillocks greater than silhouette height of the vehicle and one or two deep gullies on the line of route. Course 3 was a partially sine-wave course with shallow bumps 2-3 ft (0.6-0.9 metres) from peak-to-peak and 20-30 ft (6.1-9.1 metres) between troughs. Its length was 1500 ft (457 metres). Whilst each Course had a different length for reasons of available terrain, the average width was kept the same for all Courses at about 50 ft (15 metres).

g. In the 'pilot' experiment, four drivers were used, three of whom occupied the positions of Commander, Gunner and Loader, when not driving during the fully manned runs. To obtain a better overall assessment of comfort and performance in each of the crew locations, no one person occupied one position predominantly. Each subject was suitably rotated in accordance with an experimental design.

h. In order to record shock-loading and accelerations, the Trials vehicle was fitted with instrumentation units consisting of the following main items:-

(1) Midas Tape Recorder

(2) Switch Timer Unit

(3) DC Amplifier Unit

(4) Impedance Converter

(5) Strain Gauge Transducer

(6) Accelerometers, Endevco Type 233

The outputs from three orthogonally mounted transducers were fed direct to the Tape Recorder via the DC Amplifier. Outputs from the remaining transducers were fed by the switch-time unit which also provided the channel identification facility. All eight modulated tracks of the Tape Recorder were used, their centre frequency was 3,500K Herz at a speed of 5 ins/second, and 5,250K Herz at a speed of 7½ ins/second.

Results

4. a. Cross-country speeds with and without a turret crew

The average speeds over each Course, as assessed from individual observer's timings, an overall assessment of percentage increase in average speed without turret crew, and a summary of means for these parameters are shown in the following Table:-

Course	1 Flat Acceleration 2300 ft (700 Metres)			2 Rough, Bumpy 1800 Ft (548 Metres)			3 Partial Sine-Wave 1500 ft (457 Metres)		
	Average Speed		%	Average Speed		%	Average Speed		%
	MPH	KPH	Increase	MPH	KPH	Increase	MPH	KPH	Increase
With Full Crew	16.1	25.8	-	10.3	16.6	-	14.9	23.9	-
Driver Only	22.5	36.2	40.6	13.1	21.1	27.2	18.9	30.4	26.7

It should be noted that the same driver covered his crewed and non-crewed runs on the same day, ie the 'going conditions' were comparable. In general, the weather conditions during the 'pilot' trial were poor, heavy rain made the 'going' very sticky and it is possible that higher average speeds would have been attained on better terrain. The various craters on Course No 2 were invariably well-filled with rain water and the effect of this on driver performance was noted in the questionnaires.

b. Crew Questionnaires

At the conclusion of each run, every crew member (or driver only) was given a questionnaire to complete covering his experience during the preceding run.

(1) Driver

The general summation of driver experience under the conditions of the trial indicated that all were willing to drive faster than normal regulations allow and that the provision of an improved seat, restraining harness and helmet protection gave them confidence in their personal safety. Some drivers commented that there was inadequate padding of the seat which led to a 'jarring of the spine' when hitting ridges on the rough, bumpy course.

(2) Turret Crew

Most of the subjects found it essential to grasp a convenient solid object during the traverse of the more difficult Course 2, and, as expected, the Loader was more subject to bumps and shocks than the other turret crew. In general the turret crew did not prefer to have helmets and safety harness when the vehicle was driven in accordance with RAC training and thought that it would be difficult to carry out their normal combat duties whilst wearing these items, with, perhaps, the exception of the Commander.

c. Shock Loading and Acceleration

As mentioned earlier, the only experimental work carried out on this Project to date has been this 'pilot' trial which was designed to examine methodology.

Some results have been produced on shock-loading and accelerations measured during the trial runs described in this paper, and these will be discussed by Mr E. Maclaurin of FVRDE in his paper.

Conclusions and Recommendations

5. a. It is concluded from this 'pilot' study that the techniques for the measurement of vehicle speed and assessment of crew questionnaires will be adequate for the purposes of the Main Trial. It was recommended that the techniques for the measurement of acceleration and shock-loading forces are re-examined to arrive at the optimum method of recording these parameters, and for future laboratory simulation studies.

b. The Main Trial will take place in April-May 1969 when eight separate AFV trained crews will be used. Two courses have been selected and each crew will traverse the courses in a random manner (full crew or driver only) according to a statistically designed experimental plan. Discussions have taken place between APRE, FVRDE, the College of Aeronautics and IAM, as to the best possible techniques available for recording accelerations and impacts and it is anticipated that valuable information will be obtained as a result.

Discussion

The Chairman Mr BAYLY PIKE said that the pilot trial by APRE suggested that the tank of today could go faster cross country than was normally permitted but that the tolerance of the crew was the limiting factor.

Major BOYD asked how increase in speed might affect the onset of fatigue and the ability to perform tasks in action.

Mr CROTON replied that investigation of these points was not the prime object of the APRE Study. However it was hoped that some relevant information would emerge from the questionnaires to be completed by the trained RAC crews taking part in the forthcoming main trial. These questionnaires would be of value to users and designers.

Mr MONGER pointed out that the tank used in the experiment was conventional. He asked if (impact) accelerations were measured and how the crew communicated with the driver their desire to go slower.

Mr CROTON replied that the first question would be covered in Mr Maclaurin's paper. Regarding communication it was the Commander who told the driver to slow down.

The Chairman Mr BAYLY PIKE reminded those present that in the pilot trial the crew were all drivers. In a trained crew the driver would know what the other members were likely to tolerate, but in the pilot trial there may have been some rivalry between drivers which may have affected the results.

Colonel MASTERS asked what contact existed between APRE and ATAC at Warren, Michigan, where he had recently seen a simulator coupled to a computer.

Dr ELWOOD pointed out that the APRE study would not give information on human tolerance to impact in terms of "g" without further laboratory work. He had discussed this during his visit to ATAC last Autumn. The ATAC simulator had four out of a potential six degrees of freedom. It would need to be decided whether this number was adequate to cover the human tolerance. The ATAC simulator would accept most of the information APRE hoped to obtain from the main trial, but not all. There was no simulator with six degrees of freedom although IAM had one with five.

Mr ROLFE stated that the IAM simulator with five degrees of freedom lacked surge which, although not important in aircraft, might be so in a vehicle. He asked APRE whether any data was available on what difference in speed was achieved by giving harness and helmet to a driver on his own. In the pilot study two variables were present: improved driver comfort and absence of crew.

Mr CROTON replied that no data had been collected on the maximum speed achieved by a driver without crew and harness. This could be done if it was thought to be of value.

The Chairman Mr BAYLY PIKE gave warning that a human being could not be tested to destruction in a research project.

Colonel TYNAN suggested that information on the requirements for harness might be valuable in future financial negotiations and he asked if one driver had been very much better than the rest and, if so, was his speed limited by the tank.

Mr CROTON replied that one driver achieved a much greater speed than the rest but that he would not repeat the performance! Driver comfort was the limiting factor.

Colonel COCKLE commented on liaison with US. He stated that a study was about to commence at ATAC to investigate ride characteristics of Chieftain v. MBT 70, and FV 432 v. M113. This investigation would also compare cross country speeds. He suggested that further information on this project should be obtained from Lt Col Douglass at BDS Washington.

VEHICLE RIDE AND CREW SAFETY

Ride of Main Battle Tanks

by

E.B. Maclaurin, Automotive/Mobility, FVRDE

The many aspects of ride can be considered under three main headings:-

1. The ground or terrain input.
2. The vibrational response of the tank to the terrain input.
3. The human response to the vibrational motion of the tank.

1. The Ground or Terrain Input

The majority of research on the measurement of cross-country profiles has been performed in the US and has produced three main findings:-

a. The surface profile of most virgin cross-country terrain is of a random nature, ie there is no predominant wavelength of undulation apparent.

b. The mean amplitude of wavelength tends to increase with wavelength, which is probably to be expected. The relationship between amplitude and wavelength is usually expressed in terms of power spectral density.

c. The amplitude distribution is Gaussian or near-Gaussian.

There are two important exceptions concerning the randomness of wavelength of cross-country terrain.

a. Cultivated land.

b. Tank testing grounds where the courses tend to take on a characteristic wavelength which is a function of the natural pitch frequency and speed of the tanks which are normally tested on them.

A further finding of this work in the US is that no instrument exists for quickly and accurately measuring cross-country profiles. The only method available which is sufficiently accurate is the rod and transit (using conventional surveying techniques) which is slow, tedious and expensive.

In considering the movement of vehicles over ground profiles two further points should be considered:-

a. The profile will be deformed, elastically and plastically, as the vehicle passes over it; this deformation will depend on the characteristics both of the soil and the vehicle. The effect generally is to reduce the vibrational input to the vehicle.

b. The presence of tracks will tend to modify the profile as seen by the road wheels.

2. The vibrational response of the tank

In its most idealised form a tank suspension system can be considered as a low pass filter which has to support the weight of the tank, stabilise it against external forces, and allow it ride over high amplitude long wavelength (ie low frequency) obstacles. Above a certain frequency ground undulations should be absorbed by the suspension which should have a travel appropriate to the amplitude of the undulations which it is required to absorb.

Figure 1 shows the response to sinusoidal displacement of a simple spring suspended and viscous damped mass. It shows how such a system is not at all ideal and how the damping has to be a compromise to control the displacement at resonance and yet not impair absorption in the "decoupling" range (above $f/f_n = \sqrt{2}$).

The usual method of improving the ride is to soften the springs and reduce the natural frequency. This enables a greater range of frequencies to be absorbed and improves absorption in the "decoupling" frequency range. However this enables the vehicle to absorb longer wavelength and hence higher amplitude bumps and it therefore is essential that the stroke of the suspension is increased as the suspension is softened. The use of a soft long stroke suspension requires the provision of a considerable amount of resilient spring medium. It is difficult to find space for this external to the hull and the space it requires inside the hull is well illustrated in figure 2 showing the Panther suspension.

The floor of the hull is carpeted with torsion bars which increase the height and weight of the tank. It is difficult to achieve a really soft suspension with a single width torsion bar. Panther had a very soft suspension (pitch frequency .5 cycles/sec, bounce frequency .86 cycles/sec, stroke - static to bump 7.1") and has probably only just been bettered by the MBT 70. Hydro-gas suspension does offer the prospect of compact, high capacity energy storage at the expense of increased cost and probably reduced reliability. Hydro-gas suspension also allows hull attitude and ground clearance to be adjusted relatively simply.

In fact a tank suspension cannot be analysed as simply as shown in figure 1 - the body is supported by a number of springs and is free to vibrate in three modes, namely bounce, pitch and roll. Roll motions are not normally considered in the analysis of tank suspensions although certain surfaces can induce appreciable rolling motions.

The processes of pitch and bounce are considered in figure 3. At slow speeds the effects of short wavelength bumps are reduced by the process of "averaging" between the many wheels. (This is in contrast to the hypothetical one-wheeled vehicle (figure 1) which in order to reduce the effect of a bump has to be travelling at a speed such as to bring the bump into the decoupling frequency range.)

As speed is increased the "averaging" process is augmented by vibration absorption.

As the wavelength increases to approximately 1½ times the wheelbase of the tank, and if the tank is travelling at a certain speed the pitch resonance will be excited. For a tank with a wheelbase of 14', a pitch frequency of .7 cycles/sec the critical speed will be about 15 ft/sec (10 miles/hr). The suspension will not start absorbing this wavelength (approximately 20') in the pitch mode until a speed of about 15 miles/hr is reached.

As the wavelength increases to approximately three times the wheelbase of the tank, at a certain vehicle speed the bounce resonance will be excited. For a wheelbase of 14' and a natural frequency in bounce of 1.0 c/sec the critical speed will be approximately 42 ft/sec (29 miles/hr).

This is beyond the cross-country speed range of most tanks and is why the pitch mode is much more strongly damped than the bounce mode. Two further points should be noted:-

a. Shorter obstacles can also excite the resonant frequencies (if they occur at the right frequency) but not so strongly because fewer wheels will be operated.

b. Wavelengths longer than the critical wavelengths will also excite the resonant frequencies if the tank is going appropriately faster.

The two modes of vibration, bounce and pitch, are usefully shown in figure 4. This is for the Leopard tank and part of a "flat-out" run in the pilot trial described by Mr Croton. The fig (redrawn from histograms) shows the root mean square acceleration in 10% frequency bands. The two basic curves are vertical rms acceleration at the driver and at the cg. On most tanks it is a fairly good assumption that the pitch and bounce modes can be considered independently, ie they are not coupled. This means we can subtract the cg or bounce motion from the total driver motion to give that due to the pitch motion. (This can only be done for low frequency motions up to approximately 5 cycles/sec.) The acceleration levels at higher frequencies are probably due mainly to inputs from the bump stops and dampers but there are also inputs from the engine and tracks. The steady continuous components can be partially absorbed in the vehicle seats but not the high amplitude peak inputs from the bump stops. It would be unwise to read too much into this sort of spectral analysis as to how efficiently the suspension is operating; to do that one would need an equivalent spectral analysis of the ground input for the speed at which the vehicle was travelling. For example the low acceleration levels in the region between 5 and 10 cycles/sec looks impressive but most likely means that the relevant wavelengths have been obliterated from the course.

The actual rotary motions produced by pitch are probably of minor importance compared with their translatory components, but they do increase the requirements of a gun stabilisation system and make observation through viewing devices more difficult. The translatory components of pitch will appear as vertical movements to the driver and as fore-and-aft movements to the commander in the turret.

It is possible to soften the pitch mode independently of the bounce mode by inter-connecting between the front and rear stations; this requires no extra spring medium but there is the weight and complication of the inter-connecting members. Again it is necessary to increase the travel of the forward and rear stations to prevent excessive use of the bump stops and there is a limit as to how much the pitch stiffness can be softened in order to prevent excessive pitch angles when braking and accelerating and when operating on steep gradients.

In an ideal suspension system there would not be a portion of the frequency response curve where the suspension system amplifies the ground input as there is around the resonant frequency of a conventional spring/damper system. A means of reducing this effect is to use an "active" or servo-controlled suspension system. A design study for such a system has been carried out under contract to FVRDE and a diagrammatic layout is shown in figure 5. This system was designed to operate only in the pitch mode. Double acting hydraulic jacks are placed in series with the springs of the fore and aft suspension stations and are fed with fluid from an engine driven pump. Control of the flow to the jacks is by means of electro-hydraulic valves which receive electrical signals from a pitch sensing accelerometer. The system can be likened to a gun stabilisation system acting on the whole hull of the tank. An analogue computer simulation of the system's performance is shown in figure 6. Pitching is considerably reduced over the whole frequency spectrum. The disadvantages are the greatly increased complication and expense of such a system and also the fact that on rough going it demands an appreciable amount of power from the engine. ATAC's Mobility System Laboratory have actually built such a system into an M 56 7.5 ton SP gun. This operated in bounce, pitch and roll and was reported to give good results.

3. Human response to vibrational motion of the tank

The vibrational motion which the crewman experiences can be considered in two categories:-

a. The continuous random vibration to which he is subjected.

b. The large shock loads which are experienced when the vehicle meets large discrete obstacles.

In the US these are called "Grinds" and "Bumps". There are three schools of thought concerning the relative importance of "grinds" and "bumps". One holds that the "grind" approach is adequate for the majority of situations, one that only the effects of "bumps" need to be considered and the third that both aspects are important. Much would seem to depend on the characteristics of the terrain, the vehicle and the time of exposure and whether the driver is attempting to give a good ride. For a long journey where the driver is trying to provide a smooth ride the "grind" approach is probably adequate but for the sprint manoeuvre of short duration and where the suspension bump stops are being frequently contacted the "bump" approach is probably more suitable.

3.1. The "Grind" approach

In considering the "grind" approach the numerous shake table experiments which have been performed have some relevance to the problem. In these experiments attempts have been made to correlate human comfort with pure sinusoidal vibration levels at different frequencies. Figure 7 shows the results of some of these experiments. There is considerable variation in the results due partly to the vague subjective criteria used, ie alarming, unpleasant, intolerable, stop - don't increase further, and also because different people respond in substantially different ways. However most of the experiments reveal a region between 5 and 7 cycles/second where the human is less tolerant to vibration and this is usually attributed to resonance of the organs inside the abdominal cavity (otherwise called visceral resonance). A recent attempt to produce a single standard for low frequency sinusoidal vibration tolerance is that by ISO, International Standards Organisation, shown in figure 8.

There are two further difficulties in trying to use the results of shake-table experiments to arrive at an objective measure of ride quality:-

a. The determination of a relationship (if any) between sinusoidal vibration and the sort of random vibration experienced in a vehicle.

b. Ride motion in a vehicle involves transverse and longitudinal vibration as well as vertical vibration and also rotational modes of pitch and roll and few shake table experiments take account of more than one mode at the same time.

Present practice on the "grind" approach is to consider the mean square or root mean square acceleration in a number of filtered frequency bands recorded in 3 orthogonal directions on the driver's or passenger's seat. Van Deusen of Chrysler considered 3 different ride criteria which emphasised different frequency bands. He found that the best correlation between subjective assessment and measured rms acceleration occurred for the criterion which emphasised the visceral resonance band. However there were marked differences in correlation between different vehicles and he concluded that no single number could adequately describe the ride quality of a vehicle mainly because the human is sensitive to vibration in three directions over a wide range of frequencies and different vehicles produce markedly different frequency spectra.

3.2. The "Bump" approach

When it comes to assessing human tolerance to "bumps" the position is just as complicated. Figure 9 shows the acceleration/time trace of some "bumps". The magnitude of the peak acceleration is important but just as important are the rise time and the duration of the peak acceleration.

a. If the rise time and peak time are short compared to the natural frequencies of various organs in the body these organs will not reach the peak acceleration.

b. If the rise time is short and the peak time appreciable there will be dynamic overshoot of organs in the body.

c. If the rise time is relatively slow then all parts will reach the peak acceleration.

There is some similarity here to the design of aircraft ejector seats where a build-up of acceleration leading to a higher final acceleration is preferred to a constant but lower level of acceleration.

However, if peak 'g' level is considered to be the only criteria of importance in the "bump" approach tables can be made on the basis of the number of peaks exceeding certain levels and one of these is shown in figure 10, again for the Leopard tank and comparing a normal crewed run with a "flat-out" driver only run. The driver only run represents an increase in average speed of approximately 30% compared with the crewed run. As would be expected there are far more peaks for the driver only run - especially peaks exceeding 2g. There are also more vertical peaks at the cg position compared with the driver's position. However what is most striking is the number of transverse peaks at the rear of the turret ring, far higher than the number of transverse peaks at the driver's position. This could indicate that the rolling inputs to the tank are important. But it could also indicate that the accelerometer was picking up some sort of structural resonance from the tank hull.

It would appear from our limited experiments so far that provided crewmen are securely strapped in or "packaged" they can accept appreciably higher vibration levels without injury for short periods compared to those which are normally tolerated. Much would depend on the seating arrangements, the confidence the crew have that they will not injure themselves and the familiarity they have with the vibratory motions.

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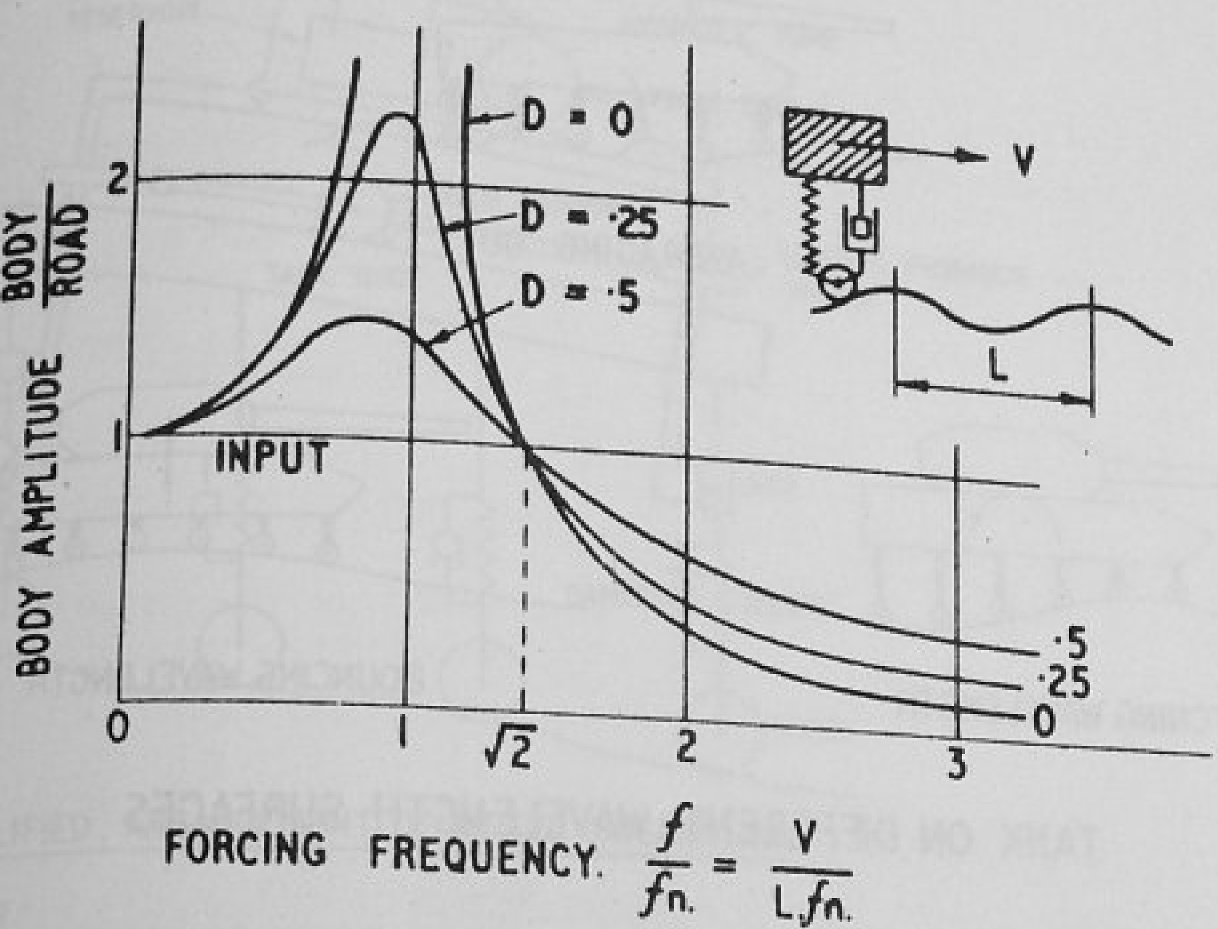


Fig. 1

Response of a spring suspended and viscous damped body to sinusoidal input.

f_n = undamped natural frequency

D = damping ratio (proportion of critical damping)

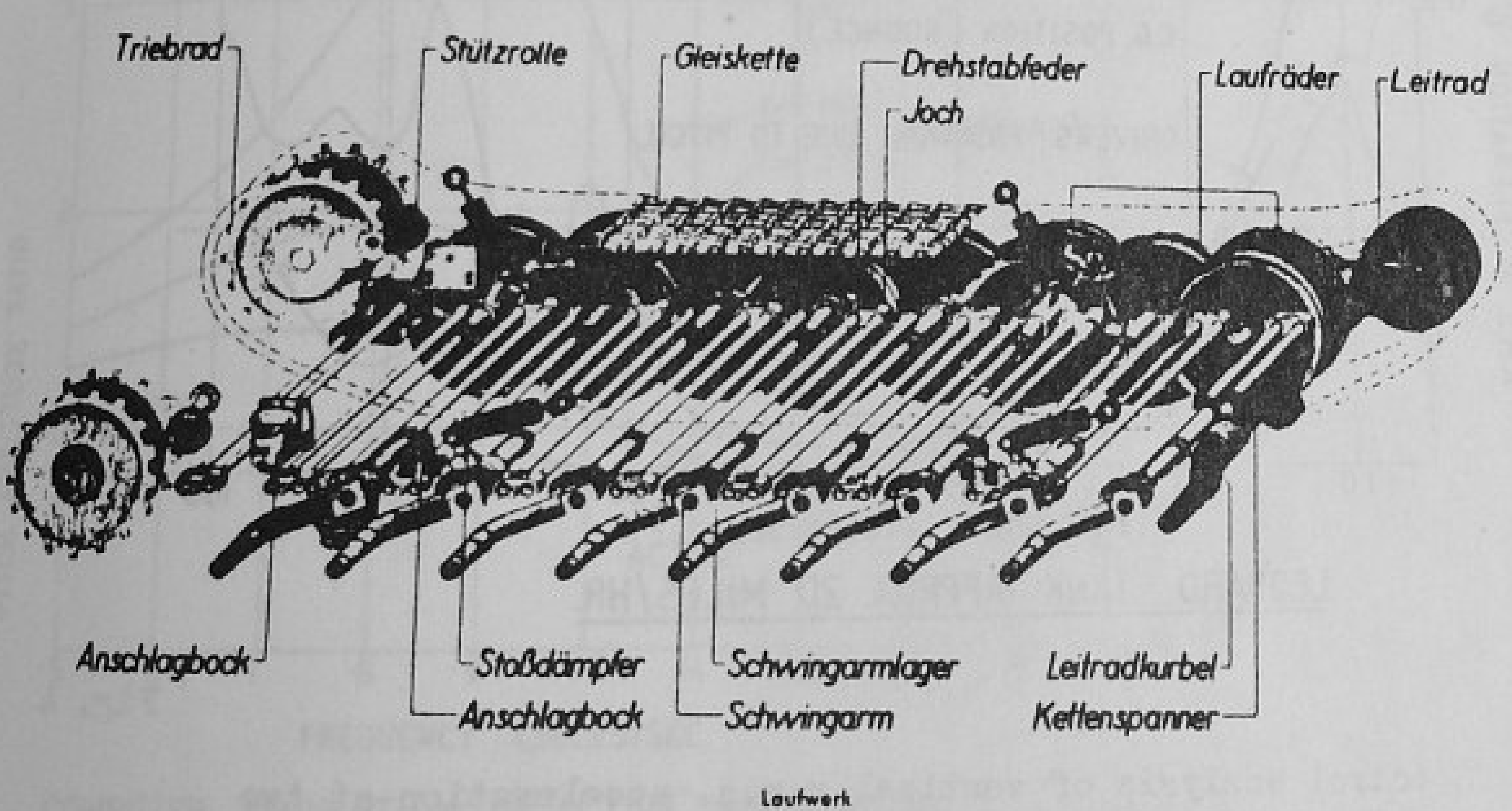
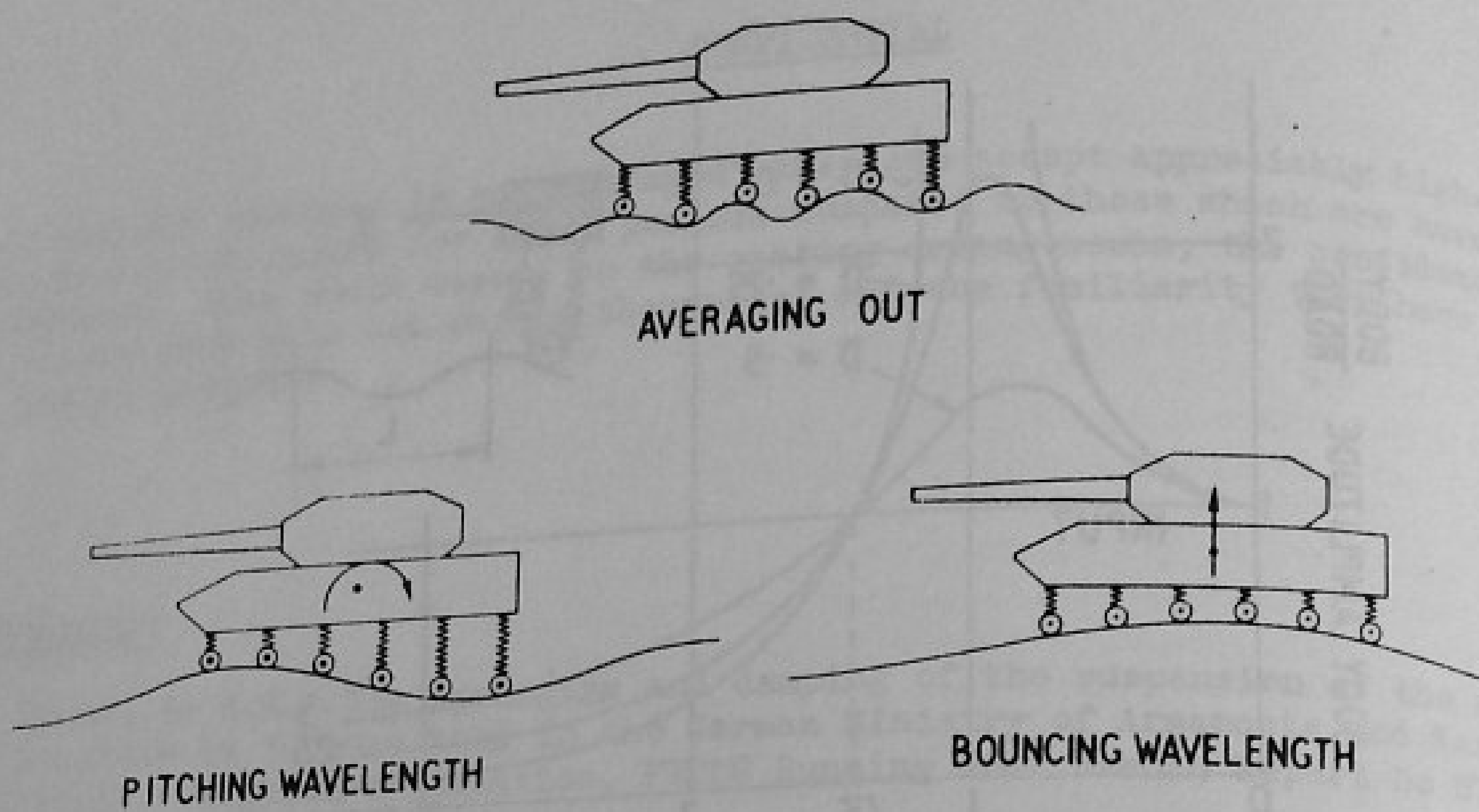


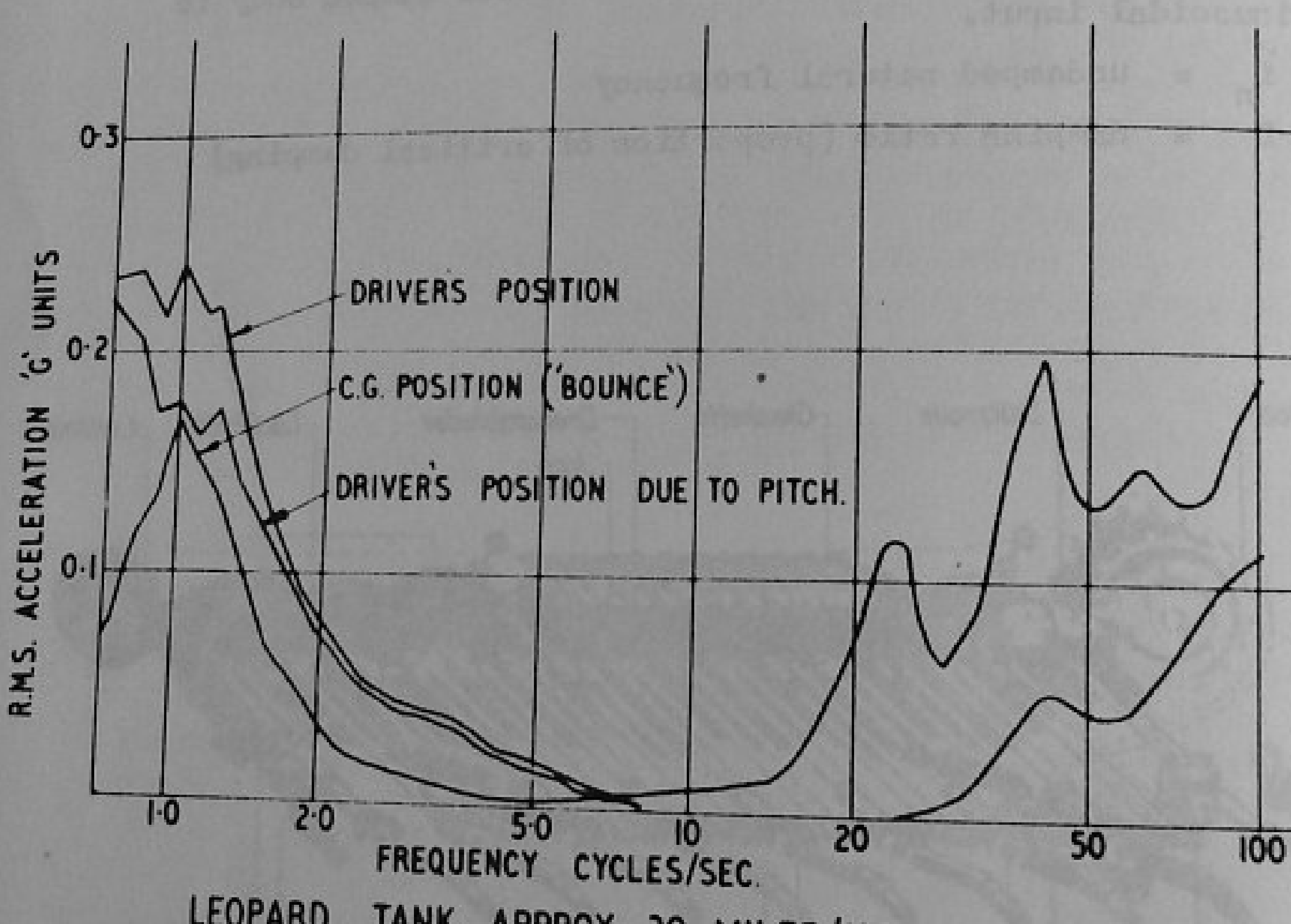
Fig. 2

Panther suspension showing the double torsion bars necessary for very low natural frequency suspension.



TANK ON DIFFERENT WAVELENGTH SURFACES

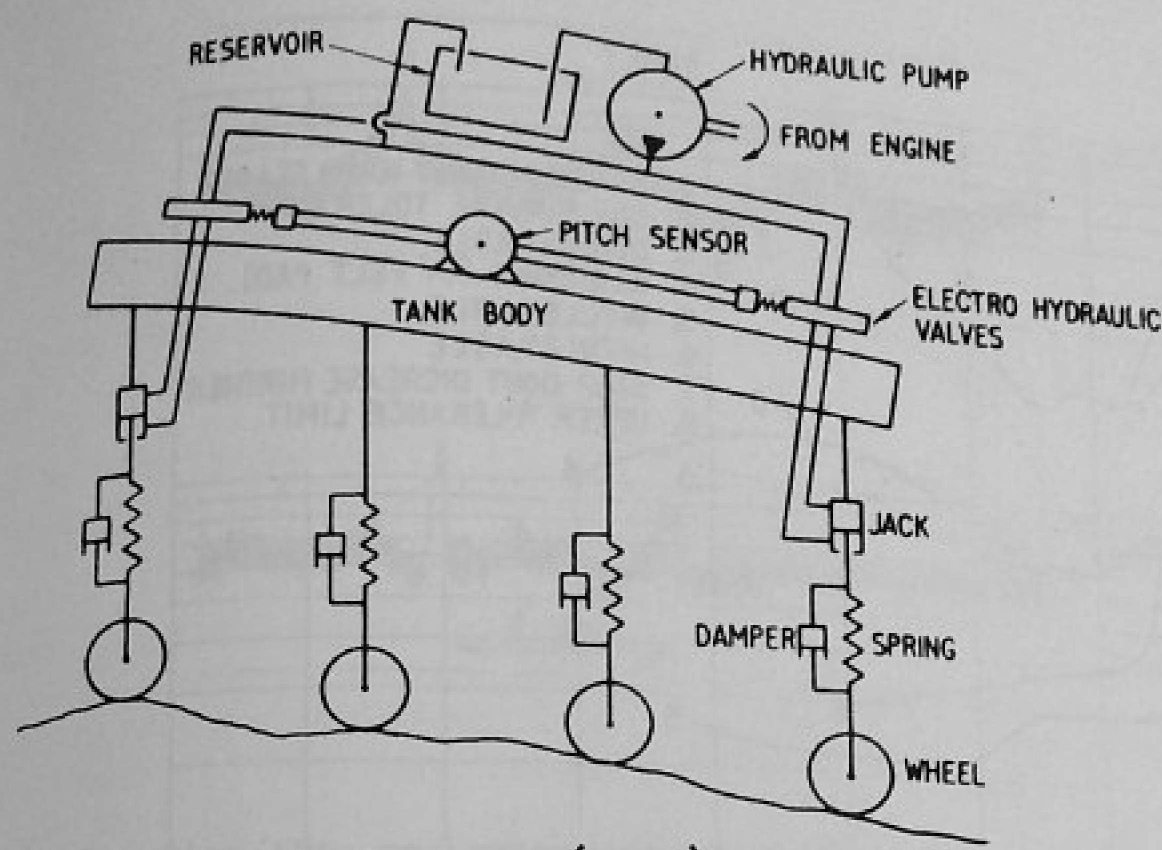
Fig. 3



LEOPARD TANK APPROX. 20 MILES/HR.

Fig. 4

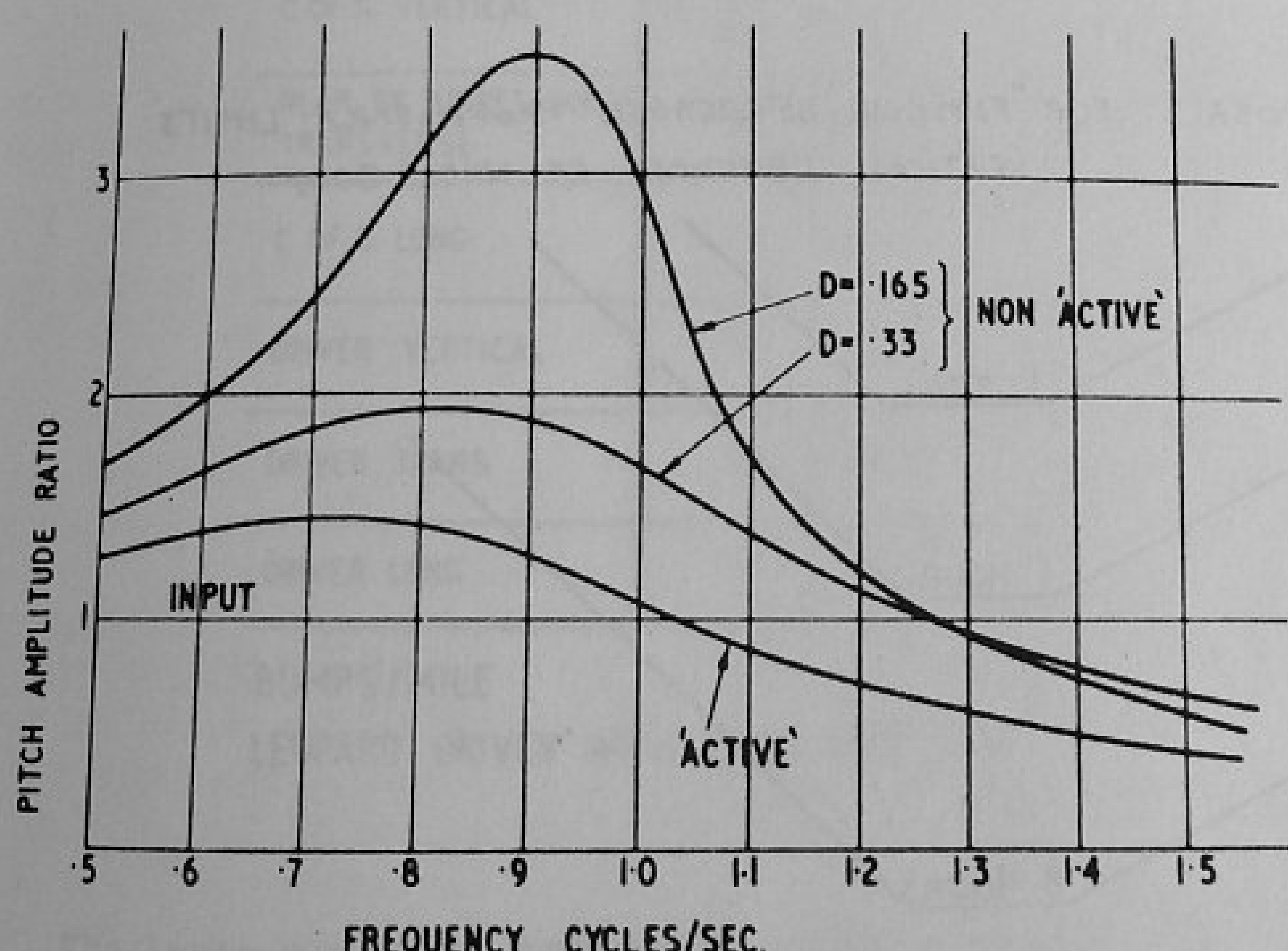
Spectral analysis of vertical r.m.s. acceleration at two positions for Leopard tank running "flat-out" cross country (driver only). Pitch motion deduced by assuming pure bounce and pitch about c.g. are the uncoupled natural modes (at low frequencies only when the bump stops are not operating.)



SIMPLIFIED ARRANGEMENT OF 'ACTIVE' SUSPENSION

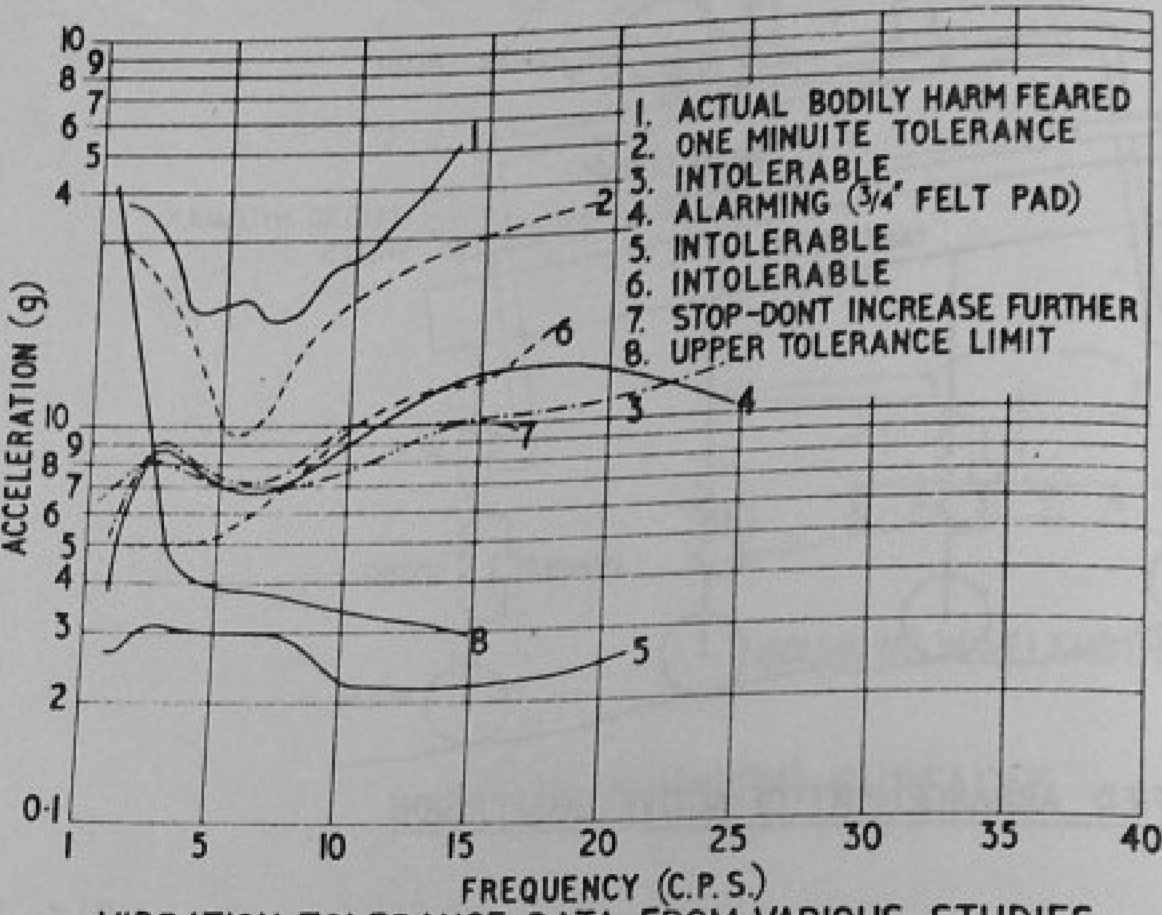
Fig. 5

Diagrammatic layout of a simple "active" suspension system acting only in the pitch mode.



COMPUTER SIMULATION OF 'ACTIVE' SUSPENSION

Fig. 6



VIBRATION TOLERANCE DATA FROM VARIOUS STUDIES.

Fig. 7

I.S.O. PROPOSALS FOR "FATIGUE-DECREASED PROFICIENCY" LIMITS
VERTICAL VIBRATION OF WHOLE BODY

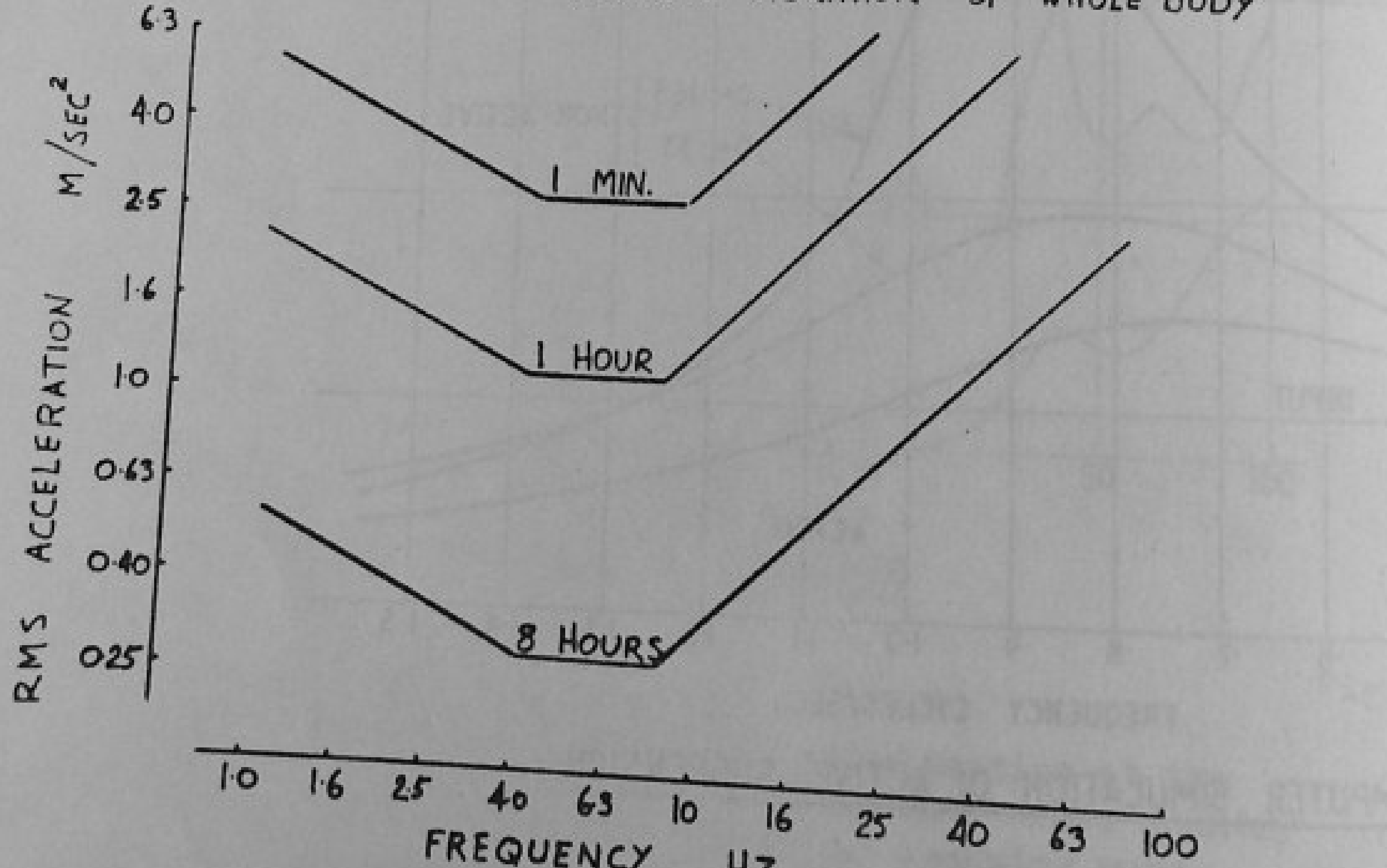


Fig. 8

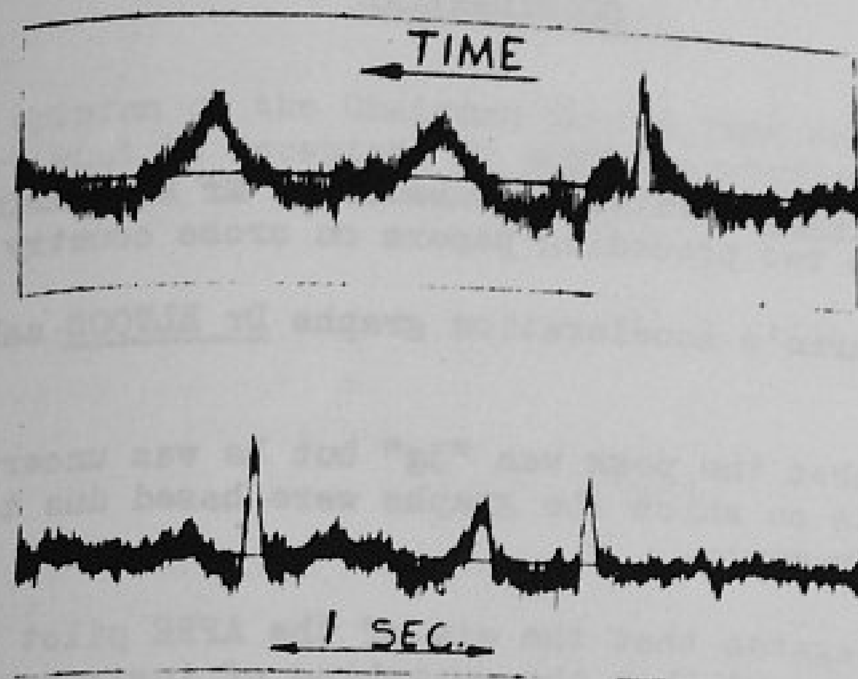


Fig. 9

Acceleration/time recordings showing vertical vibration of tank hull. The "bumps" show markedly different waveforms which will effect the human response to "bumps" of the same peak amplitude. (Maximum peak amplitude of recordings shown is approximately 1.5 g.)

POSITION	No. OF PEAKS EXCEEDING 1g		No. OF PEAKS EXCEEDING 2g	
	WITH CREW	SOLO	WITH CREW	SOLO
C. OF G. VERTICAL	905	1595	4	134
REAR OF TURRET RING TRANSVERSE	63	2879	-	574
C. OF G. LONG	14	24	-	-
DRIVER VERTICAL	70	535	18	60
DRIVER TRANS	14	35	-	-
DRIVER LONG	4	11	-	-

'BUMPS'/MILE

LEOPARD, DRIVER WITH CREW AND SOLO

Fig. 10

The large number of transverse peaks at the rear of turret ring with driver solo probably indicates the excitation of a structural resonance by the bump stops since spectral analysis reveals a sharp peak at approximately 117 cycles/sec (.5 g r.m.s.) with little low frequency vibration.

Discussion

The Chairman Mr BAYLY PIKE invited discussion on Mr Maclaurin's paper and any outstanding topics from the two preceding papers on cross country speed.

Referring to Mr Maclaurin's acceleration graphs Dr ELWOOD asked what was maximum "g".

Mr MACLAURIN replied that the peak was "3g" but he was uncertain of the validity of the measurements on which the graphs were based due to frequent changes in the location of the instruments.

Dr ELWOOD reminded delegates that the aim of the APRE pilot trial had been to test instrumentation. He agreed that the switching of instruments from one level to another had led to inconsistent measurements. He pointed out that there were two aspects of human tolerance: that which men were prepared to accept and that which was acceptable from the medical point of view. The results of the main APRE trial would give information on the former. However the level which men would be prepared to accept might exceed that which was medically acceptable and he urged that the trial should be followed by medical laboratory experiments.

The Chairman Mr BAYLY PIKE stressed that it must be kept in mind that a tank was a weapon of war. In his view, speed was essential for survival and some discomfort must be accepted.

Mr MONGER supported the Chairman and added that the designer's aim was to produce a tank that would do its job. The results of the APRE trial would be a guide on the maximum impact acceleration to be tolerated.

Colonel COCKLE raised the question of the reliability of hydraulic suspension. This must be of a high order, but Mr Maclaurin had said in his paper that such systems had reduced reliability. However this was not the view of the US.

Assuming that in the 1980s hydraulic suspension coupled with attitude control proved reliable, Brigadier SIMPKIN asked if it would be possible to build in pitch suspension control.

Mr MACLAURIN confirmed that past experience of hydraulic systems had shown reduced reliability mainly due to leakage. This was a development problem which he hoped would be overcome. He considered that eventually a hydraulic system would have to be adopted. It would be possible to build in pitch suspension control but the necessary power supply would be high: he quoted 25 BHP for a 14 ton tank, adding that the higher the power supply, the better would be the system. A system of metal springs as effective as a hydraulic system would result in great increase in weight. The weight of metal spring suspension systems would be proportional to the overall weight of the tank; but the lighter the tank, however, the greater would be the proportion by volume required for such a suspension.

Mr MONGER added that the more the weight of the tank can be kept down the better can be the wheel lift.

Brigadier SIMPKIN said that in order to get the cross country performance we want, it appeared that it would be necessary to put a proportion of engine power output into suspension.

Supporting an opinion of the Chairman that a tank was a weapon of war and that some discomfort must be accepted, Mr MONGER considered that existing suspension systems could still be improved and efforts should be directed toward that.

FINAL DISCUSSION

Chairman's Introduction

The Chairman, Brigadier SIMPKIN said that his aim was to provoke discussion by developing a controversial theme. As General Crookenden had said in a lecture to the Royal United Services Institution:

"The Royal Navy and Royal Air Force man equipments whereas the Army equips men."

We are a soldier based army; equipment is an extension of man's senses and physical capacities and we must not resort to complex equipments needing skilled maintenance unless substantial gains will accrue.

Because UK has a standing Army of long service regulars, the concept is that we will have to fight through with the men and equipments we have at the outset. This requires a high standard of training and equipment matched to the potential of the soldier. It may pay countries with conscript or short service armies to use complex electronic devices where it would not pay us.

Current Combat Development thinking is in terms of ten days continuous intensive conflict with a 24-hour battle day in a CW environment. This would test men to the limits of their tolerance and everything possible must be done to aid the man.

He pin-pointed six problem areas requiring study. Four - distribution of crew duties, sustained operations, noise and ride - were relevant to this symposium. Two - NBC protection and thermal environment - would be discussed at a later conference. An early decision was required on whether the control of the environment should be directed towards the vehicle as a whole or towards the man as an individual. The present trend was aimed at protecting the man.

The personal views of the Chairman were that in future tanks we would be forced to stow ammunition outside the crew compartment, perhaps even outside the main armour. Automatic loading would be necessary. Replenishment, servicing and minor maintenance must be improved. As it would not be generally possible to plan unit relief, tanks would have to operate for ten days with the same crew. Men cannot be kept awake, alert and efficient for this period of time and some provision for sleep must be made. He envisaged a tank with a crew of three operable by two except in short periods of intense activity. The two crew stations would be identically equipped to fulfil the primary functions of the tank. The third crew station would be for rest and certain secondary functions. Comfort must be provided in view of the demands made on the crew who should be protected against shocks, bumps, yaw and surge.

He suggested existing RAC trades would be replaced by three grades of tank crewmen:

Grade 1 - Commander
Grade 2 - Deputy Commander
Grade 3 - This crewman would occupy a control position during periods of less intense activity.

He considered that there were four requirements:

1. A major attack on methods of replenishment servicing and maintenance;

2. All crew should be together and able to change position;

3. Crew stations 1 and 2 should be duplicated (with slaved secondary armament), crew station 3 should be for rest or emergency;

4. A second major technological attack on control engineering;

and concluded that the major research and development effort should be directed towards:

1. Replenishment/Servicing/Maintenance.

2. Autoloader.

3. Control Engineering.

Discussion

Lt Col SENNA opened the discussion be expressing his appreciation for the invitation to the symposium. It was his first occasion to attend a meeting between users, designers and research workers on the human sciences at such an early stage in the concept of future equipment. This was the time to define the problems. In the field of US/UK collaboration on stress on the crew due to vibration, ATAC had expressed interest and he understood that Chief Scientist (Army) would endorse this collaboration. UK would be able to provide information from field studies and US from the simulator. He suggested that UK should send a letter to BDS Washington recommending that this matter should be discussed further.

Dr PENTON thanked Lt Col Senna for this suggestion and accepted action on behalf of DAOSR.

Mr BAYLY PIKE questioned whether an autoloader need be unreliable as had been suggested earlier. He referred to automation which had proved reliable in industry and suggested that a firm producing automation equipment could probably design a reliable autoloader.

Brigadier SIMPKIN replied that it would be necessary to prove reliability of an autoloader before acceptance of a concept dependent on one.

Colonel WHEELER emphasised that an autoloader must be able to cope with a number of different types of ammunition and load the appropriate type of round without delay. It must also permit manual loading under armour if all rounds in the magazine had been used.

Lt Col HAWKINS quoted the Swedish 'S' Tank in which the autoloader was an integral part of the magazine. It was able to select without delay either of two types of ammunition.

Major EVELEGH stated that so far the airmobile nature of the battle had not been mentioned. The trend was towards the increasing use of various types of helicopters. In the past, for the purpose of observation, retention of high ground had been important. In the future, observation would be one of the roles of the helicopter. Tanks of the future should, therefore, be able to cope with this aspect of airmobile warfare.

Brigadier SIMPKIN replied that a fourth member in a crew might be required for air surveillance.

Brigadier PIERSON said that Brigadier Simpkin had thrown over the belief that propellant must be stowed under armour. He was convinced that Chieftain was a winner largely because of the protection given to the ammunition, in particular the propellant. If ammunition was to be stowed outside we would be throwing overboard one of the concepts sacred to the RAC. He suggested other concepts that might be reviewed: firing on the move; 360° rotating turret; and the need for the tank Commander to be first to see over the top of a hill.

Brigadier SIMPKIN replied that ammunition stowed outside the main armour did not necessarily mean that it would be exposed. He did not however want to open up the field of tank design as this symposium should be centred on the man.

Following up suggestions made by Brigadier Pierson, Lt Col BEARDSWORTH hoped that such steps would not be at the expense of accurate and effective fire. He emphasised that Chieftain was a logical development using well understood practice lasting some thirty years, it was now a reliable and quite excellent tank with a superbly accurate gun and good fire control. Referring to Brigadier Simpkin's idea of stowing the ammunition outside the armoured envelope he said that this must mean that the ammunition would be subject to greater hazard and, in suggesting this idea, Brigadier Simpkin's thoughts appeared to lean towards the example proposed by Mr Monger involving an entirely new gun mounting, new gun/sight relationship, new methods of fire control etc. This would tend to degrade the expected accuracy of the weapon system. Lt Col BEARDSWORTH thought that the alternative was to discard the requirement for a very high degree of accuracy in tank guns beyond 2000 metres and give long range to someone else. He gave a note of warning: the techniques we have got now might be worth keeping since, with the best will in the world, the problems likely to be encountered in the type of solution which had been discussed would almost certainly degrade the weapon system - and would not be overcome by the 1980s. He suggested that the solution might be found in a vehicle the size of Chieftain and starting by placing two crew members in the space where there are now three, and fitting an automatic loader. He stressed that fire power was still the first priority.

Referring to the stowing of ammunition outside the main armour, Brigadier SIMPKIN said that the performance of the gun currently exceeded the fire control system but this situation could change. An important feature of Chieftain was the stowage of bag charges in special containers which increased the chance of survival in the event of penetration. He thought it likely that it would be necessary to return in the future to fixed ammunition which, if stowed internally, could not be given the same degree of protection. It would therefore need to be stowed outside the main armour.

Mr MONGER agreed and added that placing the gun outside presented a smaller target to the enemy.

Brigadier PIERSON stated that a Summed Selection Group Standard of 3 minus for tank crews placed a limit on the equipment men could use. If a tank crew were reduced from four to three men then a higher level of intelligence would be needed. He suggested that APRE should correlate the IQ of recruits with their ability to operate equipments.

Brigadier SIMPKIN wondered what was the current distribution of SSGs in an armoured regiment.

Mrs HARRIS stated that the quality of recruits in the Army was under investigation; a pilot scheme was in progress in Southern Command where all recruits were attending a centralised selection centre for job briefing, selection and allocation. APRE was involved. A number of experimental tests were being tried to find out if the battery of selection tests could be improved. Job briefing was based on interest and ability levels and not on Arms and Corps.

Brigadier PIERSON raised the problem that in a crew of three with duties as specified by Brigadier Simpkin almost every other crew member must be a potential tank Commander.

Brigadier SIMPKIN's view was that this would require a man of SSG 2 level.

Dr PENTON stated that the new selection centre provided an opportune moment for a review of RAC requirements and suggested that direct contact should be made with the Senior Personnel Selection Officer attached to the RAC. He mentioned that a Defence Fellowship could be used by a suitable RAC officer to study the cognitive and other requirements of tank crews.

Colonel BULL thought that the problem was how to attract higher grade civilians into the Army. At the moment as many as 40% were not being accepted at Army Information Offices.

In Brigadier SIMPKIN's view the problem was to forecast the quality of men likely to come into the Army in the 1980s. Human factors research workers could then assess what such men could do and feed this to the designers. He asked Lt Col Ulfhielm what was the standard expected in the crew of an 'S' tank.

Lt Colonel ULFHIELM replied that Sweden had a wholly conscript Army and higher grade men were available for special tasks. The 'S' tank, with a crew of three, could, in an emergency, be operated by one man. At least one of the crew, therefore, must have a high IQ. A reasonable intelligence level was required of the other two crew members.

Brigadier SIMPKIN asked whether it was difficult to train an 'S' tank crew; this would be a problem in the British Army.

Lt Col ULFHIELM replied that the tank Commander had 15 months training and the other two crew members 10 or 11 months. Thereafter crews underwent intermittent short periods of training in a mobilisation unit.

Brigadier SIMPKIN then referred to the two remaining fundamental issues: sleep and simultaneous tasks; and asked the authors of papers on these topics if they had any further thoughts to contribute.

Dr ELWOOD added that APRE wanted information that would enable them to channel their future research. He would like to know users opinion on the requirement for human factors research into the problems of: two men of SSG 3 minus grade operating a three man tank over a 24 hour period in a NBC environment; and operating the same vehicle for 10 days with a crew of three (two active and one resting or performing subsidiary tasks). One of these three would be acting as a Squadron Commander. He also queried whether complex equipments would always require high grade men to operate them and suggested that APRE might look into this. Other unknown factors were minimum ability levels required for all round surveillance during the absence or sleep of the Commander.

Dr CORCORAN said that most of the points concerning sleep had been raised. He put forward some suggestions for research into prolonged efficiency with nap sleep.

Accepting the crucial encounter may last ten consecutive days and nights, he said that there would appear to be two major problems from the standpoint of maintaining human efficiency over this period.

The first problem was whether the human being was capable of maintaining an adequate level of performance over 240 hours given irregular periods of sleep averaging 4 hours per 24 hour period. The second was whether drugs would be required to maintain efficiency and if so, (a) which drugs; (b) in what quantity; (c) how should they be deployed; and (d) would they be harmful over the long term.

The second of these problems need not be considered unless an unfavourable answer was reached on the first. Both problems were peculiar to the requirements of tank warfare and affected mainly the design consideration as to whether comfortable sleeping accommodation should be provided. It should be assumed, he thought, that if it was possible to maintain efficiency by sleep periods alone over 240 hours then adequate facilities should be provided.

Existing work on the first problem (Chiles et al, Human Factors, 1968, 10 (2), 143-196; Wilkinson, Psychon Sci, 1969, in press) was inadequate in a number of respects from the point of view of Army problems. He considered there was, therefore, a clear need for research which incorporated the essentials of the tank situation.

Colonel MASTERS considered that the problems of a 10 day battle should be regarded as applicable to the battle group as a whole and not just the RAC. Other arms would have similar problems. Furthermore, the time element in planning could well prove wrong: it could be disastrous if men could be kept going for ten days but were rendered useless on the eleventh when they might be needed. There should be no adverse after effects.

Brigadier SIMPKIN agreed that the problem should be treated as an all arms one.

Major LEESE added that in a new age of night fighting and a possible NBC environment the RA would fight more at night than previously and would therefore need similar research to answer their problems.

Lt Colonel WEEKS said that the infantry who were also users of AFVs would benefit from any research undertaken and he supported the pursuit of any ideas.

Dr PENTON stated that a clearer definition for future research had emerged from the symposium. To supplement Dr Corcoran's paper relevant bibliography should be studied. He advised that visits should be made to teeth arm units to find out in great detail the tasks which have to be performed. This information should be used as a basis for further experimentation in collaboration with the Army Personnel Research Committee.

Major BOYD raised the point that a 3 man tank with a rest position was virtually a 2 man tank. This could mean more tasks for the Commander and result in a lowering of his efficiency as a Commander.

Brigadier SIMPKIN said that we would have to determine when and whether it would be easier for a tank Commander to delegate his tasks or perform them himself.

Mr ROLFE considered that a clearer definition was needed for the resting position. The position would provide facilities for resting but not always would one man be resting.

Regarding the man, he had come to the conclusion that the problem was physical and psychological, it was the man's limitations which limited the efficiency of the weapon system. Equipment was becoming more complex and there was difficulty in attracting the right type of man. REME and R Sigs, for example, could offer better career prospects after military service. He thought there was a need to examine tasks, reduce them and simplify them, and he quoted the RAF who were introducing reliable automatic devices and displays providing information on a need-to-know basis.

He pointed out another aspect which had not been considered: the effect of ageing on the acuteness of visual perception; this might be important as far as the tank Commander was concerned.

There was a need to analyse the tasks of the crew as Dr Elwood had said and define the requirement by quality. He considered that there was a need for a multi-discipline research group to solve problems of engineering, physiology and psychology in turn.

CLOSING ADDRESS

Brigadier SIMPKIN said that much had been gained from the symposium. A clear image of the problems and possible lines of attack had emerged. He thanked Dr Penton for sponsoring the symposium; the speakers for presenting such interesting and full material; the overseas visitors for attending and whom he was delighted to see; and the secretariat. He gave warm thanks to the Royal Military College of Science for their excellent administration and provision of all facilities that could have been wished for; the briefing on the College by the Deputy Commandant; conducting a visit to the tank hangars; and for participation in the symposium by the College staff. He asked that thanks be passed on to all those in the College concerned.

ANNEX A

LIST OF PAPERS

Crew Duties and User Aspects
by Lt Col D.H. Hawkins MC, MM

Sustained Operation and the Need for Sleep
by Dr D.W.J. Corcoran

Multiple Task Performance
by J.M. Rolfe Esq

Noise
by Dr M.A. Elwood

Skill Combinations and Training
by Colonel A.H.N. Reade and
Major J.R.L. Caunter

Crew Number in Future Armoured Fighting Vehicles
by C.Q. Large Esq

Introduction to the Problems Facing the Vehicle Designer when Considering Fitting the Crew into Combat Vehicles
by L.C. Monger Esq

Cross Country Speeds and Agility
by Colonel J.D. Masters

Cross Country Speeds of Armoured Fighting Vehicles - Shocks and Bumps
by L.M. Croton Esq

Ride of Main Battle Tanks
by E.B. Maclaurin Esq

ANNEX B

LIST OF THOSE ATTENDING SYMPOSIUM

Brigadier R.E. Simpkin, OBE, MC	BGS(OR) Mobility, MOD(AD)
Colonel J.D. Masters	GS(OR)17, MOD(AD)
Dr J.C. Penton	Director, Army Personnel Research Establishment
Dr M.A. Elwood	Army Personnel Research Establishment
Mr C.Q. Large	Army Personnel Research Establishment
Mr L.M. Croton	Army Personnel Research Establishment
Mr D.F. Bayly Pike, OBE	Director, Armoured Warfare Studies
Colonel P.C. Bull	Directorate of Armoured Warfare Studies
Major D. Linaker	Directorate of Fighting Vehicles and Mechanical Equipment
Brigadier H.T. Pierson	Fighting Vehicles Research and Development Establishment
Mr L.C. Monger	Fighting Vehicles Research and Development Establishment
Mr D. Kerridge	Fighting Vehicles Research and Development Establishment
Mr E. Wilson	Fighting Vehicles Research and Development Establishment
Mr E.B. Maclaurin	Fighting Vehicles Research and Development Establishment
Capt C.C.C. Cheshire	Fighting Vehicles Research and Development Establishment
Major D.M. Letson	Royal Armament Research and Development Establishment
Major R.E. Holy-Hasted	HQ, Director Royal Armoured Corps
Colonel G.P.M.C. Wheeler	Royal Armoured Corps Centre
Colonel A.A.V. Cockle	Royal Armoured Corps Centre
Colonel A.H.N. Reade	Royal Armoured Corps Centre
Lt Col D.H. Hawkins, MC, MM	Royal Armoured Corps Centre
Major K.C. Dudley	Royal Armoured Corps Centre
Major S.A. Boyd	Royal Armoured Corps Centre
Major J.W. Prosser	Royal Engineer Wing, RAC Centre
Capt A. Brown	Royal Engineer Wing, RAC Centre
Major J.R.L. Caunter	Army Work Study Group, RAC Centre
Professor A.J. Woodall, OBE	Royal Military College of Science
Colonel P.G. Tynan, OBE	Royal Military College of Science
Lt Col I.A. Haycraft	Royal Military College of Science
Lt Col S.J. Beardsworth	Royal Military College of Science
Mr L.G. Penhale	Royal Military College of Science
Mr P.J.H. Wormell	Royal Military College of Science
Major J.R.G.N. Evelegh	Directorate of Combat Development (Army)
Major M.I. Leese	School of Artillery, Larkhill
Major A.B. Wallerstein	Royal School of Military Engineering
Major A.F. Giblett	Directorate of Electrical and Mechanical Engineering (Army)
Lt Col J.H. Marriott, MC	HQ, Director of Infantry
Lt Col J.S. Weeks	HQ, Director of Infantry
Mr P.D. Verschoyle	Chief Scientist (Army) Secretariat

Dr J.P. Bull	Army Personnel Research Committee/ Medical Research Council
Dr P.J. Chapman	Army Personnel Research Committee/ Medical Research Council
Professor W.T. Singleton	Army Personnel Research Committee/ Medical Research Council
Dr R.J. Whitney	Army Personnel Research Committee/ Medical Research Council
Mr L.D. Hamlyn, OBE	Army Personnel Research Committee/ Medical Research Council
Dr D.W.J. Corcoran	Applied Psychology Research Unit/ Medical Research Council
Group Capt T.C.D. Whiteside, MBE	Institute of Aviation Medicine
Mr J.M. Rolfe	Institute of Aviation Medicine
Lt Col J.F. Senna	US Army Standardisation Group (UK)
Lt Col J.W. Shallcross	US Army Standardisation Group (UK)
Major F. Hlohovosky	Canadian Defence Liaison Staff (London)
Colonel Paget	Direction Technique des Armements Terrestres, French Army
Commandant P. Quiniou	Service des Problèmes Humains, French Army
Lt Col H. Ulfhielm	Fighting Vehicle Section, Materiel Department, Swedish Army
Mr K.S.R. Hultgren	Aktiebolaget Bofors, Sweden
Lt Col E. Woehl	MOD(Tech) Kamph Panzer 70, FRG, Bonn
Dr D. Wiegand	BWB/AT 24 Federal Office of Defence Technology and Procurement, Bonn
Major O. Hegner	Assistant German Military Attaché, London

<u>Secretariat</u>

Major C.A.S. Robinson, MC	Chief Scientist (Army) Secretariat
Mrs J.I. Harris	AOSR 4, MOD(AD)
Mrs J.M. Seekings	AOSR 4, MOD(AD)

Apologies were received from:-

Colonel J.C. Evason	Directorate of Fighting Vehicles and Mechanical Equipment
Mr K. Corkindale	Institute of Aviation Medicine
Colonel I.J. Wilton	Australian Army Staff (London)
Lt Col E.A. McCloskey	Australian Army Staff (London)

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