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(6) Army Human Factors Engineering in Research and Development of More Conventional Weapons and other Equipment Systems, Report Number 1,

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* Report Number 2 will be concerned with the application of human factors engineering concepts to more advanced and unconventional systems.

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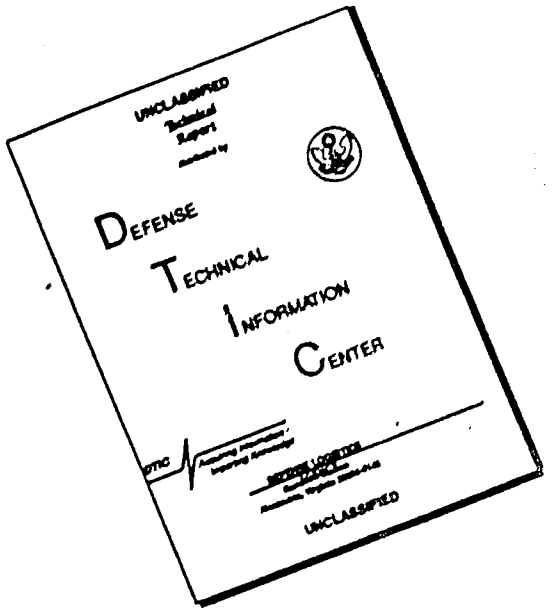

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ARMY HUMAN FACTORS ENGINEERING:

A REPORT OF

THE HUMAN FACTORS SUBPANEL OF THE

ARMY SCIENTIFIC ADVISORY PANEL

1. INTRODUCTION

A. The Concept of the Man-Machine System

THIS REPORTS IS CONCERN WITH

Human Factors Engineering (HFE) involves the application of data on human performance capabilities and limitations to the design of man-machine systems (and related equipments and environments) for the accomplishment of specific missions. It is a scientific endeavor to relate the design of such systems, equipments, and environments to the abilities and limitations of the human beings who will be selected and trained to use the equipment, taking into account operational and maintenance tasks and safety considerations. The objective of this endeavor is reached, a system if "optimized" as regards human factors, only when:

1. the operator is treated in the design process as an integral component of the system with statable intellectual, physical and psychomotor characteristics; and

2. similarly statable characteristics of maintenance personnel are fully exploited for maximum system reliability.

This concept of the man-machine system has long been fundamental to sound doctrines of military tactics and strategy. During recent times its importance has been emphasized by General Maxwell D. Taylor: "The awesome arsenals of modern weapons have as their sole purpose the extension and strengthening of man's arm for the purpose of imposing his will on the enemy." General Lyman L. Lemnitzer has stated the basic concept very clearly: "Man is and will remain the essential element in war. Men, not machines, win or lose the battle. Machines cannot wage war; they can only increase the effectiveness of man. The importance of the individual increases with the complexity of the weapons he must employ. The importance of the man will increase until we reach the stage of having weapons which can meet reverses with resolution; and which can match hardship and danger with devotion and courage, and carry on to the final victory. There is no such weapon on the horizon."

It is unrealistic at any stage in the research and development cycle either to assume on the one hand that man is perfect, and thus fail to make allowances for his limitations; or to assume on the other hand that he is necessarily an undesirable source of error, and thus fail to exploit

fully his unique capabilities. The Army's HFE program will have attained its highest value in this cycle when the concept of the man-machine system, as it is validated finally on the battlefield, is brought fully to the designer's drawing-board, the engineering proving ground, and the user's test.

B. Assumptions Concerning the Army's Mission

From our discussions and briefings we are led to assume that the Army's mission during the next number of years will be to deter aggression short of all-out war; or failing this, to gain the post- war objective for which the war is waged. Conditions now imposed by the possible use of nuclear weapons, by the concept of limited warfare, and by the widely different environments in which battles may be waged, place emphasis on wide dispersion and great mobility. The linear front of the classical battlefield would be replaced by smaller, semi-independent battle groups deployed in depth. Under such circumstances effective decision-making and coordination will depend upon the existence of highly efficient intelligence, communications, logistical and transportation systems, and upon the highly efficient operation of available weapons once the battle groups are committed to action.

Human factors are basic components in all these systems. Experience during World War II and the Korean War indicated that supremacy of our weapons and other equipment systems over those of an enemy often depended upon our more effective use of human resources. The increasing complexity of present and future systems suggests that the effective use of human resources may in the future be even more critical to success than it has been in the past.

C. Plan of Study: Mission, Resources, and Phasing

Recognizing the importance of the above man-machine concept, the Human Factors Subpanel of the Army Scientific Advisory Panel in 1958 established a Working Group on Army Human Factors Engineering. Stated in general terms, the Group's mission is: "to recommend improvements of the organization, facilities, and procedures for human factors engineering research and development, and applications, in the Army." In all of its work since its establishment, the Group has had the full cooperations of the Army Commands concerned.

To date, members of this Group have met on nineteen different occasions, which are here listed briefly to indicate in a general way the sources and nature of the information on which this report is based:

1.	Planning Meeting, Madison, Wisconsin	July 1958
2.	Orientation Briefing, Department of the Army	September, 1958
3.	Fourth Annual Army Human Factors Engineering Conference, Army Chemical Center, Maryland	September, 1958
4.	U. S. Army Scientific Advisory Panel Meeting, Colorado Springs, Colorado	October 1958
5.	U.S.Continental Army Command, Fort Monroe, Virginia	November 1958

6.	Transportation Corps Research and Engineering Command, Ft Eustis, Va.	December 1958
7.	Ordnance Corps Human Engineering Laboratories Aberdeen Proving Ground, Md.	January 1959
8.	U.S.Army Armored Test Board, Army Medical Research Laboratory, and Armor Human Research Unit, Fort Knox, Kentucky	February 1959
9.	U.S.Army Scientific Advisory Panel Meeting, Asbury Park, New Jersey	April 1959
10.	Project MICHIGAN, the Univer. of Michigan	May 1959
11.	U.S.Army Electronics Proving Ground, Fort Huachuca, Arizona	June 1959
12.	U.S. Army Quartermaster Corps Research and Engineering Center	July 1959
13.	U.S.Army Chemical Center, Fort Detrick, Maryland	August 1959
14.	U.S.Army Engineers Research and Development Laboratories, Fort Belvoir, Virginia	August 1959
15.	Working Group Session for preliminary drafting of report, Cincinnati, Ohio	September 1959
16.	Fifth Annual Army Human Factors Engineering Conference	September 1959
17.	U.S.Army Scientific Advisory Panel Meeting, Fort Monroe, Virginia	September 1959
18.	Session for Review of Draft Report, Northwestern University, Evanston, Illinois	November 1959
19.	Working Group Session for final drafting of present (Phase 1) report, Bloomington, Ind.	March 1960

Because of the many facets of HFE in the Army the Group has deemed it advisable to accomplish its mission in two separate phases; with two separate reports, of which this is the first. We have already stated the basic concept of the mission of HFE in the Army R&D cycle; and we propose in the present report, to examine the organization, facilities, and procedures through which this concept should be applied to the development of conventional weapons and other equipment systems. In our second report, we propose to extend this examination to the processes of development of more advanced concepts and systems of missiles and other weapons and equipments.

II CURRENT STATUS OF ARMY HUMAN FACTORS ENGINEERING

A. Background and Overall Leadership

The importance of human factors in the design of Army materiel has long been acknowledged in innumerable separate actions of USCONARC and of the technical services directed toward increased simplicity and ruggedness for operation and maintenance of military equipments. In response to such requirements each of the technical services, at various times in various ways and using various combinations of technological resources, has taken separate and somewhat independent steps to take account of human factors in the design of new items.

In 1955 the Chief of Research and Development, recognizing the basic common nature of these separate efforts, sponsored an Army-wide conference in the Pentagon to which Army Staff agencies, USCONARC, and the technical services sent representatives. An important recommendation of this conference, later concurred in by the Army Staff, favored the annual repetition of such conferences under OCRD sponsorship. This has been done: the Fifth Annual Army Human Factors Engineering Conference was held at Redstone Arsenal, Alabama, in September 1959; the Sixth is scheduled to be held at Ft Belvoir, Virginia, in early October 1960.

B. Army Human Factors Engineering Committee

Currently, AR 70-8 dated 1 July 1958 provides that such a Conference be held annually under sponsorship of the Chief of Research and Development. The same regulations established an Army Human Factors Engineering Committee, under the chairmanship of an OCRD representative and with representation from USCONARC and each of the technical services, to: plan and arrange for the Annual Army Human Factors Engineering Conference; and to follow through and take appropriate action on its recommendations. It should be noted that this AR also authorizes an Army Human Factors Advisory Committee (AHFRAC), composed of Army Staff and USCONARC representatives, to coordinate and recommend approval of the annual work programs of all other Army Human Factors R&D activities (Human Resources Research Office; Personnel Research Branch, TAGO; Special Operations Research Office, and the Army Participation Group at the Naval Training Device Center). No such central program coordination is provided by this Regulation for the Human Factors Engineering activities of the technical services.

C. Community of HFE Interests Among the Technical Services

As will be further apparent in subsequent paragraphs, there are wide differences in the very nature of requirements for human factors engineering in the various technical services. The Ordnance Corps, for example, conceives and develops ab initio systems of weaponry which have no non-military counterpart; the Corps of Engineers, on the other hand, finds that fully eighty percent of its development effort involves conversion to military purposes of equipments already in civilian industrial use. Recognizing these differences in requirements among the technical services, the Chief of Research and Development has successfully concentrated his initial leadership efforts on pulling together and creating an acknowledged and self-aware community of mutual interests in human factors engineering, whose members remain separately in USCONARC and the technical services.

We can attest to the unique success of this effort of leadership. Thus, for instance, the appendices to the Report of the Annual Army Human Factors Engineering Conference contain a complete, succinct, and detailed compendium of all of the tasks in each of the current human factors engineering work programs of each of the separate Army technical services. Although we are aware of certain omissions (which are to be corrected in future) we know of no other comparable scientific program, in this country or abroad, which is so fully documented and communicated

to so widely dispersed a membership.

Having successfully established a self-aware "community of mutual interests" in human factors engineering, CRD can now appropriately consider whether the boundaries of this community could profitably be extended. In his keynote address to the Fifth Annual Army Human Factors Engineering Conference, General Trudeau acknowledged its past accomplishments, but took specific exception to the absence of adequate representation in the Conference from other Army human factors R&D activities and related activities of private industry.

D. Current Levels of Effort

Beyond, but related to, this problem of widening the community boundaries is the question (implied above) of increased program coordination for Army human factors engineering R&D comparable to that accorded the programs of HumRRO, PRB, APG/NTDC, and SORO. As will be further indicated subsequently a successful human factors engineering program will usually contain a substantial element of ad hoc consultative effort difficult to program in dollar terms. This is true in the related current Army technical services programs. We have not systematically sought specific budgetary information, but have preferred to concentrate on the numbers of talents employed in a sustained level of effort. Within these terms we consider that a rough but fair approximation of current Army annual levels of effort in human factors engineering can be estimated at about $3 million distributed roughly as follows:

1.	Army-wide, OCRD	less than 1/2 professional man-year
2.	Army Medical Service	about 23 professional man-years
3.	Quartermaster	about 12 professional man-years
4.	Signal Corps	about 5 professional man-years
5.	Ordnance Corps	about 35 professional man-years
6.	Transportation Corps	about 1 professional man-year
7.	Chemical Corps	about 5 professional man-years
8.	Corps of Engineers	about 1 professional man-year

By reason of the nature and scope of this over-all HFE program, and the desirability of further HFE effort, it would appear desirable to provide adequate strength in the coordination of the program. It is our opinion that such strengthening would require the addition of at least one professionally qualified person in OCRD, with adequate clerical assistance.

E. Flexible Program Guidance for Strengthened HFE Coordination

In effecting the strengthened coordination of HFE which the above discussion indicates to be desirable, CRD would be ill-advised to attempt to force each of the participating USCONARC and technical service activities into a single rigid mold. As the missions and local circumstances of the various field participants vary greatly, so should the considerations to which CRD gives priorities of emphasis also vary.

As stated above, the complete HFE work programs of all of the technical services are fully and currently summarized annually in the Report of the Army Human Factors Engineering Conference. No purpose therefore would be served in summarizing this information here, beyond stating that it exhibits the appropriate mission-related variability noted above.

In the paragraphs immediately following, we propose to indicate the major characteristics on which variation can be anticipated, and from our minutes summarize some of the more useful expedients which have shown sufficient promise in one or another technical service to deserve consideration by all. We consider that the content of these paragraphs should serve as useful guidance, to be flexibly applied, in strengthening the over-all coordination of the Army's HFE program.

1. Basic Research in HFE and Psychophysiology. The mission of the Army Medical Research Laboratory program in psychophysiology, as well as TSG's coordinate contract research program in the same general field, stresses "basic" research which is justified otherwise than in terms of specifically foreseeable practical applications. The great importance of basic research in providing new knowledge upon which improvement of HFE practices depends cannot be overemphasized. We believe that the Army has a need; occasions on which information thus "deposited in the bank" is put again and again to valuable use. We give but one example of many brought to our attention during the present study: three of AMRL's scientists have had ten occasions for consultation with Army contract industrial designers within a recent 3-month period. The general problem areas and contract industrial activities involved were as follows:

Vestibular and Rotation Problems:	Bell Telephone Company
	Goodyear Aircraft Company
"Quiet Ear" Helmet Concept:	Radio Corporation of America
Vestibular Problems:	Minneapolis-Honeywell Corporation
Vestibular and Vibration Problems:	Glen L. Martin Company
Gun Flash and Noise Problems:	Boeing Aircraft Company

It is the substantive scientific value of such information which justifies support of "basic" research in the technical services. Its availability for practical use in the cases indicated above gives added confirmative justification.

2. HFE in the Technical Service Phases of the R&D Cycle. The largest and most inclusive Army HFE program in any single technical service is that presided over for the Ordnance Corps at the Human Engineering Laboratories (HEL), Aberdeen Proving Ground. Both by formal Ordnance Corps doctrine (e.g.: OCTI 200-1-59, dated 8 January 1959) and in the execution of the HEL program under this instruction, HFE contributions are systematically made at all OrdC stages in the development cycle. For consideration of similar action as appropriate in the other technical services, we list the major stages in this cycleas follows:

a. Phase I - Feasibility Studies (including, e.g.: Mathematical analysis, and preliminary engineering design): HEL participates as a regular member of the Steering Committee on (selected) development items.

b. Phase II - Engineering Design (including, e.g.: fabrication of test models; preliminary flight tests; engineering flight tests; and engineering evaluation) . . . HEL participation in Steering Committees is (also) relevant at this stage . . . Fabrication of three-dimensional models and mock-ups . . .(permits) early recognition of human factors . . . and preliminary development of operating and maintenance procedures . . . (for) design changes and training and selection factors.

c. Phase III - Component Development (Prototype) including, e.g.: manufacture of components; flight test of components;(and evaluation of redesign changes). Again HEL participation in Steering Committee is relevant . . .

d. Phase IV - System Demonstration (including liaison with USCONARC)

3. Coordination of HFE Activities Within the Technical Services. A single technical service itself often represents such widely separated and varied HFE activities and requirements as to warrant attention by a single qualified full-time officer in the Chief's Office. An example is furnished by the Signal Corps HFE activities and requirements, which span efforts at U.S. Army Signal Development Laboratories (USASRDL), U. S. Army Electronic Proving Ground (USAEPG), and the Army Combat Surveillance Agency's project MICHIGAN.

At USARDL, the most critical problems appear to involve the handling, with a small staff augmented by contractor capabilities, of:

Applications studies on individual items of equipment in development;
Participation by USARDL HFE personnel in the evaluation of contractor and subcontractor designs for man-machine systems; and
Selected exploratory human factors research in areas critical to the communications process, especially in view of rapid shifts in the division of duties between men and machines (e.g., automation)

At USAEPG in a conference of this Group with top echelon personnel it was agreed that there will almost certainly be an increase in the future problems involving interchange of HFE information both within the proving ground and between USAEPG and other Signal Corps and Army-wide agencies in this field.

Substantially similar problems of information exchange were noted at Project MICHIGAN.

4. Relative Emphases on Operational Efficiency, Maintenance, and Safety. Examples of appropriate variability, and bases for judgment of appropriate program balance, arepresented by the Transportation Corps and the Corps of Engineers.

Save for its HFE concern with the Army Aircraft program, the major emphasis of TRECOM requirements for HFE appears to relate appropriately to the maintenance, rather than the operation, of TC equipments. By letter of 22 January 1959 to TRECOM, subject: "Proposed Project 9-95-20-000, Human Factors Engineering," OCT has taken action to effect budgetary consolidation of TRECOM HFE requirements and activities. This should, in turn, permit increasingly realistic evaluation and allocation of the related resources. Thus CRD will be more readily able in the future to determine whether adequate emphasis is given in the TRECOM program to HFE for maintainability.

As previously noted, an outstanding characteristic of the C/Eng problems in HFE relates to conversion to military use of equipments already employed in civilian industry. Within its mission ERDL is currently considering what form of HFE program would be most appropriate to C/Eng needs. We suggest that when that program has been more fully developed, it will need to take express account of the possible differential effect of the civilian-to-military conversion characteristic noted above on HFE for maintenance, as contrasted with operator problems; and the coordination within this concept of relations with current C/Eng programs on camouflage, optics, and night vision and their correlation with Project MICHIGAN, Personnel Research Branch, TAGO, Project IMAGERY, and other related R&D efforts.

5. Acquainting Technical Personnel with HFE Concepts and Practices. The pilot work at the Army Chemical Center to produce a seminar series for HFE training of design engineers has already been separately noted with favor by this Working Group in informal conversations with Major General Stubbs and interested officers of OCRD. We are now gratified to note that this useful experiment has been extended as a "circuit seminar series" available on request to a number of other technical service and USCONARC installations. If subsequent evaluation of the results of this effort warrant, CRD should consider the advisability of its further extension or periodic repetition. This, as well as such other efforts as participation by officers in the McGill and Ohio State University short courses, furnishes an outstanding example of the way in which the elementary principles and practices of HFE can usefully be made known to engineers who are not specialists in this field.

6. Increasing Availability of Specialized HFE Manpower for Research and Engineering. In the face of an extremely short supply of specialists qualified to conduct either HFE research or design application studies, the Army technical services will need to consider means for increasing and using to the fullest possible extent their available manpower resources. An interesting example of effort in this direction is given by the contract with the National Academy of Sciences (see NAS-NRC announcement: "Visiting Scientists Research Associateships for 1959-60 tenable at Quartermaster Research and Engineering Center Laboratories and Quartermaster Food and Container Institute for the Armed Forces"). In this effort the QMC hopes to establish a number of "visiting professorships" to which outstanding scientists can be recruited on a world-wide basis for one or two year periods. This pilot program deserves close attention by the other technical services with a view to its adaptation to their use as appropriate

for HFE or other outstanding specialists.

7. Long-Range HFE Requirements and Program Coordination. In addition to USCONARC's "user" interests in HFE, as directly exercised by the USCONARC Boards under purview of USCONARC Hq. Combat Materiel, discussions with USCONARC Combat Developments peronnel have led us to conclude that further consideration should be given by USCONARC and CRD to the manner in which Combat Developments activities, including CDEC, could appropriately generate long-range HFE requirements. Such long-range requirements should in many cases be associated and coordinately evaluated with the often relatively shorter-range HFE requirements to be generated by USCONARC Board tests leading to corrections, retro-fits, or second-generation improvements. The evaluation should also include related USCONARC human factors R&D requirements to be served by HumRRO, PRB, and NTDC work program tasks.

A primary objective of all of the above should be to maximize the incorporation of HFE considerations at the earliest possible stages in the formulation of Qualitative Military Requirements (QMR's) and Military Characteristics (MC's). As will be made evident in later discussion under the heading "Levels of Human Factors Engineering Problems," different types of development require varying levels of application of HFE knowledges and skills. To attempt to apply HFE to the same degree to every item which enters the development cycle would be wasteful. A major aspect of evaluation during the formulation of QMR's and MC's should be the preliminary determination as to whether the development in some cases will warrant incorporation of HFE in a full-blown "systems approach" or whether, in other cases, only particular components will require HFE attention.

III CONSIDERATIONS BEARING ON IMPROVEMENT OF ARMY HFE

A. Roles of a Human Factors Engineering Program in the Army

We believe that there are two major roles of a HFE program in the Army; one concerned with the application of HFE knowledge and skill to current R&D activities, and the other with the continual improvement of the Army's HFE capabilities.

1. Support of Current R&D Projects The primary objective of a coordinated HFE program in the Army should be to insure, as fully as possible, the application of data on human performance capabilities to the engineering design of new man-machine systems and related equipments. Achievement of this objective could contribute significantly to the effeciency with which new items could be operated by troops, and could help in reducing time lags and costs arising, sometimes very late in the R&D cycle, from inadequate consideration of human components. We believe that such a coordinated HFE program should include:

a. Early review of individual projects and determination of HFE needs. By "early" we refer to the initial stages of the R&D cycle when Qualitative Military Requirements (QMR's) and Military Characteristics

(MC's) are being drafted and approved. Review during these early stages would have two principal outcomes:

(1) Suggestions concerning human factors considerations which may be helpful in drafting MC's.

(2) Preliminary determination of whether or not particular projects were likely to need special HFE attention.

b. Application of HFE knowledge and skills. A second feature of a coordinated HFE program would be to provide for the application of HFE knowledge and skills to the design and development of these systems which have been determined, during the early review, to have pertinent human factors aspects. In this connection, two points are made. In the first place, it is critical that these considerations be taken into account no later than at the design stage; failure to do so can be (and has been) extremely costly in terms of later refitting or in terms of consequent degradation of use of the system. In the second place, such support should not be viewed as a "one-shot" affair at the design stage, but rather should be viewed as a matter of continuing concern through subsequent stages of the R&D cycle, such as at mock-up, prototype, and engineering test stages, in order to identify and correct any human factors deficiencies which may not have been foreseen at the design stage.

The primary responsibility for insuring the application of HFE principles to design problems is of course that of the technical services.

To the extent that Army contractors are charged with the specific design and development of military items, the responsibility of the technical services in the application of HFE knowledge and principles becomes one of monitoring the work of the contractor. Toward this end, contracts should provide for the contractor to assume this function; the contractor, however, should be provided with adequate initial and continuing guidance by the technical service in question to insure that the item is designed properly for human use.

A special facet of the process of applying human factors knowledge and skills to design problems is the question of evaluation of the solutions that are developed. It is the opinion of the Working Group that the Army should look toward the development or adaptation of ways and means whereby the design features can be evaluated with reasonable objectivity in terms of their suitability for human use. It is recognized that, at the present time and probably for some time to come, the HFE capabilities of the Army will be limited and thus preclude the systematic application of HFE principles to all R&D projects. It is also recognized that not all projects will require the detailed attention of HFE Specialists. Therefore, we believe that the available HFE capabilities should be assigned to particular projects on the basis of considered judgment as to potential pay-off. Confidence in the judgment could be increased by review at two points during the drafting of MC's: at the initial

USCONARC stages; and later at the stage of technical service feasibility study.

c. Terminal review and feedback of information. A third feature of a coordinated HFE program would be a terminal review of the new item at the USCONARC Board Test stage. This final review would have two principal objectives:

To provide assistance to the Test Board by evaluating the item for satisfactory performance from HFE points of view.

To summarize information of potential value to those concerned with HFE at earlier stages in the R&D cycle.

2. Development of the state of the art . A successful HFE program depends upon full use of the most up-to-date information on human performance capabilities and limitations. Equipment can be designed in widely different forms, but man's capabilities and limitations remain fixed within the sometimes rather narrow limits of individual differences. We believe that an Army HFE program can contribute significantly to the body of knowledge concerning these capabilities and limitations; that the Army stands to gain much by contributing to the development of the state of the HFE art.

a. We have already suggested that a coordinated HFE program should include the feedback of information from the users of new items. Without such feedback much valuable information may be lost and old errors repeated, as is strikingly illustrated in the following quotation from any Army report on HFE: "Many of these deficiencies have been observed previously by testing boards, but the data have neither been systematically reported nor put into systematic or quantitative form so they could be used." We also wish to point out that alertness for sources of inadequate HFE may help to prevent recurrences of human factors problems in succeeding generations of a new system. We recall one report on HFE deficiencies in the NIKE AJAX and NIKE HERCULES systems which included the statement: "deficiences tend to be perpetuated from system to system in a family of missiles." Elimination of this extremely unfortunate state of affairs would have the effects of increasing the efficiencies of new systems and at the same time, decreasing costs and time lags.

b. During the course of applying HFE knowledge and skills new problems arise and are solved, solutions often requiring some applied research. Information from experience of this kind can aid greatly in expanding the state of the art.

c. Basic research on human capabilities is another extremely important source of new information. The activities of the Psychology Department in the Army Medical Research Laboratory illustrate the ways in which Army support of basic research can contribute to improvements in the state of the art. Despite heavy commitments in the application of HFE skills, other Army Laboratories, e.g., the Ordnance Corps Human Engineering Laboratory

and the Quartermaster Research and Engineering Center, are able to carry on some basic research. We believe that these are efforts which should be encouraged: which should be viewed as integral features of an Army program in HFE.

d. An Army HFE program must always be alert for developments in the state of the art introduced by other programs, both military and non-military. During recent years there has been a very substantial increase in efforts to extend knowledge and skills in the general field of HFE. Much is to be learned from the activities of private industry, university research laboratories and other government agencies, particularly the U. S. Navy and Air Force. Positive efforts should be made to insure the adequate dissemination of HFE information to interested individuals and appropriate units throughout the technical services.

e. Lags in R&D are matters of vital concern in times when significant innovations in weapons and other equipment systems are being introduced so rapidly. One important component of over-all lag is the time taken to put new developments to work. Delays of this kind affect the HFE art just as they affect other arts involved in the R&D process. We believe that particular attention should be given to means of identifying new information of potential value to Army HFE and to the communication of such information in the most usable form with minimum delay to those Army personnel who are in positions to apply it.

B. Levels of Human Factors Engineering Problems

Consideration of how these roles of an HFE program in the Army may be served effectively requires that we discuss what we conceive to be widely different levels of HFE problems recurring in the Army's research and development programs. In discussing each level we shall illustrate the general type of problem involved by citing only a few of the many examples given us during our visits to Army installations. These are levels of problems which, to be solved successfully, require varying amounts of knowledge and skills in HFE. It is our opinion that, in many specific instances, HFE problems may be solved by members of the R&D team who are cognizant of the man-machine concept, but who are not trained as HFE specialists. Most of these people can judge relative effectiveness in the location of equipment controls, the extent of adequate work areas, the ruggedness and portability of equipment if they are concerned with the importance of such features of man-machine systems. They become acquainted with HFE handbooks and other sources of information which can aid them in arriving at their final decisions. Being alert for the roles man will play in a system, they can seek assistance from HFE specialists when such assistance is needed. But HFE problems extend far beyond the relatively simple matters of operating or structural detail to problems of considerably greater complexity, which do require the knowledge and skill of HFE specialists.

1. Problems which involve an operating or structural detail. The most frequent examples given us during our visits to Army R&D installations were problems which we would place in this category; many of them were

overlooked during design of the equipment and required expensive, time-consuming refits.

Examples:

a. The unloading ramp of a new troop-carrying vehicle was constructed of smooth metal, often becoming wet or otherwise slippery and causing falls which injured personnel or their equipment. Cleats on the ramp would solve the problem.

b. The amunition box for the Vigilante system was designed for such a heavy weight of shells that it was difficult for one may to carry it any distance. The metal carrying handle was of a shape which cut into the man's fingers and could not be used if gloves were worn (aperture too small to admit glove and hand). The Human Engineering Laboratory, Ordnance Corps, redesigned the box to overcome these difficulties and to enable somewhat lighter boxes to be carried one in each hand, thus increasing the total amount of ammunition transportable by a single man.

c. The dials and gauges panels of a new amphibious vehicle were located in such a position that they could not be seen when the vehicle was loaded; any shift in cargo might smash the panels. Monitoring of these dials and gauges was essential to operation of the vehicle.

d. Manhandling the data and power transmission cables for the Jupiter system proved to be a serious problem in the efficient use of the system, a problem which was solved by adaptation of the standard Army "mule" for moving the cables into position. We understand that this solution, suggested by a member of the Ordnance Corps Human Engineering Laboratory, resulted in the saving of several million dollars over other solutions considered. Redesign of the connectors for these cables eliminated human error in setting up the system.

2. Problems which have already been well-researched and solutions to which are available in handbooks and guides. Many HFE problems have been recognized for a number of years and have been thoroughly studied. Information which may be used directly or may aid in solutions to similar problems arising in the development of new items is already available from such sources as the Interservices Handbook on Human Factors Engineering.

Examples:

a. Control panels frequently use color coding, e.g., panel lights, for presenting information essential to an operator. We have seen instances in which the general illumination surrounding the panel was such as to make accurate discrimination of color difficult or impossible, thus increasing the probability of operator error. A very considerable amount of information on minimum illumination levels for human cone vision is already available.

b. The relations between the display of dials and the controls for operating a weapon or vehicle can have very serious effects on the efficiency with which a human operator can function in a system. We have been shown instances, e.g., tank aiming and firing systems in which the relations between displays and controls made impossible effective use by operators normally available. There now exists considerable information on population stereotypes for display-control relations.

c. In other instances we have been shown items in which the design of features of the working space, e.g., seat size, height, etc., and of the characteristics of working parts; e.g., force required to operate a control, restricted the effeciency of an operator. Anthropometric tables and other data already available could be put to good use during the development of many items, thus reducing costs and time lags required for refits.

3. Problems which may require a HFE specialist to recognize the nature of a solution. Even when the existence of a human factors problem is recognized, a solution may not be obvious, but may require the knowledge and skills of a specialist in HFE -- of someone who is fully versed in the present state of the art.

Examples:

a. We have been shown several items which, to function properly, require leveling at night. Solutions to problems of night lighting of leveling bubbles depend upon knowledge of characteristics of human vision, including the effects which exposure to any light source may have upon later dark adaptation.

b. Knowledge of the results of research in this country and in Britain can aid significantly in recognizing solutions to problems arising in complex intercommunication systems.

4. Problems the existence of which may be more readily recognized or anticipated by someone expert in HFE. We have had pointed out to us human factors problems which were not apparent until late in the R&D cycle; some, perhaps many, of these might have been anticipated if the item involved had been examined early in development by someone expert in HFE, who had turned his attention specifically to possible sources of human factors problems. In other instances problems may be recognized, but the fact that human factors may be important contributing causes may be overlooked even to the stage of final user tests.

Examples:

a. The La Crosse forward guidance station, examined in "mock-up" by the Ordnance HEL, showed deficiencies whose subsequent correction improved the weapon's effectiveness.

b. Substituting an extra fuel tank for one of the pilots of light aircraft may enable it to stay aloft for many additional hours, but can a single human operator maintain adequate efficiency for such a long time?

c. A new range-finder requires that 44 adjustments be made for its operation. Is it possible for a human operator adequately to make and coordinate these adjustments within allowable time limits?

d. The counter-rotating cupola of a new tank has 18 different controls. Can operators be selected who can coordinate these controls properly? What commitments will be required for the training and replacement of operators?

5. Problems which may require supporting HFE research for solution. Awareness of the need for research usually comes from rather complete knowledge of the present state of the art -- of what is and what is not known from past research. During our visits to Army installations we have seen a number of instances in which HFE specialists have found it necessary to conduct new research before suggesting solutions to a variety of problems.

Examples:

a. Research on the acoustical problems arising in the development of a new combat vehicle crewman's helmet.

b. Research on man's "work contours" to provide information basic to decisions on the nature and loadings of control sytems -- information on how much work can be done at different distances and directions from the operator.

c. Research on relations between head movements and the induction of motion sickness, which will provide data for use in designing such new items as early warning system now under development in which the operator is seated in a revolving antenna.

C. Manpower Requirements for Improved Army HFE

In the course of discussing the roles of an HFE program in the Army and the levels of HFE problems which such a program would be expected to recognize and solve, we have established a basis for considering the manpower requirements of a coordinated program. Our general principles are that personnel with other specialties who are already engaged in the R&D process should be used as fully as possible and that HFE specialists should be employed on tasks which required their particular competences.

1. R&D technical personnel. HFE problems arise at various stages throughout the R&D cycle. We believe that it would be advantageous to acquaint as many of the R&D technical personnel as possible with HFE

concepts and principles. The main advantage would be that such informed personnel, although not specialists, could aid in anticipating and recognizing HFE problems, could solve many of the problems involving operating or structural details, and could seek the advice of HFE specialists when needed.

Several of the technical services, e.g., the Army Chemical Corps and the Corps of Engineers, have already considered the feasibility of increasing their non-specialist HFE capabilities in this way and have sponsored series of seminars as a method of acquainting their technical personnel with HFE. The success of the Chemical Corps Seminars was reported at the Army's Fourth Annual Conference on Human Factors Engineering and we are gratified to note that a similar series of seminars, on a "circuit-riding" basis, is now being conducted in all the technical services and for the USCONARC Boards.

Other methods which deserve exploration include: attendance at short courses on HFE such as those conducted at Ohio State and McGill Universities; attendance at the Army's annual conferences on HFE; study of handbooks and other summaries of HFE principles and data, e.g., the Human Factors Guide for Design Engineers and the Quartermaster Human Engineering Handbook Series; and periodic reading of HFE publications as a means of refreshing knowledge of the state of the art.

2. HFE Specialists

At the present time the Army's specialized HFE capabilities lie principally within the Technical Services. In some of these, e.g., the Ordnance and Quartermaster Corps, special HFE laboratories or units have been established and their functions integrated with those of other groups of specialists engaged in the R&D process; in others, HFE personnel have been assigned to groups of specialists in other fields, their services frequently being used for other than HFE purposes. This wide variation in HFE capabilities among the Technical Services is related understandably, to the amount of attention which can be given to the review of new projects for potential HFE problems and to the application of HFE knowledge and skills to the solutions of problems once they are recognized. When civilian contractors are involved, HFE requirements can be and often are, specified in contracts; but, unless provision is made for monitoring such requirements, there is no certainty that they will be given other than cursory attention.

The present serious shortage of adequately trained HFE specialists makes in unrealistic to suppose that any demand by the Army for additional HFE personnel to expand HFE capabilities within technical services could be met in any short period of time. We believe that the establishment of a coordinated HFE program as a continuing feature of Army R&D and of adequate conditions of employment might add the services of a few competent specialists. Some additional assistance could be obtained through contracts with suitable industrial consulting organizations. However, if the Army were to consider a more systematic HFE program than it now supports, it would seem wise also to consider at the same time methods by which new

requirements for HFE specialists could be met. We believe that some of the following approaches deserve attention:

a. Training Army officers under provisions of the Army Civil School Program.

b. Training present Army civilian employees under such provisions as the Secretary's Fellowship.

c. Establishing a university training program, which might be similar in organization to the Surgeon General's program for training clinical psychologists, involving commissioning selected graduate students and assigning them to university programs in HFE, following graduation from which they are obligated to active service in the Army.

d. Establishing a special Army HFE training program to which officers and civilians could be assigned, involving collaboration in training between an Army, HFE capability, e.g., the Ordnance Corps Human Engineering Laboratory or the Quartermaster's Research and Engineering Center, and a university department.

e. Providing facilities for an Army HFE "internship" or "apprenticeship" program which would accept well-qualified persons for training under experienced staff direction within an Army HFE capability.

3. Contributions by the Human Resources Research Office. We have emphasized the importance of early and terminal review of new R&D projects; without such review the Army stands to lose much in cost and time for refitting, for unsuccessful projects, and for the loss of information which could be valuable to the improvement of future projects. During our study we learned of the close and effective working arrangements between USCONARC and the Army's Human Resources Research Office. We also learned that, although HumRRO's concern is with problems of training, it has had to be cognizant of HFE issues, since final evaluation of new training methods must of necessity study man-machine systems: man's performance during and after training is affected by the characteristics of the system of which he is a part. It is also important that training programs for new items be considered as early in the R&D cycle as possible, if the itms are to be put to maximally effective use with a minimum delay following release to the troops: minimizing this delay can contribute significantly to reducing the overall lead times for new items. For these reasons, HumRRO Units located at the Army's Armor, Infantry, Air Defense, and Aviation Centers have already had informal contacts with USCONARC Boards at the Centers. At the Armor Center the contact has been most extensive and the Board has, on various occasions, requested assistance from the Human Research Unit on HFE problems. HumRRO, therefore, has some experience in and an important potential for contributing to HFE in the Army. We believe that this potential should be put to use.

At the MC and QMR stages in the R&D cycle advantage could be taken of:

a. The cumulative knowledge of HFE personnel of the combat arm concerned,

b. their experience with Man-Machine systems acquired through their research on training, and

c. their professional background and training in HFE.

Man is the one limiting factor in military systems whose basic nature cannot be altered. HFE specialists, knowing the characteristics of man-machine systems, may be able to suggest new and imaginative applications of hitherto little used or recognized capabilities of man.

At the test stages in the R&D cycle HumRRO's capabilities have already been recognized. HumRRO personnel could contribute to:

a. the development of good test designs when special consideration of subtle human factors, e.g., control of motivation, past experience, etc., is required,

b. the analysis of test data, particularly data which bear upon human factors affecting the system under test, and

c. the feedback of information on human factors which is valuable in the development of future generations of an item and which may be applied to future R&D on related items.

The process of putting HumRRO's HFE potentialities to full use could well progress through three phases:

a. Phase 1: HumRRO personnel would serve as consultants in HFE to USCONARC and its Test Boards, providing information and advice.

b. Phase 2: HumRRO would incorporate in its research program studies which were fundamental to both HFE and training; HumRRO already possesses the basic research capability.

c. Phase 3: HumRRO would provide, on request, HFE and training services to Technical Service Commands which require increased capabilities.

To use HumRRO's potentialities the mission of HumRRO as stated in AR 70-8 should be expanded to specifically include HFE as it is defined in AR 705-5. On the financial side, phase 1 would require some increase in professional staff for each of the four HumRRO Units now located on the same establishments as USCONARC Boards; implementation of phases 2 and 3 would require additional resources.

IV SUMMARY AND CONCLUSIONS

Our findings have led us to conclusions which may be summarized as follows:

A. A well-organized HFE program in the Army should provide support for current R&D projects and also contribute to improvement of the state of the HFE art.

B. The concept of early review of new projects is important as a safeguard against failure to apply HFE principles when they are essential to the adequate development of an item.

C. There are wide differences in the nature of the requirements of HFE in the various commands and technical services contributing to the over-all R&D process. These differences affect the way in which HFE support for R&D projects may best be organized in each command or technical service. We have described certain features of HFE programs which should be considered in making decisions about organization.

D. The concept of terminal review of new items at the USCONARC Board Test stage is important, since, when properly applied, it guarantees the feedback of information which is valuable in the development of future generations of an item and which may be applied to future R&D on related items.

E. Since a successful HFE program depends upon full use of the most up-to-date information on human performance capabilities, the Army stands to gain much by contributing to the development of the state of the art and from staying alert to contributions from sources of information outside the Army.

F. From the HFE point of view, one of the most impressive features of the Army's R&D programs is the wide variability in levels of HFE problems which R&D personnel must solve. Certain levels of problems can, and should, be solved by members of the R&D team who are cognizant of the man-machine concept, but who are not trained as HFE specialists. The knowledge and skill of the HFE specialist are essential to the solution of more complex problems which extend far beyond matters of operating or structural detail. We have described the various levels and given examples from recent R&D projects of the kinds of problems involved.

G. The manpower requirements of a coordinated HFE program can be met by using as fully as possible personnel with other specialties who are already engaged in the R&D process and by employing HFE specialists on tasks which require their particular competences. We have discussed ways in which R&D technical personnel may become acquainted with the man-machine concept and its application to certain levels of problems. We have also discussed ways in which the present serious shortage of adequately trained HFE specialists may be reduced.

V RECOMMENDATIONS

We interpret the wealth of information with which we have been provided during this first phase of our study as pointing clearly to the fact that present HFE capabilities are contributing significantly to the Army's R&D mission but that still further development of these capabilities is necessary if the full potential of HFE contributions is to be realized. Human performance is only one of several major components in modern weapons and other equipment systems, but, like each of the other components, it may prove to be critical when not integrated properly

in the system as a whole. The probability of human factors becoming critical deficiencies is enhanced when the man-machine concept is overlooked and when special HFE knowledge and skills are not available when needed. In order to minimize the possibilities of such critical deficiences occurring, it is essential to view the Army's HFE requirements as a coordinated program even though the R&D cycle involves a number of separate commands and technical services. This has been our approach during the present study; it is reflected in the following recommendations.

A. Recommendation 1: The Army should state the official objectives of its HFE program. The objectives should be:

1. To insure that review of individual projects for determination of HFE needs occurs early in the R&D cycle.

2. To apply HFE knowledge and skills to all R&D projects, in no instance later than the engineering design stages in their development.

3. To provide terminal review and feedback of information about HFE problems arising and solutions achieved during the development of each new item.

4. To support facilities for applied and basic research leading to advancement in the state of the HFE art.

5. To provide facilities for identifying information of potential value to the human engineering of future items and for making the information readily available in the most usable form with minimum delay.

B. Recommendation 2: For the accomplishment of the above objectives the Army should strengthen its central coordinative mechanism in OCRD by assigning at least one additional human factors scientist (with clerical assistance) to the program, and by developing detailed procedures under existing Army Regulations 705-5 and 70-8 to assure adequate central program review.

C. Recommendation 3: Since there are wide differences among the various commands and technical services concerned with R&D in the nature of their HFE requirements, each command and technical service should be encouraged to determine the organization of its own internal HFE program. The nature of the organization in each instance and any changes in it should be reported to OCRD in order that it may provide support and aid in interrating the individual programs with an over-all Army program.

D. Recommendation 4: Capabilities essential to achieving the objectives of early and terminal review of individual development items should be established in USCONARC. Because the Human Resources Research Office units already work closely with USCONARC Boards at the Armor, Infantry, Air Defense, and Aviation Centers; and because these units already possess a degree of the required capability, we recommend that consideration be given to requiring HumRRO to provide the necessary technical assistance to these Boards for such review.

E. Recommendation 5: To meet other objectives of the Army's over-all HFE program, the technical services should develop HFE capabilities, if they do not already exist, which will insure that: (1) at the feasibility study phase, individual R&D projects are reviewed for determination of HFE needs and (2) when such needs exist, knowledge and skills are applied throughout the remainder of the R&D cycle.

F. Recommendation 6: In order to make full use of R&D personnel resources: (1) Technical personnel in Army R&D should be trained and acquainted with HFE concepts and practices to the extent that they can:

(a) Aid in anticipating and recognizing HFE problems:

(b) Solve HFE problems at the levels of operating and structural details; and

(c) Know when to seek the advice of HFE specialists.

(2) HFE specialists in the Army should be employed on tasks which require their particular competences.

G. Recommendation 7: Special methods, e.g., seminar series, short courses, handbooks, should be developed to acquaint R&D technical personnel with HFE concepts and practices. The Army's present "circuit seminar series" is an important step in this direction.

ARMY HUMAN FACTORS ENGINEERING IN RESEARCH AND DEVELOPMENT OF MORE CONVENTIONAL WEAPONS AND OTHER EQUIPMENT SYSTEMS

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23 June 1960