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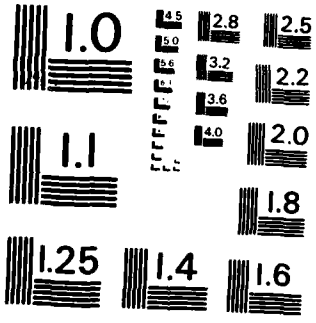

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THE ERGONOMIST'S ROLE IN THE WEAPON SYSTEM DEVELOPMENT PROCESS IN CANADA

D.Beevis,

Head, Human Engineering Section, DCIEM, Toronto.

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INTRODUCTION

At DCIEM the terms Human Factors and Human Engineering are used as defined by the US Air Force (Ref 7). Human Engineering is therefore seen as a sub-set of Human Factors, and Ergonomics and Human Factors are considered to be synonymous. In the Canadian Forces a weapons system is defined as a composite of equipment, facilities, skills, and techniques forming a self-sufficient instrument of combat (Ref 8). In this review the weapon system development process is taken to include those activities associated with the conception and aquisition of new or modified systems, in response to a requirement for a specified capability. Such activities are taken as starting with studies leading to the establishment of a Statement of Requirements and concluding with the acceptance of the new system.

THE SYSTEM DEVELOPMENT PROCESS IN CANADA

Since the DDH 280 destroyer construction program in the mid 1960s, no major weapon systems have been designed and built entirely within Canada. For the past fifteen years, therefore, many of the weapon systems procured by the Canadian Forces (CF) have been either developed from existing systems, to meet Canadian requirements, or selected from available systems with no development.

The weapon system design process has evolved to meet these circumstances. In most major system aquisition programs the design responsibility is vested entirely with the contractor. The CF design authorities are responsible for developing functional specifications and system specifications to which candidate contractors respond. In many cases little design guidance is provided to contractors beyond these specifications, although contractors may be informed of the results of in-house design studies which are used to establish baseline criteria against which candidate designs can be judged.

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ERGONOMIST INTERFACE POINTS

There are several points at which ergonomists can interface with the weapon system development process. In general, these points are those which have been outlined in texts on human factors in systems design, such as Van Cott and Altman, (Ref 6), Meister (Ref 2), Singleton (Ref 4), and US MIL-H-46855 (Ref 9). The points at which ergonomists working within the CF can interface with the system

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design process include:-

- the evaluation of ergonomics problems in the operation of existing systems,

- the development of the Statement of Requirements,

- the development of functional and engineering specifications for the system,

- the evaluation (during development) of the system concept,

- the evaluation of candidate proposals,

- the detailed evaluation of final proposals,

- the field evaluation of candidate systems and equipment.

The activities through which ergonomists employed by contractors can enter the design process correspond more closely to the stages of Analysis and Detail ~~Design~~ of MIL-H-46855. These activities include:-

- the development of new system concepts,

- the evaluation of system concepts,

- the preparation of proposals,

- preliminary design,

- detailed design.

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ORGANISATION OF MILITARY SERVICE

In the CF the process of aquiring new or upgraded systems is managed on a project basis within the overall Defence Services Program. Project Directors and Project Managers obtain specialist advice on such matters as policy, operations, personnel, finance, engineering and maintenance, research and development etc. from a variety of CF directorates. Ergonomics is is another area in which project personnel may seek specialist information. There is no order or instruction, however, which mandates that project directors and project managers consult ergonomists in any systems development phase.

The Chief of Engineering and Maintenance, CEM, is the authority responsible for the conduct of engineering and maintenance in support of project development. Reporting to CEM are a number of directorates responsible for system aquisition and maintenance covering the technologies associated with maritime, aerospace, land, and communications and electronics engineering. Specific directorates within each of these areas have some responsibility and capability for considering ergonomic issues in weapon system design, but the approach and the resources are not standardised. These directorates include Director of Maritime Engineering Support, Director Aerospace Support Engineering, Director Clothing and General Engineering and Maintenance, the Aircraft Engineering Test Establishment, and the Land Equipment Test Establishment.

The Chief, Research and Development (CRAD), is the authority responsible for the conduct of R & D in support of project development. CRAD administers four Directorates of Technology Application (DTAs), and seven R & D laboratories. (DCIEM is a unique CRAD laboratory in that it is partially supported and funded by the Surgeon General of the CF. Thus the Institute reports and responds to representatives of the Assistant Deputy Minister Material, and also of the Assistant Deputy Minister Personnel).

The DTAs are responsible for administering development contracts for new system concepts within the areas of aerospace, land, maritime and communications and electronics. The seven R & D laboratories undertake research in a wide variety of sub-programs including human performance. Those sub-programs include the majority of the ergonomics capability of the CF. That resource can be, and frequently is, called upon to support project (ie. systems) development activities. Such work is normally carried out at no cost to the project office requesting it, apart from necessary capital equipment costs, or unusual operating costs. Due, however, to the limited personnel resources available within the CF, some projects are now being sub-contracted. In some of those cases the cost of the contract may be passed on to the project office requesting the work.

UNIVERSITY/ LABORATORY INPUTS

Inputs To Technology Base Development

If they involve R & D, inputs from universities and laboratories can be made under contract to one of the four directorates of Technology Application (DTAs), run by CRAD. Such inputs can also be made to the work of the CRAD laboratories by means of research contracts. At the present time such inputs are not usually related directly to weapon system aquisition projects, but are related to the longer term R & D programs of the CRAD laboratories. Recent examples include the study of load carriage by infantry, the application of biomechanics to categorising the physical demands of CF trades, the development of criteria for helmet impact protection, and research on the relationship between physical fitness and performance during sustained operations.

Inputs To Projects

If they do not involve R & D, inputs from universities and laboratories can be made under contract directly to any CF directorate. Such inputs could, therefore, be used as specialist advice to the Project Director and Project Manager in the systems aquisition process. There is, however, comparatively little capability to undertake ergonomics studies related to weapon system development within universities or other laboratories in Canada, and few cases are known of such inputs. Recent examples of university inputs to CEM directorates include studies of the development and maintenance of physical fitness among service personnel, and a study of the visual capability of servicemen having high weapons firing scores.

GOVERNMENT/ INDUSTRY ROLES

Roles In Technology Base Development

Industrial ergonomics, or human sciences, capability is used in some of the R

& D projects run by the CRAD DTAs. Examples of inputs directly to CRAD DTAs are studies of the application of automatic speech recognition to aircraft, studies of authoring languages for Computer Aided Instruction, and development of new display technologies.

Industrial ergonomics resources are also used to support R & D activities related to the ergonomics technology base within the CRAD laboratories. Examples of such work are are a review of industry capabilities and needs to undertake ergonomic studies for weapon system development, a study of the application of multi-attribute decision making techniques to the ergonomic evaluation of candidate weapon systems, a review of the effects of mono and multi chromatic displays on visual comfort, a study of the ergonomics of Search and Rescue observer performance, and the development of spatial data bases for use with computer based maps.

In R & D activities associated with the development of the ergonomics technology base, CF ergonomists can provide advice to industry or work with industry. The cases when CF ergonomists have advised industry have usually arisen either because of a lack of ergonomics expertise within a company contracted to CRAD, or because of a need to interpret the CF requirements to a contractor. In a typical example, the contractor developing a new infantry-fielded sensor was advised by the responsible DTA to obtain ergonomics advice in the development of the operator:machine interface. From the initial discussions of the operational concept of the system it became clear that the key operational issue was the system reaction time. Ergonomics activities included briefing on the CF requirement, assistance in the determination of the required reaction time, development of a matrix of design options for the operator:machine interface, and design and assistance with the conduct of a simple trial using military personnel to evaluate the two most promising candidate designs. Other typical examples of such inputs include research into novel sonar displays which was undertaken to enable the responsible DTA to advise a contractor on the required display characteristics, and the development of display and control specifications for a multi-function command and control console being developed under research contract.

Roles In Projects

As noted above, there has been a trend in recent aquisition projects for all design responsibility to be vested the contractor, once the requirement and specification for a new system have been developed. In this context, the role of government (ie. CF) agencies with expertise in ergonomics is primarily to develop the requirements for new systems, to audit the responses to such proposals, to audit the design proposals of the selected contractor, and to continue to develop a technology base in ergonomics in order to provide specialist advice to weapon system project managers.

In some cases such technology base information is provided to the project managers for transmittal to the contractor. This has happened in several instances when the contractor did not have in-house ergonomics experts available. It has also occurred when interpretation of the system specification has been required, or when advice has been required on conflicting design requirements. In one case assistance was requested from the engineering design department of a company because they could not, easily, produce an operable system based on the design concept which had been prepared and submitted by their marketing department. In such cases the CF ergonomists play an advisory role only; contractors are not obliged to incorporate any design requirements which are not in the contract specification. They are, however, encouraged to consider the opinion of the CF specialists, as they are in all areas of weapon system technology.

Judging from a number of projects over the past ten years, the role of industry ergonomists, when such persons have been employed by the contractor, has been to assist in the development of responses to requests for proposals for new systems, and, primarily, to provide ergonomics input into the detailed design of the system. Comparatively little other work is undertaken for the CF by those few ergonomists who do work in industry, but a growing amount of related work is undertaken by human sciences specialists, or by those in related disciplines. Some of this capability is employed in feasibility and development studies for individual directorates within CEM. Recent examples of such inputs are the development of training requirements for weapon system operators based on task analyses prepared by CF ergonomists, and a study of the requirements for technician training.

ERGONOMIST'S ROLE IN EACH MAJOR PHASE OF THE PROCESS

For the purposes of this review the major phases of the system design process will be referred to using the terms of MIL-H-46855, namely Analysis, Detail Design and Test and Evaluation.

Analysis

This phase is concerned with the specification of the requirements for a new system, and the development, by contractors, of concepts to meet that requirement. A variety of ergonomics activities have been undertaken during this phase, depending on the particular project and the judgement of the project managers on the need for such support. Such activities have ranged from R & D studies to reviews of Statements of Requirements or system specifications.

A good example of the former type of activity is the work which was undertaken to develop a new machinery control console for CF ships. The work was undertaken for the Director, Maritime Equipment Engineering, to "examine the state of the art display technologies and develop design requirements for the propulsion control consoles of a proposed warship". Activities by the CF ergonomists included a thorough review of available electro-optical displays and the associated ergonomics issues, ship visits to observe existing machinery console use including simulated emergency procedures, discussions with operators of the limitations of current designs, and analysis of machinery control operator's and supervisor's tasks, and the development of lists of undesirable and desirable design features. In addition the literature on human supervisory and monitoring behaviour was reviewed, and similar developments in the electrical utility industry were reviewed. This work then lead to the development of a concept for the machinery control console, and its interface with the control system. Static mockups were produced of the consoles, and the proposed information displays were "mocked up" using a microprocessor controlled CRT display system.

In those cases were ergonomics support has been requested to review the Statement of Requirement or the System Specification for a new system, the work of the CF ergonomists is significantly different. The emphasis of such work is to ensure that the ergonomics issues in the operation and maintenance of the proposed system are properly addressed, and that those requirements can be expressed in terms which are contractually sound. This activity poses some problems. It is easy, to take an actual example, to specify that the crew compartment of a vehicle shall be "integrated" and "optimised"; it is a great deal more difficult to specify such requirements in terms which do not lead to differing interpretations by customer and contractor, and for which contractual compliance can be demonstrated. This problem is related to the acknowledged difficulty of predicting and measuring

system performance, including operator performance, in wholistic terms, and to the difficulty of expressing and manipulating ergonomics design data in terms which are congruent with those used in engineering design.

Whenever possible contractors are required to prepare Human Engineering Plans, identifying the ergonomics activities (Work Items), that will be undertaken in support of the project, and to produce specific documents providing information on ergonomic issues in the system design (Data Item Descriptions or DIDs). Such requirements provide a greater degree of control over the ergonomics effort than the more general human engineering specifications. While the specification of MIL-H-46855 should ensure that the contractor undertake an appropriate ergonomics effort, and the specification of the design standard MIL-STD-1472 should ensure that ergonomics principles are applied at the detail design level, there are sufficient "let out" clauses in both documents that critical issues can be interpreted differently by contractor and client.

Given this situation it is perhaps significant that the projects in which we have had most success in seeing the ergonomic requirements addressed by the contractor are those where full size mockups of the concept were produced and shown to the contractors. For example in the CP-140 Aurora aircraft program a "CF preferred" crew compartment was developed using a flexible mockup. Drawings of crew compartment and crew station layouts were produced and forwarded to contractors working on design definition, with the request that the principles used to develop the preferred design be reflected in their proposed designs, or that alternative designs produced by the contractors be supported by equally compelling rationales.

The role of the ergonomists employed by industry during the analysis phase can be expected to follow the outline of MIL-H-46855. Whenever necessary ergonomists may be employed in preparing scenarios, conducting mission and task analyses, allocation of function analyses etc. In some projects CF ergonomists have duplicated such work to provide a baseline for comparison with the contractor's work. Such activities have included reviews of contractors operator workload analyses, reviews of specific workplace design proposals using link diagram analyses based on operational sequences, and reviews of full scale mockups.

Detail Design

During design development, ergonomics inputs can be made by contractors personnel, as specified by MIL-H-46855. Inputs can also be made by CF ergonomists, whose advice to the project manager can be passed on to the contractor. Such inputs are most frequently made through design reviews, mockup reviews and reviews of Data Item Descriptions. In some projects the CF ergonomists have not been involved prior to such reviews. In those cases their work centres on the extent to which the contractor has fulfilled the contractual requirement for human engineering. Because of the vagueness of some of the requirements in MIL-STD-1472 and MIL-H-46855 mentioned above, such work often involves the interpretation of the requirements of those specifications in a manner which is acceptable to both the contractor and the client.

Again one of the most useful aids to communication with the contractor's designers and also with the future system operators has been found to be the full scale mockup. In the case of the CP-140 Aurora mentioned above, the mockup used in the Analysis phase was retained, and, as the contractors developed the detail of their designs the mockup was modified. For example once a specific item of equipment had been selected by the contractor it was represented in the mockup in lieu of the initial generic representation. In a similar way investigations into the

size, scaling and formating of the tactical displays for use in the aircraft were supported by full size representations of the displays. In two projects the mockup developed at DCIEM during the Analysis phase was shipped to the contractor for use by the design team during the Detail Design phase.

Design proposals are also evaluated against information from the existing ergonomics technology base. For example specifications for lighting, noise and vibration levels can be compared with the measurements which have been made on existing CF systems, as well as with other data on such issues.

Test and Evaluation

In recent years most of the activities of CF ergonomists in this phase have been concerned with the evaluation of competing systems being considered by the CF for an off-the-shelf buy. Typically these evaluations are carried out in the field, in as realistic conditions as possible. The principal technique used is to observe the operation of the equipment, or to simulate the operation of the equipment through all anticipated operational routines. The technique is similar to the dynamic checklist approach evaluated by Malone (Ref 3). Little use is made of static checklists such as those discussed by Morony in Panel II of this workshop, or by Wiegand in Panel III. Service personnel who have been trained on the candidate systems, or who at least are familiar with current systems and operations are used as system operators. The CF ergonomists observe the operations of the candidate systems on a non-intrusive basis whenever possible.

The field evaluation of candidate howitzers was typical of such activities. CF ergonomists attended the troop trials involving live firings in winter. Operator activities were observed to identify design features which could cause accidents, mistakes or a loss of efficiency. Where problems were identified, such as the need for excessive force when turning a handwheel, measurements were taken, and the parameters compared with existing standards or with other sources of ergonomics data. Measurements were taken of specific design features such as the lighting of the weapon sights, the noise levels and toxicity levels to which the operators were exposed.

The evaluation of some new aircraft instruments, proposed for retro-fitting into existing single place CF aircraft, required initial emphasis to be placed on laboratory evaluations. The instruments were examined in the laboratory from a strict human engineering point of view, including measurements of brightness and chroma. Subsequently flight trials of the instruments were planned by the ergonomist in conjunction with the test directorate. The flight profile was designed to put the aircraft into situations where the deficiencies identified in the laboratory evaluation would be encountered if they were operationally significant.

In other cases such evaluations cannot be conducted on a non-intrusive basis. For example the evaluation of a candidate set of diving tools and equipment required an ergonomist trained as a clearance diving officer to accompany divers who carried out simulated tasks in test rigs set up on land and under water. Physiological measurements which were taken introduced another aspect of artificiality to the study. Other evaluations have required the use of simulator facilities, and in a few cases it has been necessary to review records, including medical records of system operators to study a problem which had occurred in a system which had been in service for some time.

The results of such evaluations are frequently made available to system manufacturers. In some cases the timescale of the project, coupled with the design

status (for example the evaluation of a prototype) has permitted improvements to be made to a design. Such results would, presumably, be passed to the ergonomists employed on the project. In general contractors are not involved in evaluations carried out by the CF unless the system is being produced under an R & D contract. In the latter case contractor's personnel participate in field trials of engineering development models of the system. In normal system design projects the contractor's ergonomists have been involved in the in-house evaluations of the system, including, for example, tests of the compliance of the prototype to contractual standards, the investigation of complaints or deficiency reports by test personnel, the rectification of design problems where possible, and the reporting of the results as required in the Human Engineering Plan.

DISCUSSION

It can be seen that the role of ergonomists in the weapon system development process in Canada can conform closely with established recommendations. What is perhaps less obvious is that the roles actually played by ergonomists vary widely from those recommendations. The majority of the ergonomics inputs to the weapon system development process appear to have been made in the Detailed Design and the Test and Evaluation phases. In comparatively few cases has it been possible to make significant inputs to the early phases of system development when decisions are made affecting personnel selection and training, or the determination of operator and maintainer tasks.

The roles of the ergonomists, and their inputs, are to some extent dependant on the project and on the capabilities of the contractor. In a review of projects in which DCIEM ergonomists have been involved during the past ten years (Ref 1), it was shown that the level of ergonomics effort expended by contractors varied from a significant input to the design process down to zero. Equally important, the majority of ergonomics design deficiencies which were identified during Test and Evaluation could have been avoided through the application of existing ergonomics design data. Few required the capability in operational research, and systems simulation and modelling referred to by Topmiller in his review of human engineering work methods (Ref 5), or discussed by Erickson in Panel I of this workshop.

One conclusion from the DCIEM review of projects was that there has been little, if any, transfer of ergonomics technology to industry. Discussion of mechanisms which facilitate technology transfer is one of the objectives of this workshop Panel. At DCIEM we have concluded that more attention must be paid to the identification and exploitation of such mechanisms. The more obvious conclusions, such as that technology transfer is facilitated by physical proximity, or that it is fostered by locating personnel from R & D laboratories in the contractor's plant have limited applicability to a small number of staff working in a physically large country.

In our experience the projects where ergonomics issues have been properly addressed by contractors have been those where the contractor recognised that new design solutions were necessary, and where the importance of those issues had been highlighted in the SOR and in concept studies undertaken by the CF. Those projects where the contractor's proposals have been minor variants on existing designs have, on the whole, been marked by little or no concern for ergonomics on the part of the contractor. Such an attitude was epitomised by the design engineer responsible for human engineering on one project who argued that it is not really all that important, because every customer wanted something different!

Communication with such engineers has been found to depend very much on their

background. Those with some training or experience in ergonomics are generally much more receptive to ergonomics inputs, and engineers in companies which have some ergonomics capability tend to be more receptive than those in companies where there is no ergonomist to facilitate communications. Ergonomics design guides and handbooks such as MIL-STD-1472 are, in our experience, inappropriate for communicating with design staff who have no familiarity with ergonomics. Such guides have been reviewed by others, and some of those criticisms are reviewed by Boff in his contribution to this Panel. We would echo the criticism that they are at the same time too complex yet too simplistic.

As noted above, we have found that one of the most successful ways of communicating with engineers and designers is the full scale mockup. The advantages of mockups have been well documented, and some are reviewed by Schuffel in his contribution to this Panel. Mockups do appear to play an important role in the communication of ideas. They represent a physical realisation of a design, rather than abstract ideas on paper, they represent the many individual design requirements as a single entity, and, perhaps most important, they represent the most tangible aspects of ergonomics such as the physical sizing of equipment, the ability to read displays and reach and operate controls.

Obviously mockups are not the solution to all ergonomics problems in detail design. Schuffel discusses the impact of the increasing use of computer controlled electro-optical displays, which has resulted in several new operator workstations consisting of nothing more than a table, seat, CRT and keyboard. The most important ergonomic problems with such systems lie in the dynamic aspects of the operator:machine interaction, calling for the use of simulators rather than static mockups. Such simulations are, however, both time consuming and expensive to run, and very little use has been made of them to date by CF ergonomists. Extensive use has been made of such simulations by the contractors developing some of the systems most recently aquired by the CF. Such developments would argue for the application of increased ergonomics effort in the systems design process, on the part of both government and industry.

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