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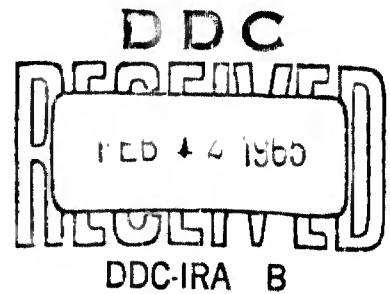
HUMAN FACTORS IN REMOTE HANDLING:
A REVIEW OF PAST AND CURRENT RESEARCH AT THE AEROSPACE
MEDICAL RESEARCH LABORATORIES

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FOREWORD

This report is based on a paper presented at the symposium on Remotely Operated Special Equipment (Project ROSE) sponsored by the U. S. Atomic Energy Commission and held at Germantown, Maryland, on the 26th and 27th of May 1964. It discusses the research on remote handling that has been accomplished since 1959 by the Maintenance Design Branch, Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, under Project 7184, "Human Performance in Advanced Systems," Task 718407, "Design Criteria for Nuclear Systems Support Equipment," and Project 8171, "Aerospace Support Equipment for Nuclear Applications," Task 817105, "Human Engineering for Remote Handling Systems."

ABSTRACT

This report discusses and summarizes the human factors research that has been accomplished, both in-house and contracted, by the Maintenance Design Branch in the area of remote handling since 1959. Discussion of this research program is made in terms of the various factors that affect remote handling operations - task variables, equipment variables, operator variables, sensory/perceptual problems, and controls. Identification of future research areas is made.

This technical report has been reviewed and is approved.

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HUMAN FACTORS IN REMOTE HANDLING: A REVIEW OF PAST AND CURRENT RESEARCH AT THE AEROSPACE MEDICAL RESEARCH LABORATORIES

INTRODUCTION

In the summer of 1959, the Maintenance Design Branch of the Human Engineering Division, Aerospace Medical Research Laboratories, initiated a program of research on human factors aspects of design and use of remote handling equipment. At its inception, this program was applied to two major problem areas: ground support for nuclear-powered systems, and extravehicular space operations.

This paper discusses and summarizes the research that has been accomplished under this program. However, before discussing this research program, a brief discussion of the role of remote handling as it applies to the two major problem areas is in order.

The hazards that necessarily arise from the use of nuclear-powered systems are many, the primary one being radiation. To protect personnel working with these systems, it can be assumed that some form of remote handling will be used to perform all of the necessary activities associated with the successful operation of such systems. Thus, as far as ground-support of nuclear-powered systems is concerned, remote handling retains its classical role of enabling man to work safely in dangerously radioactive environments.

In space systems, remote handling has this role in addition to many others. These "other" roles are apparent in connection with tasks accomplished outside the space vehicle. Because of the quantity and severity of physical hazards, it is improbable that man will be able to work effectively without some means of extending his perceptual and physical skills beyond a considerable amount of protective devices.

Remote handling will allow man to accomplish necessary functions in areas of high radiation, near or total vacuum, extreme temperatures, etc. Thus, many space proposals include notions of the use of remote manipulative equipment, ranging from the simple to the complex, for many jobs in places where man either cannot or would not go (ref. 12).

Among the tasks for remote handling in space will be assembly, disassembly, and maintenance of space systems, including inspection, repair, servicing, and checkout; experimentation, including exploration, sampling, and testing; transfer of personnel, supplies, and equipment; and emergency operations, such as escape and rescue. These tasks have much in common with ground-based remote handling tasks. Thus, many of the research results relating to ground-based tasks will have application in design for remote handling in space (ref. 12).

DISCUSSION OF REMOTE HANDLING VARIABLES

In discussing the human factors research that has been conducted by the Maintenance Design Branch, it is convenient to classify the research in terms of the various factors that affect remote handling operations. Thus, we can talk about task variables, equipment variables, operator variables, sensory/perceptual problems, and controls.

I. Task Variables

Since the manner in which a task to be performed remotely is designed, arranged, or presented to the operator affects his performance, several of these variables have been studied:

A. Task Distance: The effect of this variable on performance of a manipulative task was investigated using a CRL Model 8 Master-Slave Manipulator (ref. 4). Performance time was found to increase as the task was moved from a position seven feet from the operator's eyes to a position nine feet away, and then to a position eleven feet away. No significant differences in performance time was noted when the task was moved from the seven to the nine feet position, however, significant differences were noted when the task was moved from either the seven or nine feet positions to the eleven feet position. This significant decrease in performance is attributed to the loss of visual resolution and depth perception brought about by the increase in distance and also to the fact that at the eleven feet position the operator was working at the range limitations of the manipulator.

B. Object Size: This variable was investigated using a task in which different size hexagonal nuts were removed from bolts (ref. 1). Results from this study indicated that performance times did not change significantly as the diameter of the nut increased from 3/4

inch to 2 1/4 inches. It should be pointed out here that the 3/4 inch nut is less than the minimum (1 inch) recommended for remote handling while the 2 1/4 inch nut represents the practical limits of the slave jaw.

C. Angle and Height of Task Display: These two variables were studied in connection with the nut-removal task just described (ref. 1). For the standing operator working at several different task angles, performance times were significantly better when the task height was 45 inches from the floor. Without regard to height, performance was found to be best between the 45° to 65° range of task angles measured from a task in the horizontal position. These two variables also interacted so that horizontally oriented tasks were performed best at the lowest working height and worst at the highest height. Vertically oriented tasks were performed best at the intermediate heights.

II. Equipment Variables

Many remote handling problems arise from the design of the equipment itself. Much attention has already been given to the effects of change among the many variables of design of manipulators and accessories. Sensory feedback (tactual, kinesthetic, etc.), movement ratios, force ratios power provisions, and auxiliary controls, to name a few, have been studied. Two studies will be reported here. However, before discussing them, it is worthwhile to look at the effect of the manipulator itself on human performance.

A. Remote Versus Direct Handling: To date, it is an undisputable fact that remote handling is employed at a price. It is generally conceded that the use of a mechanical master-slave manipulator involves a significant loss in efficiency of performance when compared with direct handling. To determine this factor, a standard manipulative task was performed with both modes of handling in an experimental setup which controlled for extraneous factors of practice and sequence of test (ref. 4). Operators of the CRL model 8 manipulator took 6 to 10 times longer, depending on task distances, to perform the task than did direct handlers. The factor of 6 was found for the seven foot task distance, the factor of 10 for the eleven foot distance. The ratio of 8:1 was most representative of remote tasks performed at the modal distance (9 feet).

B. Weight Discrimination: Two studies were conducted to determine the effect of remote handling on the ability of subjects to make differential judgments of weights (ref. 6 and 7). In comparison to direct handling, remote handling produced absolute estimates of weights which were greater and more variable but closer (on the

average) to the actual weights. The tendency for estimates to be influenced by preceding handling operations (contrast effect) was found to be less for remote handling. Difference thresholds (DL), the amount by which two stimuli must differ to be perceived as different at least 50% of the time, were nearly doubled for remote handling. Thus, differential sensitivity for weights is attenuated by remote handling such that two objects differing less than 8% in weight cannot be effectively discriminated. For direct handling it is 5%.

C. Mass Discrimination: Since objects in space will have no weight, it is useful to know what the difference threshold will be for remotely handled masses. Using objects supported by compressed air (i. e. using the air-bearing table, one of several frictionless devices used by the Maintenance Design Branch to simulate the frictionless environment of space) the remotely handled weight discrimination study was replicated (ref. 9). Since the cue of weight was rendered inoperable, the study essentially becomes one of mass discrimination. The difference threshold for remotely handled mass was 23%, approximately three times the difference threshold for remotely handled weights. In summarizing the results of these several discrimination studies, we find that discrimination on the basis of mass, per se, results in doubled difference thresholds for direct handling (5% to 10%) and tripled difference thresholds for remote handling (8% to 23%) (ref. 12).

D. Mode and Rate of Indexing: To overcome the restrictions imposed on the "Y" motion (fore-aft) by the hot cell wall and the work area of the operator, mechanical master-slave manipulators have a feature which allows movement of the slave arm in the "Y" axis without corresponding displacement of the master arm. This is called angular indexing. It is normally controlled by a hand-operated two-way switch. A study was conducted to assess the merits of having this feature controlled by a foot-control as opposed to the standard hand-control (ref. 2). Three representative rates of indexing were used (2.1^o, 6.2^o, and 11.4^o per second) in the performance of a task requiring indexing. No advantage, in terms of speed of performance, was found for either mode of indexing but fewer errors (dropping blocks and indexing in the wrong direction) occurred with the foot control. There was also evidence of faster learning using the foot control. These results were not altered by the change in the rate of indexing, even though such change was shown to affect speed of performance significantly, i. e., higher rate produced shorter task time, for distant tasks. For tasks, involving short indexing distance, there was no advantage in faster rates of indexing.

E. Color Coding of Jaws: In another study, an attempt was made to improve correspondence between the operator and the slave jaw through the use of color coding (ref. 4). It was anticipated that this would also improve work performance. The fingers of the slave jaws were painted red and green, the red fingers representing the operator's "fingers" and the green his "thumb." No significant performance differences were noted. It is suggested that the use of color coding as an aid to improved remote handling performance may be more appropriate if used in the design and layout of the task to be performed.

III. Operator Variables

As in any task requiring skill, individual differences exist in remote handling performances. These can result from differences in manual dexterity, coordination, depth perception, etc. The effect of some of these factors on performance have been investigated.

A. Practice: Naive subjects were used for remote performance of a block-manipulation task. Performance time decreased to a practical asymptote within just a few trials, indicating that beginner operators adapt to the grosser aspects of the master-slave manipulator with little difficulty (ref. 4). For satisfactory performance of more intricate tasks (or using manipulators other than the master-slave), training periods of longer duration may be required.

B. Seated Versus Standing Operators: A study was conducted to determine the extent of limitations upon the work range resulting when the operator is seated (ref. 3). This was thought to be a way of approximating the effect of confined quarters which may exist in space applications. Contours of effective work area were found to be progressively reduced in area as the plane of the task (horizontal) was lowered to the knee and below. In general, the range of effective work area for the seated operator was approximately one-third the range for an unrestricted standing operator.

IV. Sensory/Perceptual Problems

The use of remote handling devices necessarily results in reduced sensory and perceptual feedback to the operator. Investigations have been conducted to determine the effects of different feedback channels - auditory, visual, etc., - upon performance.

A. Television Viewing: This study was conducted to compare 3D (stereo) television with 2D television as a means of attaining visual access to the task when direct visual access is not feasible (ref. 10). No significant differences in performance were noted between the 3D

television condition and the 2D television condition even though performance was initially worse for the 2D condition. This lack of a significant difference is attributed to loss of resolution (2D to 3D), availability of other sensory cues, and the ability of subjects to use monocular depth cues successfully.

B. Monocular Versus Binocular Viewing: In a related study, performance of a simple task under monocular and binocular direct viewing conditions was compared (ref. 5). Performance under these two conditions differed significantly, operators under the monocular viewing condition requiring 20% more time to perform the task. Furthermore, binocular performance reached an asymptote sooner, stabilized quicker, and was less susceptible to deterioration (from session to session).

C. Remote Driving: In a recently completed study, the ability of subjects to successfully maneuver a mobile remote handling unit up to a specified target during the terminal phase of remote driving using a 2D television system with and without augmented depth cues - shadow cues (using a single flashlight which cast a shadow of the manipulator jaw on the target) and converging lights in which two light beams intersected at the jaw - was investigated.* A significant difference in performance was noted between the augmented and unaugmented television viewing conditions. Error scores were approximately 12 times larger for the unaugmented television condition. It was also noted that overshooting occurred under the augmented conditions while undershooting dominated the unaugmented condition.

D. Auditory Feedback: To assess the value of providing auditory feedback, subjects performed several manipulative tasks under three auditory conditions - sound, no sound and noise - using the CRL model 8 manipulator (ref. 11). No significant differences in performance were noted between the three feedback conditions; although surprisingly, performance under the noise condition turned out to be the best. This lack of difference in performance is attributed to the availability of other sensory channels - visual and tactual - and the nature of the tasks used (essentially positioning type tasks which places a heavy demand on visual rather than auditory information).

V. Controls

The large number of different remote handling systems in existence today results in a number of different control systems. The effect of different controllers and control systems upon performance was investigated.

*Unpublished

A. Joy Stick Versus Multiple Levers: Two modes of control, a joy stick and a multiple-lever system, were investigated using a Lee Associates manipulator (ref. 8). Performance was found to be superior with the joy stick control. However, with practice, the effectiveness of the multiple-lever system tended to approach that of the joy stick.

B. Remote Manipulator Control Research: Recently a contract on remote manipulator controls research has been let. The purpose of this contract is to obtain timely solutions to critical problems relating to the design of efficient remote manipulator control systems by (1) reviewing the applications and manipulative requirements of remote handling systems, (2) analysing and defining the various man-machine dynamics involved in remote manipulator controls, (3) identifying critical problems, particularly those requiring additional research, and (4) determining the feasibility of deriving solutions to remote manipulator control problems by extrapolating or generalizing from previous controls research and by utilizing traditional approaches to control system research.

CONCLUSION

This paper has dealt only briefly with the results obtained through a program of research designed to investigate some of the human factor problems relating to the design and use of remote manipulators. A great number of other research efforts pertinent to these problems are being carried out by many different agencies. Successful application of remote handling in ground support for nuclear systems and space operations will depend a great deal on the success of these and future efforts.

While the total, necessary, additional human factors effort cannot be specified, further work which should be done to extend the usefulness of the results reported in this paper can be identified.

Additional research is needed to develop basic remote handling concepts, and to establish criteria for comparing and evaluating different types of remote handling systems with respect to their useability in ground support and space operations. Solutions to perceptual problems connected with remote operations are needed. Problems of remote visual access (including use of closed and open circuit television), depth and movement perception, illumination, glare, contrast, tactual, auditory, and kinesthetic feedback are representative.

Additional research is also needed on remote manipulator controls. Human engineering information and/or criteria must be developed and validated. Included in this research are determination of the appropriateness of different control orders (positional, velocity, etc.) for various manipulator control functions; of the advantages and disadvantages of mixing control orders within the same control system; of the effects of variation in control resistance, lag, and gain on manipulator control system performance; of the man-machine relationships, etc.

These are just a few of the many considerations important to the effective use of remote manipulators in support of nuclear-powered systems and space operations. Research is underway to provide needed answers for many of the questions. Much more must be undertaken to satisfy the overall need.

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