AMRL-TR-64-98

AN EVALUATION OF PROPOSED APPLICATIONS OF REMOTE HANDLING IN SPACE

GERALD P. CHUBB

OCTOBER 1964

BEHAVIORAL SCIENCES LABORATORY
AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

BLANK PAGE

AN EVALUATION OF PROPOSED APPLICATIONS OF REMOTE HANDLING IN SPACE

GERALD P. CHUBB

FOREWORD

This report is based on a paper presented by the author 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. The author is a member of the Maintenance Design Branch, Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories. The work was performed in support of 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."

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory

ABSTRACT

This report discusses problems of applying remote handling techniques to assembly and maintenance operations in space. Some of the methodological problems are pointed out and current conceptions of remote handling in space are evaluated. Areas where more research is required are pointed out. Remote handling systems based on the state-of-the-art are feasible, but may not be adequate for all proposed tasks, and certainly not all are optimal or efficient.

BLANK PAGE

AN EVALUATION OF PROPOSED APPLICATIONS OF REMOTE HANDLING IN SPACE

INTRODUCTION

Background

The Air Force's interest in remote handling was stimulated by problems connected with nuclear weapons and propulsion systems. But as Dr. Clark has pointed out (ref. 5) the technology developed for dealing with nuclear materials is equally applicable to other hazardous tasks. Maintenance and assembly of orbiting space stations will eventually require man to perform in the hostile environment of space where he will be subject to meteorite bombardment as well as radiation. The chances of puncture are relative small (ref. 2), but our inability to predict the precise time of their occurrence makes this problem important to the astronaut. Since meteorite puncture could occur the first time he ventures out of his vehicle, it means very little to him that he should encounter this event only once every "x" number of years.

For orbits below 500 miles, the earth and the space vehicle can act as shields (ref. 2), thus greatly reducing the exposure to both meteorites and radiation (e.g. solar flares). However, exposure increases as the orbital altitude increases. As yet, no one has determined what data are still needed to ascertain at what point the suited operator will need additional protection. It has simply been assumed that ultimately the need will arise.

Design Considerations

Proposed methods for circumventing these difficulties have ranged from encapsulation of the astronaut ("hard" suit rather than "soft" suit) to the use of a telechiric system (ref. 5 and 6). A preliminary evaluation of these proposed alternatives will be attempted here in an effort to delineate what design trade-offs can be made at our current level of knowledge and where future efforts should be directed to alleviate the remaining problems. Although the final design will probably be dictated by cost-effectiveness trade-offs relative to mission and task requirements, the vagueness with which mission requirements and resulting work tasks have been so far defined necessitates taking a somewhat different approach at this stage of development. Design evaluation here will be primarily based on the human factors aspect of the configuration. Little attention will be given to the possible engineering problems this may create. For example, an optimal design from a human performance standpoint, may be too costly, complex or weighty to be practical. Our concern will be with the human factors design trade-offs that enable the systems engineer to optimize the final design in light of more pragmatic considerations.

Methodological Considerations

From the human factors point of view, the best configuration would be the one allowing the best operator performance. This entails both display fidelity and control effectiveness. Performance decrements could conceivably be functionally related to quantitative measures of each relevant parameter of the display and control systems. Before this task is undertaken, additional research should be directed toward performance measures themselves, the dependent variables against which control and display configurations will be evaluated. Usually, only time scores have been extensively used, but error scores have also been mentioned occasionally (e.g. control reversals, dropping objects, overshoot – undershoot, etc.). Time data, i.e. time to complete a given task element, are usually contaminated, in an undetermined or at least unspecified manner, with (or biased by) errors. Either the data for a trial on which an error occurred is ignored or the data, if included, reflect not only the task time but both the time to commit and correct the error. The information content of the data is not fully utilized in either case, and no one seems concerned about this confounding of performance metrics. Actually this may represent not only a confounding of dependent variables but of the corresponding independent variables as well (in that it is the latter which determine the former).

Other performance metrics could also conceivably be used. For example, rate of travel, acceleration, collision-impact force, etc. could all be used. The unanswered question is how these interact. Some of these metrics may be independent of each other. If this is the case, a weighted composite of these measures may provide a more sensitive performance metric. The applicability of multivariate analysis would, therefore, appear worth investigating.

Along these same lines, each of these performance metrics will probably be affected differentially by the task parameters. While Sheridan (ref. 14) has suggested an index of task difficulty based on Fitts' work (ref. 8), this index is not altogether acceptable. For one thing, it does not differentiate between distance from the starting point to the end point of paths and the actual path dictated by restrictions such as degrees of freedom of movement, task orientation, alignment, etc. So that a quantitative specification can be made, considerable attention must still be given to what factors affect the difficulty or complexity of a task.

EVALUATION

Classification of Proposed Configurations

Two previous reports (ref. 1 and the symposium proceedings mentioned in ref. 5 and 12) have reviewed proposed applications of remote handling in space. The techniques proposed can be classified in two categories: (1) encapsulation, where the operator is positioned in a vehicle having manipulanda which he can operate directly and (2) telechirics, where the operator is positioned at a control module physically distant from the manipulative device which he must operate remotely. The terminology is inadequate here in that the encapsulation technique is an application of remote handling just as much as the telechiric technique. In the former case, the remoteness is due to the barrier formed by the vehicle encapsulating the operator. With telechirics the barrier is the distance separating the operator from the device, in which case control and display information must be conveyed over some sort of communication channel.

Encapsulation then makes fuller use of man's sensory abilities by taking him to the task. A telechiric system, by design, in effect brings the task to the operator. Sensory displays provide feedback information about the operator's task performance (e.g. via television). Currently, proposed encapsulation designs require that the operator be suited. The necessity of operating under suited pressurized conditions may restrict control effectiveness if position controls are employed. On the other hand telechiric devices may be controlled from the shirt-sleeve environment of a primary vehicle or from the ground.

Encapsulation

To date, greater emphasis has been placed on encapsulation techniques. They do not require the data-control link of the telechiric system, but on the other hand, life support equipment must be included in the capsule. Lockheed recently completed a study for the Aero Propulsion Laboratory (Research and Technology Division, Wright-Patterson Air Force Base) in which they evaluated several design configurations for an orbital maintenance and material transfer shuttle (ref. 7). The Lockheed project is representative of the state-of-the-art and will form the basis for evaluating the concept of encapsulation. A full-scale mock-up of the prototype Lockheed has proposed to develop is currently being exhibited at the World's Fair in New York.

During the project, Lockheed empirically tested several maintenance concepts. They found the sleeved-glove approach (analogous to the glove box) proposed in early designs was not feasible for some tasks when the operator was suited. This appears reasonable in that the operator had to work through two pairs of gloves, and the decrement with only one pair is significant (ref. 3) even without considering ballooning effects with pressurization. The operator must constantly struggle with the inherent rigidity of the suit and the friction of joints and couplings (ref. 13). These effects increase as a function of the level of pressurization. Although both the Air Force and NASA are endeavoring to produce suits that will significantly improve mobility, the state-of-the-art is not sufficiently advanced to allow prolonged muscular activity that requires more than a moderately coordinated, gross, motor response. For a while yet the system designer will have to contend with the fact that even a simple button-pushing task can become quite fatiguing in a fairly short period of time.

Lockheed also studied the possibility of performing maintenance through the access hatch of the shuttle. Of the four tasks studied, average times across tasks for the unsuited, suited, and suited-pressurized operator were 12.350, 17.925 and 36.825 minutes, respectively. The pressurized condition thus resulted in task times approximately three times as great as the unsuited condition. The tools used for the tasks interacted with the suited conditions, and recommendations were made concerning modification of the tools; but the times obtained might also serve to illustrate another point. If manipulator controls are not modified and controls do not interact with the suited conditions, Lockheed's task times must be increased by another factor of 6 or 10 to obtain an estimate of remote maintenance times (ref. 12). For example, a task taking 12 minutes normally may take two hours if done remotely, and if the operator must work in a pressurized suit, the time could increase to six hours. These figures suggest that a re-evaluation of the encapsulation concept may still be in order, even with marked improvement in pressure suits, simply because of the difficulty of performing a task remotely. Provisions should be considered for either shirt-sleeve or unpressurized operation so that remote manipulation task times are not further inflated. Alternate methods of actuating the desired controls might also be investigated (e.g. force controls, myoelectrics, etc.).

Telechirics

If provisions are made for a shirt-sleeve environment in the primary vehicle (as currently proposed for MOL and APOLLO) and operation of the telechiric system never requires a suited operator, state-of-the-art methods of actuating control movements appear adequate. However, the second assumption may not be realistic under certain emergency conditions.

Although Dr. Clark has demonstrated the feasibility of the telechiric concept (ref. 5 and 6) and Lockheed has designed a Space Cargo Handler and Manipulator for Orbital Operations (SCHMOO) which utilizes the telechiric concept, no data are available on the operator's ability to perform maintenance and assembly tasks. It is, therefore, difficult to compare the telechiric concept with the encapsulation technique. Even though Lockheed has designed vehicles using both concepts, these devices are quite dissimilar even in gross external features. The manipulanda of the space shuttle are not specifically described in detail whereas the space tug (SCHMOO) has been designed for rate controlled manipulanda. The type of manipulator employed, its control dynamics, and the characteristics of the vehicle to which it is attached can all affect operator performance, directly or indirectly. A comprehensive analysis of these problems cannot be attempted here.

The major advantage of a telechiric system rests in increased control effectiveness resulting from the ability to perform in a shirt-sleeve environment. If these increases are greater than the decrements due to remote viewing, the system may be practical. In short, display fidelity must be optimized given the restrictions imposed by other engineering and human factors considerations, e.g., reliability and maintainability of the system itself. Since these restrictions have not been specified, the problem must be considered in its more general aspects, and the evaluation of the telechiric approach degenerates into a review of research that could establish trade-offs between relevant display parameters. The fidelity of each is only bought for a price. The problem becomes one of establishing the importance of fidelity in each parameter relative to that obtained in others. In other words, since an optimally resolvable, color, stereo display would probably be of prohibitive cost, weight, and complexity, the designer must know which of the parameters are less important and to what extent. Only then can the evaluation of the telechiric system be completed. This will ultimately determine its practical feasibility.

Research to date has mainly been exploratory in nature and only serves to better define those parameters having sufficient importance and relevance to warrant further investigation. True auditory feedback cannot be obtained in the vacuum of space. Since auditory feedback has been shown to be of equivocal importance (ref. 9), the auditory channel might be used to augment the display of force exertion, positioning, or other vital data. General Electric and the Air Force Weapons Laboratory have done work on camera angle (ref. 10 and 11) that indicates camera positioning is an important area for further investigation. Both Dr. Goertz and Dr. Clark have expressed interest in continuing studies in this area. Mr. Kama and I have been investigating the effects of stereo cues, but further research is needed, especially on the effects of degraded resolution. Bilateral force reflection may not be technically feasible, and there are no data available on the effects this factor has on performance. Operator performance with a rate controlled, rectilinear arm has proven adequate for many tasks although the CRL-8 is usually preferred by the operator for those tasks that can be performed with either device.

The real issue is how all of these factors interact with each other. While a decrement in any one may not be severe, the combined effects of decrements due to several parameters may be more than a simple summation of the independent effects and may result in totally inadequate performance on some or all tasks. It is apparent that considerable research is still needed before the necessary trade-offs can be established. While telechirics are feasible, they must yet be demonstrated as practical.

Shared Problems

In addition to the problems besetting each of these systems, there are other questions, common to both systems, that must still be answered. Among others is the problem of control dynamics. Up until now, each manipulator was designed for a fairly specific purpose in mind, and only later it was found to be applicable to other tasks. Some of the more basic questions have never been empirically examined. No one knows the functional relations between effector arm length, degrees of freedom, rates of movement, leads, lags, and order of control as these relate to operator performance. Although statements have been made about the ability of the operator to identify with the machine, no one knows how nonanthropomorphic controls quantitatively affect performance or how various manipulator configurations distort the hypothesized body-machine identification process.

A contract program sponsored by the Maintenance Design Branch of the Aerospace Medical Research Laboratories is currently under way to determine the feasibility of simulating the control problem. If a versatile simulation technique can be developed, much of the work needed in this area can then be undertaken without the expense of full-scale models of each proposed configuration. Investigation of task variables, hardware design, and tool modifications might otherwise be prohibitive. Further studies are also being contemplated for determining the volumetric workspace required for performance of maintenance tasks. Hopefully, design criteria can be established that will allow compatibility of soft suit and remote manipulator maintenance. Optimistically, tools and adaptive fittings for suited maintenance may prove useful for remote maintenance.

Solutions from other Sources

The problems of rendezvous and docking are shared by both systems although under slightly different circumstances. NASA and the Air Force are both involved in this problem, and results of their studies should be applicable. Both Lockheed studies discussed this matter in some detail (ref. 7).

The problems in performing under pressurization may be at least partially eliminated by employing myoelectric control (ref. 15). While this technique shows considerable promise, a much more sophisticated range of outputs must be possible before myoelectric control could be considered for practical application. Within the foreseeable future, the state-of-the-art should advance to the point where movements in several degrees of freedom can be effected simultaneously. The ability to vary the rate of movement may not come for some time yet; and without sufficient knowledge of the effect control dynamics have on manipulator performance, the importance of continuous control relative to discrete rate control cannot be conclusively ascertained.

CONCLUSIONS

Both telechiric and encapsulation approaches to space maintenance appear feasible. Considerable research and development is needed to make either concept practical. In that the situations in which these devices will be employed are associated with systems still in the design stages, consideration might first be given to better definitions of specific mission and task requirements.

Advances in other areas of investigation should be monitored fairly closely. Work being done in rendezvous techniques and myoelectric control are relevant to problems to be overcome in applying remote handling devices to assembly and maintenance tasks in space.

REFERENCES

1. Baker, D. F., Survey of Remote Handling in Space, AMRL Technical Documentary Report 62-100, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, September 1962. (AD 288 863)

2. Belasco, N., Extra-Vehicular Protection During Orbital and Lunar Explorations, Missile and Space Vehicle Department, General Electric Company, T.I.S. 61SD206, 6 December 1961.

3. Bradley, J.V., Glove Characteristics Influencing Control Manipulability, WADC Technical Report 57-389, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, August 1957. (AD 130 836)

4. Clark, John W., "Unmanned Ground Support Equipment," Human Factors of Remote Handling in Advanced Systems (Symposium), 18-19 April 1961, ASD Technical Report 61-430, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, pp. 43-63. (AD 268 656)

5. Clark, John W., "Role of Remote Handling in Space," Survey of Remote Handling in Space, AMRL Technical Documentary Report 62-100, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, September 1962, pp. 27-30. (AD 288 863)

6. Clark, John W., "Telechirics - for Operations in Hostile Environments," Battelle Technical Review, pp. 3-8, October 1963.

7. Goodall, Ray, et al., A Study of an Orbital Maintenance and Material Transfer Shuttle, RTD Technical Documentary Report 63-4057, Research and Technology Division, Wright-Patterson Air Force Base, Ohio, March 1964.

8. Fitts, Paul M., "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement," J. Exper. Psychol., 47, pp. 381-391, June 1954.

9. Kama, W.N., Pope, L.T. and Baker D.F., The Use of Auditory Feedback in Simple Remote Handling Tasks, AMRL Technical Documentary Report 64-46, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, May 1964.

10. Martindale, R.L. and Lowe, W.F., Use of Television for Remote Control: A Preliminary Study, AFSWC Technical Note 58-12, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico, August 1958. (AD 144 536)

11. Murphy, W.W. and Wirta, R.W., The Effects of Visual Feedbacks in Remote Handling, Scranton Operation, Ordnance Department of the Defense Electronics Division, General Electric Company, T.I.S. 63POD35, 31 October 1963.

12. Pigg, L.D., "Human Factors in Remote Handling," Human Factors of Remote Handling in Advanced Systems (Symposium), 18-19 April 1961, ASD Technical Report 61-430, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. (AD 268 656)

13. Sharp, E.D. and Bowen, J.H., An Exploratory Investigation of Wearing Full-Pressure Suits on Control Operation Time, WADD Technical Note 60-90, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, May 1960. (AD 244 889)

14. Sheridan, Thomas B. and Ferrell, W.R., "Remote Manipulative Control with Transmission Delay," IEEE Transactions of the Professional Technical Group on Human Factors in Electronics, Vol HFE-4, No. 1, September 1963.

15. Sullivan, G., Martell, C., Weltman, G., and Pierce, D., Myoelectric Servo Control, ASD Technical Documentary Report 63-70, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, May 1963. (AD 410 898)