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Technical Report - SDC 279-3-7

**EXPERIMENTAL METHODS OF EVALUATING
A SYSTEM: THE AIRBORNE C.I.C.**

New York University SDC Human Engineering Project 20-F-4
Human Engineering Project Contract N6onr-279, T.O. III
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FOR THE SPECIAL DEVICES CENTER

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1.0 SUMMARY

1.1 Purpose

The New York University Human Engineering Project is concerned with the evaluation, from the human engineering point of view, of an airborne Combat Information Center (Cadillac III). The purpose of this report is to describe the nature of the research problem by listing the variables which possibly influence the system's performance, to state some principles for systems research which have been evolved, and to report certain tentative results.

1.2 Source of Information

The data reported were gathered in some 50 orientation runs of the system. The remaining portions of the report are derived from that data, from laboratory experience, and from extensive staff conferences.

1.3 The Structure of the Problem

As the result of an intimate consideration of the research problem, it has been possible to prepare a series of statements which provide a preliminary structure for further study. The following topics, in particular, which are discussed in the body of the report, will illustrate the nature of the structure evolved.

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1.4 Recommendations

It is recommended that the statement of the research problem in its various aspects be carefully examined by cognizant agencies. Suggestions should be conveyed to the NYU group, through the Special Devices Center Human Engineering Division, to ensure that the research results are appropriate to the task.

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2.0 INTRODUCTION

During the course of the development of the airborne Combat Information Center, the Bureau of Aeronautics recognized the need for investigating how the equipment in that Center could be used most efficiently by the crew. As a consequence, the Special Devices Center, Office of Naval Research, was asked to contract for a human engineering study of the airborne Combat Information Center. The New York University College of Engineering was selected to do this work.

This report will discuss the problem of studying an airborne CIC from a human engineering viewpoint. Before an outline of a research program is presented, consideration will be given to what an airborne CIC is and what it is supposed to do, what human engineering is and how it can improve the performance of a system, and what research methods are appropriate for this sort of study.

2.1 The Airborne Combat Information Center and What It Does

The Combat Information Center (CIC) is a space in a ship or aircraft so equipped and manned, so arranged and organized, as to provide for the collection, display, evaluation and dissemination of combat information. It performs the combat control functions assigned to it.

Information is received from various sources such as radar, intelligence reports, radio, radio direction finders (RDF), electronic counter-measure equipment (ECM), sonar, visual look-outs, aerological data, operation orders, and other publications. This information must be sorted and displayed. It must then be analyzed as to its tactical meaning. That requiring action

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must be acted upon; that requiring dissemination must be relayed to the necessary places.

During the latter days of World War II, low-flying Japanese aircraft were able to approach within 20 to 25 miles of our Naval forces without being detected by shipborne radar. To correct this limiting of coverage resulting from radar's line-of-sight characteristics, the radar set itself was sent aloft, and then more and more auxiliary equipment was included. Each succeeding version of the airborne CIC has been developed to provide more potentiality.*

The particular version of the airborne CIC under study is the third--Cadillac III--that system installed in the Lockheed Constellation aircraft designated by the Navy as the PO-1W. It should be noted that the PO-1W is an experimental model. The airframe chosen for the operational Airborne CIC aircraft is the larger version of the Lockheed, Navy designation PO-2W, called commercially the Super-Constellation. Hereafter all references will be to the operational PO-2W.

Certain assumptions regarding the operational use of the PO-2W have been found to be appropriate and can be stated as follows:

2.1.1 Task Group Organization: The nature of the tactical situation facing the combat control system, of which the PO-2W is a part, requires centralized control with decentralized action. This would mean that any air control functions performed by the airborne CIC would have to be explicitly authorized

*For a more detailed discussion of the history and development of the airborne CIC, see Technical Report SDC 279-3-5, "Layout of the Combat Information Center in the PO-2W Aircraft."

either by the provisions of the Operation Order or by the Officer in Tactical Command (OTC), who usually commands the Task Group with which the PO-2W operates, and whose staff prepares the Operation Order. The principle of centralized control requires that the reports made by the airborne CIC go to the OTC, to such places as he directs, or where the Operation Order specifies.

2.1.2 Function: The primary function of the PO-2W, as defined by the Chief of Naval Operations, is that of airborne early warning (AEW). Its secondary function is that of controlling air intercepts. Additional functions may include: anti-submarine warfare (ASW), air control, air-sea rescue coordination, weather reconnaissance, and amphibious landing coordination. In more detail, these functions are:

- 1) Detection. Search, detection, and tracking of targets within an area not covered by the radar of surface ships.
- 2) Evaluation. The evaluation of targets as to friend or foe, air or surface, raid or snoopers, number and type of enemy weapons in each raid.
- 3) Air control. Offensively, this would include such duties as providing friendly bombers with warning of the approach of enemy fighter groups, of acting as navigational director to friendly strike forces, of directing mine laying aircraft to the point of release of their mines. Defensively, it would include control of on-station CAP in the interception of enemy snoopers, vectoring of killer aircraft to submarine contacts, aiding returning strikes and interceptors to effect rendezvous with their home base, and performing "de-lousing" actions.
- 4) Reporting. Giving evaluations of tactical situation to the OTC, reporting detailed positions, courses, speeds, and altitudes of enemy raids to other CICs into whose area raids are going.

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2.1.3 Operating Area: In performing its airborne early warning and "anti-snooper" functions, the PO-2W will have to operate at that distance from the force which will provide adequate early warning and/or snooper protection.*

2.1.4 Communication Links: The primary communication links at such a distance from the force will be MRF or CW radio, or VHF or UHF radio through relay stations. At this distance, and at the present stage of technical development, the use of the PO link to OTC seems unlikely. There very well may be several communication nets: one which links the various PO-2Ws to the OTC, and others which link the PO-2Ws to other CICs. The amount of traffic will crowd these nets so that careful consideration will have to be given to the type and amount of information permitted on the channel.

2.1.5 Command of the Airborne CIC Aircraft: For the airborne CIC to accomplish its stated mission most effectively, the CIC Officer must be in command of the plane while it is on station. If the CIC Officer deems it necessary to change the flight pattern of the plane because of the tactical situation, his decision must govern.

2.1.6 Load Conditions: The load condition to be faced by the Combat Control System is, of course, most difficult to predict. The load condition for a single picket such as the airborne CIC may vary even more. An assumption is made that it may range

*An operational research study on the function of the airborne CIC is in progress under the direction of the Special Devices Center. The published report of this study will indicate the ideal operating conditions for this system.

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between 20 and 50 raids per hour.

2.2 Research Task As Stated in the Contract

New York University has been instructed to conduct research (under the cognizance of the scientific officer assigned by the government) in the following areas:

- (a) Conduct a study of existing and proposed airborne CIC installations for the purpose of (1) ascertaining the most efficient layout of equipment and controls for CIC functions, and (2) investigating the possibility of adding, eliminating, or modifying component equipment of the CIC system for more efficient operation.
- (b) Investigate new techniques in presentation, layout, and operating procedures with particular emphasis on reduction of operator fatigue.
- (c) Make recommendations to the Bureau of Aeronautics via the Special Devices Center of the Office of Naval Research for desirable changes in CIC equipment which can be incorporated in models now or soon to be developed.
- (d) Collaborate with other research and development groups to assist in the submission of a study of an ideal airborne CIC system which is considered capable of development in the next five years.

There were a number of reasons why this task could not be stated in more detail. The rapid rate at which new electronic devices are being developed has many tactical implications for the military organizations, of which the airborne CIC is only a part. Thus there must be constant effort on the part of each element of the larger program to remain flexible to new developments; ultimately the parts must fit together. An appreciation of this situation keeps the contracting agency from restricting the range of the research work.

Equally important has been the fact that because human engineering systems study is relatively new, the precise nature of the results of such study could not be anticipated. The

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contract terms must permit the exploration of both subject matter and techniques; the research task will be defined in part by the effectiveness of the techniques developed by the researchers.

Broadly interpreted, the research goals are two-fold: a) research leading to the best utilization of present equipment (that designed for inclusion in the PO-2W Lockheed Constellation), and b) research leading to the development of future versions of the airborne CIC. The PO-1W, and its associated electronic gear, was intended to be an experimental airborne CIC to be tested operationally and experimentally. The world situation, however, made the need for a production model of the airborne CIC more urgent; it has been necessary to proceed with that design with limited experience.

2.2.1 The Way the Contract Will be Carried Out: Inferences as to the kinds of results that may be expected from this project may be drawn from the following assumptions regarding the relation between New York University and organized agencies:

a) In improving the performance of the CIC system, New York University is to exploit the capacities of the human being by so designing equipment and procedures that operation is adapted to man's abilities. Recommendations for improvement of the system will be made in this order of preference:

- 1) Statement of preferable operating procedures
- ii) Adaptation and modification of present gear, or gear being developed currently, with respect to kind and positioning of controls, design of displays and dials, size and shape of component, and lighting facilities.

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- iii) Suggested development of displays and operator aids to facilitate performance.
- iv) The addition or deletion of machine and/or operator links. The addition of a machine link will be suggested only if it is to be a simple electro-mechanical device.
- v) Suggested development of new electronic equipment only when other methods will not suffice.

b) In comparing alternative evaluations of equipment, doctrine or layout, the present equipment, existing doctrine and the present layout must be one of the arrangements that is tested.

c) It is in the best interest of the Navy that New York University not limit its concept of operating procedures and doctrine to present-day operational thinking in proposing alternative methods of operation. NYU must temper its suggestions, however, by thorough discussion of its ideas with operating personnel.

d) While there are many ways of deriving recommendations to improve the system, the NYU project is limited to those suggestions which it can support by fact.

e) In general NYU conceives its role as a consultant as one in which it is obliged to describe in explicit terms the load-carrying capacity of the airborne CIC under various conditions. For example, New York University will be able to describe the load-carrying capacity of the system when different numbers of consoles are used. The Navy can then determine on the basis of tactical need how many consoles to provide in an airborne CIC. The necessary facts are thus available to determine requirement, compromising the ideal with the practical.

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f) The NYU Human Engineering Project is obliged to draw on basic data which are contained in the professional literature of the various disciplines which it represents and in classified research reports of other government agencies. Coordination with the Special Devices Center Human Engineering Division and its contractors may result in reallocation of research tasks which are more appropriate to the respective contractor's facilities. Fundamental research will be performed only when essential to the progress of the project and when information is not otherwise available.

g) In order that the value of experimental results obtained on this project may be fully realized, NYU should consult with cognizant agencies during planning, design and construction phases of the development program.

2.3 NYU Human Engineering Project Research Facilities

This section will describe the equipment now contained in the NYU Human Engineering Project laboratory. How completely the airborne CIC has been duplicated, the extent of the inputs to the system simulated, and the facilities for observing systems performance will be illustrated.

2.3.1 The Airborne CIC Itself: Figure 1 pictures the laboratory airborne CIC. The following components of the airborne CIC have been installed:

a) One set of the APA-56 (XN-1) equipment which consists of five PPI repeater consoles with associated equipment -- video insertion, recording camera, electronic grid map insertion, and ground stabilization.*

*Ground stabilization is presently being accomplished by a simulator, the APA-57 equipment having been removed for another BuAer project.

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Figure 1 - The CIC portion of the Lockheed P0-2W simulated in the NYU Human Engineering Project laboratory at the Special Devices Center.



b) A simulated APA-56 height finder console made by General Precision Laboratories including the priority and data transmission systems.

c) A Lockheed intercommunications system which includes both that for the CIC and flight crew -- only part of the flight crew facilities are being used.

d) Simulation of the command, liaison, VHF radio transceivers. Four VHF channels are provided.

e) The two PO-2W edge-lighted status boards have been duplicated and mounted. In addition, a visual aids projector developed by the Special Devices Center for other purposes is being used as one experimental display.

f) This equipment has been contained in a hull section on which blowers have been put in an effort to duplicate the air conditioning system of the plane. The lighting in the PO-2W has been duplicated, additional facilities have been provided, however, so that this factor can be varied for experimental purposes. An audio sound generator has been installed to add the realism of engine noise.

2.3.2 The "Radar" Input: In order that there would be a readily controlled "radar" input to the repeater scopes, the Special Devices Center contracted with the General Precision Laboratory for the construction of a target simulator. This simulator provides the relative movement of 24 air, 5 surface, and one stationary target with respect to the plane. (The ground stabilization equipment aboard the plane must then translate this relative movement into a ground-stabilized picture.) Each of the targets can be initially positioned at any point

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on a 480 mile square grid, can be keyed to respond or not respond to IFF, can take any altitude from 0 to 57,000 feet, and can be varied as to brightness. The moving targets, and the PO-2W itself, can be given any course; air targets, and the PO-2W, can be ranged in speed from 100 to 600 knots, the surface targets from 0 to 40 knots. From 20 to 120 knots of wind can be applied to the air targets as a whole. Sea return is also simulated and the radar picture can be "smeared" by the turns of the PO-2W. Figure 2 shows the simulator area manned by the experimenters.

2.3.3 The Officer in Tactical Command (OTC): The Officer in Tactical Command is the person to whom the output of the airborne CIC is directed. A station has been established in the laboratory to represent this element. It has the radio communication facilities that would be provided between the airborne CIC and the OTC. In addition, it has a plotting surface for displaying the information that comes to the OTC.

Actually this is an anomalous position because it is manned by experimenters both for OTC and experimental control purposes. For example, the plotting surface is a VG scope on which the radar input is presented. The OTC would not have such a picture under operating conditions, but that picture is useful in the laboratory for purposes of controlling the experiment being run.

2.3.4 The Experimenters' Tools: The following facilities for observing the systems' performance have been or soon will be installed:



Figure 2 - The experimenters' portion of the NYU Human Engineering Project laboratory showing both the simulator and some of the experimenters' tools.

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a) Six tape recorders with which any verbal communication of the crew can be recorded. Other signals can be imposed on this verbal record for measurement purposes.

b) A motor-driven motion picture camera and special projector for micromotion analysis of the crew's use of equipment.

c) A VG and a VJ radar scope for experimenters' use in observing and controlling the radar input.

d) The recording camera, which is a part of the APA-56 equipment, used by the experimenters in some cases to record the radar picture.

e) Special communications facilities so that experimenters stationed in and out of the CIC can coordinate their efforts.

2.4 Personnel Assigned to the Project

To complete the system, the Navy has assigned a crew to the project. The minimum crew necessary for an operational airborne CIC would be as follows: a CIC Officer, an Assistant CIC Officer, four Air Control Officers, a Navigator, a DRT Operator, an Altitude Determining Radar Operator, a Search Radar Operator, a Radio Operator, an Electronics Counter-Measures Operator, an Electronics Technician, and a Talker. This makes a total of fourteen, not including the Pilot, Co-pilot, and Flight Engineer. It should be emphasized that this number does not allow for the necessary relief of personnel during long operational flights under heavy load. Six experienced CIC officers serve the project as consultants and as crew members; they fill the first four of the tabulated positions. Three enlisted men at present represent the remainder of the crew. Additional enlisted men have been requested.

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New York University has assigned full-time industrial and electronic engineers, experimental psychologists, technical and clerical personnel to the project, and utilizes a number of part-time specialists when necessary, making a total of approximately 25 contractor personnel.

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3.0 THE MEANING OF HUMAN ENGINEERING

After consideration of the airborne CIC and what it is supposed to do, as well as the contract terms and project facilities, the question logically arises: What is human engineering, and how can research in that direction improve the performance of the airborne CIC?

Since the beginning of time man has been devising tools to aid him in obtaining food, shelter, and security. Through the years he has harnessed the energy to power those tools and now only controls them. Where the man of the Stone Age relied on his own strength to shape wood to his needs, modern man only guides the electric saw.

As tools are built that perform more intricate functions, the job of controlling them gets tougher. Guiding an electric saw through a piece of wood, driving a Model T down a country road, and flying a jet fighter plane are control functions of increasing difficulty. Nine times out of ten the piece of wood can be cut properly; perhaps in only one out of ten "passes" can a jet plane shoot down an enemy. More often than not, the failure can be attributed to "improper controlling." Thus, as mechanisms are built to do more complicated tasks, inadequate controlling limits the effectiveness of those mechanisms.*

*One way, of course, to do away with human error is to do away with the man. This attitude is expressed in today's move towards "push-button warfare." It is true that electro-mechanical and electronic devices have been built which perform marvels in controlling, often outdoing the human on comparable tasks. These devices can only perform the function for which they were designed, while man, on the other hand, spontaneously performs control functions that have not been anticipated. Present day planners must not lose sight of the most capable, compact, reliable electro-mechanical gadget of all--man himself, whose full capacities have not yet been determined. But it is necessary to give man, the controller, a break--make it easier for him to control by adapting the machine to human capacities.

3.1 The Nature of Human Control

What is involved in the human control of machines? In general, good control is making the appropriate response to a cue, or stimulus, at the proper time while poor control is either making no response at all, making an erroneous response, or being too slow or too fast with the right response.

Good control requires optimal cue-response associations. These associations will depend upon three things which the psychologist would describe as follows: physiological limitations in man's sensory and motor capacities; motivation, which includes the development, or reinforcement, of optimal associations; and the basic processes of discrimination and generalization of stimuli and differentiation and induction of responses. These terms can best be explained by illustration.

3.1.1 Physiological limitations: Limitations in human sensory capacity must be considered in providing cues. Man cannot hear frequencies above 20,000 cycles per second, for instance, nor can he see objects unless there is some illumination. Also there are limits to the degree to which man can tell the differences between stimuli.

Man's responses are restricted both by his anatomical measurements and by the strength of his various muscles. The fingers can exert less force than the shoulders, for instance, and there are limits for both, not only as to the amount of force which can be exerted but as to how long this force can be applied.

3.1.2 Motivation: Such terms as ambition, morale, anxiety, conscientiousness describe motivating elements of human behavior. Even though the amount of motivation may be difficult to measure, the

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degree of motivation is believed to affect the speed, frequency, and precision of responses. When a particular cue-response association satisfies the dominant motivation, one can say the association has been reinforced. The same response will be more likely to follow this cue when the latter occurs again.

For example, a soldier may make a variety of aiming responses before he hits the target. In subsequent attempts, the successful aiming response will occur more frequently. The acquisition, improvement, and maintenance of this response will depend in part on the soldier's motivation--how eager he is to hit the target. They will also depend on such reinforcement factors as how often the response is successful and how quickly he finds out the results. Not only will motivation and reinforcement have a big hand in determining how quickly this man will learn good control of a mechanism, but they will also have a lot to do with whether such control continues.

3.1.3 Discrimination of Stimuli and Differentiation of Responses:

When a response is learned for a cue, there will be a tendency--perhaps innate, perhaps learned--for the same response to occur for "similar" cues. Suppose an operator has learned to throw a switch to the left when a light above it shows red. He will be inclined to throw a second switch to the left if a similar light should show red. This generalization can lead to unfortunate errors. If the first switch should be turned to the left but the second switch to the right, the tendency to make the same left response might cause an accident.

When a man sets a control knob, there will always be some variation in the way he does it as he tries to find a response that

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is successful--a phenomenon sometimes called response induction. On the other hand, the process of making responses more stereotyped and precise once he has made a successful response may be termed response differentiation. It is the principal component of muscular skill, together with stimulus discrimination. Like the latter, differentiation comes about through differential reinforcement, which in turn depends on motivation.

Such are the things which determine the nature of human control over mechanisms. This discussion, though simplified, does demonstrate that the research scientist can deal with man-machine relationships in much the same framework that psychologists use in describing the rest of human behavior. The human being performs as usual. The machine supplies the cues and transmits the responses. Its successful operation provides the reinforcement responsible for the cue-response associations which comprise good control.

3.2 Human Engineering Research

There are two distinct aspects to human engineering research: the study of components and the study of systems. A component can be defined as a man-machine element; the term system, as used in this report, refers to a particular group of men and machines. The group in question is a team; effective team performance depends, of course, not only upon performance of the components of that team, but also upon maintaining the proper coordination between elements and integrating their individual efforts. Human engineering research until this time has been devoted primarily to component research; the NYU Human Engineering Project is one of the first experimental research projects that has been explicitly directed to the study of a system.

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The effective performance of either a component or a system depends on equipment that is designed to permit the development of optimal cue-response associations. It also depends on the selection of operators who can operate that equipment, and on training them properly. Training involves the establishment of motivation to learn and the reinforcement of optimal associations through reward and/or punishment. Whether an operator continues to perform effectively depends, of course, on maintaining both motivation and reinforcement; this is a function of leadership.

The emphasis in human engineering research is upon the proper design and use of equipment. The selection of operators is a problem for another branch of applied psychology, as is the establishment and operation of training programs. Maintaining operator effectiveness is the job of the leader in the operational situation.

3.2.1 Study of Components: Component study concerns itself with the exploration of man's physiological limitations in sensing and responding. It also deals with man's capacity to discriminate stimuli and to differentiate responses. The type of control problem illustrated in Section 3.1.3 by the example of the switches with similar lights is common in component study and is resolved generally by modifying the equipment or the operating procedure. Training in discrimination provides another answer to the same problem. Redesign is preferable, however, because discrimination training leads to less reliable results. For example sudden increases in motivation such as occur in panic may lead to responses which, through discrimination training, had become subliminal under conditions of normal stress. Thus, in a sudden emergency, even the highly-trained operator might turn the switch the wrong way.

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There are many practical considerations, however, in redesigning equipment to permit the development of optimal cue-response associations. The optimal design cannot always be adopted either because of engineering difficulties or because some standard but inferior design has already been widely adopted. The keys on a typewriter can be arranged in a more efficient way, for example; The Dvorak keyboard is better than the standard keyboard. But millions of typists would have to be retrained to the new keyboard, and millions of typewriters would have to be modified.

The practical result of human engineering study of components--improvement of equipment or procedure--can be done only through proper regard for human engineering principles, technical design and training problems, and economic factors. The human engineer can fulfill his function in component study by considering these factors and participating in the discussions that lead to an appropriate compromise.

3.2.2 Study of systems: The study of a system involves those considerations of component research plus additional factors pertaining to group activity. How the equipment is arranged, what operating procedures are used, what communications facilities are available, and what displays are provided on which to assemble and integrate information are all critical questions with which system study deals.

System study, from the human engineering standpoint, does not concern itself with questions of formal training any more than does component study. However, consideration of motivation and reinforcement factors may become more critical in systems research because of the dynamic interactions involved in group behavior.



For example, the performance of operators gathering information may be seriously affected by the group procedures used. One procedure, by facilitating transmission and display of information, has consequent reinforcing effects on the operators. Another procedure may discourage them by hampering such transmission and display.

For the experimenters, an appreciation of the elements that affect human performance leads to a better understanding of the way a system operates. Interpretation of results may be more adequate, and it may be possible to develop better operating procedures.

System study and component study should proceed concurrently. The design of a mechanism depends on the function required of the component by the system; on the other hand, a system design depends on the full realization of the capacities of its components.

The study of a system poses real difficulties in scientific methodology; these will be discussed in the next section of this report.

3.3 The Professions Contributing to Human Engineering Research

Frank and Lillian Gilbreth were among the first human engineers; through motion analysis they studied the operator's task to make it simpler for him. Since then industrial engineers and methods engineers have improved industrial efficiency with job simplifications. During World War II, the experimental psychologist began to make significant contributions on the same practical value. Physiologists, physicians, psychiatrists, engineers from different areas of specialization, and men from allied fields have all been active in this area. The keynote in human engineering work seems to be inter-disciplinary cooperation.

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It is hard to distinguish between activities of the various professional groups in terms of subject matter. Each of these disciplines is concerned with man and his environment; each group does, however, bring special techniques to bear on the problem.

The industrial engineer's tools are time and motion study and micromotion analysis. He is also familiar with the technical difficulties facing design engineers in other areas of specialization. In addition, he understands manufacturing techniques and production problems. The industrial engineer's special skills equip him to obtain particular kinds of information about operator behavior. He is in a favorable position to help compromise conflicts between the desired and obtainable design.

The experimental psychologist has an appreciation of the intricacies of the human mechanism, its physiological limitations, and the factors which influence human behavior. He has a thorough background in scientific methods, the design of experiments, the analysis of data, and the interpretation of results. Moreover, the psychologist has learned to accept human behavior for what it is, rather than worry about what it should be. By exploring the ways that humans behave in controlling machines and working with each other as a team, the psychologist discovers the facts which permit him to modify conditions so that the desired result is obtained.

4.0 PROBLEMS IN RESEARCH METHODOLOGY

Before turning to a discussion of the particular system under study, the airborne CIC, consideration should be given to one additional matter: research methods for studying systems in general. While each of the issues to be discussed has obviously been met in previous research, there does not seem to be a source which treats the overall methodology problem as it pertains to study of a system. This section is intended to fill that lack.

The fundamental paradigm which structures system research is the familiar-stimulus, organism, and response. The stimulus is complex. The organism, or system, is made up of a number of sub-systems, each of which may be composed of a man and a machine. The response, or system output, is also complex; it can be measured in several ways. Which of these measurements can serve as criteria of system effectiveness is another question.

There are a number of criteria of effective research: that it deal with pertinent problems; that it be objective; and that the results be such that it is possible to predict what might happen under other conditions which are similar. By pertinent is meant that the crucial questions in any research area are found and answered. An objective result is one that has not been biased by the person making the observation. Although this criterion will not be fully met in any observation, an objective answer can be defined as one that can also be found by another experimenter working with different subjects in a different place and at another time. A result should also have general predictive value; it should not be so particular either to laboratory conditions or to specific

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operating conditions that is not generally useful.

Such criteria are fairly easy to state but can be only partially realized at best, and only then by the most painstaking, and well-considered work on the part of the scientist.

These criteria may be useful in distinguishing between applied research, which is the type called for in this contract, and pure research. In applied research, the agency that buys the scientist's services participates in the determination of "pertinency." It would be a mistake, however, if the contracting agency alone contributed to this decision. In that case, the scientist might be called on to administer to the symptom rather than the disease. The full utilization of the scientist's capacity depends on making use of his perspective. Discovering pertinent questions for experimentation in systems research demands mutual understanding and respect on the part of the scientist and the operating man, each for the other.

There is usually an urgency about applied research to which the scientist must be sensitive. This often dictates that he try to answer immediate rather than long-term questions. The scientist and the operating man can resolve this controversy satisfactorily only in terms of particular situations, not in terms of a principle.

Objectivity must sometimes be compromised as well. The experienced applied scientist is willing to make "educated guesses" where his observations provide him with compelling evidence. This is true in proportion to the number of the scientist's colleagues who will agree with him. It must be remembered that without experimental results the scientist has a batting average at predicting

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human behavior only a few points higher, at best, than anyone else. A prediction is not scientific because a man whose profession is science says so, but because it is based on fact.

It is always desirable in applied work to have results that are useful in predicting performance under general rather than specific conditions. Whenever a question can be framed in such a way that the answer will apply not only to an airborne CIC but also to a shipboard CIC and to radar operation at large, much has been gained. If the result has predictive value for another system, yet unborn, it will be that much better. The applied scientist cannot always deal with fundamental questions whose answers have predictive value for many different situations; in order to get quick answers he sometimes has to tackle very specific questions. He would prefer, however, to deal with as fundamental a question as is consistent with the client's need.

The human engineering study of systems of men and machines is largely an uncharted field. It can be understood, therefore, that a human engineer is interested not only in answers to particular questions but also in discovering useful techniques. This is hardly an impractical research product, especially for a contracting agency that will undoubtedly require similar research on other systems.

Research in a new area usually proceeds in several stages. At first the experimenter simply observes the phenomenon he is to study, in this case the performance of the airborne CIC. He knows in general what the airborne CIC is supposed to do, but he doesn't know how different operating procedures will affect system

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performance. Nor does he know how different aspects of the input will affect output. But as he observes, he begins to have ideas of his own about what is happening. At a subsequent stage of investigation, the scientist begins preliminary experimentation by systematically changing what he considers to be input to see what happens. Are there any changes in output? Is there a linear decrement, if any, in a certain output, or is that decrement exponential? What is the general functional relation between aspects of the output and those of the input?

In the same way, he manipulates a system variable to find the relation between that variable and output. In later stages of research, when the crucial variables have been identified and the functional relations among them have been determined, the experimenter may try to get a precise estimate of the parameters of those functions.

It might be pointed out that few areas of human knowledge are considered so unexplored that investigations are proceeding at the preliminary observation level. Research in most areas involves the study of the relations between the important variables which have been identified. Human engineering study of systems is devoted for the most part to the earlier phases of research: the identification of important variables--the structuring of the domain--and the discovery of the functional relation between those variables and output.

As preliminary observation of a system's operation is made, the scientist will begin to list the various factors which he thinks affect system performance. He relies on his observations, on a limited amount of data, and on his previous experience in study-

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ing other phenomena. Once the scientist feels that he has located the principal variables in system operation, he can start to classify them into logical groups. A classification scheme helps to structure the problem and to provide a reference frame for a research program.

The initial listing and classification of variables must, however, be considered as tentative. As study of the system continues, the classification scheme must be re-evaluated. New variables will be added and others dropped. Research in a new area can be productive only if the scientist maintains an open mind about the structure of that field, incorporating into the structure the results of experience gained as the study progresses.

The results obtained from experiments conducted in this framework answer the question: in what different ways can the system be structured or why does the corresponding system performance vary? The experimenter must not, however, lose sight of the question: which system performs best? This means, of course, that the scientist must be concerned with finding criteria of system performance and designing a system that will best meet these criteria.

This is one of the difficulties in systems research--to find the best system while also discovering why that system performs so effectively. While these aims are not completely independent--that is, one cannot meet one without partially meeting the other--the two are difficult to arrive at simultaneously. Both objectives have very practical results: to find which system is perhaps a more immediate problem, while finding why the system performs so is a long-range problem. The airborne CIC is, of course, in a state of development, as is the larger system of which it is a part.

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It is essential to find out enough about the way the system operates so as to be able to design a system which will perform slightly different functions under different conditions. The research results should describe the intricacies of the airborne CIC's operation. The engineer faced with designing a vastly superior airborne CIC should be able to discover from these results where the system requires drastic improvement.

Each of the issues involved in the questions raised in previous pages must be met in studying a system experimentally. It will be noted that considerable human judgment is called for at each succeeding stage of investigation. That is, inferences have been drawn as to how input and output can be measured and what the system variables are. As research progresses, however, there are many points at which the adequacy of those judgments can be checked. If system performance can be predicted with reasonable accuracy in terms of these variables and constructs, these judgments are adequate.

4.1 The Nature of the Stimulus

A scientist is always faced with two problems: discovering the population of stimuli that impinge on the organism he is studying, and sampling from that population in such a way that his results will have general predictive value. It can be recognized that the population of stimulus conditions facing an airborne CIC is hypothetical. It is true that there is a real population of stimulus conditions that have faced CICs in the past. With some practical difficulty, this population could be defined and samples taken from it. This would, in effect,



test the adequacy of the newly developed system to handle a past situation, whereas the research aim is to design a system that will work for future situations. Only the wildest sort of guess can be made about them. Authoritative estimates as to the nature and strength of the attacks that might be expected by this system have, of course, been obtained. In general, the load that is forecast is considerably higher than that which has been experienced by present operational units. Aspects, other than load, distinguish predicted from past operational situations.

There is no need to use a stimulus that represents such a high load that complete and utter confusion will prevail no matter how the present system is changed. Nor is there any profit in using a stimulus that represents such a light load that any arrangement of the present system produces good results.

What is desired is a stimulus load somewhere between these two extremes which yields a "spread" of results. That is, a load condition under which performance of the system differs depending on the system variable used. This stimulus load condition will prove valuable unless, of course, it is much lower than the range of predicted operational loads.

A different range of stimulus load might be required if it was necessary to obtain the load limit that a particular system could handle. Implicit in this discussion of load conditions is the fact that the experimenter must be able to control load conditions. He must either use equivalent loads to test the effectiveness of different systems or be able to compare outputs under different load conditions by balancing out the differences in input.

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In practical terms, it is pointless to develop an airborne CIC which can turn out more information than the control unit of its present system can handle. While this larger system is being studied intensively in its various aspects, such inequalities are tolerable. Some research coordinating agency must, however, recognize the demonstrably weak links in the larger system and take steps to bring the developmental program into line.

4.2 The Nature of the Organism

To develop the best system, or organism, the outputs of many variations of the same basic system are compared under controlled stimulus conditions. But how can this basic system be changed? First, there are behavioral changes that can be made in it; that is, different operating procedures can be used. Second, environmental conditions can be modified--the lighting level, the temperature, noise level, etc. Third, there can be design changes; the equipment can be rearranged, or the content of a display board can be reorganized or coded differently.

The best system is obviously that which has the best form of each system variable; to find the best system, various forms of each variable must be compared. The question immediately arises: How can the effects of these many system variables be explored?

It would be much easier from the experimental point of view to find the best form of one variable by studying it in isolation from the others. But will the best form of each variable--found in separate, isolated experiments--combine into the best system? It would, of course, if its effects were completely independent. That is, the best form of one variable may be dependent on the form of another variable. This possible interdependence of variable can

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best be illustrated by an example. Suppose in one study it is found that so far as talking procedures are concerned selective switching technique is better than a round robin technique. (These terms are more fully explained in Section 6.0 where the system variables are listed.)

Suppose also that the direct reporting procedure is better than the indirect reporting procedure. However, it might be that using a direct reporting procedure in combination with a selective switching talking procedure would be an impossible combination, that these two procedures simply do not work together.

The possible interdependence of variables mitigates against studying the variables one by one. Why not, then, study all reasonable forms of each system variable in one experiment? This would require a very complicated experimental design, and the conduct of this experiment would take a long time. (It would be a case of putting all one's eggs in one basket.) At the very time when the scientist's experience with the system is limited, he would be committing himself to an extensive experiment that would provide no answers at all for perhaps a year or more.

It is suggested that a compromise between these two extremes-- isolated study of each variable and a simultaneous study of all variables--might be used while exploring system operation. But if more than one variable is to be studied at a time, how should one select those variables to be included in any one experiment? In terms of the previous discussion, it would seem that the scientist would study those variables which, in his judgment are interdependent. This is, of course, a very general principle and one that would be hard to implement. To a certain extent,

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each variable will depend on each other variable. It should be possible, however, for the scientists working on the problem to agree on combinations of variables that seem to be very closely related. This judgment should be based on accumulated experience.

It will be noted that as study of a system proceeds there are fewer system variables. During preliminary observation the scientist selects out of all possible variables in human performance only those which seem to have to do with system operation. During exploratory experimentation, the number of important variables is further reduced. The process should lead to a crucial experiment where all the important variables that remain are studied simultaneously. This crucial experiment will be more complicated than the exploratory ones that preceded it. The scientist will, at that point, however, have a good deal of experience with system operation, will have refined his classification of system variables, and will have formulated a series of critical questions which warrant the extensive experiment.

There remains the problem of fixing the constant values of those variables not being manipulated in any study. Although the variables held constant are believed to be independent of those studied, values for them should be found that facilitate stable operation of the system. It is suggested that the experimenter specify for the crew only general operating alternatives. Through the exercise of initiative and resourcefulness, the crew in preliminary runs will find appropriate values for those constant variables.

The crew itself is an important variable in system performance in addition to the behavioral, environmental and design variables.

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Again there is the problem of defining a population, this time of crew members. There is a real population of CIC crew members at present, but the population which would exist under emergency conditions is hypothetical. Many men who are now civilians would become CIC crew members; who they are and what they are like is not known. Adequacy of sampling of operators is not as crucial to human engineering work as it would be to research on selection or training of those men. As a matter of fact what is desired of a crew working under experimental conditions might not be found in a representative sample. The crew member should have CIC background, some scope experience, an interest in the work, and should be able to avoid strong personal preferences for particular ways of operating. The subject should be able to perform to his utmost under any condition that is specified.

The especially proficient operator is not wanted because he has already developed a "style" which he has completely mastered. The crew member on this project is not being trained for a CIC job, but is serving as an experimental subject. He may even turn out to be less capable than a newly trained crew member. The new crew member will have been trained to a particular set of operating procedures while the experimental subject will have been operating in many different ways. The man who has served as an experimental subject will have to unlearn many behaviors that are no longer wanted under operational conditions.

It is important to design system studies in such a way that individual differences in the present crew are balanced out. This involves rotation of the individuals through the various crew positions in some systematic way. At present, it is possible

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to rotate the Naval officers through those positions which are to be filled by officers. The enlisted man complement is not large enough to permit this. A request has been made for additional enlisted men so that this rotation of individuals through jobs will be possible.

The fact that the experimental crew is not a representative sample of the population of future CIC crew members prohibits prediction of the exact parameters of functional relations. This does not prevent the study of the nature of those functions, however. There are a number of other factors inherent in the laboratory situation which prevent the determination of exact parameters; inadequacy of sampling of the crew may be one of the lesser evils in this respect.

4.3 The Nature of Measurement

The first step in measuring output is to consult with operational organizations to find what is expected from the system. Preliminary observations may then be made of system output to see what sort of measurements can be made.

Applied research differs from pure research in part in the matter of the unit of measurement. The molar unit of measurement is required here. A molar unit is comprised of a number of smaller units. For example, there are these time elements in reporting a new raid:

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<u>Element</u>	<u>Description</u>
A	From the time a target gets within range until the radar sweep gets to the azimuth
B	From A until the operator notices it
C	From B until he's sure it's a target and not noise
D	From C until he reads its position
E	From D until he can throw the switch on his ICS
F	From E until he gets his party
G	From F until he finishes his report
H	From G until the Status Board Keeper records it
I	From H until the Talker can notice it
J	From I until the Talker contacts OTC
K	From J until the Talker starts the report

These small elements can be combined into the molar unit: time for a system to detect a new target. A molar unit is one of practical usefulness appropriate to the quality being measured. A man's height, for instance, is measured in feet and inches rather than in thousands of an inch. The ultimate test of the appropriateness of a molar unit is whether predictions can be made using it.

There is another determinant of the size of a unit, and that is the extent of instrumentation necessary to obtain it. To measure some elements in the example cited would be a difficult task. It is necessary in applied work to deal with data which is relatively easy to collect and which is amenable to rapid analysis.

Thus far, the measurement of system output alone has been considered. There is an additional way in which the experimenter insures the value of his study. That is by describing as many of the internal workings of the system as he can. If variation in

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performance of the system cannot be accounted for in terms of the design variables, the experimenter must try to find other reasons. There are a good many aspects of the behavior of the crew members which cannot be specified. While the CIC officer might be instructed to direct most of his attention to a particular display, it is improbable that under the stress of a problem he could look at Display A four times as often as Display B (in carrying out his instructions), without seriously hampering his performance. Activity analysis of individual behavior can be made; records of environmental conditions can be kept. The experimenter can then correlate performance variations with these records to see if there is a strong relation between output and the indicators of internal activity. This procedure provides a continuing check on the appropriateness of the variables that are being used in the experimental design. It will also provide insights of the basis on which additional experiments can be designed.

In problems of measurement it is often necessary to make certain assumptions regarding the nature of errors in order that a rationale for measurement can be developed. This will also be the case in system measurement. Such assumptions involve the randomness of certain errors as contrasted to constant or systematic errors which must be treated separately.

It is necessary to order the resulting data of systems study in such a way that they can be combined with data available from other sources. A laboratory study does not provide information on the performance of the radar gear itself. Nor does it provide data on the detection of pips by the operator working off a true radar picture where noise is distracting. While the target

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generators which represent a CAP do fail, they do not do so with the same probability that an aircraft does. Ultimately, the data on the system must be combined with that of the other links. This can be done only in later stages of the study, but the experimenter must have his results in the form that lends itself to that process.

4.4 Design of System Experiments

The matter of incorporating system variables and crew member differences into experimental design has already been discussed. There are several other factors which also must be considered in designing an experiment. Do certain operating procedures work well under low load but not under high load? The system variables should be tested over a range of stimulus loads. Is there a marked decrement in output with some operating procedures as the system continues to perform? The system should best be tested over a period of time to see whether performance falls off more rapidly with some operating procedures than with others.

There are two factors almost too obvious to mention. Human engineering study is not so much concerned with finding how quickly operating conditions can be learned as with comparing them once they have been mastered. Therefore, sufficient practice in any operating condition is given to bring the crew past the initial learning stage. However, the experimenter should check to see whether performance is stable or whether it continues to improve throughout the experiment. He should also balance out the order in which various operating conditions are used so that differences in performance can be attributed to the procedures themselves rather than to the order of presentation.

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The object of the exploratory experiments is to gather data rapidly on the effects of all the system variables. What sort of experimental design lends itself to this purpose? There are, of course, many experimental designs, each of which has its particular advantages. A factorial design yields the most complete information, including detailed estimates of the interactions between the variables in the design; it is also the most time consuming. The Graeco-Latin square design is less time consuming, but does not provide as much information on the interactions between variables. An incomplete block design is very similar to the Graeco-Latin square design. In it the effects of some of the variables are systematically balanced out. It seems appropriate during exploratory experimentation to utilize either of the latter designs, sacrificing detailed knowledge of the interaction effects to the rapid accumulation of results.

In testing the differences in performance under various operating conditions, the statistical results could be wrong in either of two ways. There could be a real difference in the performance between two conditions which would not be shown as statistically significant. Or there could be no real difference in the two conditions, one of which would be shown to be significantly better than the other. In system study, an effort is being made to find new and better ways of operating. In terms of the purpose of the research, it would be better to infer that one operating procedure was better than another even if it were not, rather than to discard a procedure because it did not appear to give, statistically, a significantly better result when actually it was superior.

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This research attitude has implications for experimental design. The desire to err in the direction of finding differences where there are none, rather than vice versa, indicates that as precise a measure of experimental error as possible must be obtained. This means that data on several runs under the same condition should be obtained and that the error estimate should be reduced by those factors which seem to contribute to a lack of homogeneity.

The need for a final crucial experiment has been indicated. This experiment might take one of several forms. A very rough check on the previous exploratory experiments might be made by comparing only two systems: one which represented the better condition for each variable, and the other which represented the poorer condition. This would provide a quick test of the validity of the general results. It would hardly be conclusive, however. If the difference between the outputs of the two systems were small, it would be almost impossible to isolate the causes.

Another possibility, to which the previous discussions have been pointed, is to conduct a final experiment of a factorial design on the refined list of variables obtained from the exploratory experiments. A tentative comparison of the exploratory results would be helpful for the design of a crucial experiment. This could be done by maintaining a common element throughout the series of exploratory experiments. This common element would be performance of the system under a standard condition, which would have to include both a standard operating condition and a standard stimulus condition. The tabulation of results of the series of experiments would take this form:

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Performance Measures

Experiment Number	Standard Condition	Condition A	Condition B	Condition C	Condition D	Condition E	Condition F	Condition G
1	X _{1s}	X _{1a}						
2	X _{2s}		X _{2b}					
3	X _{3s}			X _{3c}				
4	X _{4s}				X _{4d}			
5	X _{5s}					X _{5e}		
6	X _{6s}						X _{6f}	
7	X _{7s}							X _{7g}
8	X _{8s}		X _{8b}		X _{8d}			

This example is a considerably simplified version of the complicated table that would result. It will be noted that the standard condition is the only one common to all experiments, and that there are many blanks in the table. But, by taking into account the difference between X_{2s} and X_{3s}, the experimenter can get a tentative comparison of performance under Conditions B and C. While this table may not lend itself to a statistical analysis, there are many inferences that can be drawn from it. It provides the experimenter with a much better basis for integrating the results of the exploratory experiments and designing the crucial one. Running the system under a standard condition in each experiment is, of course, the key to this sort of comparison.

There is one final caution that should be given. During the early Thirties an experiment was run at the Hawthorne plant of the Western Electric Company. There the production of a small group was compared under different working conditions. It was found that the fact that this group was given special attention caused production to increase irrespective of what working conditions were used. This has sometimes been called "the

Hawthorne effect." The scientist must be concerned that the improvement of the performance of any system is due to better operating conditions rather than to the improved morale that results from the special attention given to an experimental group..... It may be that the crew will become so highly motivated and so skilled that they can perform almost equally well under the various operating conditions that are tested. This is another reason why the experimenter must obtain precise measures of experimental error so that he can find any differences in the effectiveness of operation procedures that may exist.

4.5 Summary of Methodological Principles

The previous discussion of research methodology can be summarized in the methodological principles which follow:

4.5.1 General:

- a) The basic model for system study is: stimulus, organism, response.
- b) The criteria of effective research are pertinency, objectivity and the "generalize-ability" of the results.
- c) In applied research:
 1. Pertinency is determined in part by the purchaser of the research.
 2. The scientist sometimes has to make "educated guesses" which are a compromise of objectivity.
 3. More often specific rather than general questions must be answered.
 4. Urgency sometimes requires immediate rather than long-term answers.
- d) Because human engineering study of systems of men and machines is a new branch of applied research, the scientist is interested in techniques as well as results.

e) System study proceeds in several stages: the preliminary observations, exploratory experimentation, and a crucial experiment. In general, the functional relations between input and output, and those between system variables and output (over a range of inputs) are found. It may not be possible to discover the exact parameters of these functions.

f) The experimenter must recognize that the aim of system study is to find the best system; he must at the same time try to find out why that system performs as it does so that he may project design for future situations.

4.5.2 Regarding the Stimulus:

a) It is not possible to sample from the hypothetical population of stimulus conditions that will occur in the future. It is sufficient, however, to select a load level which is a reasonable representation of the stimulus complex, so that it produces a range of outputs which will distinguish between the effectiveness of the conditions tested.

b) In order that the effectiveness of several versions of the system can be compared, the stimulus condition must be controlled either by presenting equivalent stimuli or by balancing out the differences in the stimuli by means of the experimental design.

4.5.3 Regarding the Organism:

a) The system itself can be modified by changing behavioral, environmental, or design conditions.

b) As research progresses, the list of system variables must be constantly re-examined. The adequacy of this hypothesized list of variables can be judged in terms of how well system performance can be predicted from it.

c) The interdependence of variables may confound the results. At least two precautions should be observed: take care to study groups of homogeneous variables, and let the system reach a stable operation condition by permitting the crew members to work out the details of general operating procedures in preliminary runs.

d) The population of future CIC crew members is hypothetical. Actually, a representative sample of the true population may not be desirable for experimental work; rather, the crew members should meet these specifications: they should have CIC background and some scope experience, should be sufficiently motivated and able to avoid strong personal preferences for particular ways of operating.

4.5.4 Regarding Measurement:

a) The molar unit is the measure needed in applied research. The molar unit is larger than that used in pure research; it usually has a practical meaning; it is appropriate to the quality being measured; it can readily be obtained and analyzed.

b) It is necessary to measure internal activity and environmental conditions as a check on experimental adequacy. By correlation techniques, the experimenter can explore inductively the causes for variance in performance not otherwise accounted for.

c) The experimenter needs to distinguish between constant and random error on the part of the crew member; he has to make certain assumptions about random error in order to get a measurement rationale.

d) The data on system performance must be so ordered that they can be combined with data on other lines for overall predictive purposes.

4.5.5 Design of System Experiments:

a) Two stages of experimentation are indicated: 1) a series of short exploratory studies of all system variables in homogeneous groups; 2) a crucial experiment in which the critical variables are studied simultaneously.

b) The Graeco-Latin square and incomplete block experimental designs seem appropriate for the first stage of experimentation where the need to accumulate results rapidly justifies the sacrifice of more detailed information. The more extensive factorial design is appropriate for the second stage.

c) A system experiment should take into account in its design these factors: a group of homogeneous system variables, the individual differences in the crew, a range of stimulus loads, the fatigue effect of continued performance, learning effects, and the order of presentation of operational conditions.

d) The nature of system research is such that the experimenter should design his studies to be sure to find any differences in performance that do exist rather than to avoid finding differences that do not exist.

e) The use of a standard condition throughout exploratory experiments will permit tentative integration of performance results; it will also provide a better basis for the design of a crucial experiment.

f) The experimenter should be cautioned about the "Hawthorne effect," the tendency of an experimental group to respond so strongly to special attention that actual differences in the effectiveness of various operations conditions are minimized or lost altogether.

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5.0 THE STIMULUS COMPLEX

It is necessary to classify the elements of the system stimulus as a first step in determining experiment conditions. The detailed description of the anatomy of the organism, or system, and of the response, and how it can be measured, will follow in succeeding sections of this report.

The stimulus complex considered here is that of the exterior stimulus, or the input to the system. There are, of course, internal stimuli that impinge on the system, such as the personalities of the operators, and the continuing process by which the response of a sub-system serves as a stimulus to other sub-systems and to the first sub-system itself. At this stage of research distinguishing the respective feedback phenomena can be neglected for the moment in favor of the response of the system as a whole to exterior stimuli.

5.1 The General Nature of the Stimulus

The general relation of the stimulus complex to system response can be stated as follows:

$$S_{11} = a_{11}x_{11} \quad a_{12}x_{21} \quad a_{13}x_{31} \quad \dots \quad a_{1r}x_{r1} \quad (1)$$

where S_{11} is the response, or performance score, of System 1 to Stimulus 1 which is composed of "r" independent elements. Each term on the right side of the equal sign is made up of two parts: the "a" which represents an independent capacity of System 1 to deal with the corresponding element "x" of Stimulus 1. This equation states that there are "r" separate and distinct qualities of the stimulus, to each of which the system must respond; it also says that a system has "r" corresponding capacities to deal with a stimulus, each of which may vary. The response of System 2



(the same system using different operating conditions) to the same stimulus can be described as follows:

$$S_{21} = a_{21}x_{11} \quad a_{22}x_{21} \quad a_{23}x_{31} \quad \dots \quad a_{2r}x_{r1} \quad (2)$$

Each of the "x's" is the same as in equation (1) because the same stimulus is used. Each of the "a's" is different, however, because there is a different system to deal with that stimulus. The independent capacities of that second system may be different from those of the first.

The actual relation between the stimulus complex and the system response may be a good deal more complicated than the linear equation in r-space. Fortunately, however, this linear equation will approximate the true function. An approximation such as this will be useful at the stage of investigation when actual elements of the stimulus and of the system's capacity are not known.

A set of equations can be written for the response of any system to any stimulus. If enough data are collected, this set of simultaneous equations can be solved to find the number of independent elements of the stimulus, and what they are. It will be more convenient if these simultaneous equations are stated in matrix form.

$$\begin{array}{c}
 \begin{array}{c}
 \text{I} \quad \text{II} \quad \dots \quad r \\
 \begin{array}{|c|}
 \hline
 \begin{array}{cccc}
 1 & a_{11} & a_{12} & \dots & a_{1r} \\
 2 & & & \dots & \\
 3 & & & \dots & \\
 4 & & & \dots & \\
 5 & & & \dots & \\
 6 & & & \dots & \\
 7 & & & \dots & \\
 \vdots & & & \dots & \\
 n & a_{n1} & \dots & (a_{im}) & \dots & a_{nr}
 \end{array}
 \end{array}
 \\
 P
 \end{array}
 \quad
 \begin{array}{c}
 \begin{array}{c}
 1 \quad 2 \quad \dots \quad N \\
 \begin{array}{|c|}
 \hline
 \begin{array}{cccc}
 \text{I} & x_{11} & x_{12} & \dots & x_{1N} \\
 \text{II} & x_{21} & & \dots & \\
 \vdots & \vdots & \vdots & (x_{mj}) & \vdots \\
 r & x_{r1} & \dots & \dots & x_{rN}
 \end{array}
 \end{array}
 \\
 X
 \end{array}
 \quad
 =
 \quad
 \begin{array}{c}
 \begin{array}{c}
 1 \quad 2 \quad \dots \quad N \\
 \begin{array}{|c|}
 \hline
 \begin{array}{cccc}
 1 & s_{11} & s_{12} & \dots & s_{1N} \\
 2 & s_{21} & & \dots & \\
 3 & s_{31} & & \dots & \\
 4 & s_{41} & & \dots & \\
 5 & s_{51} & & \dots & \\
 6 & s_{61} & & \dots & \\
 7 & s_{71} & & \dots & \\
 \vdots & \vdots & \vdots & (s_{ij}) & \vdots \\
 n & s_{n1} & \dots & \dots & s_{nN}
 \end{array}
 \end{array}
 \\
 S
 \end{array}
 \quad (3)
 \end{array}
 \end{array}$$

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This is a shorthand notation for the series of simultaneous equations which indicates the relation between the response of n systems to N stimulus complexes. The general statement of the relation is:

$$S_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + a_{i3}x_{3j} \dots + a_{ir}x_{rj} \quad (4)$$

The relation can be stated more simply as:

$$PF = S \quad (5)$$

The right side of the equation contains the observable results, or the data that are gathered. How can the equation be solved once the performance scores, the S's, are known? These answers can be found by means of factor analysis. The correlation matrix, R_1 , which expresses the correlation coefficients between pairs of systems tested throughout the range of stimuli can be obtained in this way:

$$\frac{1}{N} S S' = R_1 \quad (6)$$

It can be shown that from the reduced correlation matrix, R, the population matrix, P, can be found by factoring and rotating to simple structure. The factor equation to be solved is:

$$F F' = R \quad (7)$$

But why should there be such concern over the theoretical relation between system response and the stimulus complex? The purpose of delineating the elements of the stimulus is, of course, two-fold: 1) to comprehend the actual stimulus thoroughly enough to be able to present an operationally realistic problem; 2) to control the stimulus so that a valid comparison can be made among the different operating conditions of the system. For, unless the stimuli presented to different forms of the system are

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equivalent, or can be scaled against some standard, the better performance of one cannot be established as superior.

If the columns of the P matrix (see formula (3)) were summed, these values would be obtained.

$$\{a_{.1}, \{a_{.2}, \{a_{.3}, \{a_{.4}, \dots \{a_{.r}} \quad (8)$$

By dividing by n, the capacity of the average system in each of the r abilities could be found:

$$\bar{a}_{.1}, \bar{a}_{.2}, \bar{a}_{.3}, \bar{a}_{.4}, \dots \bar{a}_{.r} \quad (9)$$

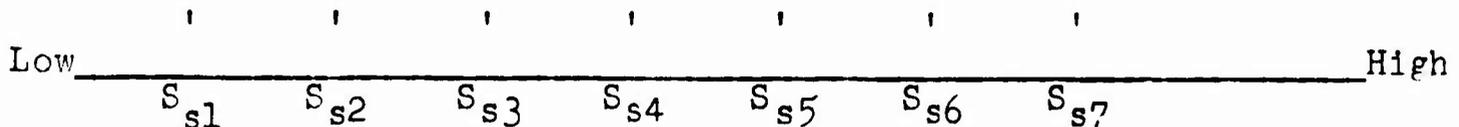
or

$$\bar{a}_{s1}, \bar{a}_{s2}, \bar{a}_{s3}, \bar{a}_{s4}, \dots a_{sr} \quad (10)$$

By using these mean values for each of the abilities, the standard response of the average system could be computed for any stimulus:

$$S_{sj} = a_{s1}x_{1j} + a_{s2}x_{2j} + a_{s3}x_{3j} + \dots + a_{sr}x_{rj} \quad (11)$$

In this way, a number of stimuli could be designed, the standard responses to which would range over a continuum from low to high.



Any system could then be tested against these stimulus conditions. The estimate of the average system's abilities will become more precise, of course, as the number of systems tested increases.

But what could these elements of the stimulus condition be?

One element may be space density,* or the number of continuous

*Another construct similar to space density which has been used is "target minutes." Instead of equating the number of targets on the scope for comparable periods, the number of target minutes can be equated. As its name implies, a target minute is the presence of a target on the scope for one minute. By multiplying the number of minutes each target is on the scope and adding these figures for all targets, the target minute load for a stimulus condition can be found.

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events occurring simultaneously. Another might be time density, or the number of discrete events occurring per unit time.

As a matter of fact, experimental results have indicated that there is a functional relation between time density and output as well as between space density and output. These functional relations prevailed when the performance of individual operators was studied. However, in systems operation there is division of labor which apportions the total load two, three, or four ways insofar as scope watching is concerned. The functional relations between these two aspects of the stimulus and system output might not be consistent under present operating conditions because of the saturation of other links in the system. For example, the physical capacity of the verbal display may be much lower than that of other links in the system. This limitation may garble the data at higher loads so that only after redesign of particular components will it be possible to get consistent data throughout the range of loads.

A problem in dealing with time density needs to be mentioned. Different discrete events take varying amounts of time for the operator to detect. That is, a speed change in a target cannot be read directly off the radar picture, but must be inferred from accumulated scope history. This means that the operator cannot report the occurrence of a speed change as rapidly as the appearance of a new target. The question then arises: should a speed change simulated at Minute 10 be considered a time density element at Minute 10 or at Minute 12--the time at which the operator can first detect such an event?

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The matter of deriving a standard response measure will require the accumulation of much data. What technique should be used in preliminary work to obtain a range of stimulus loads? It is suggested that proportional parts of each hypothesized element of the stimulus be used. For instance, if it is desired to use four different load conditions, 1, 2, 3, and 4, Load 1 to be lighter than 2, 2 lighter than 3, and so on, the stimulus problem could be set up in this fashion:

<u>Load Condition</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
1	5	3	4	2
2	10	6	8	4
3	15	9	12	6
4	20	12	16	8

It would seem that Load 4 is greater than Load 3 and Load 3 is greater than Load 2. Although it is a question whether Load 4 is as much greater than Load 3 as Load 3 is greater than Load 2, this will provide a first approximation. Of course, the design of these stimulus conditions is limited by having to use proportional parts of each element.

It seems that there are two distinguishable aspects of the exterior stimulus to the organism, or system: the scope stimulus, and the verbal stimulus. These two kinds of stimuli will be discussed separately and in more detail in the sections to follow.

5.2 The Scope Stimuli

The scope stimuli are those which are presented to the operators watching the radar displays. They can be categorized into two groups: continuous and discrete stimuli.

5.2.1 Continuous Scope Stimuli: Included in this category are the following:

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- Position
- Course
- Speed
- Altitude
- Composition of raid
- General tactical situation

The first five of these are reportable aspects of one target on a radar scope; the content of the report depends on the moment when it is made. The composition of a raid is judged in terms of "pipology" and the initial range of detection, course, speed, and altitude of the target. In the laboratory, "pipology" is not meaningful because the simulated "pips" are all the same; the remaining aspects of a raid can be used, however, to judge composition. A composition report tells whether the target is surface or air, and in the latter case, how many planes of what type.

The general tactical situation is a continuously developing condition determined by the prevailing relations among the targets on the scope.

The space density, or continuous stimulus, load thus becomes a function of the number of targets on the scope.

5.2.2 Discrete Scope Stimuli: Included in this category are the following:

- New targets
- IFF signals
- Target fades and reappearances
- Course changes
- Speed changes
- Altitude changes
- Loss of target through entering weather area, leaving the area of surveillance, or entering the sea return.

Each of these events occurs at a specific point in time; each is distinguishable from the continuous stimuli in that these

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reports can be compared with the time at which the event actually occurred and are not a function of either the time at which the operator reports or the number of targets on the scope. The position of a target, for instance, will depend on whether the operator is reporting at Minute 10 or 12, whereas the onset of a new target can be reported as of a particular time even if the operator cannot get his report on the channel for several minutes.

5.2.3 Particular Internal Scope Stimuli: Although, in general, consideration of the stimuli is limited to those external inputs to the system, there are several scope stimuli, internal to the system, which are critical to system operation. An example of this is when a target crosses a sector boundary and surveillance of it must be transferred from one operator to another. Problem inputs are so designed to include a number of these occurrences and to keep the number of these events constant from one problem to another. These are continuous rather than discrete stimuli because the process involves both anticipation and follow-through rather than an instantaneous transfer when the target crosses a boundary.

5.3 The Verbal Stimuli

Under this heading come all general stimuli other than the scope stimuli. As with scope stimuli, the verbal stimuli can be classified as either continuous or discrete.

5.3.1 Continuous Verbal Stimuli: The operators in the CIC bring with them a general background on both the enemy and friendly forces derived from training and operational experience. This includes knowledge of the characteristics and capabilities of the enemy's weapons: the speed and service ceilings for the

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enemy's planes, the range at which particular weapons can usually be detected, and their characteristic tactics and disposition. The operator has the same sort of information on his own forces: the characteristics of friendly planes, their usual tactics and disposition. On the basis of these facts, he is able to judge the threat of particular configurations of raids.

An operation order is provided for any military activity. This written order indicates the mission of the airborne CIC, details specific actions to be taken and reports to be made, provides intelligence on enemy activity to be expected, as well as information on the mission, disposition, and strength of friendly forces. All of these verbal stimuli qualify the system's operation.

The continuous verbal stimuli can be considered an element of the space density of the total stimuli to the system. They are not particularly manipulatable in constructing problems of different load. It is true that both the background information and the operation order furnished to the operators can be increased in complexity, but it is extremely difficult to scale this load. In general, the continuous verbal stimuli will be held constant during a particular experiment, although the other elements of load may be varied. The complexity of the continuous verbal stimuli has been gradually increased in succeeding system studies and probably will be further increased in studies to follow.

5.3.2 Discrete Verbal Stimuli: Included in this category are the following:

- Specific requests, instructions, and information from the OTC on the Command radio net
- Specific requests and information from other Combat Information Centers on the Command or liaison radio nets

[REDACTED]

Specific requests and information from friendly forces (other than CAP) on liaison or VHF radio nets
Specific requests and information from CAP (Combat Air Patrol, or the friendly intercepting forces) or VHF radio nets

These discrete verbal events modify the way in which the airborne CIC operates and determine its responses; they are a part of the time density load. Here, of course, the combining of events into a time density score must be most carefully done; it can be readily understood that the performance score in answering a request from higher authority can range over a wide scale. This variable is manipulatable and may be changed within an experimental run.

In considering the effects of these various stimuli on the system, it is important to understand which links of the system a particular kind of event is likely to stress. For the most part, the verbal stimuli are "stressful," at least immediately, for the man charged with integrating the system's operation. The scope stimuli are components of load for the radar operators or Air Control Officers. Ultimately, but within the system, the detailed information from the scope picture must be collected and redisplayed for the use of supervisory and ancillary personnel. It is at this point where internal scope stimuli become important for the effective operation of other links in the system.

5.3.3 Other Discrete Verbal Stimuli: Another group of stimuli is sometimes presented to the system. For instance, the CIC Officer might be informed by an experimenter (on channels other than the radio) that the ACO 4 Console is to be considered to be inoperative. This might be done to simulate equipment failure. Other stimuli of the same sort may be presented to the system for experimental purposes.

6.0 THE SYSTEM VARIABLES

6.1 Techniques of Obtaining the Variables

The nature of the input to the system has been discussed; in this section the anatomy of the system will be considered. The way in which the system responds and how those responses can be measured will follow in Section 7.0.

Some six months of exploratory work went on in the laboratory prior to the specific consideration of system variables. During this time a good many insights were obtained both by the crew members themselves, who had prior CIC experience, and by the experimenters, whose experience both in CIC work and Navy protocol in general was limited. A preliminary listing of the variables served as an agenda for staff conferences devoted to this subject. Over a period of some five days discussions of the operation of the system were carried on in which Naval Officers, experimental psychologists, industrial and electronic engineers participated. These conferences were aimed at a complete consideration of the system and the possible sources of variation in system operation without trying to develop a set of categories into which the variables might fall. Subsequent to these staff conferences the variables were grouped under different headings in an attempt to order the many elements. The listing went through a number of reviews, and its statement in this section of the report represents considerable digestion and integration.

Analysis of the system into its possible variables can be done as a result of experience with the airborne CIC system

[REDACTED]

and with related systems. Actually, the list that follows can scarcely be called experimental variables in the usual sense. It is rather an intimate consideration of the system and how it works. Nor does the listing of experimental variables indicate the way in which answers are to be found. As a matter of fact, experimental work both in military organizations and in fundamental science has provided answers that can be drawn upon. Some of the variables must be studied with complete operation of the system; others in component studies.

The discussions that follow, as mentioned above, indicate sources of variation in system operation without the explicit statement of reasonable alternatives. It is felt that these "reasonable alternative" methods of operation will emerge as experimental work proceeds. In reviewing the list of variables it has been apparent that some procedures are more critical and important for study at this time. It is believed that in approaching the experimental work in this fashion the more critical problems to study will develop one by one together with the logical alternative methods that might be employed. Nor does the listing necessarily imply that there are no available answers to the particular questions--indeed both compelling operational experience and psychological data may indicate the appropriate solution without additional work.

The variables in the airborne CIC can be classified under three general headings:

- (1) Behavioral or procedural variables
- (2) General or environmental conditions under which the system operates (in this category fall problems in criteria of effective operation)
- (3) Design variables

████████████████████

Each of these three general categories is manipulatable to some extent: that is, the operating procedures for the system have not as yet been established, and appropriate manners of working can be recommended: there is freedom to recommend the environmental conditions which should prevail for most effective system operation; and finally there are a good many aspects of the design of the equipment itself and the establishment of the links that should exist in the system which are quite independent of technical issues.

6.2 List and Description of Variables

6.2.1 Behavioral Variables: The behavioral variables can be categorized under several headings:

6.2.1.1 Procedures Governing the Scope Activity of One ACO

Locating Procedure

Grid or polar coordinates

Type of grid

Centered or off-centered scope

Ground stabilization and grid positioning corrections

There are a number of elements contributing to the way in which the ACO orients his scope picture. Should he use a grid or should he use polar coordinates comprised of angle and range marks? If he is to use a rectangular grid, what should be its relative brightness to the radar pips, the width of line, the scale and the numbering technique under the four range conditions with which he may operate? Should he work with his sweep centered or should he offcenter his sweep in order to search particular sectors? Inasmuch as the operator is in a plane which moves very rapidly with respect to the ground, should he work from a radar picture that is ground stabilized? (This facility is provided in the PO-2W and in effect moves the sweep over his scope face.) The navigator has at his disposal controls which enable him to correct the grid position as the result of his navigational fixes. What difficulty does this pose for the radar operator and his tracks? Correction will be disturbing to the tracks, and the question is how can the corrections best be incorporated into the operator's activity, and at what time?

Search Procedure
Optimum illumination

Grid on or off

Scanning habits

During search activities what illumination levels are appropriate for the scope in order to get best contrast in performance? Should the grid (either polar or rectangular) be "on" or "off" during search phases? What scanning habits should the operator adopt?

Estimating Procedure

Plotting tools

Use of desk board

In estimating courses and speeds, what plotting tools and computational aids are necessary? How best can the operator's desk board be used for storing information? In fact, what kind of information is it necessary for the operator to "store"?

6.2.1.2 Between ACOs

Communication

ICS

Video insertion

One aspect of coordination between ACOs is that of communication technique. Should the ICS be used exclusively or does video insertion have a useful function in this procedure? What kinds of information need to be passed or can be best transmitted by each of these means? What ICS procedure best accomplishes inter-ACO communication?

Division of Work

Collective or divided search
Scope division by azimuth or range

Sector size
Scope division by function

Number of scopes

Another question of resolving inter-ACO activity is that of division of work. Should the ACOs divide the radar surveillance area into sectors, or should each ACO search the entire area? If the scope is to be divided into sectors, should that division be by azimuth or range sectors? Should the division of the scope be into equal sized sectors, or sectors determined by extent of activity? Should the work of the ACOs be divided by function rather than by area; that is, should some ACOs only search for new targets while others track the targets that have been detected? How many scopes are necessary in the system in order to achieve the desired performance under various load conditions?

6.2.1.3 Between ACOs and Other Information Sources

Height Finder
Priority

If the ACOs are going to request altitude information from the height finder, which of the two priority systems should be used (automatic or manual)?

Navigator-ground
stabilization

Another source of information for the ACO is the navigator. What coordination is necessary between ACOs and the navigator in the process of correcting the ground-stabilized grid?

Assistant CIC
Officer

Communication-ICS
or Video Link

Target designation

The Assistant CIC Officer's functions include coordinating the activity of the ACOs. In this connection what kinds of information should the Assistant CIC Officer furnish the ACOs? To what extent should he coordinate their efforts? Should he rely on the inter-communication system or the video link for transmitting particular kinds of information? Should the Assistant CIC Officer designate new targets and control initial reports?

6.2.1.4 Between ACOs and Information Destination

Channel

ICS to local
display
Radio to OTC
PO link

In communicating the information which he reads off his scope should the ACO convey it by the ICS to a local display, or should he transmit it by radio directly to the OTC? Or should this information be transmitted by the PO link in part? The question is that of direct vs. indirect reporting.

Procedure
Round robin

Selective
switching

In effecting best communication of information, should the ACOs maintain a "round robin" talking procedure, which means that all the ACOs listen to each other's transmissions at all times, or should each ACO transmit individually, either to the local display or via the radio to OTC, only when cued by someone else in the team? This latter procedure would mean that the ACO would not be burdened with listening to information which might be extraneous to his particular job and would only have to listen on the communication channel when it was his turn to make a report. It would enable him to engage in cross-communication with other ACOs and to perform his various estimates without concerning himself with other information.

6.2.1.5 Height Finder

Methods

Source of Request

ACO
CIC Officer

Local display

The height finder operator has several ways in which he can operate. He can use his scope both as a PPI and as a height finder. He can either survey the entire area, finding altitudes on targets on his own initiative, or respond to requests for information about particular targets. What should be the source for the request for altitude information? Should the ACOs initiate all requests for height information; should the CIC Officer or his Assistant initiate requests, or should the height finder operator find altitudes on the basis of current information which he sees in the local display?

Outlet

ACO

Local display
CIC Officer

Alternative methods of operation of the height finder operator can also be categorized with respect to the outlet of his altitude information. Should he transmit the altitude on a particular target to the ACO requesting it by means of the data transmission system only, or should he give that information to the ACO over the ICS? Should he transmit altitude information to the local display by means of the ICS or to the CIC Officer either by ICS or in other fashions?

Alternative Methods

There are alternative methods by which the height finder actually manipulates his gear. He is cued when requests for information come through the priority system by having the height finder antenna slewed into the azimuth area of the target on which information is desired. A range strobe also appears on his display which indicates the range of the target in question. There are, of course, occasions in which several targets appear in the same area which make it difficult for him to discriminate on the basis of the strobe (which may be somewhat off in range) without additional information from the requestor. Other questions involving method of operation of the same sort probably exist.

6.2.1.6 The CIC Officer

Integration and Liaison

ACOs

Local display

ACICO

Height finder

ECM operator
Radio & radar operators
Pilot & Navigator

The CIC Officer not only supervises and integrates the activity of the Combat Information Center, but is also the one man who performs certain functions. How does he maintain liaison with the members of his team within the plane and integrate their activity? On the basis of information which comes to him from outside sources it may be necessary for him to modify ACOs' reporting procedures. How does he communicate this to the ACOs? Should he use the ICS or should he move next to the man in question and communicate the information orally? Should he insert information on the central display board from which the ACOs will get their cues? What are the appropriate kinds of information to flow between the CIC Officer and his assistant, and what vehicle should be used? Should the CIC Officer administer the height finder priority system, or should that function be delegated to his assistants? What kinds of communication flow between the CIC Officer and ancillary personnel such as the ECM operator, the radio operator, and the radar operator? What kinds of coordinating function prevail between the CIC Officer and the plane crew such as the pilot and the navigator?

Contact with OTC

Evaluation and tactical comment

In maintaining system contact with the OTC, to what extent should the CIC Officer participate? Should he request all information from the OTC? Should he do all evaluation and make all tactical comments? Should these evaluations or tactical comments be made only upon request, or spontaneously as situations develop?

Contact with Others

CAP

Position

At scope

Standing

At desk

To what extent is it necessary for the CIC Officer to supervise intercepts, communicate with CAP, and have immediate physical surveillance of the work of his team members? In order to best serve his functions should the CIC Officer actually work at a radar scope, maintaining tracks, or should he be free to move around? Should he stand where he can watch a radar scope which is being plotted; should he have access to the airborne DRT, verbal displays or geographical plots? Or should he work at a desk where he can best accomplish the paper work that is necessary for carrying out the operation order?

6.2.1.7 Local Displays

Type

Kinds of status board

Geographical plot
DRT

Position

Content

Graphic

Verbal

What types of local displays are necessary, and to whom should they be available? What kinds of verbal displays or status boards are necessary? Should there be several types of status boards--for instance, one with radio calls, one with information on surface targets, one for air targets, one for "hot" information as against more permanent information? Should there be a vertical or a horizontal geographical plot? Will the airborne DRT be sufficient? Of course, it may be that a combination of these display boards is necessary, and it is then important to determine the most advantageous position for each of them.

A question that is very closely correlated with the type of display needed is that of appropriate content. What kinds of information need to be contained in each of the selected displays? In the case of graphic representation, how should the information be coded? In the case of verbal displays, what tabular form is most appropriate?

6.2.1.8 Miscellaneous

Video insertion

Under this "catch all" heading are a number of questions which are not easily classifiable. How is information from sources other than those listed obtained and integrated? How can the video insertion unit be best used procedure-wise, and what kinds of information best

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ECM
Radarman
CW operator

lend themselves to this type of transmission. How are the activities of the 'ECI' operator, the radio man, the radar man, and the electronics technician best integrated into this system? What kinds of information does the CIC Officer need from these crew members, and what kinds of direction do they require from him?

Camera
Information from
other sources

How can the camera unit be best used? How should the PO link be administered, and what types of information can best be passed by this means? How can the incoming PO link from other AEW planes be used? Should the CIC Officer watch this display, and how can he best insert this sort of information into the system's operation?

6.2.2 General or Environmental Variables: The general

variables can be classified into four groups:

- (1) Nature of the Mission
- (2) Environmental Factors
- (3) Personnel
- (4) Contingencies

All of these factors have to do with the milieu within which the system operates. These are the exterior forces that establish the environment.

6.2.2.1 Mission

AEW only
With intercept
Other functions

The PO-2V aircraft can and probably will serve a number of functions in any operational condition. It may serve such functions as AEW, ASW, amphibious landing coordination or air/sea rescue, each separately on one mission or several functions simultaneously within one mission. Each of these missions will influence the kind of output desired from the system.

Information to OTC

Type
Amount

Even when the mission has been established, the precise way in which it is to be carried out will be subject to the desires of the OTC and certain operational conditions. The system will require different procedures, and possibly different links, if it is to furnish large quantities of detailed information rather than periodic general summaries of the situation.

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These questions are at the core of the problem of criterion of effective performance. Reasonable alternative methods of operation can be found only by a consideration of the larger system into which the airborne CIC fits. Operation research methods can help determine what types of information are essential for this element of the entire system to perform.

6.2.2.2 Environmental Factors

Weather

The general flying conditions which prevail will probably substantially affect crew comfort and may under extreme conditions thoroughly disrupt both the physical operation of the equipment and the ability of the human operators to perform.

Illumination

In a CIC different kinds of illumination are required at different points. Perhaps in the past CIC's have erred in the direction of keeping the illumination level too low. The problem here is to reach effective compromises which will permit optimal scope-watching activities while providing sufficient general illumination for other operators to perform their work conveniently and without error.

Noise Engine

The noise level that prevails within the airplane, primarily because of the airplane's engines, effectively reduces the possibility of oral communication without the benefit of earphones. Whether this effect contributes substantially to operator fatigue and ability to perform is an open question. The radio noise, of course, reduces the intelligibility of the communications and may also have the overall effect of inducing operator fatigue and error.

Radio

Temperature

The temperature and humidity prevailing in the work area are very important for operator comfort. Previous studies have indicated that unfavorable temperature and humidity conditions adversely affect operator performance and stamina.

Vibration

Vibration, in contrast to pitch or roll of the plane due to weather, will probably also contribute to operator fatigue.

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Some of these environmental conditions are readily manipulatable, and specifications should be drawn up which will establish optimal working conditions for the operators. Experimental investigations will show the specific amount of performance decrement accruing because of adverse conditions. These data will demonstrate how important it will be to modify existing conditions.

6.2.2.3 Personnel

Motivation

Operational realism

A matter of great concern in any investigation of human behavior is that factor termed motivation. It has been demonstrated both under experimental and operational conditions that an operator who is highly motivated can maintain high efficiency for long periods of time under adverse conditions. Average human beings do remarkable feats which even they did not consider themselves capable of under stress conditions. It is questionable whether any laboratory study can duplicate the high motivation existing under an operational or wartime condition. Of course, operators do not always perform "over their heads"; very good operators sometimes break down completely under stress. The experimenter does not usually have at his disposal any means to vary this factor over a significant range for experimental subjects.

Learning

During any performance an operator learns. Sometimes he shows remarkable improvement from day to day; at other times his effectiveness seems to have reached a "leveling off." In laboratory experiments different operating procedures could be compared as to the ease with which they could be learned by a crew. The other approach which is used in these investigations is to try to orient the crew sufficiently in a particular procedure so that they have reached a "leveling off" in proficiency. This latter procedure provides a comparison of different operating conditions under more stable conditions.

Fatigue

The human operator, of course, gets tired, and as he performs over a period of time his effectiveness is reduced. There are many factors which contribute to fatigue, and a systematic exploration of fatigue against performance can be made.

Rotation

Duty Watches

Any operational condition involves a great deal of boring waiting for something to happen. This substantially affects operator performance. It may be desirable to explore the effect of system performance under conditions where nothing happens for long periods of time. It also may be worthwhile to study how frequently operators should be rotated from job to job under load conditions.

6.2.2.4 Contingencies

Most missions do not run as planned; something always seems to happen. Equipment may fail at a critical time; there may be a human disability resulting from natural conditions or enemy action, or it may be necessary to shift procedures to meet a new threat. Each one of these contingencies is a shock to the smooth-running system and may disrupt operations completely. It will be possible to study in the laboratory the effects of these various contingencies on system operation.

6.2.3 Design Variables: The design variables are those that change the physical aspects of the equipment in the system in accordance with human engineering principles. Also included are those in which links are added to or taken from the system. For example, adding a new display with the personnel necessary to maintain that display would be considered a modification of the systems design.

One of the major questions in the human engineering design of a system is the arrangement of the main items of equipment within the space allowed.

An example of the positioning of subunits within each major station, for instance, is the proper placing of the ICS box at an ACO's station. Another problem is the design of auxiliary equipment such as crew seats. Such an area is termed component study where the operator is considered in

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relation to the dials that he must see and the controls that he must use. The component must be designed to facilitate operator performance.

The link studies are also tied up with the behavioral variable because an operating procedure is necessarily influenced by the links available.

7.0 THE PROBLEM OF MEASUREMENT

In previous sections the nature of the stimulus and the organism have been discussed. In this section the types of response of the system and the ways in which these can be measured will be considered together with ways of describing internal system activity.

The system's output, which will vary with the kind of mission that is performed, could include the following:

- (1) Reports on the command channel which are substantially those to the OTC.
- (2) Reports on the liaison channel to other CICs or friendly forces.
- (3) Reports on the five VHF transmitters (which may be on any of some ten channels) which send information to CAP.
- (4) PO link transmissions to the OTC or to other CICs.
- (5) System actions which cause the flight pattern of the AEW plane itself to be modified.

The problem of measurement will make it necessary to describe the nature of data which can be collected, indicate the kinds of responses that the systems can make, categorize the measures of systems' outputs and review the possible internal measures.

It is important to state that the measures to be used must be efficient. While it may be possible with a great deal of trouble to get very precise measures requiring considerable expense and time to collect and analyze, it is more important to get data in such a fashion and to use measures of such a kind that analysis can proceed very rapidly. It should be emphasized that molar units are needed in applied research.

7.1 Nature of the Data

Although the data which are collected during an experiment can be categorized into (a) those which pertain to output, (b)

██████████
██████████
██████████

those which are checks on input, and (c) those which are checks on how precisely the organism functions according to the experimental design, the measures do have uses for other purposes than those into which they have been classified. In other words, the categories are not mutually exclusive.

(1) The output measures are obtained from tape recordings of activity on the four radio channels mentioned above, and on the flight crew ICS.

(2) The following records are used to check on the input to the system: the tracing paper plot of the radar picture as it appears at the VG, the camera recordings of the radar picture on the APA-56 equipment, and the script followed by the simulator operators.

(3) The way in which the system itself operates can be checked by data gathered from: reports of the crew members following each experiment, tape recordings of the activity of the intercommunication system, and observations of the activity of the various crew members during a problem. This last source of information may be obtained by time-study techniques or micro-motion analyses.

7.2 Responses

The stimuli to the system have been described in detail; the responses that the system can make to the stimuli are equally varied and can be grouped into single and multiple responses.

7.2.1 Single Responses to Stimuli: Included in this category are responses to the discrete scope and verbal stimuli plus those responses to continuous scope and verbal stimuli which, once made, need not be repeated unless there is a change.

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The responses to discrete scope and verbal stimuli include:

- New targets
- Fades and reappearances
- IFF signal
- Change in course
- Change in speed
- Change in altitude
- Motion of target due to entering weather area
- Leaving the area of surveillance
- Entering sea return
- Certain reports specifically requested

Those single responses to continuous scope and verbal stimuli include:

- Initial course on target
- Initial speed
- Initial altitude
- Composition
- Initial vector to CAP
- Turn vector to CAP
- Homing information to CAP
- Certain reports on the tactical situation called for by the Oorder

7.2.2 Multiple Responses to Stimuli: In this group of responses are those made to continuous scope and verbal stimuli as follows:

- Position reports
- Reports to pilot which modify plane track
- Vectors to CAP (other than initial and turn)
- Certain tactical reports called for by the Oorder
- Certain reports established by specific request

7.3 Output Measurements

The system performance can be measured in three ways: by production rate, latency, and accuracy of the output. These three basic aspects of output may vary in importance depending on the mission of the AEW plane. The problem becomes that of determining the relative importance of these three elements in systems output. For example, it may be found that a certain maximal error in accuracy of position reports can be tolerated in certain types of missions--any improvement in accuracy would

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██████████

not improve the performance of the system. It may also be found that the initial vector to a CAP requires the shortest latency but very little accuracy.

Time and space density, together with the time at which the stimulus occurs during a work period, have been suggested as elements of the stimulus load. Besides comparing the system's performance under different operating conditions, it is essential to discover the function between the various outputs and the elements of the stimulus load. It will be noted that a number of measures suggested are so oriented.

7.3.1 Production Measures:

The production rates are perhaps the easiest to measure. The measures listed below become progressively more specific; they are based on a number of reports made per unit of time. This unit of time may be a minute or longer, depending on the homogeneity of the stimulus during the time unit. The time unit should be selected so that the analysis will compare homogeneous units.

7.3.1.1 Total Number of Reports Made by the System per Unit Time

This is a gross measure which may reveal the characteristic response rate for the system over a range of load conditions. That is, the system may continue to make the same number of position reports per minute with a load of six bogies as with 12 bogies, simply making twice as many under the first condition. As a characteristic response rate, it may be both a gross indicator of the effectiveness of a particular configuration for the system and of the effect of continued operation on output.

7.3.1.2 Number of Reports per Channel per Unit Time

The measure of the number of reports made on the command channel, liaison channel, and on the VHF channels, will be much affected by the nature of the mission assigned to the AEW Plane.

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7.3.1.3 Number of Reports per Type per Unit Time

By type is meant those responses itemized in Section 7.2. The bulk of reports will probably be position reports.

7.3.1.4 Number of Reports per Target per Minute

The measures indicated above do not take into account how adequately the system provides reports on all of the targets with which it has to deal. The system could maintain a high output rate and not report the position of Target 1 as frequently as Target 2. This measure is an attempt to see how uniformly each of the targets is reported when no priority on them is used. It may serve as well as an indicator of how effectively any priority system works. The ideal system would adapt itself to report more frequently those targets which represent a greater threat. Whether a significantly higher report return is maintained on the threatening targets can be determined.

Also included are those reports made to CAP. It would be a matter of interest to discover whether the success of an intercept depends on the frequency of vectors to CAP.

7.3.1.5 Transmission rates

This measure proposes to explore the efficient use of radio time. It is, of course, affected both by the amount of "dead" time and the rate at which information is talked. There is some difficulty in determining a useful unit for measuring information, but by measuring dead time or the duration of actual transmissions an estimate can be made of how effectively air time is used. It will allow an estimate of the ideal information load in a period of time, with a later determination of how efficiently any form of the system uses this capacity.

7.3.2 Latency Measures:

Latency is a less available measure. The transcript of the responses of the system is all that is required to get the production data; however, for latency measures it is necessary to have as a reference the time at which the stimulus occurred to find the latency of the response. Three means of providing this reference point have been used:

- 1) A film record of the happenings on the scope face
- 2) The script
- 3) A signal imposed on the tape recording of the system output indicating the time at which the stimulus occurred.

[REDACTED]

The first technique mentioned is the most laborious. The other two have their disadvantages as well, and the value of the respective techniques can be determined finally only from more extensive experience.

7.3.2.1 Latency of Report by Type

There will be substantial differences in the latency of reports as tabulated in Section 7.2. For some latency should be measured from the time of the stimulus; in others the latency should be measured from the time of a previous response. Latency of reports of new targets and loss of targets should be measured from the time of stimulus. The latency of the initial course, speed and altitude reports should more properly be measured from the report of the first appearance of that target.

7.3.2.2 Latency of Report by Target or Group of Targets

This is a finer measure which serves the same purpose as does that in 7.3.1.4 in indicating how well a priority system is providing quicker reports on more threatening targets.

7.3.3 Accuracy:

A criterion of accuracy is even more difficult to establish than that for latency. In any study of performance of mechanisms operated by man, it is difficult to distinguish machine from operator error. Errors themselves can be either of the constant or random type. The random error is a lack of consistency; the constant error is a result consistently at variance from the true. For example, if a rifleman is shooting a tight group into the target but off bull's eye, he can remedy this rather readily. If another rifleman is scattering his shots all over the target, he is faced with more trouble in correcting. The first is an example of a constant error, the second of random error.

Constant errors in the radar gear are probably of greater magnitude than random errors. Experience would indicate that while

[REDACTED]

the simulated target will not necessarily follow the designated course exactly, it will follow a straight-line course. While the operator's performance could have both constant and random errors, the random errors are cause for more concern. As the example illustrates, consistent but inaccurate performance on the part of the operator can usually be modified by training or redesign of equipment, while inconsistent performance is much harder to correct.

By assuming that the bulk of the random errors in performance are the result of the operator, a measure of precision can be obtained by finding the least square fit to the data that he produces. Operator precision can be computed under the different conditions of the experiment by finding the spread of results about the statistically obtained criterion.

Accuracy measures can be divided into two groups: accuracy of fact and adequacy of judgment.

7.3.3.1 Accuracy of Fact

Included in this category are these responses: appearance of new targets, fades and reappearances, IFF signals, initial course, change in course, initial altitude, change in altitude, loss of target, initial vector to CAP, turn to CAP, homing instructions to CAP, all position reports on targets, subsequent vector to CAP. As can be seen from this list, the reports can be compared directly to actual occurrence, which may in some cases have to be estimated.

7.3.3.2 Adequacy of Judgments

Into those categories fall those kinds of actions which can be judged only in terms of their operational adequacy. This would include the determination of proper priority or composition of raids, reporting of targets, tactical evaluations, changes in the AEW plane's course, and commitment of CAP to intercept.

The stimulus does not truly represent an operational situation, and so it is necessary to develop some "rules of the game." For the composition and nature of a raid, there are certain practices which are followed in the

[REDACTED]

simulation of problems which indicate certain kinds of weapons. A comparison of the scope situation with these "rules of the game" should provide the operator some leverage to judge composition and tactical situation. Scaling techniques can be then used to rate such reports. The opinions of persons who are skilled in operational judgments can be systematically combined to evaluate these judgments.

7.4 Internal Measures

The output measures given in Section 7.3 can also be used internally. It is possible to get production rate, latency, accuracy measures of each ACO as well as the same measures for the status board. A comparison of these values with the output will indicate, for instance, the loss at the status board.

It may well be that certain forms of the system will accumulate much more information at the status board than ever becomes a part of the output of the system.

A principle of systems research is for the experimenter to locate sources of variation in output by description of the internal activity of the system. In this way, if the variables of the experimental design do not account for the variation in output, it is possible to check further to try to relate these differences to internal activities. These activities belong to two major groups; the activity on the inter-communication system and the actual motor activity of the crew.

7.4.1 Activity on Inter-Communication System (ICS):

Particular patterns of communication can be related to system output to see whether certain procedures contribute to a more effective performance.

By gathering data as to the number of communications passing between the various crew members, together with distinguishing the initiator of the communication and analyzing the content of these

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messages, several results may be anticipated. First it is possible to check on the formation of preferred patterns between individuals. Many sociological studies have explored the phenomenon of how team members organized themselves for effective communication.

If social patterns affect system performance, they should be located and studied. It should also be possible to discover the accuracy and appropriateness of the communication gear itself. By finding which channels have the higher loadings and which are least frequently used, it should be possible to determine what facilities are required.

Another measure of communication activity would be "cycle time." Under any communication pattern where a group must take turns sending information over a common channel, it would be of interest to find how long a time elapsed between successive uses of the channel by the same individual. There may be a characteristic rate inherent in a particular kind of cycle that could be distinguished. This information would be of value when the experimenter tries to interpret differences in system performance under different operating conditions.

7.4.2 Motor Activity of the Crew:

Into this rather broad category fall time and motion studies of the CIC officer and other key people in the team. An effort should be made to find what sources of information these people use most frequently. In addition to discovering the proper placement of these displays, studying the spontaneous crew behavior of this kind under stress as it relates to the performance measures should help to discover which type of display is the more useful.

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Detailed studies of the motor activity of the individual crew members such as a micromotion study of the Air Control Officers' use of the controls on his console would probably be more indicative for the design of components than for the system design, but may have some value for understanding relations between operators.

8.0 SYSTEM PERFORMANCE DURING PRELIMINARY INVESTIGATIONS

Previous sections have shown that the experimenter simply observes during preliminary investigations. He tries to get a general idea of how the system works. The principal results of introductory studies of the airborne CIC have already been discussed in Sections 5.0, 6.0, and 7.0 which cover the stimulus complex, the system variables and measurement. In addition, these investigations served the purpose of training the crew in the use of new CIC equipment and orienting the researchers to their experimental facilities. The information collected was primarily subjective; however, in the latter phases of the preliminary work, it was possible to gather some objective data.

There were three distinct phases to the preliminary investigations. The first 22 practice sessions, which were run between 7 June and 27 September, 1950, comprise Operation "Art." During "Art" the project's electronic engineers were completing the installation of the laboratory airborne CIC.

Operation "Bold" was run between 29 September and 26 October, 1950; it includes practice sessions 23 through 35.

The nine experimental sessions conducted during the period 8 to 15 January 1951, make up Operation "Candy." "Candy" was, in fact, the preliminary run to the first exploratory experiment, which will, of course, be reported subsequently in a technical report in this series.

8.1 Description of Operational Conditions

Throughout Art, Bold, and Candy an effort was made to explore different ways of operating the system. During this survey, a record was kept of the operating conditions used, the nature of the



stimulus presented, and the kinds of data collected. Tables 1A, 1B, and 1C summarize these facts for the three operations. This information is reported in detail to illustrate the range of conditions explored in the preliminary work.

8.2 Results of Operation Bold

The refinement of experimental controls and the training of both the crew and experimenters during Operation Art permitted the collection of some objective data during Bold. However, even the objective data obtained during Bold and Candy were collected under loosely controlled experimental conditions. These data will serve to indicate only the general range into which system performance falls. It will be possible to infer, for instance, that the number of reports per minute will be in the range of two to eight rather than in the range of 20 to 30. The presentation of these results is in order because they are the first indication of what an airborne CIC can do. These performance records are, as a matter of fact, the first gathered on the operation of any CIC in a laboratory situation.

In reporting the results, the outline of measures described in Paragraph 7.3 will be followed. Only production measures will be reported for Operation Bold, however; instrumentation had not been developed at that time to obtain latency and accuracy measures.

8.2.1 Production During Operation Bold: Two production measures can be reported for the system performance during Bold.

8.2.1.1 Number of Reports per Minute

On the average the airborne CIC produced slightly less than five reports per minute. This measure includes all types of reports and is a gross indicator of the amount of work done by the system. In Figure 3 is shown the average number of reports

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total
1	X	X														X	X	X	X				6
2		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X					14
3					X		X	X	X	X	X	X	X	X	X				X	X			12
4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X		18
5	X	X	X							X													4
6																				X			1
7																							0
8	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X		X	X		18
9															X								1
10													X	X					X				3
11	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X						15
12				X					X		X							X	X				5
13																			X				1
14																							0
15	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		21
16																					X		1
17	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X			13
18	X	X	X		X			X	X	X	X					X			X				9
19									X	X	X	X	X	X	X	X	X	X	X	X	X		12
20A	A	A	A	A	A				A	A													8
B						B					B								B				3
C							C					C											2
D																							0
E								E					E							E			3
F									F				F								F		3
21A									A				A										2
B	B	B	B	B	B				B	B													8
C						C					C									C	C		4
D																							0
E								E					E							E			3
F									F				F										2
22	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	20
23																				X			1
24		X	X	X						X	X	X	X	X	X	X	X	X	X	X	X	X	14
25						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
26															X	X	X	X					4
27	X	X	X	X	X																	X	6
28					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
29					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	17
30																							0
31																							0
32															X	X	X	X					4
33																							0
34	X	X	X	X	X	X	X	X	X	X													11
35		X	X						X	X	X	X	X	X	X	X	X	X	X	X	X	X	13
36																							0
37	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	22
38																							0

Table IA
Description of Conditions
For Operation Art

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	23	24	25	26	27	28	29	30	31	32	33	34	35	Total
1	X		X	X	X	X		X	X	X	X		X	10
2	X	X		X	X		X	X	X	X	X	X	X	11
3	X	X	X	X	X	X	X	X	X	X	X	X	X	13
4	X	X	X	X	X	X	X	X	X	X	X	X		12
5			X			X								2
6								X	X			X	X	4
7														0
8		X			X	X			X		X		X	6
9	X													1
10			X	X			X	X		X		X		6
11										X				1
12	X	X	X	X	X	X	X				X		X	9
13								X		X		X		3
14														0
15														0
16	X	X	X	X	X	X	X	X	X	X	X	X	X	13
17	X	X		X		X			X		X		X	7
18			X		X		X	X		X		X		6
19	X	X	X	X	X	X	X	X	X	X	X	X	X	13
20A														0
B	B								B				B	3
C								C						1
D			D		D	D	D				D			5
E		E								E				2
F				F								F		2
21A			A		A									2
B														0
C						C				C				2
D				D					D			D		3
E							E	E						2
F	F										F		F	3
22	X	X	X	X		X	X	X	X	X	X	X		11
23					X									1
24	X	X	X	X	X			X	X	X			X	9
25	X	X	X			X	X	X	X	X	X	X	X	11
26				X	X						X	X		4
27		X	X	X		X	X		X	X				7
28	X				X			X			X	X	X	6
29	X							X	X	X	X	X		7
30		X				X	X							3
31			X											1
32											X	X		2
33				X	X									2
34														0
35	X	X	X	X	X			X	X	X			X	9
36						X	X				X	X		4
37	X	X	X	X	X			X			X	X	X	9
38						X	X		X	X				4

Table IB
Description of Conditions
For Operation Bold

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	1	2	3	4	5	6	7	8	9	Total	Grand Total		
1	X	X	X	X	X	X	X	X	X	9	25	Script	
2	X	X	X	X	X	X	X	X	X	9	34	VG plot	
3	X	X	X	X	X	X	X	X	X	9	34	Recording of OTC	AVAILABLE
4										0	30	Crew comments	DATA
5	X	X	X	X	X	X	X	X	X	9	15	Other data	
6	X	X	X	X	X	X	X	X	X	9	14	Sea return used	OTHER
7										0	0	Plane movement	CONDITIONS
8										0	24	30 min. or less	
9	X	X	X	X	X	X	X	X	X	9	11	30-60 minutes	LENGTH OF
10										0	9	60 min. or more	SESSION
11										0	16	Less than 15	
12	X	X	X	X	X	X	X	X	X	9	23	16-25	NUMBER OF
13										0	4	26-35	TARGETS USED
14										0	0	More than 35	IN PROBLEM
15										0	21	Sound Phones	COMMUNICATION
16	X	X	X	X	X	X	X	X	X	9	23	ICS	FACILITIES
17	X		X		X		X		X	4	24	A.M.	TIME OF
18		X		X	X		X		X	5	20	P.M.	SESSION
19	X	X	X	X	X	X	X	X	X	9	34	Rectangular Grid Used	
20A	A			A						2	10	A	
B		B	B							2	8	B	WHO SERVED
C					C				C	2	5	C	AS C.I.C.
D						D				1	6	D	OFFICER
E							E			1	6	E	
F								F		1	6	F	
21A			A							1	5	A	
B						B	B			2	10	B	WHO SERVED
C				C						1	7	C	AS ASSISTANT
D		D			D					2	5	D	C.I.C. OF-
E	E							E		2	7	E	FICER
F									F	1	6	F	
22										0	31	3 ACO's	HOW MANY
23	X	X	X	X	X	X	X	X	X	9	11	4 ACO's	WERE USED
24		X	X		X	X	X			5	28	Talker Used	ADDITIONAL
25	X	X	X	X	X	X	X	X	X	9	36	Stat. Bd. Keeper	CREW
26										0	8	Plotter Used	MEMBERS
27										0	13	At Scope	POSITION OF
28	X	X	X	X	X	X	X	X	X	9	31	Not at Scope	CIC OFFICERS
29	X	X	X	X	X	X	X	X	X	9	33	Visual Aid Proj.	STATUS
30										0	3	PO-1W Board	BOARD
31										0	1	Table	USED
32										0	6	Table	GEOGRAPHICAL
33										0	2	Paper Plot	PLOT USED
34										0	11	CICO Alone	WHO REPORTED
35	X	X		X			X	X		5	27	CICO and Talker	TO THE OTC
36			X		X	X			X	4	8	ACO's	
37	X						X	X	X	4	35	Round Robin	TALKING PRO-
38		X	X	X	X	X				5	9	Selective Switching	CEDURE

Table IC
Description of Conditions
For Operation Candy



made, minute by minute, during Bold. Both the actual data, and a "smoothed" curve are shown. There is irregularity in production from minute to minute, and no pattern emerges. In the first ten minutes of any session the stimulus load was being built up, accounting for the low production at that time.

8.2.1.2 Number of Reports per Target per Minute

Actually, the inverse of the number of reports per target per minute is used for convenience in computation; that is, the time between successive reports on the same target. Table 2 shows the average time between successive reports on the same target for nine of the 13 sessions of Bold; the results from the remaining sessions could not be used because of the manner in which performance was recorded. For example, in Practice Session 23 an average time between successive reports was found for each of 12 targets. A mean of 2.71 minutes and a standard deviation of 1.44 minutes for these 12 values was then found. Table 2 shows the number of targets upon which the reported mean and standard deviation for each session was based. This means that if a position report is given on Target 7 at time 10, another position report on that target will not be forthcoming until almost Time 13.

TABLE 2

AVERAGE TIME BETWEEN SUCCESSIVE REPORTS ON SAME TARGET (BOLD) (IN MINUTES)

Practice Session	Mean Time Between Successive Reports	Number of Targets Used	Standard Deviation of Values for Each Target About Mean Value for Session
23	2.71	12	1.44
24	6.37	11	3.30
25	2.25	14	3.19
26	4.35	8	1.29
27	4.55	3	1.22
30	3.23	18	1.20
32	2.58	16	.92
33	3.27	12	.89
35	2.03	11	.58

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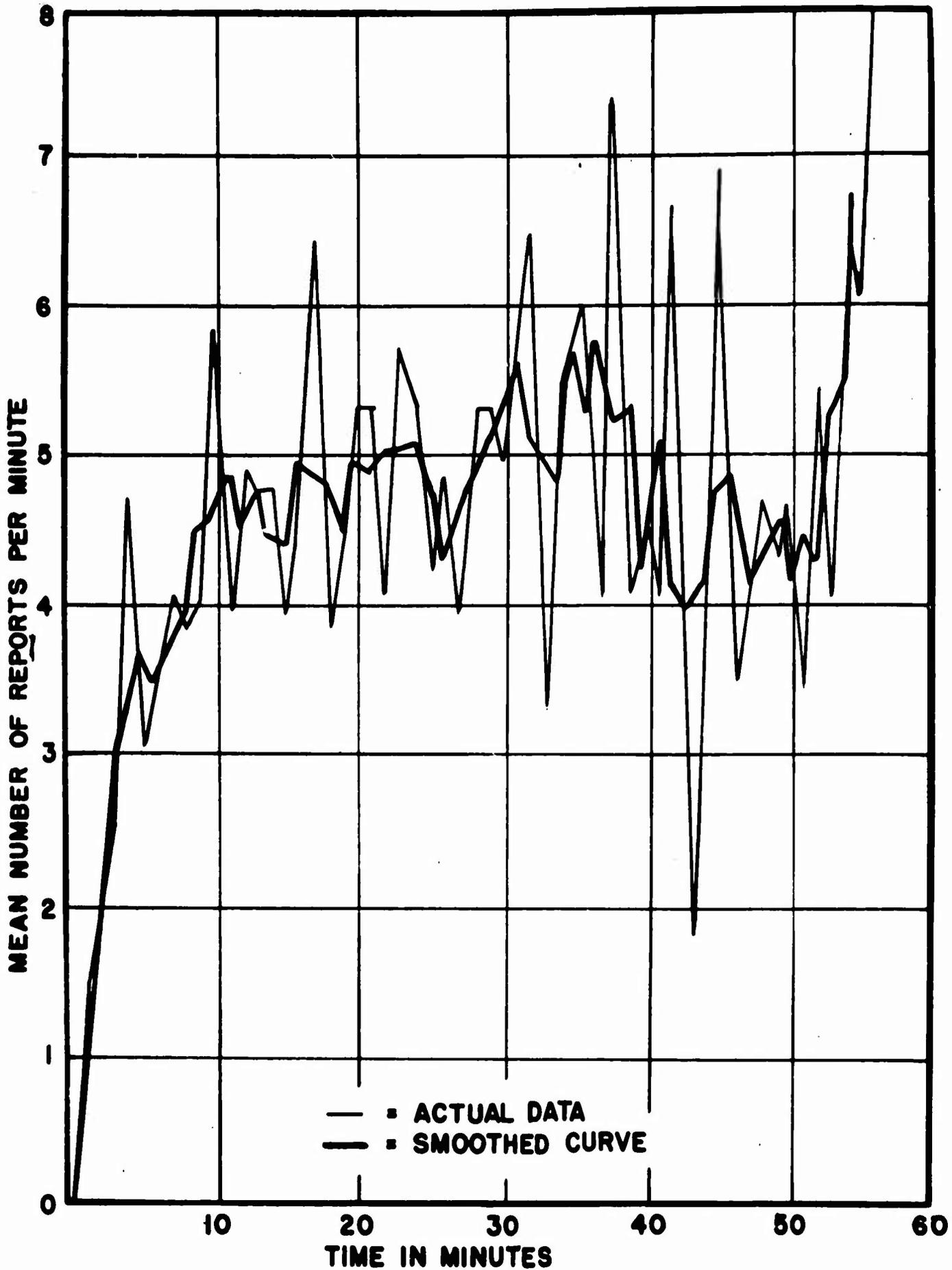


FIGURE 3. AVERAGE NUMBER OF REPORTS, MINUTE BY MINUTE FOR OPERATION BOLD.

[REDACTED]

The average value for the nine means in Table 2 is 3.48 minutes; the standard deviation is 1.31 minutes. The average time between succeeding reports is a more refined measure than the number of reports/minute shown in Figure 3. The consistency with which the targets in any stimulus are handled is shown by the standard deviation in Session 35, for example, where the standard deviation is .58 minute. The system is reporting on one of the 11 targets as often as it reports on another. In Session 25, however, where the standard deviation is 3.30, the system is not producing the same number of reports on one target as consistently as on another. The data also indicate that there is considerable improvement in the system's production throughout Bold. There is less lag between successive reports as the investigations continued, possibly because of the experience that the crew was gaining.

8.3 Results of Operation Candy

Candy was a preliminary run of a system study designed to compare the effectiveness of four different operating procedures. These procedures are designated Ant, Bat, Card, or Dove. Further identification of the operating conditions is not necessary because valid comparisons cannot be made on the basis of these data. Candy served its purpose by clarifying the issues which were then subjected to experimental study in Operation Dandy, to be reported later.

It is possible to report more extensive results of Candy in all three categories of measurement: production, latency and accuracy.

8.3.1 Production During Candy: These production measures will be reported: number of reports per minute; average time between successive reports on the same target, the average time to transmit a position report.

8.3.1.1 Number of Reports Per Minute

Table 3 shows the number of reports made by the system during eight of the nine sessions (laboratory difficulties occurred during the first run in the series so that those results are not given). Position reports, course and speed reports, number of composition or evaluative reports, together with the total number of reports, are tabulated for each run.

TABLE 3

NUMBER OF REPORTS MADE BY THE SYSTEM PER MINUTE

Kind of Report	Condition Ant		Condition Bat		Condition Card		Condition Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Position	3.7	3.2	3.0	3.2	4.0	3.5	4.1	4.7
Course and Speed	.5	.5	.4	.4	.5	.3	.4	.5
Evaluative	.5	.2	.2	.4	.2	.3	.2	.3
Total	4.6	4.0	3.7	4.1	4.7	4.1	4.8	5.4

It will be noted that the data in this table compares to that contained in Figure 3. About 83% of the total reports are position reports, another 10% of the total are course and speed reports, while the remaining 6% are evaluative reports.

8.3.1.2 Average Time Between Successive Reports on Same Target

The same measure as reported in Table 2 with regard to Operation Bold was calculated for Candy. Those data are contained in Table 4. In each case, the mean and standard deviation is based upon the average values obtained for each of five targets.

TABLE 4

AVERAGE TIME BETWEEN SUCCESSIVE REPORTS ON SAME TARGET

Statistic	(CANDY) (IN MINUTES)		Condition		Condition		Condition	
	Ant		Bat		Card		Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Mean Time Between Successive Reports	4.74	2.66	2.47	1.90	2.13	2.57	2.35	2.12
Standard Deviation	1.29	.12	.51	.55	.21	.30	.47	.16

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System performance during Candy seems to be better than that during Bold. This is, of course, to be expected. Both the means and standard deviations are lower than in Table 2, which indicates improvement.

8.3.1.3 Average Time to Transmit Position Report

This measure is one indicator of transmission rate. There are many difficulties in trying to get a precise measure of verbal activities over such a short period of time. The values for the mean time to transmit one position report, the standard deviation and the number of measures upon which those statistics were based are tabulated for eight runs in Table 5.

TABLE 5
AVERAGE TIME TO TRANSMIT A POSITION REPORT
(IN SECONDS)

Statistic	Condition Ant		Condition Bat		Condition Card		Condition Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
No. of Observations on which statistic is based	21	36	17	7	80	33	28	23
Average Time	6.5	6.9	5.5	6.3	6.8	8.5	7.0	8.0
Standard Deviation	2.26	1.99	2.85	*	2.11	3.26	1.94	2.93

*N too small to compute meaningful standard deviation

8.3.2 Latency Measures During Candy: These latency measures will be reported: latency in detection of new bogeys, and latency in detecting courses and speeds on new targets.

8.3.2.1 Latency in Detecting New Targets

Table 6 shows how long it takes the system to detect a new target. The mean and standard deviations of this detection time are based, in each case, upon ten detections.

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TABLE 6
TIME NECESSARY FOR THE SYSTEM TO DETECT A NEW TARGET
(IN MINUTES)

Statistic	Condition Ant		Condition Bat		Condition Card		Condition Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Mean latency for detecting 10 targets	3.30	1.02	1.90	1.70	1.06	1.17	1.48	1.56
Standard deviation	1.76	.53	.80	1.13	.56	.62	1.04	.86

8.3.2.2 Latency in Reporting Courses and Speeds

This latency measure indicates how long it takes after the initial detection of a bogey before a course and speed on that target is produced. In each run the latency figures reported in Table 7 is based upon performance with four targets.

TABLE 7
TIME NECESSARY FOR THE SYSTEM TO REPORT COURSE AND SPEED AFTER
DETECTION OF NEW TARGET
(IN MINUTES)

Statistic	Condition Ant		Condition Bat		Condition Card		Condition Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Average Time	17.1	1.4	3.1	1.3	>19.0	5.1	>5.2	4.5

There is considerable variance in system performance so far as this measure is concerned. Where the sign ">" is used, the average time is somewhat greater than the value quoted; this is occasioned by the fact that the system did not produce course and speed on one of the four targets during the time that recordings were made. Some procedure is indicated to insure that courses and speeds on all targets are produced.

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8.3.3 Accuracy Measures during Candy: The following accuracy measures will be reported: accuracy of position reports and accuracy of course reports.

8.3.3.1 Accuracy of Position Reports

This measure was obtained by first plotting, for each run, the position reports on five targets. Because each of these targets proceeded in a straight line, it was possible to lay a transparent strip along the plotted positions for any one target. This strip was cut to be five miles wide according to the scale of the plot; it was put down to include as many points under it as possible. The reported positions lying outside this range were counted as bad reports. Actually, under operational conditions, a track determined by positions falling within a ten-mile strip, for instance, might still be considered "good." The five-mile limit was set arbitrarily in order to get an indication of the per cent of "bad" reports; these are contained in Table 8.

TABLE 8
PER CENT OF BAD POSITION REPORTS

	Condition Ant		Condition Bat		Condition Card		Condition Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Per cent of "bad" position reports	27	35	28	24	32	21	30	31

There is considerable question about the appropriateness of this measure. Different techniques for describing the accuracy of position reports will be explored in future studies.

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8.3.3.2 Accuracy of Course Reports

In order to get an estimate of the accuracy of course reports, it was necessary to find a criterion against which to compare the reported course. This was done by recording the course represented by the transparent strip which was placed to find the number of "bad" reports. The criterion course was an average fit to the position reports produced. The differences between the reported courses and the criterion courses were tabulated for five targets in each run. The average errors are tabulated in Table 9.

TABLE 9

COURSE ERRORS (IN DEGREES)

	Condition		Condition		Condition		Condition	
	Ant		Bat		Card		Dove	
	Run 7	Run 2	Run 5	Run 6	Run 3	Run 8	Run 4	Run 9
Course of Error	10	(1)	42(2)	16	13	5	17	43(2)

- (1) Errors not reported because of transcription difficulties.
- (2) Large average error caused by a report on one target, in each case, being 180 degrees wrong, or a gross error.

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