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THE METHODOLOGY OF CONTROL PANEL DESIGN

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BUNKER-RAMO CORPORATION

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AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
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FOREWORD

This research was conducted in support of Project 8119, "Checkout and Hazard Control Techniques," which is directed by the Support Techniques Branch (Robert D. Sherrill, Project Engineer) of the Air Force Aero Propulsion Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio.

This study was initiated by the Performance Requirements Branch, Human Engineering Division, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, under Project 7184, "Human Performance in Advanced Systems," Task 718404, "Advanced Systems Human Engineering Design Criteria." The research was accomplished by the Systems Effectiveness Department, Bunker-Ramo Corporation, Canoga Park, California, under Contract No. AF 33(615)-1350. Dr. David Meister was principal investigator, assisted by Mr. Donald Farr. Mr. Steve Heckart of the Performance Requirements Branch of the Behavioral Sciences Laboratory was the contract monitor for the Aerospace Medical Research Laboratories. The research sponsored by this contract was started on 1 February 1964 and was completed on 30 April 1965.

This technical report has been reviewed and is approved.

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ABSTRACT

Nine control panel drawings were developed by designers using standard design criteria from a designer's guide. The drawings were then evaluated by five experts representing the disciplines of human factors, industrial design, maintainability and reliability engineering. Sample panels were mocked up and subjects were tested in operational use of these panels. The major results of the overall study were that (1) Designers manifest a high degree of variability in developing control panel drawings even when presented with a standard package of design information; (2) human engineering design criteria appear to be significant only in relation to anticipated operator performance characteristics, and difficulties in applying these criteria stem from lack of empirical knowledge of these relationships; (3) a major source of difficulty in securing the application of human engineering design criteria by designers is the latters' lack of a system-behavioral approach to design. The major need in the control panel design area is empirical research to refine and standardize simple and quickly applied evaluation techniques. More information is needed concerning the manner in which designers utilize human factors and other design inputs.

TABLE OF CONTENTS

PAGE

PART I. THE PROBLEM OF CONTROL PANEL DESIGN 1
PART II. THE SYSTEM CONCEPT IN CONTROL PANEL DESIGN 14
PART III. EMPIRICAL STUDIES OF CONTROL PANEL DESIGN AND EVALUATION 21
PART IV. RECOMMENDED RESEARCH 45

APPENDIX I. Factors Affecting Control Panel Design, Development and Operation 49
APPENDIX II. Instructions for Design Task 53
APPENDIX III. Control/Display Requirements 55
APPENDIX IV. Design Summary 61
APPENDIX V. Design Implications 62
APPENDIX VI. AGE Panel Evaluation Ranking Scale 64
APPENDIX VII. AGE Panel Evaluation Rating Scale 65
APPENDIX VIII. AGE Panel Evaluation Checklist 66

REFERENCES 69

PART I

THE PROBLEM OF CONTROL PANEL DESIGN

Despite 20 years of formal human engineering practice[1] which has involved the writing of human engineering specifications (United States Air Force, 1963, 1964a, b), as well as books (Javitz, 1956, McCormick, 1964, Morgan et al., 1963, Woodson and Conover, 1964) and popularized accounts of human engineering principles (Bradley, 1957, Celent, 1960, Pape, 1958, Peters and Michelson, 1959, Williams, 1960), many control panels for operation of both airborne and ground equipment contain characteristics that reduce their operating effectiveness. Typical of many deficiencies are:

(1) Controls and displays are not organized on the basis of operating procedures, even when these procedures are available.

(2) Unnecessary controls are included on the control panel purely for aesthetic purposes.

(3) Controls and displays associated on the basis of operating requirements are arbitrarily separated from each other.

(4) Maintenance controls and displays, which should be separated from operating hardware, are mixed with the latter.

(5) The anthropometric limitations of the operator are not considered in the placement of controls and displays.

(6) Controls and displays are not standardized between associated consoles.

(7) Nomenclature is often too abbreviated, too cryptic, and not descriptive of the functions performed by controls and displays.

Each of the dozens of checklist items which are included in the most comprehensive military standards on human engineering criteria (MIL-STD-803A-1 and -2, United States Air Force, 1964a, b) and which have been commonly used as criteria of adequate control/display arrangement will be, predictably, violated many times during future system development.

The engineering psychologist is aware of the potential[2] significance of these design defects for inadequate operation of the panel. In this respect, we find few essential differences between airborne and aerospace ground equipment (AGE) control panels. AGE control panels have often been "tail-end Charlies" in terms of the attention paid to them; but the human engineering principles applied to airborne equipment usually apply equally to AGE, except perhaps for the somewhat more restricted work space and response-time constraints imposed on airborne equipment.

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[1] From 1945, arbitrarily taken as the birthdate of human engineering as a formal discipline.

CAUSES OF DESIGN DEFICIENCIES

What has gone wrong? Why does so commonplace a problem to which so many human engineers have addressed themselves, still exist? Two factors are primarily responsible for the continued design of deficient control panels:

(1) The lack of operationally applicable human engineering criteria. Although detailed human engineering criteria exist in great abundance, they are difficult to apply in the course of actually developing a control panel.

Available human engineering design criteria are essentially "attribute" criteria; that is, they often describe static characteristics which the end product should have, but do not describe how one can dynamically include them in the design process.

Human engineering criteria also display a range of detail. At one level, they are relatively broad, abstract generalizations, such as the suggestion to arrange control and displays on the basis of functional grouping. At another level of detail, they represent a relationship of quantitative points along two or more continua, as, for example, a graph relating speech interference levels with various distances and voice levels. At still another level of detail, we find prescriptive statements such as, "The minimum separation between adjacent edges of pushbuttons shall be...."

Two things are immediately apparent, one of which follows from the other. First, even when quantified values are presented, as in the aforementioned graph, the choice of the particular value to be applied to an individual design problem is left to the designer or his human factors advisor, except perhaps for certain nontolerable extreme values (e.g., toxic ranges). Secondly, there is a degree of permissiveness about these criteria, often demonstrated by qualifying phrases such as, "wherever possible." The designer must be allowed a certain freedom of choice if these criteria are to apply to more than a restricted range of design situations, but the inevitable consequence is that the designer and the human engineer must select from among the various design values made available to them.

(2) A second factor producing design deficiencies is the failure of some designers to approach control panel design with what has been termed "the system approach" (Christensen, 1962), i.e., the recognition that a multitude of factors potentially affect the design and operation of the control panel. The system viewpoint is particularly necessary in control panel design because the panel is a model of the operator's behavioral processes, with all of the potential variability implied in these processes.

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[a] We say "potential" because the dearth of well-documented experimental studies of the effects of control panel deficiencies on operation does not permit determination of accurate error rates resulting from individual defects. It is difficult to get satisfactory error rate measures in laboratory tests of control panel operation because many operating cycles are required before sufficient errors are made to provide reliable quantitative estimates. Moreover, the operator's ability to adjust to and compensate for obvious control panel deficiencies produces a lower error rate than one might logically expect. Nevertheless, both logic and development experience suggest that when procedures are performed incorrectly, these errors can be traced back in many instances to inadequacies in control panel design.

Only by considering the range of conditions which may affect panel operation can the designer select from among the many criteria values which might apply to his panel.

DESIGN RELATIONSHIPS

Implicit in the system viewpoint are two kinds of relationships with which the designer must be concerned:

(1) It is postulated that a logical relationship exists between conditions of system operation (including operator requirements) and the characteristics of the panel to be designed. This relationship may not be immediately apparent, so the designer must analyze the relationship in terms of his particular design problem. Analysis is required because the statement of a required action on the part of an operator may not directly imply a relevant design criterion. For example, the procedural command "select operational mode" may require a complex decision on the part of the operator, but unless one analyzes the prerequisites for the command, the decision may not be apparent. If the designer fails to perform the necessary analysis, the relationship (the link between the operational condition and the design parameter) will still be implicit in whatever design configuration he chooses, but now that relationship may be completely inappropriate. The task will, for example, still require the reading of a meter, but the designer will have provided a discrete indicator, which is inadequate for task accomplishment.

A consequence of this relationship is that any criterion statement describing appropriate design characteristics will be valid only for particular sets of operational conditions. This relativistic orientation to control panel design is one of the more difficult problems besetting both the designer and the human engineer. In a particular situation, a design characteristic will be significant or insignificant, important or unimportant, relevant or irrelevant in terms of the required operational performance of the operator, as measured by the probability of his error in operating the panel, the speed of his response to stimuli, etc. This problem pervades all design; but because of the high degree of operator variability, it is particularly important in the design of control panels.

(2) Apart from any relationship between design characteristics and operational conditions, there is a relationship among the design features incorporated in the design. One design feature cannot be viewed in isolation from the others present in the design. At the heart of this relationship is the problem of how design features summate, and the influence of one upon another. For the designer, this relationship involves what we may call "panel organization."

These two relationships are the major themes of this report and will be discussed in greater detail later. But first we will further explore the nature of control panel design. Control panel design has been so much taken for granted that the subtleties involved have usually been overlooked, particularly by the designer himself.

DEFINITIONS

(1) A control panel design feature is an attribute of some control, display, the physical panel, the lettering, etc., or its two-dimensional representation on paper. The design feature corresponds to the molecular level of design organization (as perceived by the designer in the form of such qualities as size, shape, color, location, etc.) just as the task element corresponds to the atomistic unit of operator behavior.

Designs are combinations of design features; thus the designer must be concerned about such features to the extent that they are coordinate with the overall design goal. Panels are, however, not operated in terms of design features, and the operator will hardly be aware of them unless some design feature is so glaringly incorrect that it intrudes upon his performance and creates difficulties in operation.

(2) A design characteristic is a relationship between one or more design features and the implied sensory, perceptual-motor and decision-making characteristics of the operator which require these design features. A design characteristic represents a higher degree of design organization because it is linked with the operational task (procedure) which it is supposed to mediate. This link gives the design characteristic meaning, which the design feature lacks. The color red, in and of itself, is a design feature because it has no significance in terms of one operator task. However, it immediately derives significance and becomes a design characteristic when it is linked with the symbolic referent "malfunction." The design feature, indicator color, becomes important only if the wrong color (e.g., green) or conflicting colors are selected to represent a malfunction.

(3) A design criterion is a rule for the selection of appropriate design characteristics. It should indicate when, under what circumstances, and how design characteristics should be applied to a design problem. Because it is a rule for selection of design characteristics, with their link to operational task performance, the effective criterion will include references to operator performance. While some criteria do, others (largely prescriptive in nature) do not.

It is necessary to differentiate between a design criterion and a technique. One must select the criterion and the criterion value before they can be applied to a design problem. The design technique is a description of how criteria shall be selected and utilized. If we tell the designer, for example, that he should select human engineering criteria in terms of what the operator's task on the projected control panel will be, this is a technique, although quite general. Unfortunately, present design criteria are not accompanied by any generally accepted and explicit technique for their selection and use. If a technique exists, it is implicit in the criterion, or can be derived by rationalizing the criterion; but this is not very effective.

THE CONTROL PANEL AS A MODEL OF BEHAVIOR

Underlying these definitions is the assumption that the control panel is a model in equipment form of the behaviors (expressed in the form of procedures) required to operate an equipment. That is, panel displays must be selected so that all task-relevant operational stimuli will be mediated by these displays, and controls must be provided to enable required manual operations to be performed by the operator. The control panel would be completely isomorphic to the operating procedure if the designer had an operating procedure which consisted of a finite series of discrete, required, nonrepeated steps, for each of which only a single control or display was needed.

The matter is not so simple. In addition to the required manual operations, the panel models contingent[3] performance of the panel, i.e., every factor which actually or potentially influences operational panel functioning must be reflected in some fashion in the panel design. Many of these factors are by no means immediately obvious from the procedure and from a consideration of required operations. Will the operator be seated or standing? In either case, his anthropometry must be considered. Will the stimuli to which the operator responds demand a high degree of perceptual acuity? If so, the nature of the displays mediating these stimuli must be examined most carefully. Are any decisions required in operation? If so, the stimuli producing that information on which that decision is based must be analyzed to insure that they are available.

It is apparent, therefore, that the particular design characteristics to be selected for a control panel may not be immediately explicit in the operating procedure[4]. The procedure will have to be analyzed in the light of the conditions of mission performance (again conceptualized in the broadest terms and including such parameters as operator characteristics as they will be manifested during operational performance).

SELECTION OF DESIGN CHARACTERISTICS

The selection of design characteristics takes place in a two-step sequential process. Criteria are utilized in both steps.

First, the nature of the system for which one is designing imposes certain selection criteria. These we may call system selection criteria. For example, among the criteria that can be applied to a control panel are those that deal with noisy environmental conditions. Thus, the very nature of the system and its conditions of operation serve to eliminate (i.e., to select by rejection) a host of design characteristics.

The other type of criteria are the conventional design criteria such as those in MIL-STD-803A-1 or -2. These are utilized once a particular design parameter is found applicable to a design. Thus, if the nature of the system requires warning signals, then the criteria that apply to warning indicators perform their function by eliminating all colors other than amber or red for this particular design feature.

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[3] The contingent nature of operational usage should be emphasized. If only required actions had to be translated into design, panel design would be essentially isomorphic to the operating procedure and design would be equivalent to a specification or listing of individual operator actions. But many stimulus conditions may or may not occur, and resultant responses may or may not be required, as may be seen by potential emergencies and malfunctions. The conditional (probabilistic) nature of these factors must be taken into account. But how? Also, every procedural action implies some operator perceptual, manipulatory or decision-making process, and if these mediating processes have a significant effect on panel operation, they must be taken into account by the designer.

[4] In many system development projects the operating procedure is not formalized until the equipment is finalized. Designers often design on the basis of implicit procedures, or develop the operating procedure concurrently with the design of the panel.

System criteria are implicit, logical and binary, while design criteria are much more explicit, probabilistic and continuous. That is, there is a more or less straight line deductive relationship between the nature of a system and its applicable design parameters. This relationship is binary because a system parameter is either applicable to the system or it is not. One does not, for example, apply considerations dealing with tracking to an equipment which is not supposed to track. The number of inapplicable design characteristics eliminated in this way is fairly large, but it still leaves a large number of design characteristics that may potentially apply.

Design criteria function within a much narrower circuit. They describe various dimensions or points on dimensions of design characteristics, all of which (except those at the extreme ranges) might be applicable. The designer must determine which value of an applicable design parameter will most effectively promote efficient panel operation. If a CRT for signal detection has been decided upon as an appropriate display device, the question then becomes which phospher coating will permit most effective detection of the signals. This is essentially a probabilistic decision to be made by the designer (or the human engineer), because it is made in consideration of operational performance which is itself inherently probabilistic.

Another point of difference between system and design criteria is that system criteria are essentially unformalized and intuitive, that is, seldom tested experimentally, primarily because this logic appears too deductively obvious. Some design criteria, (e.g., relationships between continua) have been tested, or at least there is some experimental evidence suggesting their correctness. Unfortunately, many more design criteria have not been tested, and their selection rests on the designer's intuitive belief in their correctness. However, these intuitive design criteria do not have the support of a relatively direct logical connection between the nature of the system and the characteristics required of that system.

In analyzing a control panel design problem, the following is a representative sequence:

(1) Analysis of the system and the operator's task,
(2) Consideration of all potentially applicable factors (e.g., noise, vibration, lighting, workspace),
(3) Determination of an actually applicable factor (e.g., lighting),
(4) Determination of design characteristics affected by factor (e.g., legibility of type on panel and viewing distance),
(5) Consideration of the range of values of the affected design characteristics (e.g., see p 35 of MIL-STD-803A-2),
(6) Determination of optimal value of design characteristic.

SELECTION TECHNIQUES

The selection process takes place in the light of the known or anticipated relationship between a design characteristic and its operational usage context. Because selection takes place, certain design criteria may assume in the designer's (or human engineer's) mind a greater priority than do others. This priority will vary as a function of how the designer views the projected operational use of the equipment and its control panel. Depending on anticipated operational conditions, the same design

criterion will have greater or lesser priority[5]. If one can think of design criteria outside of particular operational conditions (a difficult feat), then all design criteria have equal applicability. As soon as the projected operational conditions are considered, however, certain of these are eliminated as irrelevant. Of those selected as applicable, a sequential order of priority is established in the mind of the designer, consciously or unconsciously. It, therefore, becomes essential to determine the subjective bias on the part of the designer in his selection of criteria, or to assign an a priori priority to these criteria which will reduce or eliminate that bias.

By little or no coverage of the principles of criteria selection, standards such as MIL-STD-803A-1 imply that each criterion has an equal value in terms of the particular control panel to be designed. Since panel design is an effort to organize design characteristics into a meaningful whole, these characteristics and the criteria that describe them assume different values as a function of the total "gestalt" of characteristics and criteria in which they are embedded (see later discussion of panel organization). Naturally, the designer does not act as if these criteria were of equal value. He picks and chooses, but since he lacks adequate guidelines for selection, he may do so erratically and inefficiently. Unfortunately, the designer may not consider all the relevant criteria because he does not know or think of all the operational conditions that could affect panel operation. If the designer fails to consider all these conditions, the selection of applicable criteria is likely to be inefficient.

In some cases, the task of selecting a criterion is quite simple. Provisions for the selection of control levers, for example, can be ignored if the control panel operator does not have any requirement for using a lever. Many other principles are of a more general nature and therefore are not so exclusive. The relativistic nature of human engineering criteria also involves some inherent contradictions. For example, if one were to emphasize or guard every critical control on a panel, the indiscriminate use of switchguards for safety and color modules for emphasis would tend to cancel out the effect of the emphasis or severely hamper operation of the critical controls. Thus, the criterion can be applied in full effect only when a technique exists for analyzing the conditions under which the criterion applies.

Any technique developed must center around the analysis of operator-performance conditions and must relate the selection and application of criteria to these conditions. The technique should ideally accompany and specify the criteria to which it refers.

There is no one-to-one relationship between a design feature and the operational condition that elicits its use. A control may be located in the periphery of a panel because it is used only infrequently, but knowledge that a control operation will be performed infrequently does not necessarily and invariably lead to positioning that control in the periphery. An analysis of the required or conditional performance of this control operation is required, following which there must be a tradeoff with other controls, their potential positions, and their frequency of use. Thus, any design criterion can only provide a general rule of thumb which may not apply universally.

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[5] Criteria for selection of type size for panel labelling may be relatively unimportant where the equipment will be operated under good lighting conditions and the operator can be close to his panel.

A design criterion may say that less frequently operated controls should be placed in the periphery of the panel, all other things being equal. But the application of the criterion first requires an analysis of the operational conditions of panel usage. Safety factors may forbid the exercise of this criterion.

OPERATIONAL CONDITIONS

What kind of operational conditions should be described by design criteria? These conditions can be categorized as follows:

(1) Required operations. These describe or more frequently imply the behavioral processes required (to the extent that task operations can be anticipated) to perform the task. By and large, this is presently accomplished on a discrete, motor level. For example, the procedural requirement to turn on panel power implies quite directly the performance of a discrete motor action; consequently, it is relatively simple to decide upon an appropriate control (e.g., two-position toggle switch). For higher level behaviors (complex perceptual and decision-making processes), procedural operations require more detailed analysis. For such higher level behaviors, available design criteria is inadequate.

(2) Contingent operations. These are the events that have some finite probability of occurrence less than 1.0 (required operations have a probability of occurrence of 1.0 except when the equipment or the operator malfunctions, in which case the system than goes into a contingent operation). When one includes potential emergencies, malfunctions and possible overload conditions, the number of contingent operations becomes fairly large and the question arises how to (if one can) include them in the design. Because of the large number of these conditions, one cannot include them all, so that when the contingent condition arises, the panel is usually inefficient to do the job required by that condition.

In overload conditions, system capacity to deal with stimuli remains the same as originally designed, but the number of stimuli increases beyond that capacity to handle. A classic example of an overload condition is the air traffic control situation at peak loads, where the number of messages to be received and transmitted may tax the capacity of the controllers. Overload conditions may involve an excessive number of stimuli or required responses, or stimuli that change too frequently or rapidly, in an erratic pattern, etc.

In malfunctions or emergencies, the environmental stimuli do not represent an overload, but the capacity of the system to respond is lowered. In a malfunction situation, the operator cannot easily cope with stimuli because his physical mechanisms of handling them are degraded. It is important to note that in contingent conditions the nature of the task for which the control panel has been designed has changed. For example, in the malfunction situation, instead of responding in a largely predetermined manner, the task becomes one with many degrees of freedom; it now becomes one of diagnosing an unknown condition. Manifestly the task of applying human engineering design criteria to even a few of the potential contingent conditions becomes extremely difficult, and it becomes necessary to trade them off (in terms of importance) against what is possible to include in the design.

The criteria generally presented in standards and checklists deal largely with required operations. Although the specification of tolerance limits for inadequate environments (those involving degraded stimulus conditions such as high noise, poor lighting, etc.), does cover one type of contingent operation, present criteria are generally inadequate for dealing with most contingent operations. This is all the more remarkable because one can hypothesize that highly degraded conditions involving stress (which are characteristic of contingent operations) are the ones in which design configuration would most affect operator performance. Unfortunately, there is a dearth of research dealing with performance responses to degraded conditions involving panel operation.

In view of the multitude of conditions actually or potentially affecting panel operation, design criteria should always be supplemented by an analysis of the operational conditions for which the panel is being designed. True, the designer may dislike the necessity for this analysis, even when the analysis is performed for him by other developmental personnel, but there is apparently no alternative.

This discussion of the effect of operational conditions upon panel operation has implicit in it an hypothesis, namely: "to the extent that the projected operational use of a panel is fully described in advance of design, and the more carefully the designer draws conclusions from that description, the more efficient the design will be." This hypothesis can presumably be tested empirically, although with great difficulty.

PANEL ORGANIZATION

A major function of control panel design is the designer's attempt to organize design characteristics, whether or not he consciously applies specific criteria to do so. The selection of individual controls and displays may be largely a discrete process, but it very quickly gives way to an organized approach in which the goal is to develop a unified and homogeneous control panel. Because the design process is a purposive one, it must contain elements of organization, even though that organization may be inefficient at times.

In designing a control panel, the designer selects and arranges individual controls and displays, but he does so in terms of the relationship between the selected control/display and the other controls and displays he must select and arrange. He may initially consider each panel control or display as an individual item, but he proceeds to select and arrange it in terms of the other items he must select and arrange. For example, if 9 out of 10 controls he selects are switch-lights, he is unlikely to select a three-position toggle switch for the 10th control (assuming he needs a control with switch-characteristics), because it would conflict (aesthetically and operationally) with the other switch-lights. In other words, the designer views his control panel design as a problem in organization and not merely as a series of isolated, independent control/display selection and arrangement problems. (If he should approach design on such a discrete basis, his design would be seriously deficient. Most designers, implicitly as well as explicitly, adopt an organized approach to their design problems.) Design is typically a holistic process, because the designer does not develop one area of his panel to finality and then proceed with another, but works on each area in succession in terms of every other.

Because of this organizational process, the control panel design process is a creative one; the sources of the activity performed are often intuitive, unstandardized and highly variable. While it involves analysis of the design problem, the analysis is in many cases largely supportive and subordinate. It is often performed in a trial and error fashion.

If the control panel design process is a creative one, we must learn about the designer's conceptual processes empirically and model any analytical methodology we submit to him on the results of this empirical investigation. Any analytical methodology given to the designer will be modified by his creative processes, unless we wish to restrict his activity unduly. It is therefore necessary to examine how designers typically solve their problems.

The manner in which the designer selects and arranges his controls and displays is conditioned by his anticipation of the role of the operator of that panel, although he may not do so consciously and with the same degree of sophistication with which a human factors specialist would consider the panel operator. Because a design characteristic has meaning only in terms of anticipated operator performance, however, the designer can hardly avoid that consideration. For example, the selection of a color for a discrete indicator implies that the panel operator must respond in some defined manner to that indication. The location of a cathode ray tube (CRT) in the upper half of a console instead of below the operator's knees implies that the designer feels the operator must be able to view the CRT to respond effectively. Such examples are relatively obvious, but they have important implications. It is not enough to say that the designer should consider the operator and his performance characteristics. He must. The only question is whether he does so consciously or unconsciously, systematically or inefficiently. Unfortunately, the element of conscious analysis plays too little part in much panel design. The insistence of human factors engineers that designers systematically consider the potential operator of their equipments represents an attempt to force a conscious approach to design analysis.

THE OPERATOR AND THE CONTROL PANEL

Not only does the designer organize his design, but the panel operator also responds in an organized fashion to that design. The control panel is initially and fundamentally a perceptual stimulus configuration to the operator. A design characteristic is important to the extent that it is incorporated (consciously or unconsciously) in or affects the operator's perceptual concept of that panel.

When we say that the control panel is first and foremost a perceptual stimulus configuration to the operator, we mean that in the process of learning to operate it, and then in the process of operating it routinely, he responds to relationships among design characteristics as perceived by him. The process of learning to operate a control panel can be conceptualized in the following roughly sequential series of steps:

(1) The operator first learns the names, positions and functions of the individual controls and displays.
(2) He then associates these controls and displays with each other (i.e., he organizes the control panel as a whole).
(3) He learns the procedure for operating the control panel.

(4) He learns to associate particular controls and displays with particular procedural steps.

In the process of operating the control panel he:

(5) Searches for and selects the (apparently) required control or display,
(6) Performs the procedural act associated with that control or display.

The quickness and accuracy of his search for the required control/display is dependent on the manner in which that control/display is organized in the panel as a whole, because the operator does not scan the panel as a series of isolated hardware items. He may do so when he first learns to operate, but ultimately he sees it as a homogeneous whole.

The operating procedure serves to activate the inherent organization of the control panel (as conceptualized in the operator's mind); even where the panel is improperly organized from a physical standpoint, the procedure as learned by the operator may force an organization upon the panel. This is why the operator is often able to compensate for panel design inadequacies, since perceptually (and to the extent permitted by speed and accuracy requirements) he can reorganize the panel configuration.

If perceptual organization is as important in panel design and operations as it appears to be, human engineering criteria describing how design characteristic relationships are related are most essential for "good" human engineering design, and the search for effective control panel criteria should focus on the development of principles of panel organization.

THE DEVELOPMENT OF DESIGN EVALUATIVE TECHNIQUES

It has been pointed out that every design characteristic has a value not only in relation to operational conditions of performance, but also in relation to other design characteristics included in the panel. Value may be defined in two ways: (1) initially in terms of the degree to which the characteristic helps to "organize" the panel perceptually, and (2) ultimately and more fundamentally in terms of effect upon the performance of the panel operator.

The problem that arises has been foreshadowed in the discussion of the designer's need for selecting criteria for application to his design. What weight should the designer give to any one criterion as opposed to all the others that are relevant to the panel? If one were to ask the designer to rank order a list of human engineering principles in terms of the ones he considered more and less important in design, the basis for his selection might be purely idiosyncratic (based on personal experience). This may be one of the reasons for the high degree of variability one finds in design. It is noteworthy that no comprehensive study of this weighting phenomenon has ever been performed.

The relationship of design characteristics to each other is even more important in control panel evaluations performed by human engineers. While it may be relatively easy to discover an individual design feature which does not meet human engineering standards, it is much more difficult for the human engineer to determine the significance of that deviant feature in terms of the panel as a whole. In the development of evaluative criteria such as checklists, the indeterminancy of design characteristics makes it difficult to develop valid evaluative instruments. Assumptions concerning the manner individual attributes combine are fundamental to the development of any measurement instrument. The nature of these assumptions for human engineering design criteria and human engineering checklists in particular is, however, open to serious doubt.

The usual human engineering checklist implies that design characteristics combine additively[6], since each one is implicitly given the same weight as any other. If one carried this assumption to its logical conclusion, one could assign a score to the evaluation of a control panel, based on the number of items passed or failed. In view of the relativistic nature of our criteria, however, this would be extremely dangerous. This is not an attack on the usefulness of human engineering checklists, because pragmatically they are quite useful, again mostly in terms of picking out inappropriate design features, not in terms of evaluating the effectiveness of the panel as a whole. Indeed, there have been few attempts to develop human engineering evaluation checklists and techniques in the same manner as that in which other psychological tests have been developed, through such methods as testing, item analysis, validation, etc. One exception is that of Siegel et al (1962). His method, while more quantitative and sophisticated than those of other workers, also suffers from some of the same problems. It is, in addition, highly complex. Most human engineers in actual practice either use an abbreviated checklist or, more frequently, have internalized certain human engineering principles which they consider most important and which they use repeatedly, referring to formal checklists and standards like MIL-STD-803A-1 when the complexity of the evaluation problem exhausts their internal inventory of applicable criteria.

Another problem in developing evaluative instruments is that we know from experience that it is possible to subdivide design characteristics to finer and more molecular details. Does this mean that every molecular detail possesses the same value in evaluation as its superordinate statement? The general criterion that a control panel should contain only necessary controls and displays has implicit in it other criteria concerning the inclusion of contingency events, such as malfunction or other emergency indications, provisions for feedback, etc. If one evaluation instrument contains only the general criterion, while another contains more detailed criteria, are the two instruments measuring the same phenomena in the same way? Again, we do not know.

Similarly, note that the same criteria are used indistinguishably for both design and evaluation of that design. Apparently, this should pose no particular problem, but we know comparatively little of the behavioral processes involved in both, and it may appear upon closer examination that the manner in which these criteria are phrased should vary as a function of their particular use.

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[6] If design characteristics interacted multiplicatively, one inadequate characteristic would completely degrade the panel; all panels would be either completely satisfactory or completely unsatisfactory. This is not the case, yet observation of human engineers sometimes shows them evaluating panels with this assumption implicit in their judgments.

As evaluators, the binary nature of our design criteria creates special difficulties. The typical checklist incorporating these criteria usually demands a binary judgment (does or does not the panel contain this particular design characteristic?). The designer who uses these criteria may be able to reinterpret them in terms of a continuum of values, but the evaluator cannot, especially if he comes to the panel "cold," as it were. Moreover, the designer can manipulate the design characteristic in several ways by redrawing his panel design. He can in effect experiment with the application of the criterion, but the evaluator cannot. Under those circumstances, the assumed binary quality of these criteria may produce false evaluative judgments.

THE NEED FOR EMPIRICAL RESEARCH

Previous research suggests the need for empirical research to attempt to establish the significance of human engineering criteria in operator performance and designer terms. The continuing inadequacy of control panel design will not yield to purely analytical refinements. Unfortunately, the research performed to investigate these relationships has usually demonstrated the relationship at one or at most two points along the continuum of a design dimension, instead of investigating the range of values along the dimension. There are two dimensions involved: (1) the range of parametric values, such as the varying degrees of separation between controls, and (2) the range of operational performance conditions, including anthropometric requirements, varying tasks, etc. (such as the relative speed with which control activations have to be made). Until a number of points along each dimension are explored, no real relationships can be described, because the nature of the relationship at one point may not be the same at another point. For example, the size of access spaces does not have the same value in terms of speed of removal/replacement activities for each access size.

It has been suggested that in comparison with some European practices, American human engineers permit considerable variability in terms of the precise design features that may be applied by designers to particular design problems (Bertone, 1965). For example, Czechoslovakian human engineering standards require that specific colors of indicator lights be used, or particular type sizes be used for panel nomenclature, while American standards merely prescribe extreme limits within which the designer has freedom of choice. Philosophically, American human engineering standards are based on what might be called a "democratic" concept, in which design standards attempt to optimize the operator's variability, while Czechoslovakian standards force the designer and operator to conform more to a fixed configuration. Undoubtedly the greater American freedom to select applicable design features leads to greater variability in design and correspondingly makes it more difficult to evaluate the correctness or incorrectness of a design feature. Although it might prove difficult to apply the Czechoslovakian concept to configurational criteria dealing with design feature interrelationships, it could be considered for relatively discrete features such as pushbutton sizes, indicator lights and the like. Whether American industry would accept such regimentation is another question.

PART II

THE SYSTEM CONCEPT IN CONTROL PANEL DESIGN

The need for considering design criteria in terms of operator performance and in terms of the operational conditions under which he performs requires what has been generally called a system approach. The system approach is simply the consideration of all known factors that may affect the performance of the equipment and the operator. Since panel design criteria are only meaningful in terms of operator characteristics and performance, this requires almost a behavioral orientation, which can be expressed in such oversimplified terms as what will the operator of this panel have to see and do, and what conditions will affect the adequacy of his performance. It is here that perhaps the greatest difficulty is experienced in communicating human engineering design criteria to designers, because the latter in large part lack the system-behavioral orientation. This is understandable because the designer's entire orientation has been developed in relation to hardware characteristics.

Communication difficulties may arise because the engineer is accustomed to handling absolute criteria (i.e., whose values are relatively stable over time, or at least can be specified for varying conditions or points on a continuum) and behavioral criteria are highly relativistic. Ideally, human engineers should be able to translate their behavioral criteria into absolute engineering values, but because of the relativism of the former, they experience great difficulty in doing so. Because the designer reacts more positively to human engineering concepts when the questions he poses can be answered in absolutist terms, he is happy to utilize human engineering data but much less willing to use human engineering principles. For example, if he is required to design an access space or a passageway, he will ask for the dimensions required to permit human passage, but he is much less likely to ask the human engineer whether an access space or a passageway is required by the operational task.

In the past few years, there has been much discussion about the necessity for communicating behavioral concepts to engineers in their own (engineering-oriented) terms. The effort to communicate human engineering principles to the designer has led to the development of handbooks, checklists and articles which attempt to specify the steps required to apply these principles to design. The reasonable assumption is made that handbooks written in terms that designers can understand and apply will assist in applying the system-behavior orientation. Even if this communication were simply a matter of translating concepts from one language to another, it would be difficult because of our relative lack of data interrelating design characteristics with operator performance. What may be actually meant by the insistence on more effective communication between engineering psychologists and engineers is the translation of concepts requiring analytical thought processes (the analysis of operational conditions, for example) to rules of thumb which do not require such analysis. The success of this latter translation is highly dubious.

As a result, it cannot be said that this attempt to replace the behaviorally oriented human engineering with nonbehaviorally oriented handbooks has been very successful. The design of control panels (as, for that matter, the design of any equipment involving operator interactions) is a highly complex process requiring, for complete success, the analysis of the operational factors that will affect panel operation. Such a process will not easily yield to demands for supersimplicity. The essence of the problem lies in considering the design problem as a configurational one, and the inability of many designers to think in configurational terms prevents the most effective use of such human engineering handbooks.

The necessity for analysis of operational conditions in design has been pointed out previously. A description of behavioral processes in the design process will serve as an introductory framework for the development of such an analytical methodology[7].

BEHAVIORAL PROCESSES IN DESIGN

Our concept of an analytical methodology has been based on a particular view of the design process. This viewpoint sees the design process, and system development as a whole, as an effort to solve an iterative series of problems which are generated by the need to accomplish system requirements. For example, the requirement to develop a system which will check out a vehicle in a specified time period (e.g., 2 hours) creates certain problems for the system developer and the designer[8].

Assuming that system engineers have told him that the checkout process will be automatic but controlled by a maintenance man, he must decide what configuration of hardware will permit the maintenance man to start, stop, and monitor the checkout process; how will the information the maintenance man needs to know be displayed to him?

The design process is assumed to be the transformation of information, supplied to the designer by means of inputs from development personnel, into a physical means of accomplishing a design goal. The inputs available to the designer include the following:

(1) System and equipment requirements (e.g., the equipment must supply 40 amperes of current). These requirements will be used to determine the adequacy of subsequent inputs.

(2) The results of functional analysis (e.g., to accomplish the equipment function, electrical energy must be translated from point A to point B),

(3) Applicable constraints (e.g., the equipment must be portable and weigh no more than 200 pounds),

(4) Design criteria, specified in the form of Military or Company specifications, and the designer's own accumulated engineering knowledge,

(5) Conclusions derived from previous data analyses and inputs.

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[7] This methodology underlies the writing of a companion report (Meister and Farr, 1965).

[8] We differentiate the designer from other developmental personnel, by reason of the former's special role in constructing equipment configurations. Other developmental personnel (e.g., system engineers and analysts, human factors specialists, etc.) supply informational inputs to the designer, but do not necessarily use these inputs to create design. There are gray areas in which developmental personnel, in the course of providing informational inputs, may impinge upon the design function by suggesting design alternatives, and designers will themselves gather and utilize information to assist in creating design. In making this dichotomy, however, we emphasize the distinction between the gathering, analysis and transmission of information and the utilization of that information for producing the final design product.

In solving his design problem, the designer will (a) ask for certain inputs on the basis of his recognition of the need for particular kinds of information to solve the problem, (b) receive quite independently of his request certain inputs, such as human engineering requirements, and (c) apply certain inputs of his own, consisting of his own fund of knowledge.

These inputs contain information which the designer will utilize to resolve his problem. An input must, however, be differentiated from the information it contains. That information is a product of the designer's interpretation of the input's design implications and his application of the input to the problem situation. If he fails to make use of an input, it lacks information value to him.

The designer does not accept all these inputs uncritically. Certain of the inputs will contradict others, and he must trade these off. Also, he may weigh their information in terms of some subjective scale of importance. He may consider some inputs as irrelevant, consisting of "noise," or as being redundant to other information he has already acquired.

Most important of all, he must examine each input in terms of its design implications. Assuming that he accepts an input as being valid and relevant to his design problem, what are its implications for design? If he fails to understand all of these implications, he has not secured all the information inherent in the input. The process of deriving the correct design implications from an input is the most difficult part of the design process. If a human engineer supplies an input to him that the average operator has a reach distance of 28 inches, how will he translate that into the correct design configuration? If he is told that the reliability of his equipment must not be less than a mean-time-between-failure of 30 hours, how can he translate this into the appropriate arrangement of circuits and components?

At the start of design there is a high degree of uncertainty about the nature of the ultimate equipment configuration. (Actually there would be much more uncertainty, except that system developers impose requirements on the design which automatically eliminate many possible configurations. Thus, to specify that the equipment must be portable automatically constrains the design within certain weight and size dimensions.) The function of the informational inputs supplied to the designer is to reduce the uncertainty still further, by eliminating alternative but less correct configuration possibilities. However, the amount of uncertainty reduced by an input depends on the correctness with which the designer reads the implications of the input. Some implications are relatively obvious (such as the portability requirement), whereas others may be relatively obscure.

In the process of deriving design implications from his inputs, the designer constantly tests them against his system requirements. For example, an analytic input which suggests that for his portable equipment he must use a 150-pound power supply must be rejected, since he cannot then meet the portability requirement.

The variability one characteristically finds in design is the result of this continuing testing and acceptance or rejection of inputs. Among these inputs are earlier designs and design revisions which the designer constructs before completing his work. The difficulty of the design process is accentuated by the fact that during the design period the inputs often arrive sequentially and must be integrated, and because these inputs may change as new information is secured and new analyses run.

OPERATIONAL CONTINGENCY ANALYSIS

Since human engineering criteria cannot meaningfully be applied without consideration of performance conditions, an analysis based on operational contingencies is essential. This analytical methodology has been termed Operational Contingency Analysis. The essence of OCA is the determination of the operational conditions that may affect the operator's performance. It can be described in the following steps:

(1) Selection of the operational conditions that may influence panel operation. There are a large number of potentially significant factors that may influence panel design development and operation (appendix I). The selection of the population of factors to be considered further requires an analysis of the mission or performance conditions under which the panel will be operated, since the factors that will be applicable will depend upon these conditions. For example, one factor is the physical environment of operation as this affects the operator. If the panel is to be utilized indoors, under regulated temperature conditions, this factor is irrelevant. If the panel is to be operated outdoors, in an extremely cold environment, the operator's performance may be affected. For example, he may have to wear gloves. Under these circumstances, the human engineer would pinpoint the environmental factor for further analysis.

Any given factor may have a significant or insignificant effect upon operator performance. Fortunately for the human engineer, the nature of the system mission will automatically eliminate a large number of irrelevant factors; otherwise his task would be inordinately difficult.

In analyzing mission conditions, the human engineer should consider the nature of the system (obviously, a tracking parameter would be irrelevant to a system in which no tracking was involved), the nature of the task involved in operating the panel (for example, if the task demands highly precise visual discrimination, the nature of displays might be affected), the nature of the physical environment, probable and possible emergency conditions (any emergencies will stress the operator and require some means of responding to them), etc. These must be considered in terms of the demands they impose on the perceptual, control and decision-making responses of the operator.

This first phase of the analysis will involve the following steps:

a. Determination Operational Events

(a) Determine which system events the control panel is supposed to monitor. (These events must be displayed on the panel.)

(b) Determine which system events the panel is supposed to control manually. (Controls for these events must be provided.)

(c) Determine how these events are interrelated. (Controls and displays may be combined where feasible.)

(d) Determine how critical to mission success, system safety and personnel safety these events are and what makes them critical. (Critical events may have to be emphasized on the panel.)

(e) Determine at which stage of the system mission these events are to be monitored and/or controlled. (Mission stage may be related to some mission occurrence which must be taken into account in designing the panel.)

(f) Determine with what other mission events, equipment and conditions of performance these events occur.

b. Determination of Event Characteristics

(a) Determine how frequently the events to be monitored and controlled occur. (Frequency may well determine panel location.)

(b) Determine how frequently these events must be monitored and controlled. (This is not quite the same as (a); high frequency events may have to be monitored only periodically.)

(c) Determine if these events occur on a single time basis, recur repetitively, occur sequentially over time, in a random fashion, or simultaneously. (Each of these may have different implications for design.)

(d) Determine whether these events change during the system mission, change sequentially, repetitively or randomly (erratically), and if the changes must be monitored and/or controlled continuously or at specific intervals.

(e) Determine how long an event persists when it occurs. (If persistence is of short duration, it may require a special display, e.g., PPI scope.)

(f) Determine at what points in the system these events must be monitored and/or controlled and, if there is a choice among these, where the control or monitoring can be exercised most effectively. (If there is a series of valves whose opening and closing must be monitored, it makes a difference whether one picks off the valve action at the electrical relay or at the valve opening.)

(g) Determine whether the events to be controlled vary over a range of values or over one or two points only.

c. Determination of Panel Operation Tasks

(a) Determine the frequency with which each panel operation must be performed. (One might wish to locate controls for more frequently occurring operations toward the center of the panel.)

(b) Determine the sequence in which these operations must be performed. (Sequence may force control/display arrangement.)

(c) Determine the interrelations of each panel operation. (If a control and a display operation are interrelated, it is probably necessary to associate them physically.)

(d) Determine which panel operations must be continuing, which are "single action" nonrecurrent and "single action" recurrent. (Single action nonrecurrent operations may have controls and displays located toward the periphery of the panel.)

(e) Determine any quantitative limits within which operations must be performed. (Such limits may determine the kind of control/display that must be used, or may have implications for stressing the operator.)

(f) Determine which panel operations monitor and/or control operating and maintenance events, routine and emergency events. (One will probably wish to segregate these.)

d. Determination of Panel Operator Requirements

(a) Determine which events appear to be most difficult for the panel operator to control or monitor. (Difficulty has obvious implications for control/display arrangement.)

(b) Determine whether the operator must respond frequently or infrequently, rapidly or slowly, and at which times in panel operations he must do so. (High frequency operations may stress the operator and may require a revised panel layout.)

(c) Determine whether the panel operator must coordinate panel operations within his own operating task, with other operators, or with particular equipment events in time. (Coordination requirements frequently lead to error and will therefore have to be accounted for in panel design.)

(d) Determine whether panel operations require a greater than normal degree of (1) motor strength or skill, (2) visual or auditory discrimination, (3) data interpretation, computation and/or decision-making, and (4) memory. (These may stress the operator and may require modification of panel layout.)

(e) Determine which panel operations must be initiated by the operator's own decision and which are initiated by the operator as a result of a preceding equipment event. (If the latter, a special display will be required to signal the necessity for a control operation.)

e. Determination of Environmental Factors Affecting Panel Operation

(a) Determine whether temperature, humidity, lighting, noise or vibration factors in the operating environment may affect panel operation adversely.

(b) Determine whether physical space limitations in the placement of the panel will affect the manner the panel must be operated.

(c) Determine whether factors derived from the nature of the environment, material or equipment being handled will adversely affect panel operation and must be controlled and/or monitored by the operator (safety factors).

f. Interfaces Affecting Panel Design

(a) Determine whether the panel must physically interface through electrical or mechanical means (e.g., cabling) with other equipment (implications for workspace layout).

(b) Determine whether panel operations influence or interact with the performance of other equipment operations (necessity for special communication displays or devices).

g. Constraints Affecting Panel Design

(a) Determine whether operator limitations (e.g., experience or training) may affect panel operation and design.

(b) Determine whether hardware limitations (e.g., required use of particular meters, off-the-shelf equipment, etc.) may affect panel design.

(c) Determine whether any required design philosophy (e.g., philosophy of automation or nonautomation) may affect panel design.

(2) Determination of the effect the selected operational conditions might have on panel operation. Once a relevant operational condition has been selected, the relationship between the operator's performance as affected by that factor and the medium through which that performance is manifested must be determined. Even though an operational condition apparently influences operator performance, it may not affect panel operation. Suppose the environmental condition to be considered was a high noise level; under these conditions only a solution dealing with the operator himself (e.g., ear plugs) would solve the problem. One must therefore trace the relationship between the affected operator performance and the panel configuration, since there are conditions under which the relationship is tenuous at best, so that modification of panel design to account for the factor would be impractical.

(3) Determination of the seriousness of the effect of the operational condition. Even after one has determined that an operational condition has an influence on operator performance and that the medium through which the effect is exercised is the control panel, it may appear after further analysis that the effect is minimal. One must, therefore, judge the seriousness of the effect by two criteria: (a) the probability that an error or time delay will result as a function of the operational condition, and (b) the consequences of that error or delay upon the performance reliability of the equipment and the system of which it is a part.

For example, assume that the panel must be operated outdoors under arctic conditions with (presumably) gloved hands. If there are many controls to be included on the panel, so that controls are fairly closely spaced, the gloved hand may make the control operator awkward. On a panel with only two widely spaced controls, however, where the controls are of the binary, toggle switch variety, the influence of the gloves may be minimal; thus one could exclude this environmental parameter from further consideration. A highly probable error which does not have any significant effect on the equipment and system can safely be ignored. The designer must therefore trace the effect of the error on the terminal output of the system.

(4) The final stage in the analysis is the determination of the design implications of the influencing factor. That is, what characteristics of panel design or modification of those characteristics would tend to reduce the probability of the error being made or the factor being manifested negatively. Here, one may run into difficulties because of the lack of knowledge concerning the relationship between particular design characteristics and operator performance.

The above analysis requires the use of judgment and subjective opinion throughout its course. For example, one must estimate the probability of error occurrence in panel operation, but data on which to base this estimation is almost totally lacking except for the sparse material provided by Altman (1964). Altman's data, however, only indirectly considers the effect of operator performance conditions.

Operational Contingency Analysis is related to two other analyses, one behavioral or quasi-behavioral, the other purely engineering-oriented. For example, the analysis of mission conditions is an essential first step in the performance of any functional system analysis (see Van Cott and Altman, 1956). Steps (2), (3), and (4) also resemble failure modes and effects analysis as performed by reliability engineers. In this latter analysis, the effect of various operating conditions upon an equipment is determined in terms of the most probable and significant failures of the equipment and the determination of design modes that will prevent failure.

PART III

EMPIRICAL STUDIES OF CONTROL PANEL DESIGN AND EVALUATION

DESIGNER BEHAVIOR

As part of this study, the Operational Contingency Analysis was included as part of a special design methodology which is described in a designer's guide (Meister and Farr, 1965). Six designers were presented with three packages of design information (appendices II through V cover a sample data package.)[9] The three sets of information described (1) part of a command control console (type A); (2) a console for controlling hydraulic/pneumatic equipment (type B); and (3) a console for an information-retrieval equipment (type C). The subjects laid out a total of nine panels (because of subject availability it was not possible for each subject to lay out every control panel). Subjects varied in experience and training from one who was essentially a draftsman to a highly senior design engineer.

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[9] Note particularly appendix IV and appendix V which represent the results of analyzing the operational factors affecting that panel.

The purpose of the test situation was to examine the utility of the design methodology. Subjects were tested in the Bunker-Ramo Human Engineering Laboratory. At the start of a test period, they were required to study the designer's guide and any questions they had were answered. They then proceeded to lay out the selected panels. The design period consumed approximately three days per panel. Since the purpose of the test period was also to secure comments on the designer's guide and the utility of the worksheet technique (the methodology developed was summarized in the form of a worksheet which also contained the design information), a fairly informal procedure was used in which subjects could work at their own pace and comment whenever they wished on any aspect of their materials. Design standards such as MIL-STD-803A-1 were available to make design conditions as comparable to operational design conditions as possible. At the conclusion of the testing period, each subject was intensively interviewed concerning his responses to the guide and worksheet. This was in addition to sampled observations of his performance during the work period.

As far as the designer's guide and the worksheet methodology are concerned, reactions were quite positive. The worksheet technique apparently facilitated the organization of the designer's information into a package which could be applied more readily to the design task. Under ordinary conditions design information is received by the designer in scattered, sequential form and consequently is difficult for the designer to organize. From a qualitative standpoint therefore, the analytical technique provided in the designer's guide proved to be satisfactory (at least with these subjects).

The following points relating to the preferred format for presentation of material to designers were also determined on the basis of interviews with subjects.

Material will be more acceptable to engineers if it is in accordance with the following rules of thumb:

(1) The material presented should be as short as possible.

(2) Chapters should be short. It is preferable to have more shorter chapters than fewer longer ones.

(3) Material should be as simply written as possible, preferably with a Flesch count or other index of reading difficulty at the high school level. (No systematic test relating reading level to designer acceptability of handbooks has been done, but it would be an excellent idea to run such a study.)

(4) Illustrations should be in at least 1:1 proportion to written material.

(5) The amount of theoretical or analytical material should be kept to an absolute minimum.

(6) Any written matter should, if at all possible, deal solely with highly specific facts.

(7) To the greatest extent possible these facts should be arranged in tabular form.

(8) The greatest possible use should be made of underlined headings and sub-headings.

(9) Material should be extensively indexed and pages tabbed.

The designs are shown in Figures 1 through 9. The figures indicate that designers vary considerably in terms of the layout they produce in response to a standard data package. Deficiencies in layout could not be attributed to background and training; for example, some of the best panels were contributed by junior personnel and some of the least effective by senior personnel. As indicated earlier, the design process is apparently highly variable, even with the provision of standard data and a standard analytical format. Note also that the use of a military standard like MIL-STD-803A-1 did not produce uniformity, even though it may have served to reduce total variability.

While the variability of the designs produced by the subjects might be questioned on several bases, including the fact that only six designers were used as subjects, or that the data packages presented were perhaps inadequate, the results were replicated by a comparable study performed by the Philco Western Development Laboratory (WDL)[10].

Nine WDL subjects were used: two graduate students in industrial design, three freshmen engineering students, two draftsmen, and two WDL human engineers. As in the Bunker-Ramo study, their subjects were presented with a standard data package consisting of an equipment block diagram, list of hardware controls and displays to be used, an operational description of the system, etc. Only a single control panel was designed, which, however, also gave them nine variations to compare. Substantial differences in layout were also found, and these too could not be ascribed to differences in background and training.

DESIGN EVALUATION

The adequacy of the Bunker-Ramo design drawings was next evaluated by a team of five experts: two human engineers, one industrial designer, one reliability, and one maintainability engineer. The reliability and maintainability engineers were included to determine the contribution of reliability and maintainability engineering to control panel design at the prehardware stage. The term "expert" refers only to personnel who practice their discipline professionally. It is not an evaluation of their qualifications. Considering the results to follow, it is difficult to define operationally who an expert is.

The design evaluation was undertaken to determine whether the control panels designed by the subject designers were satisfactory from a human engineering standpoint. This being true, one might say that the analytic technique described in the designer's guide (Meister and Farr, 1965) was satisfactory. It, of course, assumes that the personnel used as experts were to make the determination of good versus poor human engineering design. It also assumes that there is a one-to-one relationship between the design of the control panels and the efficiency of the designer's guide, an assumption that is highly questionable considering the many intervening variables that affect design.

The manner of evaluation, in the absence of any more objective criteria, was subjective, relying on checklists, ratings and rankings (see appendix VI). The checklist constructed for this evaluation was developed after study of a number of well-known checklist forms (e.g., Krumm and Kirchner, 1956), none of which seemed particularly adequate for evaluation of design in the drawing stage. A limitation was imposed upon

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[10] We are indebted to Mr. Elliot Ushkow of WDL for the results cited here and subsequently.

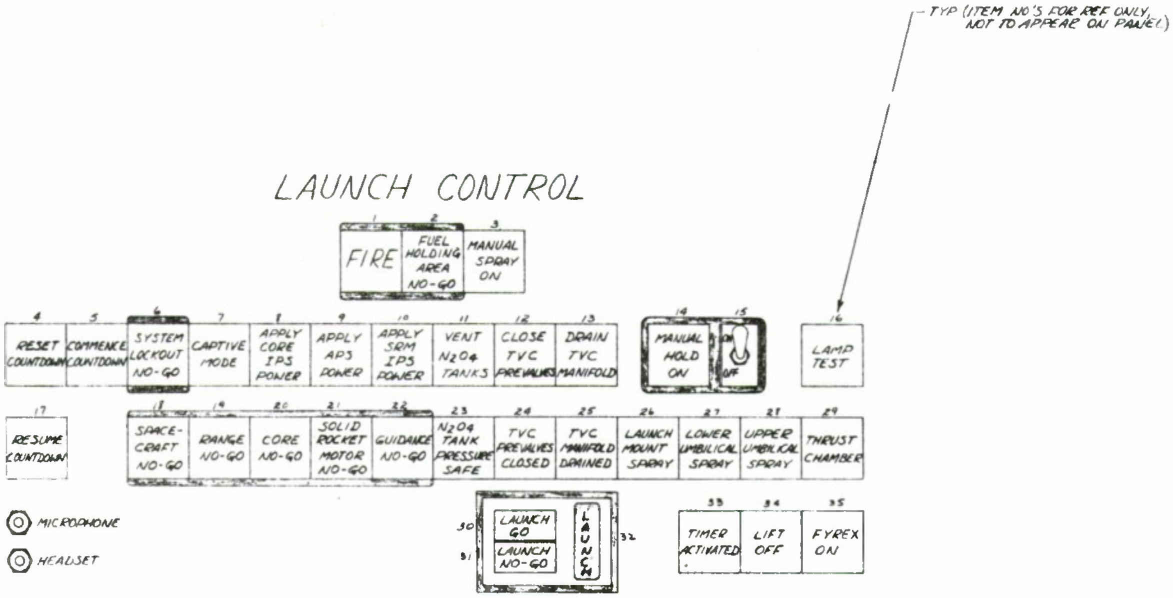

Figure 2. Launch Control Panel (A-2)

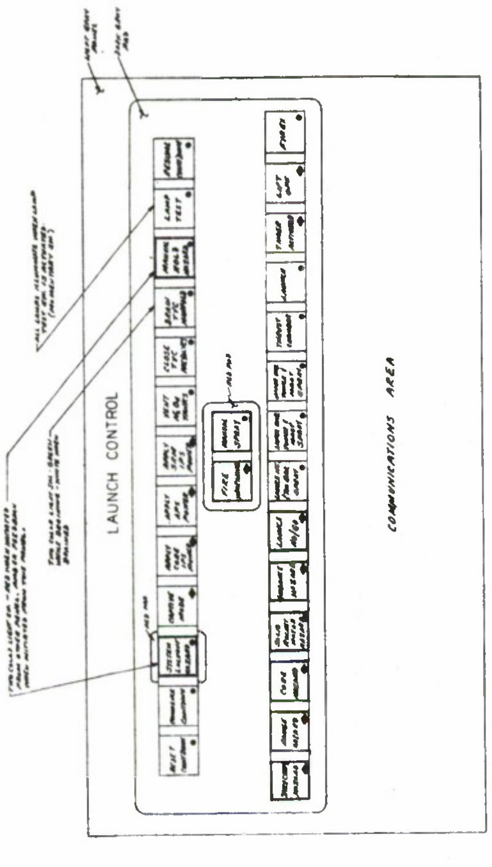

Figure 1. Launch Control Panel (A-1)

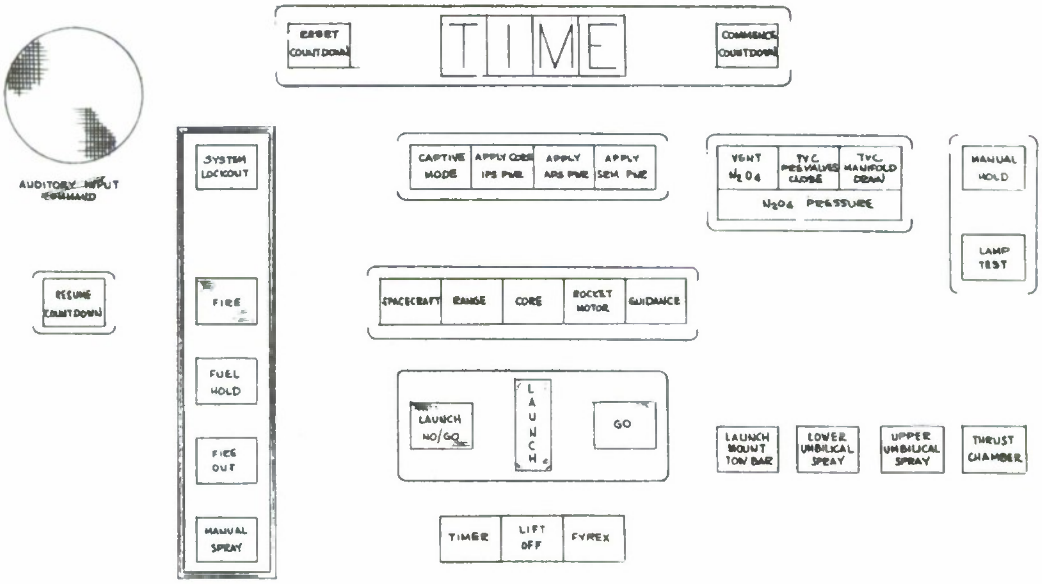

Figure 3. Launch Control Panel (A-3)

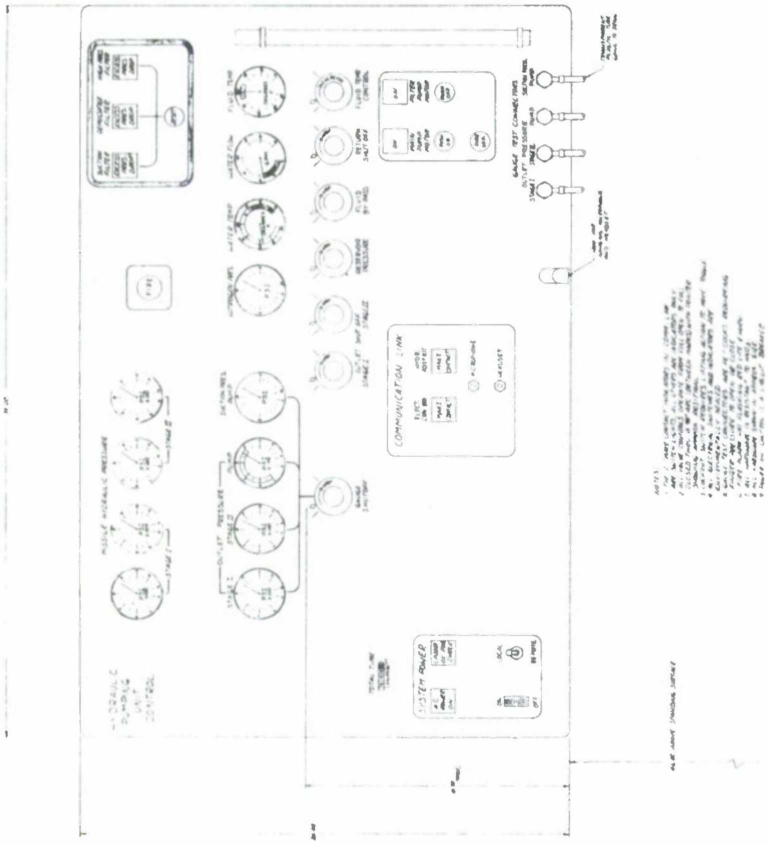

Figure 4. Hydraulic Pumping Unit (B-1)

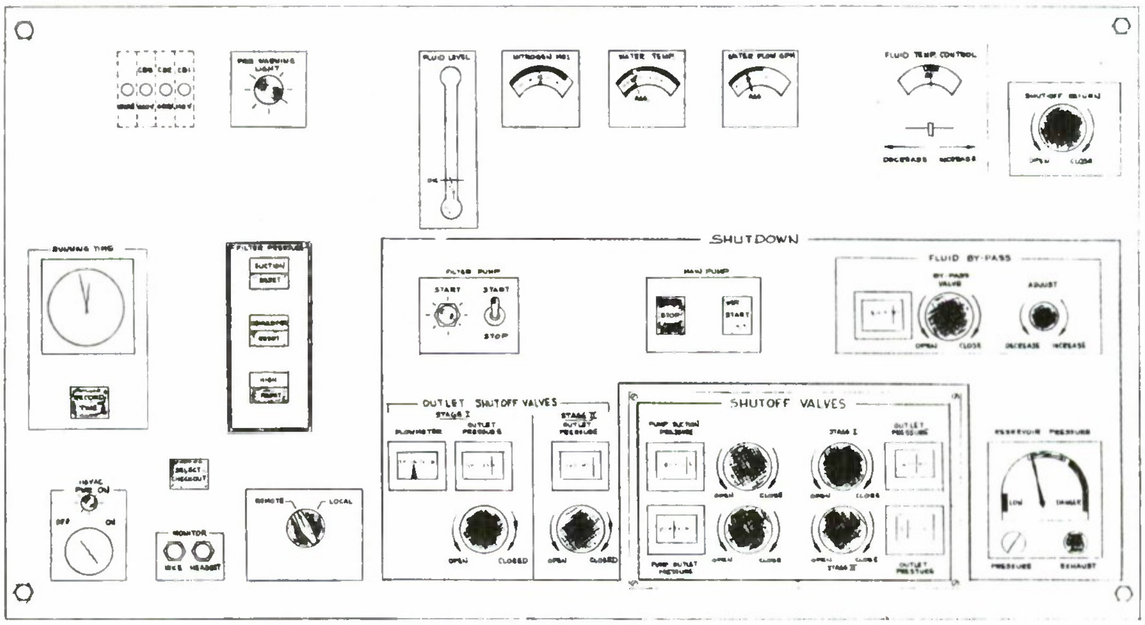

Figure 5. Hydraulic Pumping Unit (B-2)

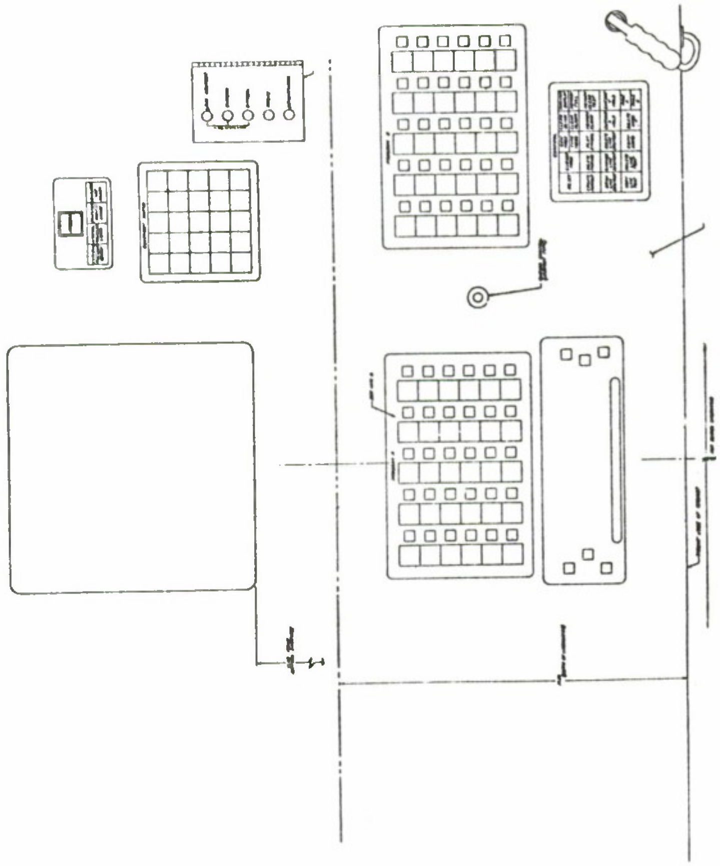

Figure 6. Control/Display Console (C-1)

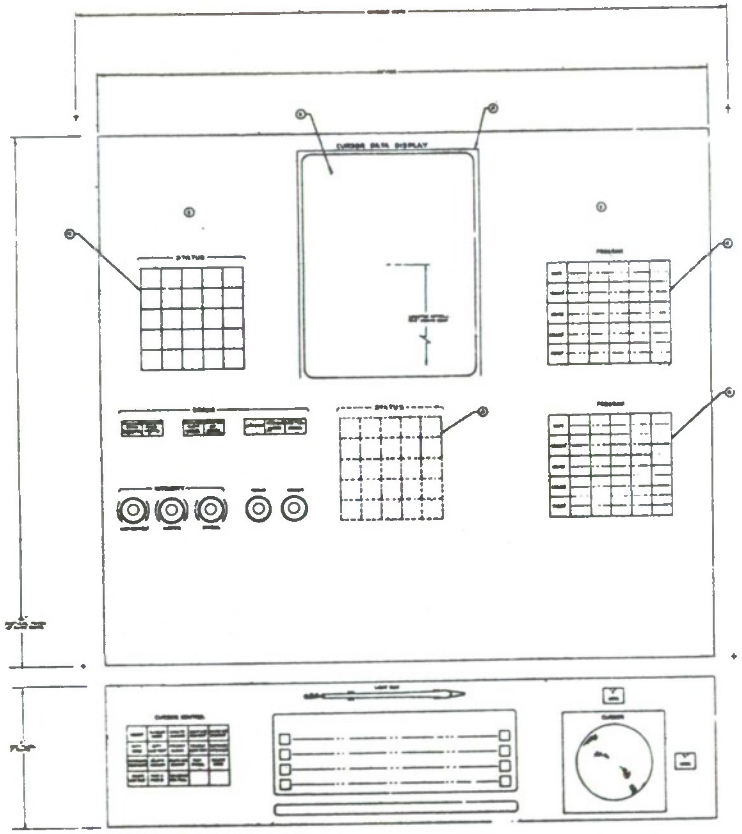

Figure 7. Control/Display Console (C-2)

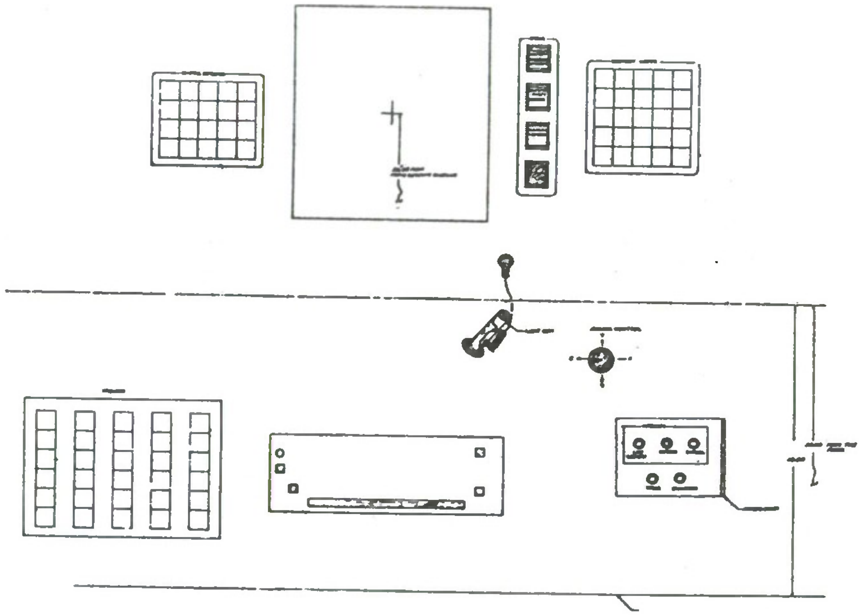

Figure 8. Control/Display Console (C-3)

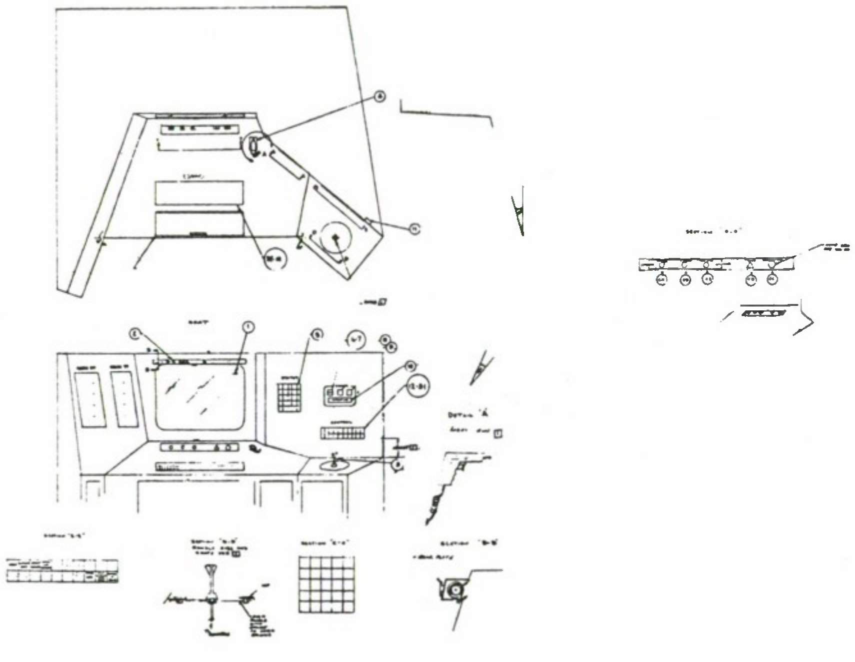

Figure 9. Control/Display Console (C-4)

the number of items selected in order to accomplish the evaluations in a reasonable time period, but all essential characteristics that would apply to layout in the drawing stage were included. Note that efficiency of the checklist cannot be determined from the number of characteristics which it subsumes, as this would assume a pure additivity, i.e., a checklist with ten items is not necessarily better than one containing five items. In the absence of more empirical knowledge, the development of such checklists must be largely a matter of subjective judgment, based on experience.

Evaluators were given two hours at the start of the session to review the designer's guide and to become familiar with the data packages used to produce the designs. Then the evaluators were given the ranking and rating scales and required to evaluate each panel design in succession and in random order. After one design had been evaluated, the rating scale for that design was removed and the evaluator was given a fresh rating scale. Since evaluators represented four specialties, four 9-point scales were presented at each trial, therefore the evaluator could rate for other specialties as well as his own. Actually, only a single rating scale was used by each evaluator.

To determine if exposure to checklist items would change their ratings, evaluators were asked to perform these ratings before being exposed to specific checklist items. Ratings were absolute rather than relative, i.e., it was assumed that the evaluators were rating against an absolute standard of panel perfection. These global ratings could be compared among designs and thus transformed into rankings.

After the rankings, evaluators were given the checklist items. To eliminate any biasing effects of comparing ratings for different panels on the same item, all items were checked for an individual panel design before another drawing was given the evaluator. It also preserved the gestalt character of panel characteristics.

Following checklist evaluation, evaluators were again asked to rate the individual panels to provide a measurement of data reliability. Finally, evaluators were asked to rank each of the panel designs in order of adequacy. Panels in a particular class (i.e., command control, information-retrieval, hydraulic/pneumatic) were ranked separately. These rankings were made to select the designs to be mocked up for the performance evaluation.

The foregoing evaluation methodology can be summarized as follows:

(1) expert indoctrination and examination of data packages,
(2) initial ranking,
(3) initial rating,
(4) checklist questions,
(5) second rating,
(6) second ranking.

The results of the study can be expressed under two headings: (1) human engineering adequacy of the designs evaluated, and (2) consistency of evaluational judgments.

DESIGN ADEQUACY

Regardless of the qualifications that must be imposed on the assumption of additivity of design characteristics, the adequacy of these designs could only be evaluated in terms of the individual checklist items and the overall rating scales. Table I indicates that all panels were rated satisfactory on 70% or better of the 22 items used to evaluate (item 23 was eliminated as being overly general). The evaluations indicated that the panels were generally satisfactory although they contained a number of deficiencies.

These designs were also evaluated by a 9-point scale ranging from completely satisfactory (9) to completely unsatisfactory (1). The ratings were transformed into equivalent 1 through 9 values, and the mean of the ratings determined. The mean was 5.4, indicating that the layouts were considered just slightly satisfactory. However, the rating responses ranged from 2 to 9, indicating that some layouts were considered highly satisfactory.

TABLE I

PANEL DESIGN ADEQUACY AS A FUNCTION OF PERCENT OF TOTAL CHECKLIST ITEMS MARKED SATISFACTORY

Panel	Percent
A1	75%
A2	86%
A3	89%
B1	70%
B2	73%
C1	83%
C2	80%
C3	89%
C4	75%

EVALUATION CONSISTENCY

The foregoing evaluations must be tempered by questioning the accuracy of our expert evaluators. Since no absolute criterion of accuracy in judging control panel design exists, accuracy must be deduced from the reliability or consistency of the judgments. Although consistent evaluations are not necessarily valid ones, inconsistent ones cannot be valid.

To test this point, the ranking data were selected for analysis. Only the second rankings were examined, since it was assumed that second rankings would be more reliable than first rankings, and that any results achieved with second rankings would apply to the first.

Consistency of rankings on the three types of panels (A, B, and C) was determined using the Kendall Coefficient of Concordance (Siegel, 1956). Table II indicates that there was no significant agreement among the evaluators for any of the three types of panels. The amount of consistency is far below what is needed for the 5% level.

It was next considered of interest to determine whether any of the five evaluators varied significantly from any others in terms of the nine panels evaluated. A separate 2-part analysis of variance was performed for (1) the number of checklist items marked satisfactory; and (2) rating scores after transmission to 1 through 9 values. Table III shows a summary of the analysis of variance for the checklist items. Obviously, all differences are nonsignificant, indicating that variations in response were nonsystematic. Table IV shows the summary of the analysis of variance performed on the rating scores. This, too, indicates nonsignificance.

A summary of the evaluation is presented in Table V. Here the average number of checklist items (for the five experts) marked satisfactory for each panel type was determined and transformed into ranks, as were the mean ratings for each panel. These can be compared with the mean rankings assigned to the same panels. Because of the different numbers of panels involved, it is impossible to treat the data statistically; however, the amount of consistency among the evaluators is again low.

The lack of consistency of the evaluations found in this study would be questioned, except for the replication of the results by a comparable study performed at Philco WDL, in which three human factors specialists rated the designs produced earlier by WDL subject designers. Ratings were secured by a paired comparison of each panel design with every other design and then transformed into ratings. The Coefficient of Concordance for the resultant data was .315, which was not significant at the 5% level. The F test performed on the coefficient was .92; for significance, 2.70 would have been required. Apparently there was no more consistency among Philco evaluators than with Bunker-Ramo evaluators. What do these combined results imply?

The overall ratings and rankings enforced a global approach to the evaluation, i.e., evaluators were required to respond to the panel as a total configuration. Any specific criteria employed by these personnel were inherent in their global attitude and were not provided by the measurement device.

The design characteristics checklist enforced a molecular approach in which only specific criteria were employed, without reference to the total panel configuration.

TABLE II

CONSISTENCY OF PANEL EVALUATORS ON SECOND RANKINGS: KENDALL'S COEFFICIENT OF CONCORDANCE (W)

PANELS

EVALUATORS	A			B		C				
	1	2	3	4	5	6	7	8	9	
M	3	2	1	2	1	1	2	3	4	
ID	2	1	3	1	2	2	3	1	4	
R	3	2	1	2	1	2	4	3	1	
HF_1	3	2	1	1	2	4	3	2	1	
HF_2	2	1	3	2	1	3	2	1	4	
	13	8	9	8	7	12	14	10	14	= 95

$$W = \frac{S}{1/12K^2(N^3-N)}$$

N = 3	N = 2	N = 4
K = 5	K = 5	K = 5
(A)S = 14	(B)S = 13	(C)S = 13
W = .03	W = 1.04	W = .02

M = Maintainability Engineer
ID = Industrial Designer
R = Reliability Engineer
HF = Human Engineer

TABLE III

ANALYSIS OF VARIANCE OF CHECKLIST SCORES
(SUMMARY OF COMPUTATIONS)

Source of Variation	Amount of Variation	Degrees of Freedom	Estimated Varisnce
Between Column means (Evaluators)	89.69	4	22.42
Between Row means (Panels)	126.31	8	15.79
Residual	429.91	32	13.43
TOTAL	645.91	44	

For Column Means (Evaluators)

$F = 1.67 \quad n_1 = 4, \quad n_2 = 32$

1.67 is $\angle$ 2.67 at the .05 level.

Differencea not significant

For Row Means (Panels)

$F = 1.18 \quad n_1 = 8, \quad n_2 = 32$

1.18 $\angle$ 2.25 at the .05 level.

Differences not significant

TABLE IV

ANALYSIS OF VARIANCE OF SECOND RATING SCORES
(SUMMARY OF COMPUTATIONS)

Source of Variation	Amount of Variation	Degrees of Freedom	Estimated Varisnce
Between Column means(Evaluators)	38.40	4	9.60
Between Row means (Panels)	17.20	8	2.15
Residual	590.31	32	18.45
TOTAL	645.59	44	

For Column Means

$F = .52 \quad n_1 = 4, \quad n_2 = 32$

.52 $\angle$ 2.67 at .05 level

Differences not significant

For Row Means

$F = .12 \quad n_1 = 8, \quad n_2 = 32$

.12 $\angle$ 2.25 at .05 level

Differences not significant

TABLE V

SUMMARY OF EXPERTS' EVALUATIONS

(CHECKLIST SCORE RANKS AND SECOND RATINGS AND RANKINGS)

		Checklist	Rating	Ranking
Panel	A1	3	2	3
	A2	2	1	1
	A3	1	3	2
Panel	B1	2	1	2
	B2	1	2	1
Panel	C1	2	3	2
	C2	3	2	3
	C3	1	1	1 tied
	C4	4	2	3

The results indicate that in a practical sense a global human engineering evaluation of a panel is not very meaningful, thus if the human engineer is asked how good is this panel as a whole, he is unlikely to provide a very reliable response. However, he is not often asked to do this in system development. Much more often he is asked to review a panel from the standpoint of which specific design characteristics need revision. This he can certainly do. Unfortunately, it is questionable whether a second human engineer, asked the same question of the same panel, would respond the same way, since no quantitative weighting or value has been assigned to the various human engineering criteria. Consequently, one human engineer may choose one design characteristic for his primary attention; whereas a second human engineer may choose another. Both design characteristics may be worth primary attention and, between both human engineers, it is likely that no discrepant design characteristic will be missed.

PERFORMANCE TESTING OF DESIGN

Rationale

The performance testing of the designs produced by the Bunker-Ramo product designers assumes, as does our basic theory, that differences in design configuration should be reflected in differences in operator performance. (This assumption is at the heart of human factors work and serves as its rationale.)

It is further assumed that the effectiveness of the designer's guide (Meister and Farr, 1965) is linked to the efficiency of design, thus if subjects perform more effectively on control panel designs produced with the aid of the designer's guide, this validates or proves the efficiency of the designer's guide. The line of reasoning is a 3-step one: efficiency of guide → more efficient control panel design → more effective operator performance.

The logic involved in this sequence must be qualified by certain considerations. As with any tutorial device, a handbook can only suggest guidelines for design. Since design is a highly creative, variable, process, there are likely to be individual variations

in ability to utilize the designer's guide, consequently, some designs will be better than others. Note that a host of uncontrolled variables affect designer performance, including motivation, experience and training. These are parameters beyond the scope of a designer's guide.

The same idiosyncratic variables affect the performance of operators in utilizing control panels. It is axiomatic that operators can compensate for inadequacies in design. Operator performance, when measured by complex indices such as time and errors, may be too gross to reflect their responses to relatively molecular differences in design characteristics, especially when these design variations are embedded in a total configuration. Only a series of tests in which individual design features are systematically varied can suggest the meaning of the relationship between design and operator performance. This suggests that the interpretation of the test results must be made with extreme caution and cannot be used to evaluate either the designer's guide or the analytic methodology incorporated in the guide.

Why then were the performance tests conducted? They were conducted to experimentally examine the basic assumption of a realtionship between control panel design characteristics and operator performance.

The designs selected for testing were A-2 and A-3, C-1 and C-3. These represent the command control and information retrieval panels respectively. The two examples of each panel type selected represented major design differences in the designs produced by our subjects. The extremes were selected to permit the greatest opportunity for verifying the basic assumption of design/performance relationships. Logically, extreme differences in design should produce mazimum differences between performances on these panels; on the contrary, should no significant differences in performance be found as a function of design differences, the absence of such differences would not be attributable to insignificant design differences, which would be the case were two somewhat similar panels tested.

Although average ratings, rankings and the checklist evaluation suggested that Design C-4 was the least effective design, it was not mocked up since it required a completely different console configuration (wrap-around type) from the one used as the basic console configuration. It is likely that this design example would have been eliminated early in design.

Since C-1 and C-2 were evaluated as being similar in efficiency, and since some anthropometric deficiencies in C-2 were found that would have been discovered during early design, the C-1 panel was chosen as presenting the most realistic layout (in terms of actual probability of becoming hardware) to contrast with C-3 (which was chosen by experts as the most efficient panel).

Panel A-2 was chosen as most efficient because of the average evaluations it received from our "expert" evaluators (see Table V).

Panel A-1 was not chosen as the comparison design because it could not be put into hardware form. In this layout, physical panel restrictions were ignored by the designer; to modify the arrangement to meet standard rack dimensions would have required changing the entire layout. Panel A-3, which was similar to A-1 except that it did meet panel size restrictions, was therefore chosen to contrast with A-2. The hydraulic-pneumatic panels were not tested because there were only two design examples of this type.

Methodology

The four panel designs selected were mocked up in two-dimensional form; that is, paper cutouts of the controls and displays were drawn, colored as appropriate, and laid out in accordance with their original drawings. The C-type panels (information-retrieval) were laid out on a full-scale console simulating an actual information-retrieval console presently under design by the Bunker-Ramo Corporation for the Air Force (see Figure 10). A-type panels, which in their operational configuration were included as part of a 6-foot-high, rack-type chassis, were placed against the wall at the appropriate operational height. The panel mockup was covered with a clear plastic overlay, on which subjects marked appropriate controls and displays with a "grease" pencil when instructed by the experimenter. A series of commands, developed on the basis of previous operationally determined requirements, was tape-recorded. For the A-type panels, there were 33 commands, for the C-type panels, 22 commands[11]. Subjects were instructed that upon hearing a command they were to find the correct control or display and mark the plastic overlay covering that control or display. The interval between commands was approximately 2 seconds. This is a time-stressed task, in the sense that the occurrence of commands was independent of the operator's performance: if the operator was too slow in finding a required item, the subsequent command was given anyway. Since operator response time was not a measure in this experiment, only errors and number of trials to criterion (two successive trials without error) were measures of performance. In rejecting time as a measure of performance, the rationale was that time measures are inherently more difficult to interpret both statistically and logically. Moreover, controlling response time permitted testing in a more convenient (compressed) fashion.

Although it may appear as if a two-dimensional mockup is far from being an adequate simulation of operational panel performance conditions, a study conducted in 1957 indicated no substantial differences between performance on a two-dimensional mockup and that on a three-dimensional mockup. In this study (Meister, 1957) two groups of subjects operated two identical tanking panels, one of which was functional (in terms of possessing hardware, operating controls and illuminated indicators), the other, a drawing representation of the actual panel. Although subject performance on the functional mockup was superior to that on the two-dimensional mockup, the differences were not substantial, and all subjects learned to criterion in the same number of trials. It appears reasonable, therefore, to utilize a two-dimensional mockup as a means of measuring panel operator performance.

Considering what is involved in operationally performing on panels, the actions required of our subjects were essentially similar to those required operationally. Operationally, the panel operator is cued either by verbal or written commands or by internal (memorized) procedures. His major task is to locate the appropriate control or display and to activate it; unless decision-making or display interpretation (not included as a parameter in this study since it tends to complicate the behavioral process) is required, his task is relatively simple.

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[11] Since it was not intended to compare differences between A-type and C-type designs, but rather differences between A-2 and A-3, and between C-1 and C-3, the different number of procedural steps is of no significance.

Figure 10. Simulated Information-Retrieval Console.

Sixteen technicians were selected at random to serve as subjects. This type of personnel was most representative of those who would operate panels in the field. All subjects performed on all panels. Since there were four test panels, order of presentation was systematically varies: four subjects performing in order A2--A3, followed by C1--C3; four in order A3--A2, C1--C3; four in C1--C3, A2--A3; and four in C3--C1, A3--A2. This permitted statistical testing in an analysis of variance design, of two main variables, two types of panels, and four orders of presentation. There was a 1-minute interval between trials, and a 5-minute interval between successive panel performances. Subjects were allowed 2 minutes for panel familiarization before testing. Subsequent to testing on each panel and also after all testing was concluded, subjects were questioned about any difficulties they may have experienced and their preferences for operating the two versions of each panel type.

Results

Two measures of performance were available: (1) number of trials to criterion (2 successive errorless trials) and (2) number of errors made during trials. The results of the statistical analysis are shown in Tables VI and VII.

Table VI indicates that differences among the panels and between subjects on the basis of total errors during test trials were completely insignificant, column means (panel differences) having an F of 1.2, while row means (subject differences) had a F of .187.

Table VII, using number of trials to criterion as the measure of performance, shows essentially the same thing. Since overall variance is insignificant for both measures, any differences between the two examples of each panel type would also be insignificant.

Certainly the panels (in any configuration) presented no great difficulties for the majority of subjects. All subjects reached criterion within 8 trials for all panel types, and the means for each panel were between 3 and 4 trials. From that standpoint one can say that whatever the factors responsible for the production of these designs, they were efficient in producing operable panels.

Far more interesting, from a theoretical standpoint, is the lack of significant differences between examples of the two panel types (comparison of A-2 with A-3, C-1 with C-3). Does this indicate that our basic assumption, that design differences are reflected in operator performance differences, is invalid? We can hardly believe this. Rather, the results suggest strongly that the statement of the relationship in broad terms only is unsatisfactory. The relationship exists, but not in simple 1-to-1 terms. Certain design features have significant effects on performance, while others do not; and the nature of this effect is dependent on the total panel configuration in which these design features are embedded. Only a substantial amount of empirical testing, using much more sensitive measures of performance, will reveal the nature of this relationship.

The reader may feel that there is an alternative explanation of the lack of significant differences found in the study; that these are the result of some experimental artifact, the lack of sophistication of the mockup, perhaps, or the nature of the experimental task.

Fortunately, we can appeal to the results of a similar study conducted by Philco WDL. It will be remembered that 9 Philco subjects each designed a single control panel. The 9 design variations of their basic panel were functionally mocked up and their subjects performed over a series of 7 trials. As in our own case, they found no significant differences in time and error measures as a function of physical differences in the 9 panels.

After testing, subjects were asked to indicate their preference between each example of the two types of panels. Two subjects refused to select a preference between the C-type panels; nine subjects preferred C-1 and five preferred C-3. Ten subjects preferred A-3, while six preferred A-2. That the preferred panels (C-1 and A-3) were the panels with the higher error rates and greater number of required trials to criterion suggests that operator preference is not an adequate method of panel evaluation. It would be highly desirable to replicate the results of this preference test in another study, using a larger sample.

TABLE VI

ANALYSIS OF VARIANCE OF OPERATOR ERROR

(SUMMARY OF COMPUTATIONS

(16 Operators x 4 panel types A-2, A-3, C-1, and C-3)

Source of Variation	Amount of Variation	Degrees of Freedom	Estimated Variance
Between Column Means (Panel types)	440.422	3	146.807
Between Row Means (Operators)	1404.484	15	93.632
Residual	5458.094	45	121.291
TOTAL	7303.	63	

For Column Means (Panel types)

Error Means (A_2) 7.563

(A_3) 10.813

(C_1) 5.063

(C_3) 4.000

F = 1.210 $n_1 = 3$ $n_2 = 45$

$<$ 2.214 at .10 indicating differences are not significant

For Row Means (Operators)

F = .187

$<$ 1 indicating differences are not significant

TABLE VII

ANALYSIS OF VARIANCE OF OPERATOR TRIALS

(SUMMARY OF COMPUTATIONS)

(16 Operators x 4 panel types A-2, A-3, C-1, and C-3)

Source of Variation	Amount of Variance	Degrees of Freedom	Estimated Variance
Between Column Means (Panel types)	10.172	3	3.391
Between Row Means (Operators)	64.484	15	4.299
Residual	1034.344	45	22.985
TOTAL	1109.	63	

For Column Means (Panel types)

Trial Means (A_2) 4.063
(A_3) 4.375
(C_1) 3.688
(C_3) 3.313

$F = .148 \quad n_1 = 3 \quad n_2 = 45$

∠ 1 indicating differences are not significant

For Row Means (Operators)

$F = .187 \quad n_1 = 15 \quad n_2 = 45$

∠ 1 indicating differences are not significant

PART IV

RECOMMENDED RESEARCH

This research has raised a number of complex questions which require investigation. The results suggest that it is no longer possible to accept the unsupported assumption of the adequacy of human engineering criteria or of human engineering evaluations. This does not mean that we need to reject these functions because, regardless of the empirical results achieved in this study, they are both in point of fact quite useful. The questions raised, however, are serious enough to demand some systematic research in this area.

The studies cited earlier do not necessarily require us to reject the underlying assumption of a relationship between variations in design characteristics and variations in human performance. They do suggest very clearly that the precise nature of that relationship is as yet unclear and needs further explication. Essentially the same plea was made by Stellar (National Research Council, 1949) writing in 1949; in the interval the necessary amount of research effort has apparently not been applied.

The lack of empirical testing of the relationship represents (at least as far as control panel criteria are concerned) a long-standing tendency in much behavioral work to accept unverified concepts and hypotheses as genuine currency simply because these have been in circulation for a long time. In this case, the assumption of a relationship between design characteristics and operator performance has been generalized to apply to all parameters and conditions. It hardly seems reasonable, however, to assume that the relationship would apply equally well in all circumstances.

At the same time that the interest in control/display research has been largely dormant, we witness increasingly more sophisticated research, usually involving attempts to quantize gross, system-type parameters (such as operability and maintainability) and to apply them in the framework of highly complex models of system behavior. There is a curious paradox, however, to these efforts. As a technology, involving the incorporation of human engineering principles in hardware, human factors activity is performed under highly degraded conditions. The term "degraded" means that in many cases the opportunity to utilize highly sophisticated methodologies is highly circumscribed. It is, for example, characteristic of many system development projects that once a hardware contract is signed, the time pressures on the project personnel become irresistible. Where a methodology requires any prolonged period of study to be utilized, where it demands precise quantitative background data, the conditions for its use simply do not exist. System development often proceeds at a gallop, with inputs arriving at the last moment, and the industrial human engineer is often asked to make judgments without the opportunity to study the problem at length or perform highly sophisticated analyses. While the practicing human engineer is being given tools of greater and greater sophistication, the opportunity to use them effectively is being progressively eroded.

This does not mean that efforts to develop sophisticated methods should be abandoned. It does, however, suggest that what is needed most urgently at the present moment is the refinement of basic techniques (particularly those that are observational in nature) that can be used quickly and simply. For example, we do not as yet have a simple, satisfactory human factors checklist for panel design that has been shown empirically to produce consistent judgments by human engineers; we do not have a simple technique for estimating the difficulty level of an operator task[12]. In our concern for bringing human factors up to the level of sophistication of other disciplines, we have left behind us large pockets of methodological ignorance which remain to plague us.

Among these pockets of ignorance is one relating to a fundamental element in the work performed by human factors technologists. We refer to the designer. The human engineer does not, except in some restricted circumstances, directly influence design characteristics by producing the design himself. He does so largely through the medium of the designer, to whom the human factors input is only one among a host of competing inputs. How much do we know about the capability of the designer to utilize human factors information, and the way in which that information should be presented to him? Almost nothing.

The orientation of the research we propose is therefore somewhat different from that customarily underlying engineering psychological research. Traditionally, the human responses examined in that research have been relatively discrete and experimentally determined, even when performed in the context of system operations (e.g., detection and discrimination judgments, time and error measures, etc.). Moreover, the behavior examined has focused on the operator as a system element. In view of the inevitable subjectivity of the work they perform, and the importance of that work in developing the design to which the operator responds, attention should also be paid to the designer as an element of total system design. The responses investigated would, instead of being experimentally directed, be products of a realistic design situation. It is shortsighted to concentrate solely on the operator when the professional activities of the designer impact so extensively on the ultimate system product which, in turn, determines discrete operator responses.

(1) It is, therefore, suggested that a study be performed to determine the subjective priority that designers assign to design criteria. It is apparent that some selection of these criteria goes on, and it would be extremely instructive to find out the biases that exist.

This could be determined in two ways: first, by having designer and human engineer subjects rank a list of human engineering criteria in order of priority of importance in the absence of specific design problems to which they could be applied (a sort of absolute level of importance); secondly, by having these subjects do the same thing when the criteria must be applied to specific design problems presented in the form of verbal or graphic descriptions. In this second case, the orientation would be in terms of having to use the criteria to assist in the development of the design.

(2) To determine the value design characteristics have for operator performance, studies should be performed in which these characteristics (e.g., spacing between controls) would be varied systematically (over a range of values) in a mocked up panel layout, and subjects would be required to operate the panel. Variations in design characteristics would be tested both singly and in combination.

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[12] Siegel's technique (Siegel et al, 1962), which has shown promise, is highly complex and would be difficult to apply in the context of most system development.

Since the number of variations in applicable design parameters is very large, "worst case" methodology would be applied to the design of the study, i.e., only the extreme values of the design dimension would be presented. If these proved non-significant in affecting performance, other values on the continuum of that dimension need not be tested.

(3) It is essential to determine in a more systematic fashion than was possible in the present study the designer's behavioral processes during design, and particularly how he utilizes design information. The theoretical formulations suggested earlier could be used as the basis for such studies. Designers could be presented with packages of design information systematically developed and varied, and they would be required to lay out control panels (or any other design) in accordance with that information. In this connection, the methodology of the present study (requiring engineers to develop designs as a function of particular items of information) appears quite powerful for studying design processes. It is not, however, necessary to limit the area of concern to design. Systems engineers and analysts and other development personnel can be presented with carefully contrived problems and inputs of design information and asked to construct designs or answer questions concerning the problem situation. The adequacy of their productions as a function of variations in the amount and type of information, its manner of presentation, etc., would be determined (hopefully without depending on "expert" judgment). The design process could be interrupted at intermediate points before completion to cross-examine subjects to determine what they were doing and why.

CONCLUSIONS

(1) Human engineering design criteria appear to be significant only in relation to anticipated operator performance characteristics. Difficulties in applying these criteria stem from lack of empirical knowledge of the manner in which these design characteristics combine and interact.

(2) The design of a control panel is an attempt to organize design characteristics into a unitary whole. The operator's performance of the panel operation task is determined by his perceptual organization of the panel. It is a reasonable hypothesis that criteria describing principles of panel organization will be more effective and meaningful than those describing discrete design attributes.

(3) Designer response to a standard format for information presentation (e.g., the designer's guide) is generally good. However, designers manifest a high degree of variability in developing control panel drawings, even when presented with a standard package of design information.

(4) A source of difficulty in securing the application of human engineering design criteria by designers is the latters' lack of a system-behavioral approach to design.

(5) The design process is viewed as an attempt to solve a series of problems by analyzing the implications of informational inputs provided to the designer by other development personnel.

(6) A methodology for providing inputs to control panel design, called Operational Contingency Analysis, has been suggested. This methodology has four major steps: (a) selection of the operational factors that may influence panel operation, (b) determination of the effect these factors might have on panel operation, (c) determination of the seriousness of the effect, and (d) determination of the design implications of the operational factor.

(7) Human engineering evaluation of the control panel may be performed either globally (in terms of an organized whole) or in terms of discrete characteristics. Empirical studies of human engineering evaluations indicate that neither type of evaluation is highly consistent.

(8) The major need in the control panel design area is continuing empirical research to refine and standardize simple and quickly applied evaluation techniques. Much information is needed concerning the manner in which designers utilize human factors and other design inputs.

APPENDIX I

FACTORS AFFECTING CONTROL PANEL DESIGN, DEVELOPMENT AND OPERATION

1. Functions
    A. Nature of functions performed by equipment.
        (1) operation
            a. control
            b. monitoring-status
            c. monitoring-tracking
            d. control/monitoring
            e. communications
        (2) maintenance
            a. adjustment/calibration
            b. servicing/cleaning
            c. checkout/diagnosis
            d. removal/replacement
        (3) Mission-determined conditions
            a. potential emergencies
            b. potential overload conditions
            c. potential malfunctions
            d. operational environment factors
    B. Functional interrelationships
        (1) between mission segments and phases
        (2) between tasks
        (3) between subsystems
        (4) between individual equipments
        (5) between panel subfunctions
        (6) between operation and maintenance functions

2. Interfaces

A. Physical interfaces with other equipment

(1) mechanical

(2) electrical/electronic

(3) hydraulic/pneumatic

B. Functional interfaces (see item 1B)

C. Operator Interfaces

3. Constraints

A. Interface constraints

B. Economic constraints

C. Schedule constraints

D. Hardware restrictions

E. Environmental constraints

F. Design philosophy (e.g., automatic, semi-automatic, manual)

G. Specifications and standards

H. Operator limitations

I. Design stage

(1) degree of design firmness

J. State of the art practices

4. Task Characteristics

A. Duration of use

B. Frequency of use

C. Task function

(1) operation

(2) maintenance

(3) command

(4) communications

D. Nature of use

(1) single purpose

(2) multiple purpose

E. Correlation with real time events in environment

(1) high

(2) low

F. Amount of feedback information from the environment

(1) high

(2) low

G. Stimulus flow from environment

(1) duration (long-short)

(2) frequency (high-low)

(3) patterning (continuous-a periodic)

(4) intensity (high amplitude-at threshold)

H. Task criticality

(1) effect of error on task performance

(2) effect of error on system performance

(3) amount of error permissible

(4) error reversability

I. Task demands on operator

(1) skill level required

a. routine vs. non-routine

b. high degree of operator activity vs. low

c. simple vs. highly skilled act

d. difficult vs. easy

e. degree of precision required in operator response

f. amount of external (to panel) information required by operator

(2) behavioral process required
    s. motor control
    b. discrimination
    c. simple monitoring
    d. decision-making

J. Task elements
  (1) varying operstions vs. stable operstions
  (2) sequentially dependent (proceduralized)
  (3) tracking (non-sequentially dependent)
  (4) homogeneous vs. heterogeneous
  (5) time dependent vs. non-time dependent
  (6) standard of performance success available or not
  (7) coordinated with tasks performed on other equipments

K. Relation to terminal output
  (1) terminal task
  (2) intermediste in mission performance

5. Operator Characteristics
  A. Number required by task
    (1) one
    (2) two or more (coordination among them)
  B. Skill level required
    (1) sensory
    (2) motor
    (3) mental
    (4) degree required
  C. Anthropometric considerations

APPENDIX II

INSTRUCTIONS FOR DESIGN TASK

1. This is not a test of your design ability.
2. In helping with this design tssk you may provide information necessary to improve the quality of data required for optimum design.
3. If you do not understand anything in the design guide, make a notation in the guide and call it to the attention of Dr. Meister or D. Farr.
4. When you feel that information is lacking or that added details would help a panel designer, please record your comments or suggestions, as you will be given an opportunity to discuss such changes after panel layout.
5. Consider the detail level required for this task to include:
    s. panel dimensions
    b. overall location of hardware (control and displays) on the panel. This will include identification of selected hardware type and size wherever possible.
    c. function names, titles and abbreviations to the extent of identifying controls and displays.
    d. functional color pads or lines identifying grouping of controls and/or displays (if used).
    e. flow lines or arrows (if used).
6. This design task requires using specific controlled data. Attached is a Design Information Worksheet containing data relevant to a particular control panel. Also furnished is one copy each of a "Designer's Guide for Effective Development of Aerospace Ground Equipment Control Panels" (Preliminary Draft) and Military Standard 803A-1 Human Engineering Design Criteria for Aerospace Systems and Equipment. When any information is required from other than the

above sources it will be necessary to indicate specifically what information is needed and why it is required for panel layout.

7. After the panel layout is complete a discussion will be held to help identify any problem areas or to record suggested changes.

APPENDIX III

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME- LAUNCH CONTROL CONSOLE
PANEL FUNCTION- The Launch Controle Console is used to initiate, monitor and control countdown and firing operations and launch complex readiness.

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
1	D	◁—	RESET COUNTDOWN - INDICATION
2	D	◁—	(LOGIC A) (See Appendix V, Page 70, "Interrelationships") COMMENCE COUNTDOWN - INDICATION
3	D	◀—	(LOGIC A) COMMENCE COUNTDOWN - NO INDICATION
4	C	—▶	(LOGIC A) COMMENCE COUNTDOWN - OPERATE SWITCH
2			
1			
5	D	◀—	(LOGIC B) SYSTEM LOCKOUT-NO HAZARDOUS INDICATION
6	D	◀—	(LOGIC B) SYSTEM LOCKOUT-HAZARDOUS INDICATION
7	D	—▶	(LOGIC B) SYSTEM LOCKOUT-OPERATE SWITCH
5			
8	D	◀—	(LOGIC B) CAPTIVE MODE-INDICATION
9	D	◀—	(LOGIC B) APPLY CORE IPS POWER-INDICATION
10	D	◀—	(LOGIC B) APPLY APS POWER-INDICATION
11	D	◀—	(LOGIC B) APPLY SRM IPS POWER-INDICATION
12	D	◀—	(LOGIC B) VENT N_2O_4 TANKS-INDICATION
13	D	◀—	(LOGIC B) CLOSE TVC PREVALVES-INDICATION
14	D	◀—	(LOGIC B) DRAIN TVC MANIFOLD-INDICATION

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME-
PANEL FUNCTION

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
15	D	←	(LOGIC B) MANUAL HOLD-INDICATE NOT ACTIVATED
16	C	→	LAMP TEST-OPERATE SWITCH
17	D	←	ALL LAMPS ILLUMINATED
18	D	←	NO INDICATION
19			REPLACE FAULTY LAMPS
20	C	→	RESUME COUNTDOWN-INDICATION
21	D	←	RESUME COUNTDOWN-INDICATION
22	D	←	FIRE WARNING-NO INDICATION
23	D	←	FIRE WARNING-INDICATION
24	D	←	FUEL HOLDING AREA-INDICATES GO CONDITION
25	D	←	FIRE OUT-TV INDICATES GO CONDITION
26			NO INDICATION ITEM 24 or 25
27	C	→	MANUAL SPRAY-OPERATE SWITCH
25			
28	D	←	MANUAL HOLD-NO HAZARDOUS INDICATION
29	D	←	SPACECRAFT-NO HAZARDOUS INDICATION
30	D	←	RANGE-NO HAZARDOUS INDICATION

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME-
PANEL FUNCTION

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
31	D	←	CORE-NO HAZARDOUS INDICATION
32	D	←	SOLID ROCKET MOTOR-NO HAZARDOUS INDICATION
33	D	←	GUIDANCE-NO HAZARDOUS INDICATION (AFTER ITEMS 29-33 AND 16-17, PROCEED TO ITEM 47)
34	D	←	ANY ITEM 29 THROUGH 34-HAZARDOUS INDICATION
35			ITEM 34 (AND) NOT NECESSARY TO ENTER PAD AREA
36			ITEM 34 (AND) NECESSARY TO ENTER PAD AREA
37	D	←	TVC PREVALVE CLOSED-INDICATION
38	D	←	TVC PREVALVE CLOSED-NO INDICATION
39	C	→	CLOSE TVC PREVALVES-OPERATE SWITCH
13			
37			
40	D	←	N_2O_4 TANK PRESSURE-INDICATION OF SAFE CONDITION
41	D	←	N_2O_4 TANK PRESSURE-NO INDICATION (NO GO)
42	C	→	VENT N_2O_4 TANKS-OPERATE SWITCH
12			
40			
43	D	←	TVC MANIFOLD DRAINED-INDICATION

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME-
PANEL FUNCTION

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
44	D	←	TVC MANIFOLD DRAINED-NO INDICATION
45	C	→	DRAIN TVC MANIFOLD-OPERATE SWITCH
14			
43			
46	C	→	RESET-OPERATE SWITCH
16			
17			
47	D	←	LAUNCH ORDER (AUDITORY INPUT) FROM CENTRAL COMMAND
48	D	←	COMPLEX WARNING RED (AUDITORY INPUT) FROM CENTRAL COMMAND
9			
10			
11			
15			
49	D	←	ITEMS 29 THROUGH 34 COMPLETE
50	D	←	LAUNCH NO/GO-NO INDICATION
51	C	→	LAUNCH MOUNT AND TOW BAR SPRAY-OPERATE SWITCH
52	D	←	LAUNCH MOUNT AND TOW BAR SPRAY-INDICATION

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME-
PANEL FUNCTION

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
53	D	←	LAUNCH MOUNT AND TOW BAR SPRAY-NO INDICATION
54	C	→	MANUAL HOLD-OPERATE SWITCH
55	D	←	MANUAL HOLD-INDICATION (RETURN PRIOR TO ITEM 49)
56	C	→	LOWER UMBILICAL TOWER AND MAST SPRAY-OPERATE SWITCH
57	D	←	LOWER UMBILICAL TOWER AND MAST SPRAY-INDICATION
58	D	←	LOWER UMBILICAL TOWER AND MAST SPRAY-NO INDICATOR
54			
55			
59	C	→	UPPER UMBILICAL TOWER AND MAST SPRAY-OPERATE SWITCH
60	D	←	UPPER UMBILICAL TOWER AND MAST SPRAY-INDICATION
61			UPPER UMBILICAL TOWER AND MAST SPRAY-NO INDICATION
54			
55			
62	C	→	THRUST CHAMBER-OPERATE SWITCH
63	D	←	THRUST CHAMBER-INDICATION
64	D	←	THRUST CHAMBER-NO INDICATION
54			

CONTROL/DISPLAY REQUIREMENTS

PANEL NAME-
PANEL FUNCTION

No	INPUT/ OUTPUT FUNCTIONS	SOURCE/ RECEIVER	DESCRIPTION
55			
50			
65	C	→	LAUNCH-OPERATE SWITCH
20			
66	D	←	LAUNCH-INDICATION
21			
67	D	←	IF NO INDICATION ON ITEM 66 OR 2J-OPERATE RESET SWITCH
68	D	←	TIMER ACTIVATED-INDICATION
69	D	←	LIFT OFF-INDICATION
70	C	→	FYREX-OPERATE SWITCH
71	D	←	FYREX-INDICATION
46			

APPENDIX IV
DESIGN SUMMARY*

Number	Inter-relation	Commun.	Emergency	Maint.	Feedback	Criticality	I-O Char.	I-O Limits	Oper Req.	C/D Req.	Environ.	Constraints	Number	Inter-relation	Commun.	Emergency	Maint.	Feedback	Criticality	I-O Char.	I-O Limits	Oper. Req.	C/D. Req.	Environ.	Constraints
1	A											ABE	49						X						
2	B												50						X						
3													51	E				X							
4	B				X								52	E											
5													53												
6	C		X										54	F				X	X						
7	C				X								55	F					X						
8													56	G				X							
9													57	G											
10													58												
11													59	H				X							
12													60	H											
13													61	I											
14													62	I				X							
15						X							63	I											
16					X								64												
17													65	J				X							
18				X									66	J											
19				X									67												
20	D				X								68												
21	D												69												
22													70					X							
23	A'		X										71												
24	A'																								
25																									
26			X																						
27	A'		X																						
28																									
29																									
30																									
31																									
32																									
33																									
34						X																			
35																									
36																									
37	B'																								
38																									
39	B'				X																				
40	C'																								
41																									
42	C'				X																				
43	D'																								
44																									
45	D'				X																				
46	A				X																				
47		X																							
48		X																							

*See design implications in Appendix V

APPENDIX V

DESIGN IMPLICATIONS

INTERRELATIONSHIPS

In Appendix III, Logic A and Logic B refer to general countdown relationships. Both are required as indicated for this launch sequence.

Similar letters in Appendix IV indicate possible use of switchlights. Functions under single title might have switch and indicator (two-color change) combined.

Any letter (X') indicates association of these inputs and/or outputs (See Meister and Farr, 1965, pages 32-35 and 48-52.)

COMMUNICATION REQUIREMENTS

(Items 47-48) Auditory inputs required for these and other possible inputs.

EMERGENCY REQUIREMENTS

(Item 6) Hazardous indication.

(Item 23) Requires immediate operation action.

(Item 26) This item indicates the absence of items 24 and 25 inputs. Since item 25 is a TV visual indication, this display will not be considered as a panel requirement.

(Item 27) Manual spray operation to put out fire.

(See Meister and Farr, 1965, pages 35-36.)

MAINTENANCE REQUIREMENTS

(Items 18-19) After lamp test - operator replacement of faulty bulbs is required.

FEEDBACK REQUIREMENTS

Items marked in Appendix IV all require positive feedback to the operator indicating valve open or closed, etc.

CRITICALITY

All items marked require some special consideration regarding location and arrangement since all must function as indicated or the operation may present critical problems. Where some items represent "no indication" of a condition it may be necessary to provide an indication of malfunction, no-go, etc.

CONTROL-DISPLAY REQUIREMENTS

The use of switchlights and matching indicator is preferred. For combined inputs and outputs see Meister and Farr, 1965, pages 32-33.

CONSTRAINTS

This panel should be designed to correspond with the Facility and Status Control Panel. Panel size should be limited to standard 19 inch width including an area for communications. No limit on panel dimensions. Requirements imposed by MIL-STD-803A must be followed.

APPENDIX VII

AGE PANEL EVALUATION RATING SCALE

Considering each control panel with regard to all its characteristics, rate the adequacy of the panel in terms of the degree to which it meets standard human engineering, industrial design, reliability and maintainability requirements. Do this for each specialty individually. If you do not wish to rate the panel in terms of a particular specialty, leave the scale blank. Place a check mark on the scale below which corresponds to your overall impression.

HUMAN ENGINEERING

+100%	+75%	+50%	+25%	0	-25%	-50%	-75%	-100%
completely satisfactory	very satisfactory	moderately satisfactory	slightly satisfactory	neither satisfactory or unsatisfactory	slightly unsatis.	moderately unsatis.	very unsatis.	completely unsatis.

INDUSTRIAL DESIGN

RELIABILITY

MAINTAINABILITY

Describe the characteristics which you felt were unsatisfactory. Please be as precise as you can be.

APPENDIX VI

AGE PANEL EVALUATION RANKING SCALE

Here is a list of the control panel designs you have examined. Considering each one in relation to all others of its same type, assign each control panel a rank until all control panels have been ranked. Do not assign tied ranks to any control panel.

Example:

Type A	Rank
A1	4
A2	1
A3	3
A4	2

Launch Control	Ranking
A-1	
A-2	
A-3	

HPU	Ranking
B-1	
B-2	

Control-Display Panel	Ranking
C-1	
C-2	
C-3	
C-4	

APPENDIX VIII

AGE PANEL EVALUATION CHECKLIST

EVALUATE EACH CONTROL PANEL IN TERMS OF THE FOLLOWING CHARACTERISTICS. INDICATE WHETHER THE CHARACTERISTIC IS SATISFACTORY, UNSATISFACTORY OR NONAPPLICABLE TO THE CONTROL PANEL DESIGN BEING EVALUATED.

1. Has the designer made a correct choice or balance among the governing principles of a. sequence; b. function; c. importance; d. frequency of use?
2. If the control panel has been designed primarily on the basis of sequence of operation, is the resulting sequence of controls and displays correctly located with respect to operating procedure and in correct vertical or horizontal alignment (top to bottom and left to right)?
3. If the control panel has been designed primarily on the basis of operating functions, are the resulting functional modules correctly grouped for ease of operation?
4. Have controls and displays which are functionally related in operation actually been so related on the control panel?
5. If the control panel design involves a combination of sequence and function, are the resulting controls and displays correctly arranged for ease of operation?
6. Does the design place most frequently operated and maximally critical (important) controls and displays in optimal panel areas?
7. Are secondary controls and displays and set up, calibration or test controls and displays placed in more peripheral panel areas or separated from operating controls and displays?
8. Are controls and displays located correctly with regard to the operator's eye level in his seated or standing position?

9. Have panel functional areas been adequately identified by color pads, outlines, nomenclature, etc., to delimit them from other functional panel areas?
10. With regard to location of components, will the operator's hand block the view of nomenclature or associated display when a control is operated?
11. Are controls and displays properly spaced to provide optimum operator use?
12. Has color coding been used correctly to identify critical panel or meter areas and have indicator colors been used correctly to describe required actions or provide status information?
13. Does the panel provide positive indication of control activation or other required feedback concerning the effects of control operation?
14. Does nomenclature clearly describe the equipment or operator function which has been or must be performed, and does it avoid excessive abbreviations?
15. Has the proper type of control or display to perform required functions been selected by the designer?
16. Have controls and/or displays been combined where they are related in operation and where it was feasible without excessively complicating the operator's task?
17. Have only those controls and display been included in the panel design that are actually required for correct panel operation?
18. Where required, have appropriate safety guards been included in panel design?
19. Have all necessary (but only necessary) malfunction controls and displays been included on the control panel?
20. Are associated control-display movement relationships adequately indicated in terms of the proper control to use, the correct control movement (conformity with the controlled display) and correct movement direction(i.e., clockwise)?
21. Does the design pose any special internal or external packaging problems?

22. Does the design present any internal problems with regard to routing and/or accessibility of wires, cabling, fittings, connectors, resistors, diodes, etc.?

23. Does the control panel design adequately take account of the following:

   a. operator requirements;
   b. criticality of inputs and outputs;
   c. input-output characteristics;
   d. emergency requirements;
   e. communication requirements;
   f. maintenance requirements;
   g. environmental requirements.

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13. ABSTRACT

Nine control panel drawings were developed by designers using standard design criteria from a designer's guide. The drawings were then evaluated by five experts representing the disciplines of human factors, industrial design, maintainability and reliability engineering. Sample panels were mocked up and subjects were teste in operational use of these panels. The major results of the overall study were that (1) Designers manifest a high degree of variability in developing control panel drawings even when presented with a standard package of design information; (2) human engineering design criteria appear to be significant only in relation to anticipated operator performance characteristics, and difficulties in applying these criteria stem from lack of empirical knowledge of these relationships; (3) a major source of difficulty in securing the application of human engineering design criteria by designers is the latters' lack of a system-behavioral approach to design. The major need in the control panel design area is empirical research to refine and standardize simple and quickly applied evaluation techniques. More information is needed concerning the manner in which designers utilize human factors and other design inputs.

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Control panels Aerospace equipment Design methodology Human factors engineering Man-machine relations Maintainability Reliability Display systems						

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