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HUMAN PERFORMANCE PREDICTION IN MAN-MACHINE SYSTEMS

Volume I - A Technical Review

by Dorothy L. Finley, Richard W. Obermayer, C. M. Bertone, David Meister, and Frederick A. Muckler

Prepared by
THE BUNKER-RAMO CORPORATION
Canoga Park, Calif. 91304
for Ames Research Center

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FOREWORD

This report is the first of three volumes constituting the final technical report completed under National Aeronautics and Space Administration Contract NAS2-5038, "Human Performance Prediction Tests." Dr. R. Mark Patton was the NASA Ames Research Center Technical Monitor. This study was performed as a part of the Human Factors Systems Program, Walton L. Jones, M.D., Director.

SUMMARY

Over the past three decades there has been an increasing demand for quantitative techniques of human performance prediction in man-machine system tasks. A somewhat bewildering variety of methods have evolved to satisfy this need, ranging from specific task simulation to classical tests of fundamental human abilities.

The basic objective of this program was to review critically tests and test techniques for human performance prediction. Such a review, however, is best facilitated by conceptual and methodological criteria. At a very basic level, therefore, four fundamental questions were asked:

1. To predict what?
2. Upon what dimensions and measures?
3. With what tools?
4. For what purposes?

Asking these questions of this literature exposed some serious and basic problems (Chapter A).

At another level of analysis, tests must be related to human performance dimensions found in human operator tasks which are executed to help achieve system performance criteria. For tests to be meaningful in man-machine systems quantitative transformations must be possible between levels. This required mapping operation turns out to be a formidable technical challenge (see Chapter F).

Both the questions and levels of analysis can be combined into a single conceptual structure, as shown in Figure 1. The question of purpose is external to this matrix, but each of the first three questions can be asked at each of the three levels. The addition of an analytic requirement to interrelate these levels results in a Generalized Methodological Model which can be (1) used to evaluate the existing literature and (2) form a framework of requirements for future test development.

To test validly by any method assumes an understanding and description of the phenomena to be tested. In man-machine system tasks, task taxonomies and task analysis methods are many but inadequate. Chapter B introduces a new method - the Meister Taxonomy - which is used throughout the program (and given a preliminary comparative evaluation against two other methods as reported in Appendix C).

For methodological and evaluation purposes, it was decided that an actual behavioral sample was necessary. A hypothetical Extended Earth Orbital Scientific Laboratory was postulated, and detailed analyses made, at three levels, of:

1. Rendezvous and docking
2. Extravehicular activity (EVA)

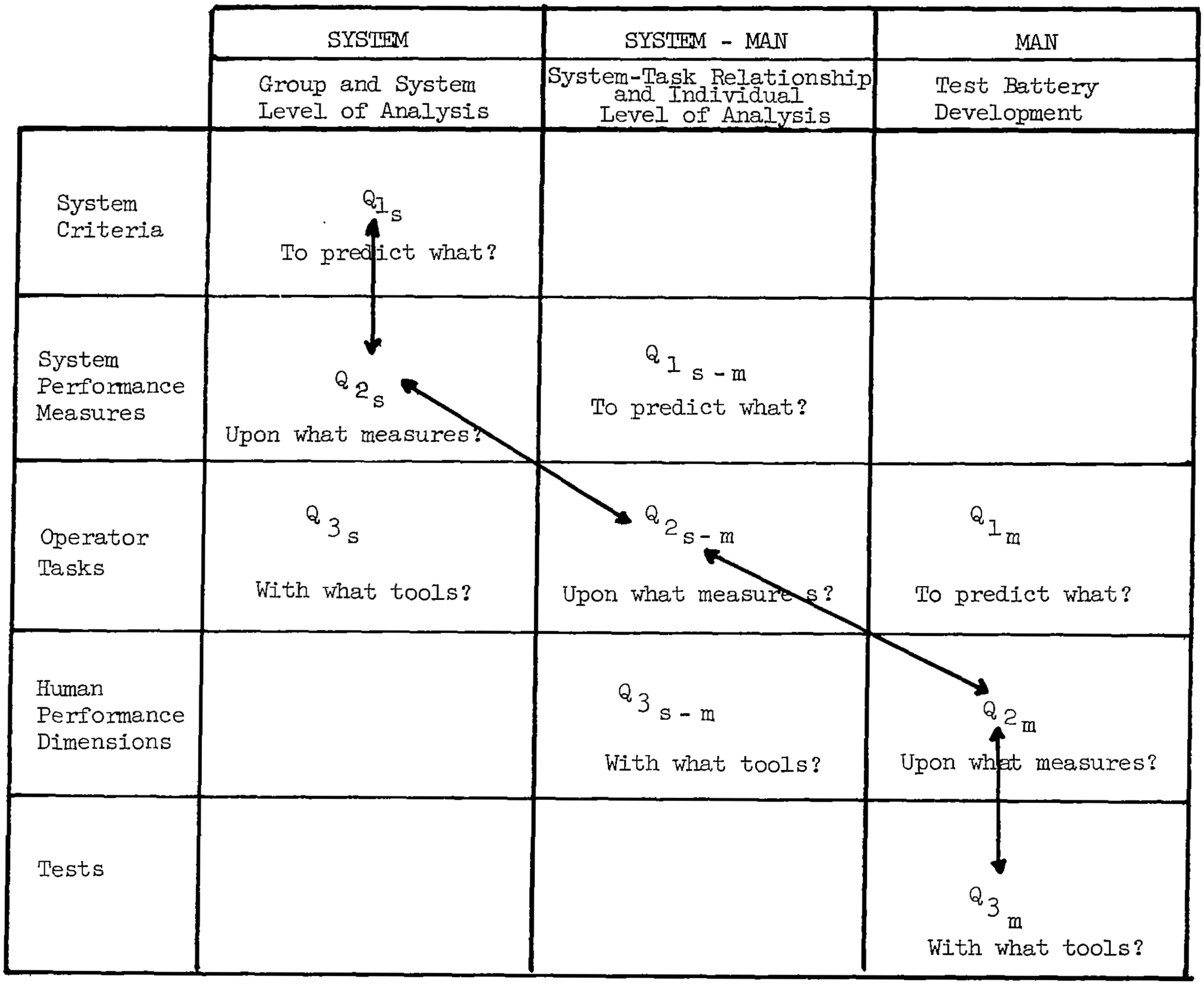

FIGURE 1. A generalized methodological model for human performance prediction.

3. EVA experiments
4. Onboard scientific experiments.

Both operational realism and a wide variety of behavioral examples were sought. (Examples of the analyses may be seen in Appendix B.)

These analyses were used in a number of evaluation contexts, e.g., in the relations of system, task and behavior measures (Chapter F). But, perhaps the most ambitious undertaking was the detailed application of the human performance prediction methodology (developed from the approach implied by Figure 1) to a specific man-machine system activity: the celestial and space-object radiometry experiments conducted during the Gemini V and the Gemini VII missions. Several intensive analyses were performed at several levels to provide specific answers to the first three of the above four basic and essential questions. The analytic outputs were in the form required for our purpose, quantitative human performance prediction; i.e., terms capable of quantitative measure were specified and the relationships between system, system-man and the human operator levels of criterial performance were identified with respect to these terms. These relationships between the system, system-man and man levels of analysis and the terms, i.e., the analytic outputs, are summarized in Appendix A within the framework represented by Figure 1.

It was felt that the existing test literature had to be incorporated into some conceptual system emcompassing individual behavior (Chapter C), response to stressors (Chapter D), and small group performance (Chapter E). From the existing literature, 75 behavioral dimensions were defined and incorporated into a Performance Descriptor X Physical and Interactional Categories Matrix. Among other purposes, this matrix served a useful purpose of mapping performance dimensions into task dimensions (see Chapter C).

The 75-dimension framework also provided a heuristic classification scheme for the existing test literature. In Volume II, over 500 tests are classified and described*, all of which are potential candidates for man-machine system problems.

Future development of test methods and test devices in the man-machine system area for human performance prediction must adhere to certain essential theoretical and methodological requirements (see Chapter G):

* Detailed descriptions are given in Volume III as part of the selected and annotated bibliography of the 486 references reviewed in this program.

1. A more precise understanding and description of system and behavioral phenomena must be accomplished; advances in test validity depend upon it.

2. Prediction problems in this area are multi-dimensional and multi-level; the Human Performance Prediction Methodology developed here is offered as a guide.

3. Future tests and test batteries developments must use modern test development techniques; utility analysis is particularly pertinent and applicable.

Human performance prediction tests can serve a great potential future role in the understanding, prediction, and control of human performance in man-machine systems; but only to the degree that many current theoretical and methodological problems are resolved.

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CHAPTER A: OVERVIEW AND TECHNICAL APPROACH

A continuing and fundamental problem and need in the human factors field is the availability of methods by which precise predictions can be made of human performance in man-machine system tasks. The objective of the present program has been in general to review the current literature on human performance prediction and specifically the test devices which have been developed to make these predictions.

This literature extends back well over three decades (cf., 88)* and it seems particularly useful at this time to evaluate the effectiveness of human performance prediction tests and test batteries. The goal of the program is three-fold:

1. To indicate the issues involved in human performance prediction in man-machine systems;

2. To analyze the published tests and test batteries that may apply to man-machine system prediction problems; and

3. To suggest approaches by which future test developments may be guided. For example, for manned space flight applications, there has been much recent interest in developing simulation or onboard human performance test batteries (cf., 190, 360, 362, 373).

That there are several serious theoretical, methodological, and research deficiencies in this area is a point that will be developed throughout this report. However, it also appears clear to us that there is a positive strategy for future work both to overcome these deficiencies as well as to make maximum utilization of existing data. As an indication of the problems we feel to be paramount, a short sample of the literature has been selected for comment.

A Sample of the Current Test Literature

Table A-1 lists some 20 references and citations covering what we consider to be a representative sample of the test literature currently available. Only certain salient features are described; additional information is provided in Volumes II and III and, of course, the original sources are best consulted for a complete treatment. From the information contained in Table A-1, however, a number of comments may be made which appear to apply to this literature.

* Throughout this volume, underlined numerical references refer to citations found in Volume III: A Selected and Annotated Bibliography.

1. Tests range from single instruments (e.g., 403, 50, 36) to multiple test batteries (e.g., 360, 355, 351, 372, 190) to varying degrees of operational task simulation (e.g., 108, 410, 447). There is no evidence of any standardized testing approach in this literature.

2. The behavior tested ranges from simple sensory phenomena (e.g., 101) to psychomotor tasks (e.g., 403) to elaborate sets of human ability measurements (e.g., 82, 83, 355, 372) to operational performance (e.g., 108, 447). There is no evidence of any standardized behavior classification scheme in this literature or of any attempt to consider basic behavioral categories across the wide range of human performance tasks in man-machine systems.

3. System performance measurements are more noticeable by their absence than presence. Only where operational tasks are involved are system performance measures even considered, and even then are often not adequately measured or reported.

4. The measurement of test validity is extremely rare. Much is made of high face validity and content validity with little concrete evidence that either is present. Only in a few cases are validity coefficients even reported (e.g., 50). Test validity in its classical sense is open to serious question in this entire literature.

5. The majority of tests in this literature are used without direct derivation of test reliability data. Only in the more extensive test programs has reliability measurement been considered by the investigators as a basic and necessary step in test development (e.g., 360, 361, 351, 96).

6. The majority of these tests are said to be sensitive to the effects of stressors on human performance. In most cases, this constitutes simply a demonstration that under some kind of stress situation (usually single dimension) performance changes occur.

These points suggest at the least that this literature suffers from some very fundamental methodological problems.

Four Basic Questions

In reviewing this literature, it has become apparent that a more basic evaluation of the fundamental approach to human performance prediction might be in order. At least four general questions ought to be asked.

1. To Predict What?

There appears to be a question in this literature as to just what is being predicted. Much of the literature is directed toward studies of human capabilities and limitations without, however, any direct relevance to man-machine system applications. On the other hand, a significant portion of the literature (although certainly a minority) attacks immediately the applications context.

At least three levels of prediction can be indicated: (1) individual performance without particular regard to the total man-machine task, (2) group performance extracted from the system task, and (3) final system performance measurement. Ideally, we would like to be able to predict quantitatively each of these three levels and the interrelationships between them. Since we are far from that objective, it would be particularly useful if investigators indicated just what levels of prediction they are in fact attempting.

At the individual and group performance levels, both in the presence and absence of stressors, we need to be able to define precisely the behavior we are trying to predict. This, in turn, requires some task taxonomy, or, at a minimum, some understanding by investigators of the definitions of the behavior exhibited by humans in man-machine systems. To use Miller's (15) distinction between task description and task analysis, we need a "...behavioral understanding (that is, an analysis) of the task requirements..." And we need rules by which data on these behavioral categories are related to final system performance measurement.

As a specific example, we may refer once again to Table A-1 and select at random the behavioral dimensions said to be measured by these tests:

Manual dexterity
Tactual sensitivity
Number retention
Arithmetic computation
Perceptual Style
Tracking
Memory
Problem Solving
Etc.

Valid and reliable testing of these "dimensions" is a minor problem compared with the immense conceptual difficulty of relating these "dimensions" to actual human performance in man-machine system tasks.

In the literature, one particular approach has been used that attempts to derive psychological performance dimensions (cf. 8, 19), within the context of man-machine system tasks. Yet, this approach has been widely criticized on grounds which are not clear. Since the basic technique is factor analytic, perhaps much of this resistance is related to a general lack of confidence in this fundamental approach. Yet, in

TABLE A-1

A Representative Sample of the Man-Machine System Test Literature

Reference Number	Test Name/ Description	Tasks/or Socio-Psychological Dimensions	System Performance Measures	Validity	Reliability
37, 403	Adaptive training	Three-axis acceleration control task STRESS: No known data	Adaptive training measures (37)	Testing pilot skills	Not specified.
50	Embedded Figures	Perceptual style STRESS: EFT related to emergency behavior but not simulator sickness	Driving performance	Emergency behavior $r = .54$ $.49$	$r = .6-.9$
367	Scow Complex Coordinator	Discrete probability matching estimated to tap psychomotor, monitoring and decision making, learning, memory, etc. STRESS: Hypoxia, 367; decompression, 366; alcohol, 376; anti-histamines, 359	None, but said to imply information processing (bit-rate) measures	Not known	Not known
36	Critical Tracking Task	Unstable first-order tracking task STRESS: No data known	Measurement set based on human operator describing function	Not known	Not known
101q	System Stress Test	Two competing tasks; discrete and continous signals STRESS: assumes task-induced stress	None	Not known Comparison of mean data from test and criterion groups	Not known

TABLE A-1 (Continued)

Reference Number	Test Name/ Description	Tasks/or Socio-Psychological Dimensions	System Performance Measures	Validity	Reliability
95	Multiple Test	(1) control panel, (2) bimanual coordination, (3) leg movement, (4) CFF, and (5) steadiness STRESS: Sleep loss	None	Not known	Not specified
96	Complex Behavior Simulator	STRESS: confinement in small altitude chamber	None	Not known	Test-retest r = -.21 to +.96
82, 83	Test battery	Tests of tactile sensitivity, grip strength, manual dexterity, tracking, group performance, mental arithmetic, symbol processing, simple problem solving, and memory. STRESS: underwater performance	None	Assumed to have high face validity to diver tasks	No data given
357, 358	RATER LOGIT	RATER: symbol and color matching LOGIT: higher mental processes STRESS: simulated head rotation, 364, 365	None	Said to be basic test device for stressors and basic abilities	No data given Normative data from 368, 369
360, 361	Integrated Crew Monitoring Test Battery	Physiological measurement plus (1) tracking task, (2) drift monitoring task, (3) arithmetic task, (4) pattern comparison task, (5) maze task. STRESS: pressure suit	None	Said to represent manned space flight tasks	r = .30-.90

TABLE A-1 (Continued)

Reference Number	Test Name/ Description	Tasks/or Socio-Psychological Dimensions	System Performance Measures	Validity	Reliability
355	COMPARE	Warning light monitoring, arithmetic computation, target identification, code-lock solving, probability monitoring, and tracking. STRESS: no known studies.	None	Assumed to test crew performance	No data given
351	Multiple Test Battery	Auditory vigilance, warning-lights monitoring, probability matching, arithmetic computation, code-lock solving, target identification. STRESS: confinement and work-rest cycles	None	Assumed to have high face validity with aircrew tasks	r = .28-.97
372	SINBAD	26 specific tests ranging from simple reaction time to complex manual tracking, monitoring a simple display to solving arithmetic and symbolic problems. STRESS designed for underwater performance measurement	None	Based on abilities analysis of under-water tasks	No specific data cited; in many cases available from other sources
190, 372	Multiple Test Battery	Tests of 18 ability dimensions incorporated into a performance test panel. STRESS: assumed for space applications	None	Based on ability analysis of manned space tasks	No specific data cited; in many cases available from other sources

TABLE A-1 (Continued)

Reference Number	Test Name/ Description	Tasks/or Socio-Psychological Dimensions	System Performance Measures	Validity	Reliability
106	Test Battery	(1) psychomotor, (2) lunar-mission specific, (3) walking. STRESS: Effect of reduced suit pressurization	Erection of lunar structure, space maintenance task	Said to have high face validity to lunar tasks	No data given
108	Maintenance tasks	(1) bolt torquing, (2) connector mating, (3) nut threading. STRESS: Effect of lunar gravity	Performance measures for each of tasks	Said to have high face validity to lunar tasks	No data
410	Simulated Space Performance	Several sample mission tests and performance tests (number retention, bi-manual matching, and reaction time). STRESS: confinement: 15-day	Measurement made, but not reported.	Assumed to have high face validity to MORL mission	No data given
398	Crew Interaction	Crew interaction during 30 day simulated space mission measured by Bales IPA. STRESS: confinement	None	Not known	No data given; available from 123
447	Water Immersion Simulation	Evaluation of water immersion simulation for EVA training. STRESS: multiple	Extensive data on simulator and actual Gemini EVA results	Predictive validity test	Insuffieient data for precise analysis
30	Underwater performance	Manual dexterity and tactual sensitivity STRESS: underwater compression	None	Test of predictive validity	No data

the present literature, only two of the test batteries (190, 372) were specifically developed based on a task analysis of the human performance of interest- using the factor analytic appraoch results.

If the history of industrial psychology is any guide, precise predictions of human performance can only be made based on a thorough (microlevel) understanding of the behavior involved. That level of understanding does not exist within the man-machine system area.

2. Upon What Dimensions?

Adequate measure sets (and the tools by which these are measured) must be based on behavioral dimensional analysis. What would be most desirable is a thorough analysis of the fundamental behavioral dimensions across all man-machine system tasks. Not only is such analysis not available, but there is considerable doubt as to how such an analysis might be obtained.

In many areas of human performance studies, however, it is becoming apparent that behavioral dimensional analysis and conceptual structuring is being attempted despite a lack of sufficient literature and the immense theoretical complexities involved. The impetus to this effort seems to be a growing awareness that some conceptual framework- no matter how tentative or intuitively unsatisfactory- is essential if any understanding is to be obtained from empirical data.* As Humphreys (65) points out in another context, one needs some sort of conceptual model to make sense out of the data.

What this all implies is that some sort of quantitative theoretical modelling is unavoidable. While such modelling has been underway for some years in the basic psychological and sociological literature, investigators in man-machine system problems have generally avoided this avenue with the exception of certain particular areas such as human tracking performance and decision making. Recently, Teichner and Olson (76) have made a major attempt to accomplish this type of modelling for predicting human performance in space environments. Their objectives are worth quoting:

> "....it is our purpose to develop an admittedly tentative theoretical framework to represent the dependence of human performance upon the physiological processes which intervene between the environmental input to the human and measures of his performance. We shall use available concepts and theories as best we can, but

---

* And to give us some indication of what kinds of data we should be collecting.

we shall not feel bound by them. Such an approach has at least heuristic value; it serves a working logic, though imperfect, to be improved upon, or replaced as evidence is gathered. It may lead to a more rigorous framework, albeit a different one. It should also serve as a basis for determining the major requirements of systematic research both to improve the concepts as such and to increase their power in predicting environmental effects."

It is to be expected that much more of this kind of work will be (or should be) appearing in the man-machine systems literature.

With the increased use of multiple test batteries and hence several behavioral dimensions, it is probably inevitable that some attempt should be made to relate these dimensions to the criterion variables. This situation suggests immediately the use of multiple regression and/or canonical correlation quantitative frameworks. Helmreich (263), for example, was able to achieve some success with multiple regression predictions in the SEALAB II results.

Finally, it may be noted that the complete lack of measurement standardization in man-machine systems is certainly not due to a lack of measures (cf., 31, 41, 123, 502) but rather to a lack of standarized dimensions which would specify what should be measured. The present measurement approach in man-machine systems problems appears to be one of measuring what is convenient in lieu of measures that have behavioral or system performance meaning.

3. With What Tools?

There is a very widely held feeling among many human factors specialists that human performance prediction is man-machine systems can only be accomplished by actual tests on the operational equipment or by high face validity simulation. With the present state of our prediction tools, this is probably a very reasonable point of view. However, there are some rather serious problems with this approach.

Prediction tests accomplished on high face validity simulation assumes that there is sufficient knowledge about the system so that fidelity of simulation can be achieved. But, by the time the system has reached that point the design need for human performance prediction has disappeared. Tests, at this point, become either the verification or rejection of predictions already long since made.

Second, one simulation approach is to test techniques within a sort of generalized application setting assuming that the results will apply to later, specific, applications (cf., 408, 409, 411). There is no evidence that this assumption is in fact valid, and there is some evidence in the case of manned booster guidance and control that the assumption was false (41).

Third, there is a small but substantial literature (cf., 30, 107, 388) that specifically shows cases where simulation results did not predict operational performance despite what appeared to be high face validity. And, in some cases, simulation techniques may be quite different from operational techniques in order to achieve performance predictions and training (cf., 405).

There is, in fact, justification for the point of view that suggests that all of our tools- from simple laboratory tasks to the most complete of simulations- are suspect (at least to varying degrees) as to their predictions of human performance. As a case in point, one might note the area of vigilance research. Over the past 15 years, a very substantial human factors literature has been created on vigilance. But what is the relevance of this research for operational performance? Kibler (404) suggests that a shift in the nature of actual monitoring tasks has resulted in the possibility that "...the results of classical vigilance research may not be particularly germane to contemporary monitoring problems." One wonders how many other areas in human factors show the same result.

4. For What Purposes?

Finally, there would appear to be much confusion in the literature as to the specific purpose for which tests are used. In general, there would appear to be a hope that a small test sample will lead to precise quantitative predictions of human performance. Further, as noted, there appears to be an implicit interest in some cases in human behavior alone. And, a good share of the test literature now available is specifically intended for selection and placement.

In some cases it is difficult to escape the conclusion that the test or test performance panel was developed to meet some specific operational setting (airborne or ground simulation) and very limiting engineering requirements at the expense of behavioral meaning, validity, reliability, and usefulness. In these cases, what has resulted is small, compact and efficient devices which produce data with no apparent human performance prediction meaning.

It would be most desirable if future investigators would consider very closely the nature of the information desired by their test tools. Selection, placement, classification or training objectives imply quite different configurations of tests.

A Generalized Methodological Model

In the review of the test literature conducted in this program, there was a substantial suspicion that the major difficulty existed not in the tests per se but in the methodological framework within which the tests were conceived and used. A simple enumeration of the existing tests led to no particularly useful result, and, in fact, simply demonstrated that a rather chaotic situation existed (cf., Table A-1).

For clarification, a generalized methodological model was developed within which (1) the current test literature could be categorized and (2) some rules could be indicated by which future test programs for human performance prediction could be developed. The generalized model is shown in Figure A-1.

What the figure says in effect is that for human performance prediction in man-machine systems we must be concerned with three levels of measurement analysis: (1) system requirements and appropriate system performance measurement, (2) human operator task analysis and the performance measures related to that level, and (3) basic behavioral dimensions involved in human task performance. Further, the precise interrelationships between these levels should be quantified. No attempt was made (nor is it presently possible) to accomplish an integration of the man-machine system and test literature within this model. Rather, it was hoped (1) to indicate where major problems exist and what solutions are presently available, (2) to provide a framework for the current test literature, (3) to indicate where specific lines of future research may be particularly useful, and (4) frankly to attempt to stem the current tide of isolated test development and random empiricism.

1. Despite the existence of many methods for human operator task analysis, there still exists serious problems in this level of analysis. In Chapter B, the problem of task taxonomies is examined, and a specific taxonomy was developed for use in a selected set of manned space flight system tasks. It may be noted parenthetically that a major long-range research program is currently underway by Fleishman and his associates (9) to develop an integration model between task dimension analysis and behavioral dimension analysis.

2. Much of the test literature is in terms of basic socio-psychological dimensions. In Chapter C, a 75-dimension structure is used for the classification of existing tests (see also Volume II for the complete test catalog.) At the present time, it is very difficult to relate these dimensions to applied human operator task performance. However, if such a mapping bridge can be made a very substantial amount of existing test literature is available.

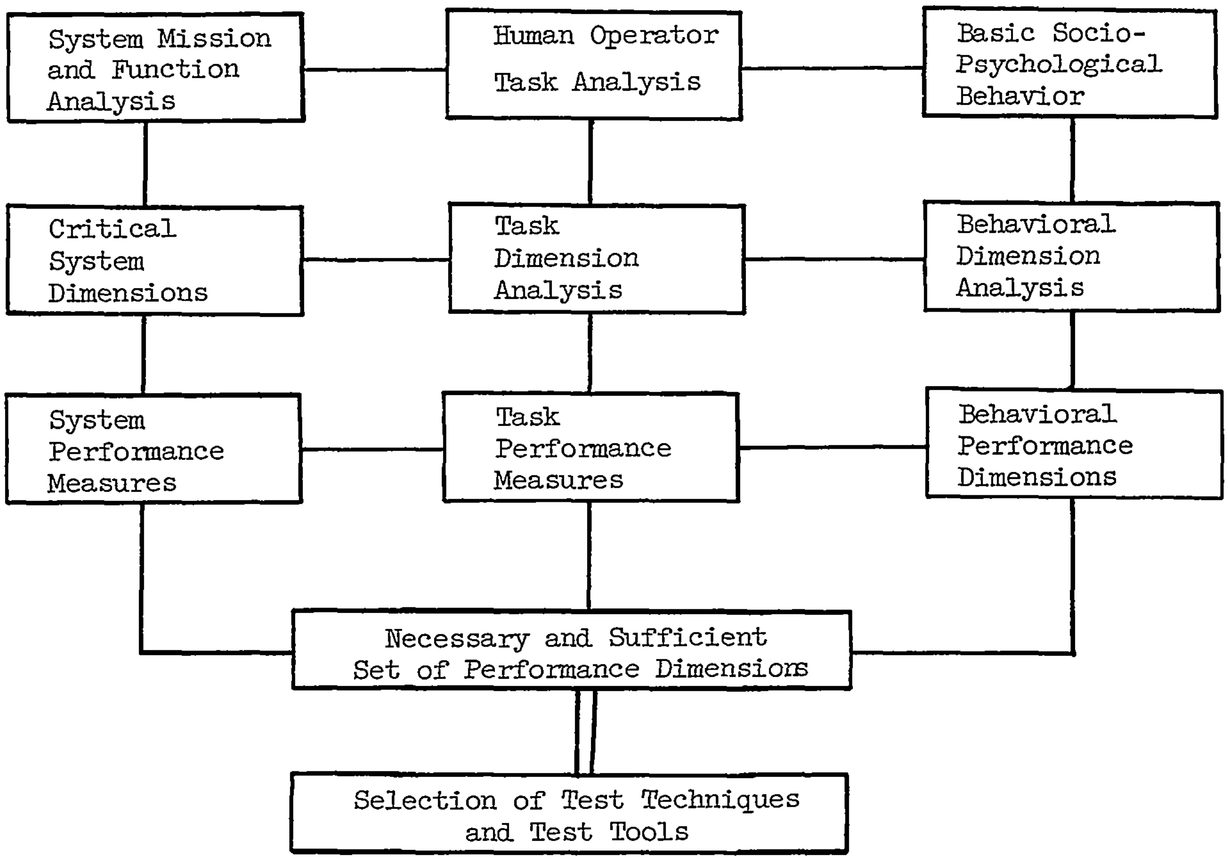


FIGURE A-1. A generalized methodological model for the evaluation and development of human performance prediction tests.

3. The problem of personality variables and stress responses is examined in Chapter D while the problem of group performance dimensional analysis is reviewed in Chapter E. In both cases, we are dealing with a very large yet very confusing literature.

4. The problem of a necessary and sufficient set of performance dimensions is explored partially with respect to behavioral dimensions in the framework of multiple regression equations in Chapter C. There is some suspicion that this space is not particularly appropriate to the complexity of human operator performance; there is no doubt, however, that the data is insufficient to make other than tentative approaches to conceptual structuring.

5. The derivation of system performance measures, and the relation of these measures to task performance and behavioral performance measures, is discussed at length in Chapter F. The full complexity of the total prediction problem becomes apparent at that point.

For over three decades a very substantial test literature has evolved on human performance testing in the general man-machine system context. This literature to date, however, is structured and conceptually fragmented. It would appear that the difficult steps to achieve our prediction goals are yet to come.

To Predict What?

As has been discussed in Chapter A, the initial starting point in the problem of human performance prediction in man-machine systems must be a precise understanding of the behavior one is trying to predict. This step, however, turns out to be one of major difficulty due to a lack of standardization of behavioral description. By inference from the literature one might conclude that we are attempting to predict: individual behavior within the context of some task, or individual behavior as if task-unrelated, or system performance measures in which individual human behavior plays an unspecified part, or some combination of all three. In fact, ultimately we would wish to predict both individual behavior and system performance and in a way that would quantitatively indicate the relation between both. The present state of the literature clearly shows we are a long way from this objective.

In line with the point of view of the present program it was necessary to select some approach to the specification of task and system behavior to which the test literature could be related. What would have been most desirable would have been to have available an analysis of all man-machine system tasks. Such, of course, is not to be found in the literature. Indeed, it is interesting to note that there has apparently never been a thorough attempt to classify the types of behavior that are to be found in this specialized domain called "man-machine system tasks."

To provide a behavioral setting, it was decided to take a specific applied setting which illustrates behavior of interest to the NASA and which provided a sufficiently wide range of behavior from which we could draw examples illustrating major prediction problems. As will be discussed in a later section of this Chapter, the setting was an extended, multi-crew, earth orbital mission.

However, a fundamental problem exists in the method by which human behavior in this, or any other man-machine system, is described. This inevitably requires some consideration of man-machine system task taxonomy- in short, the way by which human behavior is classified within man-machine systems. Many methods of task analysis exist within the literature (cf. 1-29, 32), but a very thorough review of these methods failed to reveal any particular method of direct usefulness, showed the lack of standardization in the field, and suggested that a new attempt at a basic taxonomy was in order.

The Meister Taxonomy

Accordingly, Dr. David Meister, of the technical team, developed an extensive technique of task analysis to be used for the system context of human behavior in the hypothetical Extended Earth Orbital Scientific Laboratory. Beyond that, it is an attempt to derive a general task taxonomic method.

Four taxonomies are presented in this approach, three of which represent different levels of description of operator behavior (Personnel Behavior Taxonomy- Descriptive Levels 1, 2 and 3), whereas the fourth represents the dimensions of the task the operator must perform (Task Dimensional Taxonomy). A number of points should be made concerning these taxonomies:

1. The purpose of using these taxonomies is to derive a set of specifications for tests to measure the various behavioral functions to be performed operationally. The task dimensions describing these functions in essence spell out the characteristics which the tests must have in order to predict the performance of personnel performing these functions. For example: Assume that the function is scientific experimentation, subfunction biological, and that as an end product of the analysis it has been determined that the following task dimensions describe that experimentation: directly viewed stimuli of a qualitative nature with a long duration, involving only one man. The responses required are primarily mediational (analytic) with some fine precision motor responses also required. Accuracy and time requirements are high, but there are no environmental stresses. Feedback is direct, consisting of measured quantitative values. There is no time sharing and consequences of incorrect performance (to vehicle integrity and personnel safety) are nil. Task instructions are unwritten.

On the basis of such specifications for each function, it should be possible to build new tests or select already existent ones on the basis of their conformity to these requirements. We are therefore not concerned with a description of behavior *per se* except insofar as it permits us to extract those dimensions of the task which produce that behavior.

2. The goal of the investigator will determine the particular taxonomy he develops or accepts. Although most researchers in the field have talked as if they wanted a taxonomy of task behavior (i.e., a taxonomy describing the tasks presented to personnel), -hence the term "task" analysis--in reality they have been looking for a taxonomy describing not tasks but the behavior elicited by those tasks. The result is that the task analysis has been largely ineffective in influencing the design of equipment of training programs.

Others have been preoccupied with developing a taxonomy of abilities underlying behavior. Consequently, their taxonomies have not described behavior in the sense in which one views an overt act, but rather have attempted to describe the parameters underlying that behavior. It is one thing to describe a man reaching for a switch; it is another to describe that act in terms of control precision, extent flexibility, etc.

It is not that any one taxonomic method is superior to another, or that universal truth is contained in one taxonomy and universal error in another. It is a fact that despite all pretensions to the contrary, no taxonomy has inherent truth in it. A taxonomy is a convention on which all concerned will agree as representing an acceptable way of denoting things.

Although they would deny it if it were called to their attention, previous workers have talked of a taxonomy as if there were only one; and if that one were developed, it would solve all their problems. This is unacceptable. There are simply a number of possible taxonomies for different purposes, leading to different consequences and outputs. Above all, the value of a taxonomy lies in what it permits one to do with the taxonomic outputs.

3. It is apparent that a number of taxonomies can be developed. The following can be identified:

(a) A taxonomy of personnel behavior or a behavioral taxonomy. Such a taxonomy aims to classify what the operator or the pilot or the maintenance man does or has to do in a given task situation. Such a taxonomy is phrased in terms of subjects' responses to task stimuli, e.g., lifts weight, reads meter, plugs in component.

Subclasses of the behavioral taxonomy include:

(1) Descriptive behavioral taxonomy. Such a taxonomy describes literally what the man does, e.g., steers aircraft, tracks target. Presumably, in its pure form, uncontaminated with other taxonomic variables, it makes no judgments concerning what cannot be overtly seen or described in explicit operations.

(2) Analytical behavioral taxonomy. In contrast to pure description of overt behaviors, this type of taxonomy attempts to classify the underlying mechanisms responsible for the overt behavior. Categories such as short-term memory, decision-making, coding, monitoring, etc. represent the analytic taxonomy. The goal is to penetrate to causal factors. Consequently, the taxonomy deals not with immediate behaviors but with intervening (possibly causal) mechanisms.

A major use has been made of this approach in the analysis of behavioral dimensions for individual and group behavior (see Chapters C and E) and as a method for stress analysis (see Chapter D). Most of the pertinent test literature has relevance only to such a taxonomy.

(b) In contrast to a behavioral taxonomy it is possible to develop a true task taxonomy, that is, literally a taxonomy which describes the dimensions of the task being presented to the operator and its environmental context. Here we are concerned not with what the man does in responding to the task, but what the task consists of. Although the task dimensions differ markedly from those used in the behavioral taxonomy, there is a direct relationship between the behavioral and task taxonomies, such that one is (or should be) readily interpretable in the other's terms.

4. Every taxonomy implies a method of analysis. This has not generally been realized. If one's taxonomy involves a very detailed description of personnel behavior, then the analytic method requires a very detailed breakdown to the subtask or individual stimulus-response combination.

5. The method implied by the concepts described in this paper involve a two stage form of analysis, as follows:

(a) Analyze the behavior required of personnel down to the task (but not to the subtask or element) level.

(b) Analyze the task which elicits that behavior in terms of four categories:

(1) Initiating stimulus (stimulus which requires performance of the tasks, e.g., communication from radio).

(2) Response requirements (action which must be taken in response to initiating stimulus, e.g., record instructions).

(3) Feedback (event which indicates that the response has been performed, e.g., base sign off).

(4) Task context, other factors impinging upon performance of the task.

With regard to the size of the behavioral unit to be described, it is not considered necessary to extract every molecular stimulus-response combination unless that combination is distinctly different from the others in the task of which it forms a part. For example, take the behavior unit, "track moving target on display." Obviously, this unit is composed of many individual behaviors, each of which has a discrete stimulus and response. However, we need not analyze down to the individual muscular action unless that action (in and of itself) is crucial to the performance of the task/function. Another example: in checkout, many switches may be thrown. It is not necessary to identify each switch and perform an analysis of each switch activation. It is sufficient to analyze down to the point of saying, "sequentially throw switches."

Under the three main headings, initiating stimulus, response requirements, and feedback, the categories listed in the task dimensional taxonomy will be applied. In effect these categories are questions about the initiating stimulus, required response and feedback which, when answered, describe the characteristics of task performed. In addition, a fourth column headed "Task Context" will be completed. Wherever possible, quantitative, specific statements should be made about these categories.

After the function has been analyzed in this way, the task dimensions which characterize that function will be summarized. This can be done by listing for each function the different qualitative dimensions with their frequency of occurrence; and, where the dimensions are quantitative, describing their mean and range.

Task dimensions for different functions can be compared to determine commonality among these functions and to extract task dimensional complexes which would require distinct tests. For example, one might find one complex of dimensions which were largely qualitative and analytic, while another might be largely perceptually oriented. These would each require individual tests.

On the following pages, the following taxonomic procedures are presented:

PERSONNEL BEHAVIOR TAXONOMY: DESCRIPTIVE LEVEL 1- Functions

PERSONNEL BEHAVIOR TAXONOMY: DESCRIPTIVE LEVEL 2- Tasks

PERSONNEL BEHAVIOR TAXONOMY: DESCRIPTIVE LEVEL 3- Behavioral Elements

TASK DIMENSIONAL TAXONOMY

They are presented in procedural form to indicate the exact items and steps by which the taxonomies are applied. Specific applications may be seen in Appendix B.

Personnel Behavior Taxonomy: Descriptive Level 1- Functions

The functions referred to do not necessarily describe segments of the manned space mission. (In fact, most of them don't). The initial functions (i.e., preparatory operations, equipment/status checkout, initiation of operations) could follow the sequence in which the mission, is presumed to start, but could also be applied at any time during the mission, as do the other functions. In determining which function the task behavior implements, it is necessary to ask: What is the purpose of these behaviors? An individual task can have but one function:

(1) Preparatory operations

(a) Task planning--involves no motor activity except possibly writing (data). May occur at any time during the mission, for example, at the start of an experiment recording. No precise perceptual activity except reading written material. May involve communication and computation. Probably will involve decision-making and data analysis.

(b) Equipment set up/warmup--This function is quite distinct from task planning in that it may be highly loaded on motor (manipulative) activity. It may, in fact, occur at any time during the mission (e.g., setting up equipment for scientific experimentation). It refers to the initial activation of an equipment where that equipment requires warmup or initial adjustment before it becomes functional. Equipment set up may involve connection or adjustment of equipment (s) before the purpose of the equipment can be accomplished.

(2) Equipment/system status checkout

(a) Pre-task check-performed prior to initiating operations. Visual inspection of displays (e.g., meters) together with some discrete activation of controls to place them in proper position prior to initiating an operation. May involve reading from checklist.

(b) Intra-task check-check performed during the performance of a job. Differs from pre-task check because it is accomplished during rather than at start of job. May involve display monitoring of subsystem status and communications. It is possible that data will be recorded and analyzed and some decision making will be involved. Differs from navigation in the sense that it is relatively discrete, whereas navigation involves continuous perceptual motor coordination.

(3) Initiation of operations

(a) Equipment activation--Involves turning an equipment on to perform its programmed function. In terms of mission sequence this function differs from vehicle activation in the sense that equipment activation may occur at any time during the mission, particularly with reference to scientific experimentation, activating life support equipment, etc.

(b) Vehicle activation--Essentially equivalent to takeoff. Involves performance of control-display operations, communication, tracking, etc. Is distinguished from navigation in the sense that vehicle activation refers to a rather discrete mission segment, whereas navigation may cut across several mission segments. Differs from equipment navigation in that equipment activation refers to the single equipment; vehicle activation refers to the total vehicle system.

(4) Navigation

(a) Course following--Essentially a perceptual-motor activity of a continuous nature (e.g., activating controls in response to or in accordance with display indications or tracking). Essentially means following a preset course when the course has been set in the mission planning function. Like flying an aircraft.

(b) Course correction--Involves major changes in course as opposed to minor corrections which would ordinarily be considered part of course following. Essentially discrete activity, but may also involve the same perceptual motor activity found in course following. Decision-making may be involved as a preparatory stage to course correction.

(c) Orbital establishment--Will involve the same perceptual-motor activity as course following, but specifically for establishing an orbit. In addition, may involve computations, as in using a computer, and decision-making.

(d) Rendezvous--Involves the same perceptual-motor activity as course following, and the same computational and decision-making as in establishing an orbit, but specifically for rendezvous. Tracking will be a major functional component.

(e) Docking--Same as rendezvous, but specifically for docking.

(5) Subsystem management

This function involves monitoring and control of specific vehicle subsystems as distinguished from overall vehicle navigation. May involve display monitoring, communication, data recording and analysis, decision-making, etc. Probably will not involve continuous perceptual motor activity.

(6) Scientific experimentation

This function may be performed at any time during the mission except vehicle departure or re-entry. All task behaviors with the exception of trouble-shooting may be involved.

(7) Installation/assembly

This function involves motor activities primarily (e.g., precise control manipulations); but may also include communication, inspection of equipment, decision-making, movement of equipment, opening/closing hatches. Monitoring, tracking and control-display operations, data recording, computation and analysis would almost never be involved. Assembly might tangentially overlap with experimentation as an initial phase, but rarely.

(8) Maintenance

(a) Programmed maintenance--this function would involve cleaning and calibration, as well as check of equipment functioning. Because of the latter there is some possibility of overlap with equipment/system status checkout, although it would be preferable to restrict equipment checkout to equipments involved in inflight, ongoing vehicle navigation and guidance operations; and confine programmed maintenance to equipment not involved in these operations. Programmed maintenance would not ordinarily be performed on equipments while they are functioning.

(b) Unprogrammed maintenance (malfunction diagnosis and repair)-- This function is a contingent one (i.e., may, but need not necessarily occur). This function should be assigned only when it is assumed that an equipment has malfunctioned. It may involve any of the following task activities; data recording and analysis, communicating, visually inspecting equipment, decision-making, and precise control manipulations (the last for repair).

(9) Emergency responses

This is another contingency function which may involve any of the task descriptors noted, except those involving maintenance and general housekeeping. Specifically excluded from emergency responses is equipment malfunction except where the malfunction has further effects such as endangering vehicle operation or life support of personnel.

(10) Communication

This function is relatively obvious. However, it may present certain problems because communication is involved in many other functions. The communication function noted here refers to an activity in which the prime function is communication; communication which is ancillary or which implements another function should be covered by the other function.

Personnel Behavior Taxonomy: Descriptive Level 2- Tasks*

(1) Perform control-display operations

(a) Activate controls in response to or in accordance with display indications

1 routine programmed procedures (e.g., checkout);
2 routine variable events (e.g., course corrections);
3 emergency situations.

Indicate whether discrete perceptual-motor coordination or continuous.

(These behaviors will involve, but not be completely restricted to, continuous perceptual-motor activity of the type found in

* The only tasks considered are those required by the mission, thus excluding general housekeeping functions.

vehicle navigation and operation. This function should also describe checkout activities when the checkout involves navigation and guidance operations but not preventive maintenance. Otherwise the preventive maintenance descriptor should be applied. A distinction should be drawn between routine and emergency events, although the behavior itself might be the same.)

(b) Activate controls (no prior display indications)

(Apply this category only when there is no reference to display indications. Otherwise apply (1a). This kind of behavior (e.g., calibration) in which there are not display indications, is likely to be somewhat infrequent.

(c) Monitor display indications (no control activation required)

1 Note change in status indications and compare displayed values with required system values. Indicate whether monitoring is prolonged or comparatively short.

(Monitoring implies apparently continuous perceptual activity. Also implies coordination of data from multiple display sources. Control actions may be completely lacking, or, if present, are so infrequent as to be neglible. For example, one might monitor a TV screen and make only those infrequent focusing adjustments needed to maintain the picture. Display monitoring is distinguished from tracking because the displays being monitored describe individual subsystem status, whereas tracking involves a moving target.)

(2) Tracking - determination of position of own and/or target vehicle.

(a) visual tracking only;

(b) visual tracking plus position plotting (recording).

(As indicated in connection with (1c), tracking involves geographic position only and not subsystem status monitoring. Position plotting refers to recording the vehicle track.)

(3) Record data received

(a) from displays

(b) from personnel

In the latter case indicate whether by intercom or face to face.

(Data recording may be incidental to a more significant task behavior, e.g., subsystem status monitoring. Therefore, this category should be applied only if the recording function is explicitly called out in the task description.)

(4) Communicate

(a) instructions and commands

(b) information

Indicate whether via radio, intercom or face to face.

(As in the case of data recording, this behavior may be incidental to a more significant task. This category should be applied only if the communication function is explicitly called out as a specific task. In many cases, it may be impossible to differentiate between instructions and information; in this event, ignore the subcategories.)

(5) Directly or by means of telescopic lens observe external vehicle events (e.g., as in observing star positions through porthole).

(This behavior is differentiated from display monitoring in the sense that with the exception of magnifying devices, no mechanisms are used to display the external event to the crew member.)

(6) Perform quantitative computations

(a) measure quantity

(b) calculate numerical values

(Two behaviors must be differentiated: (a) in an experiment, to perform some measurement behavior, such as measuring magnetic force through the adjustment of an equipment--the equipment manipulations, unless extensive, would not be the major behavior; (b) to calculate numerical values as in adding up a column of numbers. (b) may follow (a), or may be independent of (a)).

(7) Perform preventative maintenance

(a) visually inspect equipment

(b) perform equipment checkout in accordance with routine programmed procedures

(c) clean, lubricate or otherwise perform gross equipment adjustments.

(Visual inspection of equipment involves no control adjustment and does not involve reading subsystem displays. It must be differentiated from equipment checkout because checkout implies control manipulation. Equipment checkout must be differentiated from control-display activation (item 1) because checkout is specifically directed at maintenance. Cleaning, lubrication, etc. involves gross motor actions in relation to an equipment being maintained. Each of these sub-categories should be applied only if the task description specifically calls out the behavior being applied. Where more than one behavior is involved in the task, the category of prime significance should be applied.)

(8) Make decisions

(a) Decide between two or more

1 hypotheses (e.g., concerning meaning of scientific phenomena)
2 discrete alternatives (e.g., modes of operating equipment)
3 general strategies

(b) Analyze alternatives (e.g., different ways of troubleshooting an equipment)

(c) Analyze data

(d) Anticipate/predict events

(e) Hypothesize causal relationships (e.g., that two events are related)

(f) Verify that an hypothesis is correct by reference to available data

(g) Troubleshoot malfunctioning equipment

In each case note whether the decision process was accomplished in relation to (1) programmed mission events; (2) unprogrammed mission events.

(The characteristic which differentiates decision-making from other categories is the amount of cognitive activity of a complex nature involved, and this must be explicitly called out in the task description. Cognition is involved in all behavior; but only conscious efforts at problem solution can involve decision-making.)

Hypotheses describe conjectures about possible contingencies.

Discrete alternatives refer to programmed alternatives for operation, as, two recommended ways of accomplishing docking.

General strategies refer to a series of hypotheses or alternatives extended in time.

Analysis of alternative strategies involves comparison of two or more general strategies.

To anticipate/predict events is to deduce consequences from one or more preliminary events.

To hypothesize causal relationships is to suggest that event A and event B (or a series of events) are related on the basis of some common class characteristic or projected consequence.

To verify hypotheses is to deduce that certain data are in accordance with a particular hypothesis.

Troubleshooting is self-explanatory.)

Note: Unless the task description is specific enough to subcategorize the decision-making behavior, the analyst should simply note the behavior as being decision-making, with a further note that it could be one or more of the subcategories. In other words, the subcategories are to be used if the analyst has in fact sufficient data to make a valid conclusion about the subcategory.

(10) Put on/remove personal equipment

(No comments necessary. Self explanatory.)

(11) Open/close doors, hatches, access covers, etc.

(No comments necessary. Self explanatory.)

(12) Move from one vehicle location to another

(a) self locomotion

(b) transport equipment

(Again this category is self explanatory.)

(13) Read written material

(It is necessary to differentiate reading from (1) monitoring of displays and (2) analysis of data. The reading of written material does not involve displays of any sort; it does not require data analysis in the sense of problem solving or decision making. If one crewman reads a checklist to another during an equipment checkout, to guide the checkout, this is reading. Again, this category should be applied only if the task description specifically calls it out as an activity.)

(14) Precise control manipulations

(a) connect and adjust equipment

(b) remove/replace equipment components

(Subcategory (a) refers to equipment set up for experimentation or equipment calibration; subcategory (b) refers to troubleshooting activities, or at least the removal and replacement of components as part of the troubleshooting process. The kind of manipulations involved are quite precise, not just flipping switches, but such things as connecting or disconnecting wires, inserting jacks, removing tubes, etc.)

Personnel Behavior Taxonomy: Descriptive Level 3- Behavioral Elements

Motor Responses

(1) Depress single control

(2) Turn single rotary control

(3) Adjust control to specified value

(4) Activate bank of controls (in series or all at one time)

(5) Type message on keyboard

(6) Insert object (e.g., component, test probe)

(7) Remove object (e.g., component, test probe)

(8) Lift object

(9) Move object

(10) Place object

(11) Open/close door, hatch, access plate

(12) Connect/disconnect (e.g., equipment, wire)

(13) Write

Perceptual-Motor Responses

(1) Align control in accordance with display

(2) Adjust display using controls (e.g., focus, change range)

(3) Detect target or other unanticipated object

(4) Monitor display

(5) Observe external vehicle events

(6) Inspect component/equipment

(7) Discriminate two or more stimuli

(8) Identify object

(9) Locate object

Mediational Responses

(1) Measure quantity

(2) Calculate values

(3) Compare values

(4) Analyze alternatives (e.g., different ways of troubleshooting, different courses)

(5) Decide between alternatives (e.g., modes of operation)

(6) Anticipate/predict events

(7) Hypothesize that events are related

(8) Verify correctness of hypothesis by reference to available data

(9) Analyze data/information

(10) Extrapolate plot of moving target

Communication Responses

(1) Communicate instructions/information

(2) Ask for information

(3) Listen to radio/intercom

(4) Answer communication

(5) Request permission

Task Dimensional Taxonomy

Analyze the task to the extent permitted by available information in terms of the following categories:

A. INITIATING STIMULUS

1. Type

a. Visual

b. Auditory

c. Kinesthetic

2. Mechanism

a. Directly viewed event

b. Display (indicate type)

c. Written material

3. Characteristics

a. Alphanumerics

b. Raw stimuli (e.g., radar pip)

c. Coded stimuli (e.g., geometric forms)

d. Changing or moving stimulus

e. Static stimulus

f. Multiple characteristics (e.g., visual plus auditory)

4. Information Presented

a. Quantitative (specify value)

b. Qualitative

c. Content (specify)

5. Duration

a. Persistent (indicate approximate duration)

b. Short-lived (indicate approximate duration)

6. Number

a. Single

b. Multiple (indicate number, as, number of indicators, number of pips)

B. RESPONSE REQUIREMENTS

1. Type

a. Perceptual

detection/recognition/discrimination (indicate one)

b. Motor

discrete activation/continuous adjustment/gross physical (lifting, moving, etc.) (Indicate one)

c. Perceptual-motor

d. Mediational

decision-making/computational/analytic (indicate one)

e. Combined (specify)

2. Content

a. Specify nature of response to be made in terms of

(1) goal to be achieved

(2) means by which response is performed

3. Number

a. Discrete/individual

b. Serial/multiple

c. Repetitive

4. Accuracy Requirements

a. High/low (specify quantitatively, if possible)

b. Indicate nature of accuracy requirements

5. Time Requirements

a. Indicate if time requirement (time in which response must be performed) exists; if so, specify time

b. Indicate how long response must be maintained.

6. Stress Factors

a. Indicate if response must be made under physically stressful conditions

b. Describe nature of stressor

C. FEEDBACK

1. Criterion of Correct Performance

a. Quantitative (specify)

b. Qualitative

2. Modality (how feedback is presented)

a. Direct

(1) visual display indicator(s)

single
multiple

(2) auditory

(3) other

b. Indirect

3. Content

a. Describe nature of information presented when subject completes response; or

b. Describe how subject determines correctness of his response

4. Duration

Indicate duration in which feedback indications will persist

D. TASK CONTEXT

1. Number of personnel (required for task performance)

   a. one

   b. two

   c. three

   d. more than three

2. Embedding

   a. Indicate whether response is part of overall procedure; or

   b. Discrete

3. Task Structuring

   a. Task performed according to routine, specified instructions

      (1) Written

      (2) Unwritten

   b. No specified instructions available for task performance

4. Failure Consequences

   Indicate consequences if task is not performed correctly (to be used in weighing task importance)

   a. Danger to vehicle/crew

   b. Possible mission abort

   c. Possible delay in mission accomplishment

   d. Task failure only

5. Time-sharing

   Describe any ancillary task which must be performed concurrently with the one being described.

The Meister Taxonomy: A Final Note

These, then, are the taxonomic methods developed for the analysis of the manned space flight behavior selected in this program. Specific examples of applications are given in Appendix B. Further, a preliminary rating test is given of this taxonomy relative to those of Alluisi and Miller in Appendix C. The Meister taxonomy is the most detailed method known to us. Some (e.g., 16) would object that it is far too detailed; however, considering the complexity of most man-machine system behavior, it is difficult to see how any less complex a taxonomy would be satisfactory. However, as noted before, it depends upon the use to which one is going to put the taxonomy.

The Mission Analysis

Specification of Mission Parameters

The mission chosen for analysis is a hypothetical* Extended Earth Orbital Scientific Laboratory. After examination of the various proposed laboratory missions and the orbital data associated with each*, it was decided that the mission under study would have the following parameters:

Duration:	180 days
Orbit:	Circular
Altitude:	307 miles
Orbit time:	96 minutes
Crew size:	2-5 man
Duty duration:	3 months

The orbital laboratory is placed in earth orbit prior to the launch of the initial three man crew. This laboratory consists of two sections, and it is the responsibility of the initial crew to rendezvous, dock, and mate the two sections, and then enter the laboratory and prepare it for the scientific experiments that will follow.

Obviously, this mission constitutes a very large sample of task behavior. From that sample, four functions were selected for further analysis:

(1) Rendezvous and docking

(2) Extravehicular activity (EVA)

(3) EVA experiments

(4) Onboard experiments

*A very extensive survey was made of the literature from which to construct the hypothetical mission and the four functions. Annotated citations of this literature may be found in Volume III (Refs. 419-486).

This choice was made so that a wide representation was possible of quite different human operator(s) tasks.

The performance of the onboard experiments was of particular interest both with respect to actual experiments that human observers might make as well as to the task analytic structure of human behavior in executing those experiments.

A detailed examination was made of the 49 experiments listed in Table B-1 in order to determine a representative sample of activities to be studied in detail. From this list, it was decided that five categories of experiments could be distinguished. They are:

A. Astrophysical Studies
   (1) Spectral observations
      (a) Solar surface radiation
      (b) Solar flare radiation
      (c) Space density
      (d) Planetary atmospheres
      (e) Stellar atmosphere
      (f) Hot star temperature
   (2) Radiation
   (3) Meteorites
   (4) Cosmic radiation
B. Geophysics
   (1) Magnetic fields
   (2) Energy flux
   (3) Atmosphere
   (4) Energy
   (5) Auroras
   (6) Meteorological
C. Chemical and Physical
   (1) Cystal growth
   (2) Micropiezo electric characteristics
   (3) Fluid interfaces
   (4) Surface effects
D. Biological Studies
   (1) Agriculture
   (2) Bacteriological
   (3) Botany
   (4) Genetics
   (5) Zoology
E. Medical and Human Factors
   (1) Cardiovascular
   (2) Zero gravity effects
   (3) Sleep analysis
   (4) Bone demineralization

From this very large set the following experiments were selected for application at the microlevel task analysis:

1. <u>Stellar atmospheres</u>: specifically it was decided to examine experiments in celestial radiometry and space-object radiometry. For further analysis of this case, Chapter F and Appendix A should be seen.

2. <u>Cardiovascular</u>: specifically heart rate as determined during inflight exercise and work tolerance experiments.

3. <u>Earth atmosphere studies</u>: specifically as conducted in the synoptic terrain photography experiments. A further analysis of this case with respect to system performance measurement may be found in Chapter F.

TABLE B-1

Sample of Experiments

Cardiovascular conditioning	Surface photography
Inflight exerciser	Space object radiometry
Inflight Phonocardiogram	Radiation in spacecraft
Bioassays body fluids	Simple navigation
Bone demineralization	Ion-sensing attitude control
Calcium balance study	Astronaut maneuvering unit
Inflight sleep analysis	Astronaut visibility
Human otolith function	UHF-VHF polarization
Electrostatic charge	Night image intensification
Proton electron spectrometer	Power tool evaluation
Tri-axis flux-gate magnetometer	Zodiacal light photography
Optical communication	Sea urchin egg growth
Lunar UV spectral reflectance	Frog egg growth
Beta spectrometer	Radiation and zero g on blood
Bremsstrahlung spectrometer	Synoptic terrain photography
Color patch photography	Synoptic weather photography
Two-color earth's limb photography	Cloud top spectrometer
Landmark contract measurement	Visual acuity
Reentry communications	Nuclear emulsion
Manual navigation sightings	Agena micrometeorite collection
Basic object photography	Airglow horizon photography
Nearby object photography	Micrometeorite collection
Mass determination	UV astronomical camera
Celestial radiometry	Ion wake measurement
Star occulation navigation	

Once the specific experiments were determined it was necessary to go back into the literature to examine the methods used in conducting these tests. This proved to be a somewhat difficult task as very little material was available on the detailed performance requirements of crew members conducting such experiments. However, detailed microlevel tasks analyses were completed, using Meister's Task Dimensional Taxonomy.

Development of Gross Mission, Operational Sequences and Task Analysis

It should be noted that, consistent with the approach proposed by Meister through the Personnel Behavior Taxonomy, that several steps had to be taken before the Task Dimensional Taxonomy could be applied. These steps included:

1. Definition of the system criterion
2. Development of the initial system functions
3. Development of gross mission tasks
4. Determination of the relationships between gross mission tasks
5. Determination of system variables, goals and indirect relationships
6. Development of operational sequences
7. Determination of relationships in the operational sequences
8. Development of detailed task analysis

For those experienced in system project task analysis, these steps will be familiar ones. However, for those specializing in research and development of generalized human tasks, it may come somewhat as a surprise to suggest that the same kind of detailed analysis is essential prior to experimentation if a meaningful answer is to be derived to the question: To Predict What?

C. MEASUREMENT: BEHAVIOR DIMENSIONS

Approaches to the Dimensional Problem

Essential to the usefulness and validity of human performance prediction tests and test batteries is the definition of the quantities and dimensions which the tests are selected to predict. Far too frequently in test development and application the content that the test is designed to measure is either not clear or is projected to an abstracted quantity derived from a theoretical viewpoint lacking in operational definitions to connect the test with the abstracted quantity. Indeed, with some psychological tests is seems safe to say that the tests measure something, but is is extremely difficult to say just what that "something" is.

Further, the general state of conceptualization and ordering of psychological dimensions can, at best, be said to be in a very crude state. Present-day psychological theory tends to the particular and specific. "Complete systems theory" is more characteristic of the psychology of the beginning of the century and of some three decades ago, and there has been an understandable reaction over the last ten years against large-scale conceptualizations.

Be that as it may, it has appeared essential to this program to attempt some theoretical structuring and ordering along some set of rational sociopsychological (behavioral) dimensions. The intent has been to draw as much as possible from all existing literature, to synthesize as wide a range of behavior as possible, to generate a structure that is compatible with the existing tests and measurements literature, and to provide dimensions that will have meaning with respect to man-machine systems tasks.

The attempt to fulfill these objectives is, to say the least, overly ambitious. In effect, this is to attempt to order and structure dimensionally all major psychological phenomena or, at a minimum, all sociopsychological phenomena that are pertinent to man-machine systems tasks. Not lesser in magnitude is the implied requirement of extracting order from a very large and very chaotic literature. In many respects the range of the possible literature for human performance prediction in man-machine systems tasks is all of the psychological data. Obviously, that is beyond any reasonable or rational bounds.

Nevertheless, some attempt at dimensional conceptualization is mandatory if test devices and test batteries are to be properly developed and utilized.

Methodologically, the most serious problem to be encountered is the fact that there exists at this time a fundamental disagreement within the appropriate psychological disciplines and human factors as to the correct approach to this problem. There are, at present, two explicitly and diammetrically opposed points of view stemming, on the one hand, from the task analytic point of view, and, on the other, from differential psychology. This conflict has been increasing steadily, and within the past two years several publications on these theoretical positions have appeared. Unfortunately, these concepts are presented as directly denying the validity of the "other" technique.

The central issue is the appropriate theoretical approach to conceptualizing man-machine system behavior. To avoid controversial labels, it is perhaps best to name the approaches after the authors who have been most vocal in their points of view. The first of these, therefore, is termed the "Miller-Alluisi" approach, and the second the "Fleishman-Parker" method.

The Miller-Alluisi Approach

In a recent and beautifully written paper, Miller (16) has summarized thoroughly his position on the correct approach to dimensional analysis of man-machine system behavior. Among other points, he establishes six criteria for the task taxonomy to be used:

1. The total number of dimensions should be in the range of 15 to 20 types of behavior that may be seen as part of human operatore performance.

2. The dimensions should allow for discriminations between observed operator activity, but they do not have to be mutually exclusive.

3. The set of dimensions can "...be learned and applied by an experimental psychologist (or perhaps anybody else) in a few hours." (16, p. 69)

4. The set of dimensions should be such as to allow application to training and part-task training.

5. The set of dimensions should allow prediction of human error.

6. "The level of detail in analysis should suggest a point beyond which predictions from available observation or knowledge is no better than random." (16, p. 69)

Miller proposes accordingly an eight-step (sequential) behavioral classification scheme which should fit these six criteria:

1. Concept of purpose: The operator, on some basis, must learn the appropriate stimuli and responses and apply them accordingly.

2. Scanning function: The operator must actively search for task- or self-induced stimuli.

3. Identification of relevant cues function: From all the available stimuli, the operator must identify significant patterns of cues and name them.

4. Interpretation of cues: The operator must assign "meaning" to task stimuli.

5. Short-term memory: The operator must retain all significant information during a given task performance.

6. Long-term memory: The operator must retain extended stimulus-response associations over long periods of time.

7. Decision making and problem solving: The operator must be capable of complex techniques, tradeoffs, and rules by which action alternatives are selected.

8. Effector responses: The operator outputs of all forms both manual and symbolic.

Miller's (16, p. 72) own evaluation of this classification scheme is worth quoting:

"As evaluated according to many criteria of scientific elegance, this list is a mess. One definition overlaps others. The definitions, even in their more extended and refined form, are ambiguous for observing activities. They lack handles for quantification. But I have emphasized that this list is an invention, not a discovery in nature. Its test is in utility, not validity in the sense of physical experiments."

Miller claims "modest professional success" is using this classification scheme in task analysis, procedure design, human engineering design, training and selection.

Others, however, have not had the same feeling of success with this kind of tool. Some experienced human engineers have found that this crude and elementary classification of complex human operator tasks provides nothing but a set of unclear and superficial labels to the behavior involved.* Further, in complex human behavior in systems

*Two members of the project team used the results of the present mission and task analyses (Chapter B, Appendix B) to apply the Miller, Allusi, and Meister taxonomies. The preliminary results are given in Appendix C.

the most casual examination of the performance involved suggests, for example, that the rubric "effector response" is a rather gross label for the incredibly detailed output patterns generated by the human operator. Last, these labels hardly contribute to an understanding of the known complexities of the human operator "scanning function" in multiple-input, poor signal/noise display contexts.

Miller specifically states that the effectiveness of this scheme is a function of the knowledge and skill of the user. To varying degrees, of course, this is true of all methods. But, without some set of guidelines of how to use the classification scheme across the wide variety of human operator tasks, this is little comfort to the human engineer with a system problem. In effect, this suggests that Miller (16) should expand his article title from "Task Taxonomy: Science or Technology?" to perhaps "Task Taxonomy: Science or Technology or Art?" And, further, it must be an art that can be learned by anyone in a few hours.

Despite Miller's denial that the utility of his system is measurable, and despite any evidence other than his reported personal experience that it is usable, some evaluation of the approach seems allowable. His own six criteria may be used:

1. By what a priori reasons can it be stated that human operator behavior can be exhaustively described in 15 to 20 dimensions? Or, for that matter, 5, 8, 10, 15 or 20? The rule really appears to say that regardless of the apparent complexity of the behavior only a relatively few dimensions are needed to adequately describe and accurately define it.

2. By the very nature of the fact that the eight categories are vague, overlapping and superficially defined, behavior discriminations can hardly be clearly differentiated.

3. The criterion of a few hours learning time to use the system is an open invitation to the misuse of human factors technical methods. If a method can be learned in a few hours, it may not be worth learning.

4. The classification scheme alone hardly implies any specific training procedure. Surely, for example, any training in decision making and problem solving will not produce transfer of training to any specific human operator decision making task.

5. These dimensions provide no apparent way of predicting human operator errors. These labels do not imply the category in which errors will occur, what kinds of errors they will be, or the frequency with which they will happen.

6. Nothing in these labels implies the level of predictive effectiveness - from randomness to perfect predictability. This criterion seems to say in effect: "Don't analyze to any more detail than you have to." If this is so, agreement can be quickly reached.

Thus, on the basis of his own utility criteria, Miller's approach seems questionable. But, there also appears to be a serious potential difficulty in this technique. The method implies (1) that a quite gross level of behavioral analysis is not only adequate but desirable and (2) that detailed understanding of human operator performance is not necessary. The possibility could be raised that this kind of approach may well inhibit future understanding of human performance in man-machine systems.

The Alluisi Method. A conceptual approach similar to that of Miller has been advanced by Alluisi (49). Based on techniques derived from several years to study of operational problems of confinement and work-rest cycles (cf. 349, 350, 352, 353), Alluisi has advanced a method based strongly on task face validity. Seven basic categories are used which must be assumed to describe the basic behavior categories found in operational man-machine system tasks:

1. Watchkeeping functions: This effectively means monitoring of the system process.

2. Sensory-perceptual functions: This refer to the task of identification of signals.

3. Memory functions: Both short-term and long-term memory are included in this category.

4. Communication functions: All aspects of man-man communication are designated here.

5. Intellectual functions: Information processing, decision making and problem solving rest in this category.

6. Perceptual-motor functions: Any system requiring psychomotor activity.

7. Procedural functions: Involving not the usual meaning of the term but rather "...such things as interpersonal coordination, co-operation, and organization." (49, p. 379)

With the necessary assumption that these seven categories encompass all significant human operator performance in operational systems, Alluisi has devised and tested a multiple-test battery for these specific functions. A very substantial quantity of data have been collected under excellent experimental conditions with admirable rigor.

The particular multiple-test battery is of course of direct interest here, and has been summarized in Table C-1. It should be particularly noted that the simultaneous use of the tests in various combinations allows for work load analysis. With the addition of physiological measures (e.g., pulse rate and axillary temperature), the multiple-test battery provides 12 measures of performance.

TABLE C-1

Specific Tests in the Alluisi Multiple-Test Battery

FUNCTION	TEST
1. Watchkeeping	Monitoring of Static Processes 1. Warning-lights monitoring 2. Static lights monitoring Monitoring of Dynamic Processes 1. Probability monitoring
2. Sensory-perceptual functions	Visual target-identification task
3. Memory functions	Arithmetic computations
4. Communications functions	Not currently measured; research in planning stage
5. Intellectual functions	Not specifically measured; code-lock task being modified for this function
6. Perceptual-motor	No specific task or test; development in progress
7. Procedural functions	Code-lock solving
8. "Synthetic work"	Simultaneous use of various tests to introduce variable work load

Some theoretical and methodological comments might be made on this synthetic task approach:

1. It is essential that the functions shown in Table C-1 have high content validity with respect to actual human operator system tasks. It would appear that these categories could probably be identified in many actual system tasks. But no attempt has been made apparently to apply these categories to a variety of system tasks to give at least some indication of the extent and limitations of the categories (in the method performed, for example, by Christensen and Mills, 7).

That these categories have superficial face validity (and Miller's as well) is apparent. But, face validity is a treacherous footing for behavioral analysis. It would seem most desirable to attempt to establish face validity in some systematic way across a variety of actual system tasks to check to what extent the categories seem to account for human behavior in systems and to what extent they do not.

2. There has been no evidence presented that these functions and tests have any predictive validity to actual system tasks. As Alluisi (49, p. 383) notes: "We have a problem with regard to predictive validity." He continues with the following comment:

"In summary, what we have is content validity- the tasks appear to include the desired content, to cover the desired functions- and some construct validity. We see no immediate possibilities of obtaining direct measures of predictive or concurrent validity."

3. The assumption that the tests noted in Table C-1 do in fact represent an adequate measure of the functions may be questioned. For example, the assumption that a single test- arithmetic computations- measures memory functions is to ignore completely a very large literature (cf., 63, pp. 110-137) showing (1) that human memory is a multidimensional ability and (2) arithmetic computations is not a particularly good way of testing for memory functions. Second, the code-lock problem has no apparent face validity for the kinds of "interpersonal coordination, cooperation, and organization" found in such real systems as command and control, manned space flight teams, air traffic control, and the like. Third, it is difficult to believe that the single visual target-identification task is truely representative of human operator sensory-perceptual functions. In short, these tests appear to ignore the existing literature with respect to construct validity and to raise some doubts at least with respect to content validity.

It is puzzling, in fact, that with the emphasis on construct validity within the Alluisi categories that a very substantial literature- that on human abilities- has been apparently bypassed.

The Fleishman-Parker Approach

The second, and opposing, approach is based on the methods of differential psychology and the identification of human abilities. Fleishman (8) has been most identified with this approach, and he has presented a thorough analysis and defense of the assumptions, techniques, and methods of this approach. Both Fleishman and his associates (cf., 40, 46) and Parker (cf., 19) have developed and used the so-called "experimental-correlational" approach to a rather wide variety of actual human engineering problems.

In a vastly over-simplified version, this technique derives task taxonomies for the human operator as follows:

1. The basic data for any realistic task taxonomy must start with human performance measures on a broad variety of actual tasks. These tasks may vary from simple laboratory tasks to actual complex man-machine system tasks.

2. From the raw performance measures, it is possible to extract fundamental categories of behavior that apply across actual tasks and categories than can in fact predict human operator task performance.

3. Through the accumulated investigation of many tasks, a basic task taxonomy can be evolved which is exhaustive for human operator tasks and which can be reasonably applied to "new" system tasks.

4. The approach is experimental and quantitative, and assumes that factor analytic methods are valid for extracting the basic behavioral dimensions.

5. One major end result of this process is that we can take system human operator performance and define quantitatively the basic human abilities that underly that performance.

Resistance to this approach has been so widespread in psychology in general and human factors in particular that some general comments might be noted:

1. The basis for much of the human abilities literature over the past 40 years has been based on very elementary laboratory tasks. Miller (16, p. 74) chooses to call these nonsense tasks, and notes: "...I believe it will be a waste of time to try to build a useful task taxonomy from a reference base of nonsense tasks." This statement ignores the extensive research literature based on actual operational tasks using the human abilities method (cf., 8, Table 3, pp. 362-363).

2. There have been no rules established by which one can apply the task taxonomies derived from the human abilities literature to

system tasks. This requires no more and no less expert judgment than, for example, the Miller or Alluisi taxonomies.

3. The list of human abilities over the past 40 years has grown from Spearmen's "G" to an unknown but very large number of basic human abilities. The question has been raised as to whether or not a point will ever be reached where invariance will be found (cf., 65). Further, there have been relatively few attempts to organize this mass into a coherent theoretical framework (but see 51, 77 and particularly 63). At one level, Gagne and Fleishman (10) attempted to create some order in this literature in their unusual introductory psychology text.

4. There is a widespread suspicion that factor analysis as a method is questionable and that the results of complex factor analytic studies may contain large artifactual components.

It might be of interest to apply Miller's six utility criteria to the human abilities task taxonomies:

1. If we are limited to 15 to 20 dimensions of behavior, these task taxonomies are already considerably beyone that point. As an example, some 75 dimensions will be used in the following sections.

2. Assuming the face validity of the factor analytic techniques, the task taxonomy elements are demonstrably mutually exclusive and should imply maximum discrimination between observed behaviors.

3. The general human abilities method certainly cannot be learned in a few hours or, for that matter, a few years.

4. Published data in this literature has clearly demonstrated consistent and significant shifts in the learning process and in the operational tasks, explicitly suggesting training procedures.

5. These taxonomies imply no direct prediction of human error.

6. Assuming the validity of the factor analytic technique, these taxonomies explicitly and quantitatively partial out prediction levels for task behavioral elements. Non-predictable elements (random variance) is directly identifiable.

Selection of the Behavioral Dimensions

In light of the preceding discussion, it is apparent that the present technical effort faced a rather critical theoretical and methodological task in selecting an approach to the definition of behavior dimensions. Our basic approach (see Chapter A) required some method of identification of the dimensions by which tests and test batteries could be organized with respect to what the tests measured.

For several reasons, the results of the human abilities literature have been used in this study to develop a set of behavioral dimensions. Some 75 dimensions were identified. The basic set of 60 dimensions are given in Table C-2. The remaining dimensions (61-75) are discussed in Chapter D.

With our present state of knowledge, the selection of any set of behavioral dimensions is an extreme but necessary risk. It is apparent that (1) no standardized task taxonomy is available and (2) the current literature is in a maximum state of conflict and controversy.* Be that as it may, this program required that some specific approach be selected if the test literature was to be coherently organized.

Several advantages- and disadvantages- were found using this approach:

1. As Fleishman (8) has noted, there is available a substantial body of experimental literature using realistic and operational tasks which show consistent results. This literature was very extensively examined in the derivation of the 75 dimensions. In some cases, such as for dimensions 1-17, a very solid experimental basis is available in the literature (57).

2. However, as will be noted, there were additional dimensions derived from the literature which did not fit easily into this set. Yet, they could not be excluded due to their direct implications to man-machine system tasks and the availability of reasonable tests for them.

3. This approach inherently provides for a microlevel analysis of the behavior. Gross taxonomies such as those of Miller and Alluisi simpley do not allow for examination of the detailed task structure of man-machine system behavior and particularly of that behavior of interest to this program (See Chapter B).

* Miller (16, p. 74) notes: "Acceptance by psychologists at large as a criterion of the validity of any taxonomy is a forlorn hope, but probably the only one if my analysis is even reasonably right."

TABLE C-2

The 60 Behavioral Dimensions

A. INDIVIDUAL GROSS BODY MOVEMENT ABILITIES

1. Explosive strength: general
2. Explosive strength: Leg emphasis
3. Explosive strength: arm-shoulder emphasis
4. Static strength: arm-hand-shoulder emphasis
5. Static strength: leg, trunk emphasis
6. Dynamic strength: arms-flexer emphasis
7. Dynamic strength: arms-extensor emphasis
8. Dynamic strength: legs
9. Trunk strength
10. Extent flexibility
11. Dynamic flexibility
12. Gross body equilibrium
13. Balance-visual cues
14. Speed of limb movement: arms
15. Speed of limb movement: legs
16. Gross body coordination
17. Stamina: cardio-vascular endurance

B. CONCEPTUAL AND THINKING ABILITIES

18. Meaningful memory ability
19. Verbal knowledge
20. Word fluency
21. Numerical ability
22. Concept fluency
23. Discovery of principles
24. General reasoning
25. Seeing implications and consequences (foresight)
26. Flexibility
27. Symbol manipulation
28. Logical evaluation
29. Practical judgment
30. Intelligence

C. PSYCHO-MOTOR ABILITIES

Category I: Fine Manipulative Abilities

31. Arm-hand steadiness
32. Wrist-finger speed
33. Finger dexterity
34. Manual dexterity

TABLE C-2 (Continued)

C. PSYCHO-MOTOR ABILITIES (continued)

tegory II: Gross Positioning and Movement Abilities

35. Position estimation
36. Response orientation
37. Control precision
38. Speed of arm movement
39. Multilimb coordination
40. Position reproduction

Category III: System Equalization Abilities

41. Movement analysis
42. Movement prediction
43. Rate control
44. Acceleration control

Category IV: Reaction Time Ability

45. Reaction time

Category V: Mirror Tracing Ability

46. Mirror tracing (Identified in Gemini tasks)

D. PERCEPTUAL-COGNITIVE ABILITIES

47. Discrimination abilities
48. Perceptual speed
49. Time sharing
50. Closure abilities: speed of closure
51. Closure abilities: flexibility of closure
52. Auditory identification abilities: auditory rhythm discrimination
53. Auditory identification abilities: auditory perceptual speed
54. Spatial abilities: spatial orientation
55. Spatial abilities: spatial visualization

E. MEMORY FUNCTIONS

56. Associate memory: rote memory
57. Associate memory: meaningful memory
58. Memory span: immediate memory
59. Memory span: integration I (large number of detailed rules)
60. Visual memory

4. The basic data in this literature is based, in general, on large subject samples with extensive measure sets over a wide variety of tasks including many human operator tasks. To the contrary, most of the tests developed strictly within the human factors applied context have been based on very selected tasks, with very few subjects, and often, unfortunately, with some question as to equipment reliability.

5. Precise definitions of each specific dimension is a matter of great controversy (indeed, even in some cases to the point as to whether such naming is proper or not). However, relatively the meanings of the definitions are orders of magnitude clearer than the other methods provide and at least they rest on the identifiable variance components of the raw performance measures.

6. There is a rather direct analytic relationship possible between these dimensions and the categories in the Miller and Alluisi taxonomies. For example, following Table C-1, these dimensions can be directly related to Alluisi's functions 2, 3, 5 and 6. Further, they can be at least tentatively identified as components in Miller's elements 2, 3, 4, 5 and 6. Further, the structure of Table C-2 allows both for detailed analysis within the Miller and Alluisi functions and analysis for dimensions beyond these lists.

7. The major advantage of the present conceptualization is that it allows an analysis not only of the man-machine system tests but the entire available psychological test literature as well. In the search for human performance prediction methods and tests- which is the objective of this program- it seems reasonable that all potentially useful knowledge should be examined.

Selection of Test Instruments

With the dimensions of Table C-2 as a guideline, the human factors literature and the general psychological literature was examined for tests applicable to these dimensions. This resulted in such a substantial body of information that separate volumes of this report were necessary to report the results. Volume II presents a technical summary of the over 500 tests examined. Volume III (References 127-376) provides source information on these tests.

When the initial basic set of 60 sociopsychological dimensions had been formed, an extensive search of the literature was instigated to locate tests pertinent to those dimensions (and to possible personality and group dimensions) and to obtain information on these tests which would allow them to be evaluated for use in a particular situation. It was necessary not only to locate an adequate set of tests in, if possible, a variety of forms for each dimension, but also to provide sufficient information on each of these tests such that it would be possible to ascertain when an adequate measurement set, or test battery, had been developed for a set of dimensions. To this end, although attention was given to test catalogues, considerable effort was devoted to the factor analytic, correlational, and experimental researches, and to theoretical and methodological presentations. It should be made clear that not every test reviewed was entered into our test catalogue. For one thing, some tests obviously did not afford direct measurement of our dimensions (e.g., "Citizenship: Every Pupil Scholarship Test"). For another thing, when it became clear that an adequate and varied inventory of tests had been collected for a particular dimension, it was possible to be more selective when evaluating additional tests on the basis of data available and dimensional measurement demonstrations.

When a test was located which was demonstrated, purported, or judged to measure a sociopsychological dimension, an attempt was made to obtain the data necessary for evaluation of the test and to make this information available as an entry in an annotated bibliography. Examples of items of information that may have been obtained for any particular test include: test descriptions; dimension loadings as determined by factor analysis; content or predictive validities as determined, e.g., by correlational analysis; stress sensitivity of the test performance as determined by experimental procedures; test reliabilities, normative data, and costs; and any additional information which appeared useful.

Access to information on the available measurement set for the dimensions.

With the accumulation of test instrument data, it became necessary to develop a system whereby that information would be available as needed. With this in mind, indexes and an information classification system were developed to answer these questions:

1. What tests are available to measure a particular sociopsychological dimension?

To answer this question, the Ability-Test Tables found in Volume II of this report were developed, where the tests are indexed with respect to the selected set of 75 sociopsychological dimensions plus additional dimensions which appeared to be of interest. For example, if one wished to measure dimension number 34, Manual Dexterity, one would turn to pages 63-66 of Volume II. On these pages would be found, in tabular form, the set of tests available to measure Manual Dexterity, the factor loadings or correlation coefficients for Manual Dexterity which have been reported, and the other dimensions also measured by each of these tests along with their associated factor loadings or correlation coefficients.

2. <u>What information is available on a particular test?</u>

An alphabetically ordered Test Index has also been included in Volume II. The Test Index provides cross references to both the Ability-Test Tables and to the Annotated Bibliography of Volume III for each test appearing in the Tables. The bibliographic entries pertaining to any particular test are cited under on or more of the following headings: Data, Descriptions, Costs, Measures (information regarding what the test measures), Stress Experimentation, and Other Experimentation.

3. <u>Can all the measurement information available in the Annotated Bibliography on a general category of sociopsychological dimensions be surveyed?</u>

Attempts to group bibliographic entries were limited by the wide range of dimensions tested in some of the researches; i.e., it was desirable to avoid the problem of extensive cross referencing. It was possible, however, to categorize the test literature section of the Volume III bibliography dealing specifically with test literature (pp. 41-338) to some extent with the following chapter headings: Gross Body Movement Dimensions; Cognitive, Perceptual, Psychomotor, and Memory Dimensions; Personality and Social Dimensions; Vision; Miscellaneous; Performance Panels; Simulators.

Conceptual Structuring of the Dimensions

Implicit in the adoption of the dimensional approach to human performance prediction was the assumption that it would be possible to denote a set of specific procedures which would define a comparatively objective mapping process, a mapping process that would be objective in the sense that the accuracy of the mapper would be more a function of available knowledge, than of the goodness of his intuition. (Mapping, as used here, refers to the a priori selection of those sociopsychological dimensions which would be required to perform an operational task.) Efforts to develop such procedures based on the currently available conceptualizations were not, however, satisfactory. As the development of a prediction methodology progressed, it became increasingly clear that the output of the efforts to bridge the human-task performance gap was necessarily a function of two things: 1) the conceptual definition of the dimensions and 2) the conceptual organization or structure of the dimensions. The various existing definitions and structures are the results of careful a posteriori analyses and appraisals of empirical data. The attempts to use these a posteriori and relatively static definitions and structures as a basis for an a priori prediction methodology for complex tasks performed under variable conditions proved, however, to be very difficult and it became evident that a redefinition and restructuring would be necessary.

Current Conceptual Definitions of the Dimensions

Ability dimensions: the most common definition given to factor analytically derived dimensions is that they are abilities, or essential constancies, whose combination will both describe an individual and serve to differentiate him from other individuals. Fleishman defines abilities with the following comments:

> "These are fairly enduring traits, which in the adult are more difficult to change....at a given stage of life, they represent traits or organismic factors which the individual brings with him when he begins to learn a new task. These abilities are related to performances in a variety of human tasks." (58, p. 148 and 8, p. 351).

Most of the dimensions in our set have been found and interpreted by persons using the "abilities" definition (e.g., Fleishman, Guilford, Thurstone and Woodrow).

Task Dimensions Another, less common, conceptual definition of factor analytically derived dimensions is that they are task classification factors or "task components". Jones (67) represents this point of view with these statements:

"According to the minority view, differential elements arise in the first instance and are organized according to genetic, physiological, and learning principles which bear no essential relationship to the correlations we observe among tests. These correlations are determined by the tests....Correlations among tests reflect the organization of the tests, not the people who take them....the number of factors which can be discovered in any area is not limited by any organization inherent in human beings. It is limited only by the industry and creativity of test makers." (p. 132)

Current Conceptual Organizations or Structures for the Dimensions

Any attempt to evaluate the obtained dimensions with respect to goodness, completeness or contribution to the understanding of the human animal requires that they be organized in a manner that appears to be logically sound. The three dominant structures today from the abilities standpoint are: the simple structure, the hierarchical structure and the three-dimensional matrix.

The String Model, based on the normative, or task component, definition, appears to represent a major conceptual organization of this viewpoint.

The simple structure is almost a lack of structure in comparison to the other two. Developed by Thurstone, it assumes that an orthogonal independence exists between the factors and that the multiple regression prediction equation, $Y = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n$, completely describes the organization of the factors; i.e., they each contribute to performance independently and bear no relationship to one another. A task, then, is considered to require a specific amount of each of the dimensions and an a priori mapping procedure would require a non-structured, albeit intuitive, search among the available dimensions. Fleishman's work on psychomotor abilities appears to be an example of a programatic effort based on this conceptual structure.

The hierarchical and matrix frameworks represent tools and relatively internally consistent and logical models which either have proved or may prove to be very beneficial to either the development of understanding of the human or as methodologies for a particular application. Burt's Hierarchical model and Guilford's SI Matrix model represent major efforts to understand the organization and operation of an internal cognitive realm. Guilford's concept of a dimensional behavioral space and continued efforts to identify these dimensions have been particularly stimulating (63) and fruitful. A major contribution of Thurstone's Simple Structure has been the repeated demonstrations that a limited number of dimensions could account for a large number of behaviors. The Simple Structure has been used successfully for the prediction of the performance of one individual on a small, well-structured task, for the analysis of skill development and a posteriori predictions for the individual on criterion tasks from batteries of ability measures (e.g., 137, 163) and for the development of test batteries that may be useful for assessment of current performance level (190, 372) in the individual. Jones' String Model may prove to be the necessary approach for the development of more efficient training programs (67, 61).

Application of the above definitions and structures to the present project presented difficulties, however. If the "abilities" definition is adopted then the mapping problem becomes a difficult and tenuous one. The mapping must be made from an internal set of abilities which represent an individual person over to a distinctly disparate task. The Simple Structure, Hierarchical, and Matrix organizations of ability dimensions do not conceptually bridge the gap between the two separate entities. The Hierarchical and Matrix ability frameworks serve to describe the internal organization of the individual; but they do not describe how the individual outputs to the external world. And, although the Simple Structure is sometimes considered to constitute a task taxonomy (e.g., 8), again the framework does not imply how the dimensions are organized into an output.

The use of the "task components" definition and it's related model focuses attention entirely on the other half of the person-task combination: the task. Selection and prediction are considered only in terms of performance on the task and on various levels of task complexity. The framework is internally oriented in much the same way as the Hierarchical and Matrix "abilities" frameworks with no functional relationship to the differential characteristics of the human being implied. Further, although research indicates that this approach may be useful for the development of efficient training programs (61), the researches also indicate that it is incapable, in its present form, of predicting total task performance from component task performance (61) without extensive research on that task.

In summary, then, the currently existing frameworks have been useful for particular purposes, but did not provide the structure needed for the mapping process. For our purpose, it was necessary to conceptualize the sociopsychological dimensions in a manner which would allow the prediction of individual and group human behavior under a wide range of circumstances; particularly, the prediction of operator and system performance in ongoing, dynamic and complex man-machine systems (like, e.g., the air traffic control situation) was desired. To reach such a goal it was necessary to 1) define the sociopsychological dimensions in a manner amenable to a priori evaluation of the operational situation in terms of the dimensions, and 2) to organize the dimensions in a manner which would aid the a priori selection of those dimensions required for the operational performance.

Definition of the Sociopsychological Dimensions as "Performance" Dimensions

"Abilities" and "task components" are actually hypothetical labels which support constructs of the psychological structure of humans and the normative structure of tasks. In factor analytic studies, however, it is actually criterial measures of performance that are taken on a set of individuals over a large battery of tests and tasks. Some representative performance measures include: number of correct answers, amount of delay or time required, number of errors, accuracy or amount of deviation from a standard, and various measures of intensity as, for example, force. The factor analytic technique than manipulates these measures such that commonalities are established across the measure set. These commonalities, called factors or dimensions, provide both the essential terms of performance prediction equations and, as the term "commonality" implies, the common performance components across tests and tasks.

It is intended, then, that the dimensions be understood to represent the human organized and differentiated in terms of performance. That is, they are considered to provide the answers to the questions: "How did that man, or that group of men, go about DOING, or accomplishing the task?" "What were the differential elements of DOING that created, and will therfore account for, the performance or behavior variance?" If the factors are conceptualized in this manner then the gap created by the separate and disparate entities of individuals with "abilities" and tasks with "task components" is considerably diminished and more amenable to objective appraisal.

If the dimensions are conceived of as performance components, attention is no longer focused on the internal structure of only the man, or the task. Rather, attention can be directed towards an appraisal of the demands on the human implied by: 1) the task structure in a particular environment, configuration and/or system and 2) the particular measurement of performance that is under consideration.

The concept of performance dimensions which are common to tests and operational tasks also fits in with an often tacit but basic assumption that is made with regard to the usefulness of tests, simulator performances, experimental conditions and training devices. That assumption is that what the person is required to do, or perform, in the test situation, he will also be required to do in the real operational situation. In other words, the tested performance elements, or dimensions, are expected to recur in the operational environment if the simulation has content validity. If stress is introduced and performance is affected, then degraded performance is expected to recur in the real situation. The operational environment may require additional performance elements but it is assumed that most of the tested elements will form at least a subset of those needed.

If the above paragraphs are accepted then four statements can be made which bear directly on the methodology development and on the methodology evaluation.

1) A simulation continuum exists extending from very narrow and specific tests (e.g., some paper and pencil personality and IQ tests and the Two Plate Tapping test) on the one hand to very extensive full dress simulations on the other hand.

2) The empirical factor analytic and multiple regression studies indicate that commonalities and predictive relationships exist between levels on the simulation continuum; and between simulations, i.e., tests, and real-world situations.

3) An organization of the dimensions is possible which will allow them to be used for both individual and man-machine levels of prediction in a system framework.

4) Placement of the emphasis on common performance components rather than on abilities, disparate from tasks, clarifies the a priori mapping process such that it becomes possible to define the process in objective terms.

Organization of the Sociopsychological Dimensions into a Performance Descriptor X Physical and Interactional Categories Matrix

It was considered desirable, if at all possible, to use the 75 performance dimensions directly in the person-task mapping activity. Random search guided by unstructured intuition was not a reasonable approach, however, if objective, quick and reliable mapping was desired. It was therefore necessary to develop a structure for the dimensions which would both guide and facilitate the mapping activity.

With the performance perspective in mind, it became evident that the dimensional set could be organized with respect to two parameters: 1) general performance descriptors and 2) human physical and interactional categories. It further became evident that the physical and interactional categories could be ordered into an input-processing-output system paradigm such that the input-processing boundary intersected the Perception category and the processing-output boundary intersected the Output Selection or decision-making category. The general form of the matrix, or human-task mapping guide, is presented in Figure C-1. The complete detailed matrix for the individual with explanatory notes is given in Figure C-2. The suggested group matrix is given in Figure E-1.

It is intended that the column headings should force orderly consideration of the human organism in terms of the demands made by the task, the task configuration, and the physical and social environments. It is intended that the row designations, or performance descriptors, should facilitate the search for that particular small subset of the dimensions which describes what the individual is doing, or needs to do, with the required column headings in terms of the criteria for that

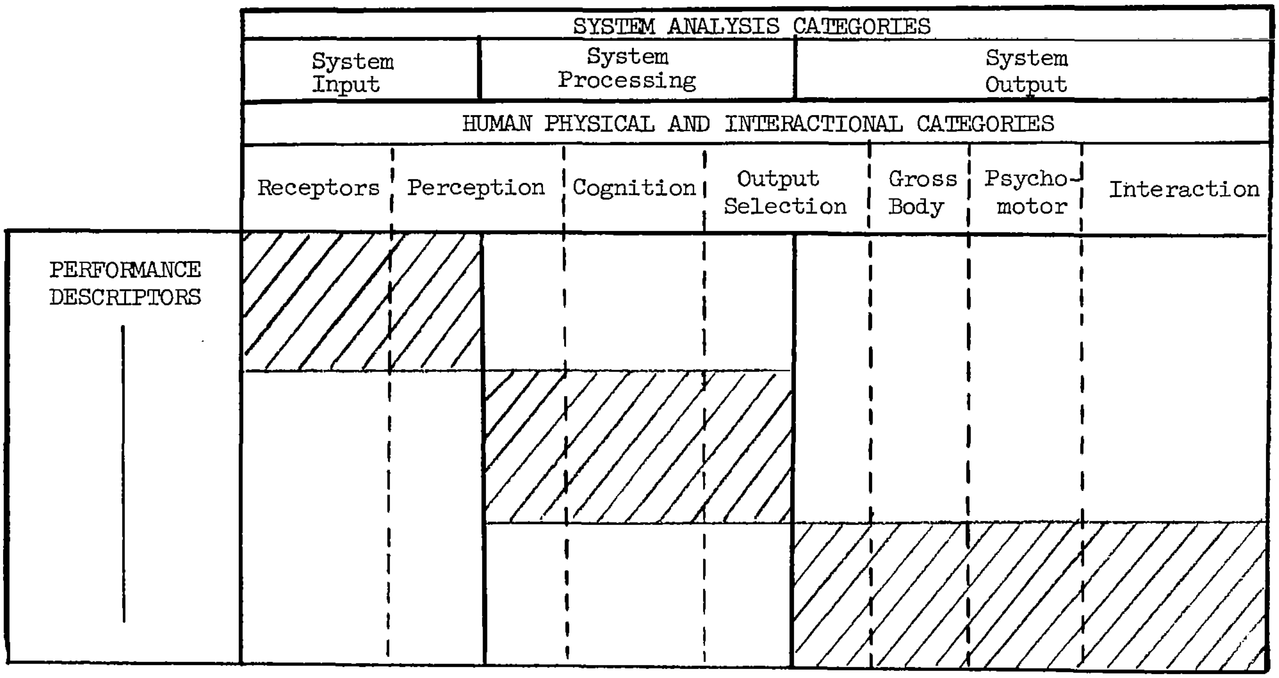


Figure C-1. The general form of the human-task mapping guide is given (the shaded areas indicate the dimension distribution tendency).

performance. The performance descriptors are not considered to be absolutely accurate nor even necessarily the best ones. But they are considered to serve as an initial list to aid the initial mapping activities. It is expected that with experience and experimental applications the list will be altered and possibly extended.

The matrix allows conception of human performance within the input-processing-output flow paradigm used for analyses of complex systems; such as, for example, a dynamic man-machine system using a 3- to 5-man crew. Using this conceptual approach, it is then possible to consider analysis at several levels (e.g., individual, group, and system performances) with relationships between the levels defined in terms of the link and node constitutions. This will be discussed in greater detail in the final section of this chapter.

Figure C-2. The Performance Descriptor X Physical and Interactional Categories Matrix is presented as a human-task mapping guide. It will be noted that the positions of the dimensions within a matrix cell are, in some cases, varied with respect to the margin. The positional variations will indicate either one of two judgments:

1. Within the Perception and Output Selection columns the positions are relative to the pertinent System Input, Processing and Output categories; i.e., the position indicates which system category was felt to be more appropriate.

2. Within the other columns the relative positions represent judgments as to the relationships of the dimensions to each other. A recessed position indicates a dimension which appeared to describe an activity that was either "smaller" (Wrist-Finger Speed as compared to Speed of Arm Movement) or more specific (Seeing Implications and Consequences as compared to Logical Evaluation).

SYSTEM CATEGORY	INPUT		PROCESSING		OUTPUT		
BODY CATEGORY / GENERAL DESCRIPTOR	RECEPTOR MECHANISMS	PERCEPTION	THINKING, CONCEPTUALIZATION, MEMORY, KNOWLEDGES	OUTPUT SELECTION	GROSS BODY MOVEMENT	PSYCHO-MOTOR	INTERACTION
DISCRIMINATION, BALANCE	(47) DISCRIMINATION ABILITIES KINESTHETIC AUDITORY VISUAL: PERIPHERAL ACUITY DYNAMIC ACUITY STATIC ACUITY DYNAMIC DEPTH PERCEPTION STATIC DEPTH PERCEPTION COLOR BRIGHTNESS NIGHT VISION (52) AUDITORY RHYTHM PERCEPTION	73. EMOTIONALITY, SENSITIVITY OF REACTION			12. GROSS BODY EQUILIBRIUM	31. ARM-HAND STEADINESS	
MANIPULATION		55. SPATIAL VISUALIZATION	27. SYMBOL MANIPULATION				64. LEADERSHIP
SPEED		48. PERCEPTUAL SPEED SPATIAL SCANNING 50. SPEED OF CLOSURE 53. AUDITORY PERCEPTUAL SPEED	21b. NUMERICAL ABILITY 22. CONCEPT FLUENCY 20. WORD FLUENCY		14. SPEED OF LIMB MOVEMENT: ARMS 15. SPEED OF LIMB MOVEMENT: LEGS	45. REACTION 38. SPEED OF ARM MOVEMENT 32. WRIST-FINGER SPEED	
SELECTION (DECISION-MAKING)		49. TIME SHARING 54. SPATIAL ORIENTATION 72. SUBJECTIVITY, OBJECTIVITY REACTION		36. RESPONSE ORIENTATION 69. CONFORMITY AND/OR CONTROL REACTION 71. SELF CONTROL REACTION 74. *DESIRED LEVEL OF OUTPUT* 75. DESIRED VALUE OF OUTPUT			
FLEXIBILITY		51. FLEXIBILITY OF CLOSURE 70. FLEXIBLITY, RIGIDITY REACTION	26. FLEXIBLITY		10. EXTENT FLEXIBILITY 11. DYNAMIC FLEXIBLITY	46. MIRROR TRACING	
KNOWLEDGES			19. VERBAL KNOWLEDGE 21a. NUMERICAL ABILITY MECHANICAL KNOWLEDGE				
MEMORY		60. VISUAL MEMORY AUDITORY MEMORY	56. ASSOCIATE MEMORY: ROTE MEMORY 57. ASSOCIATE MEMORY; MEANINGFUL MEMORY 58. MEMORY SPAN: IMMEDIATE MEMORY 59. MEMORY SPAN: INTEGRATION I 18. MEANINGFUL MEMORY ABILITY				
GENERAL REASONING			24. GENERAL REASONING 30. INTELLIGENCE				
DEDUCTION, ANALYSIS			28. LOGICAL EVALUATION 25. SEEING IMPLICATIONS AND CONSEQUENCES (FORESIGHT) 29. PRACTICAL JUDGMENT 41. MOVEMENT ANALYSIS				
COORDINATION, INTEGRATION			23. DISCOVERY OF PRINCIPLES		16. GROSS BODY COORDINATION	39. MULTILIMB COORDINATION 34. MANUAL DEXTERITY 33. FINGER DEXTERITY	
PREDICTION			42. MOVEMENT PREDICTION			43. RATE CONTROL 35. POSITION ESTIMATION	
VISUAL FEEDBACK USAGE				13. BALANCE-VISUAL CUES		AIMING 37. CONTROL PRECISION	
STRENGTH					1. EXPLOSIVE STRENGTH, GENERAL 2. EXPLOSIVE STRENGTH: LEG EMPHASIS 3. EXPLOSIVE STRENGTH: ARM-SHOULDER EMPHASIS 4. STATIC STRENGTH: ARM-HAND-SHOULDER EMPHASIS 5. STATIC STRENGTH: TRUNK, LEG EMPHASIS 6. DYNAMIC STRENGTH: ARMS-FLEXER EMPHASIS 7. DYNAMIC STRENGTH: ARMS-EXTENSOR EMPHASIS 8. DYNAMIC STRENGTH: LEGS 9. TRUNK STRENGTH		
STAMINA					17. STAMINA: CARDIO-VASCULAR ENDURANCE		
POSITION REPRODUCTION						40. POSITION REPRODUCTION	
AGGRESSION REACTION							68. AGGRESSION REACTION
INTERACTION, SOCIAL							65. CLOSENESS OF INTERATIONS 66. AMOUNT OF INTERATION 67. STRENGTH OF INTERAOTION

A basic assumption and the resultant procedures. The utility of the grouping and ordering of the Physical and Interactional categories with respect to the input-processing-output flow paradigm is contingent, of course, on the correctness of a basic assumption. The assumption is that the performance measure taken on an individual can be correctly thought of as being sequentially dependent on the effectiveness of a series of activities. For example, how fast and accurately a particular switch is thrown (two possible performance measures) in response to an input from the system may be seen to be a function of:

(1) the level of input effectiveness (e.g., how clearly and quickly was a CRT display seen as a function of Visual Acuity and Perceptual Speed),

(2) The level of processing effectiveness (e.g., how well were the equations solved using the CRT information, possibly degraded in (1), as a function of Logical Evaluation, Numerical Ability and Rote Memory), and

(3) The level of output effectiveness (e.g., how well was the movement selected and were the controls manipulated as a function of Response Orientation, Speed of Arm Movement and Manual Dexterity, enacting what quality of decision as a result of (1) and (2).

There exists some empirical evidence that the assumption of serial activity and sequential dependence is correct in the simple case at least (e.g., 50 and 69).

As has been implied in previous sections, it does not appear that the simple additive form is correct for the prediction equation except under very limited conditions (i.e., where certain terms assume zero or constant values). Until the relationships are tested and better understood, however, this form will be used for a demonstration of the above predictions, "how fast and accurately a particular switch is thrown." The relative contribution of each of the above dimensions to the output, or performance measure, is expressed by the size of the beta weight (beta weight functions are discussed in the next section) in the simple structure form of the regression equation. The order of the terms reflects the assumption that the measured level of the final performance output can be conceived of as being serially dependent on ordered sets of dimensions. The predictions, expressed as standard scores, would be derived as follows:

$$y = f(x_1, x_2, x_3, \ldots, x_{75})$$

$$= \beta_{47va}x_{47va} + \beta_{48}x_{48} +$$ Input dimensions

$$\beta_{21}x_{21} + \beta_{28}x_{28} + \beta_{56}x_{56} +$$ Processing dimensions

$$\beta_{34}x_{34} + \beta_{36}x_{36} + \beta_{38}x_{38} +$$ Output dimensions

where y might be the individual's standing with respect to response time, accuracy or a weighted combination thereof;

x_i represents the individual's standing on a dimension i;

and, β_i specifies the proportional contribution of that x_i to the performance variance.

How extensive and complex a set of operations like the above is will be determined by:

(1) the level of prediction, i.e., system, group or individual and

(2) the time, skill and situational stress-motivation ranges to be covered by the one equation.

The application of the matrix to prediction will be discussed in further detail in the final section of this chapter, and demonstrated in Appendix A for a set of activities occuring during the radiometry experiments, conducted on the Gemini V and VII flights.

Benefits The matrix and its organization into a system analysis paradigm not only defines a set of procedures for the mapping and prediction activities, it also makes available some other important bodies of experimental research. For example, the extensive investigations of manual control (e.g., 75), information processing behaviors (e.g., 54, 73, 308), and on the characteristics of performance when man is considered a processor are more assessible from this framework (e.g., 74).

Either the appeal of the information processing framework for analysis purposes or the desire to tap the available performance literatures seems to have been the basis for some one-dimensional organizations of the sociopsychological performance dimensions which have appeared in print recently. Reilly and Cameron (372) and Teichner and Olson (76) have used the input-processing-output categorization directly to attempt to fit the human operator into the overall system. Fleishman, et. al. (9, 60), appear to be using a similar approach with a perceptual-cognitive-motor categorization which they are attempting to relate to task complexity and performance. Apparently, however, none of the above has yet utilized a second, performance related, dimension or attempted to specify mapping procedures applicable to more than one level within complex systems under a variety of operating conditions.

Two other sets of experimental and differential researches are made more pertinent to mapping within a systems analysis context in that they may be said to represent the interfaces between input and processing and between processing and output. These areas of investigation are perception, or spatial behavior, and decision-making, or output selection, respectively. In referring to Figures C-2 and E-1, it will be noticed that certain of the performance dimensions were assigned to these two categories. A substantial portion of the perceptual (e.g., 78, 79) or spatial (e.g., 165, 166, 330), researches are immediately available for use because they have evaluated both individual differences and effects on performance.

Although only a limited amount of the decision-making literature seems to relate to operational performance, it is extensive (55) and seems to provide a basis for evaluating the objective utility of each of a set of possible decisions. With further research efforts the processing-output interface may be more clearly understood and the relationships to subjective utility defined.

A Conceptual Framework for Group Performance

How to conceptually organize the performance of small groups in a meaningful manner, suitable for prediction purposes, presented perplexing problems of the same nature, but greatly multiplied as were met with the 75 dimensions for individual behavior. A discussion and a tentative solution is presented in Chapter E.

Critical Evaluation of the Dimensions

Introduction

As discussed in Chapter A the dimensional approach to human performance prediction is a necessary one to effectively answer the question, "Upon what measures?". And, as discussed in this chapter, the factor analytic researches have yielded the most consistent, general, and satisfactory dimensions. In addition, they are sufficiently robust and quantitative to offer the possibility of being handled in a relatively exact analytical manner as, e.g., in prediction equations of the regression form.

The very positive aspects of the dimensional approach will be briefly summarized with references to the pertinent detailed discussions in other sections. The technical problems and difficulties associated both with 1) the factor analytically derived dimensions as prediction terms and 2) with the adequacy and completeness of our set of dimensions will be elaborated upon in detail. It should be emphasized at the outset, however, that the problems primarily result from the lack of adequate current knowledge. The use of the dimensional approach, despite the technical difficulties, is expected to result in greater precision and more complete information than would be obtainable from empirical or task analytical efforts alone. Accuracy, precision and efficiency will not be maximized, however, until the problems and basic methodology have been evaluated in both the operational and the laboratory environments.

Positive aspects of the dimensions

One of the really positive aspects of the factor analytically derived dimensions is the fact that many of them have been demonstrated to represent commonalities across a wide range of tests and tasks that occur relatively consistently. The existence of such commonalities implies that measurement efficiencies are possible when predictions must be made to a large number of tasks.

A second very important feature of the dimensions is the fact that they represent relative constancies with respect to individuals. That is, a person is identified as different from other people as a result of his score on each one of the dimensions, as, for example, his score on the Manual Dexterity factor. A full set of dimension scores should serve to identify an individual as occupying a unique location in a behavioral space.

The combination of the above two facts, 1) the sociopsychological dimensions represent commonalities across tests and tasks and 2) they represent constancies with respect to individuals, allows the all important suggestion that a priori performance prediction may be possible. Given the development of an appropriate conceptual framework the dimensional approach, using primarily those dimensions which have been derived by factor analytic methods, may provide a vehicle for both performance prediction and performance level assessment. That is, a priori performance predictions based on measurements from a previously administered test battery and the concurrent evaluation of performance capability based on on-line measurements from an on-site test battery may become a reality.

Finally, a list of the major positive attributes of the dimensional approach must include the advantages of using an approach which can benefit from the extensive performance data which has been collected throughout this century and from the attendent application methodologies. For example, criteria of well established value are already available for evaluation of test instruments to measure the dimensions and for optimizing the test selection process when developing a test battery.

For a large number of tests there exists large quantities of literature containing normative and validation data (e.g., 1394 reports are listed in the reference section for the Minnesota Multiphasic Personality Inventory in Buros' Sixth Mental Measurements Yearbook (226)). The dimensional approach makes it possible to take advantage of this previous effort.

Further, it allows prediction equations to be initially structured in terms of the basic multiple regression framework. This facilitates the initial analyses in that attention can then be focused on beta weight functions within an equation of additive form. It again allows a large, already established, data base to be evaluated for current use. The data base in this case consists of the history of regression equations which have been developed in an a posteriori fashion to account for performance variance.

In summary then, the major positive aspects of the dimensional approach are a function of six attributes held by the sociopsychological dimensions: 1) they represent task commonalities, 2) they represent individual person constancies, 3) they provide the basic elements needed for performance prediction and assessment based on a measurement set, 4) they are measured by test instruments for which there exist well established evaluation criteria, 5) they make available an enormous data base concerning test performances and task performances, and 6) they fit into the basic structure of the regression prediction equation.

Problem 1. Technical evaluation of the factor analytically derived dimensions as terms in a prediction equation.

In the process of reviewing factor analytic, experimental and correlational studies to obtain information on empirically established dimension-related measurements and demonstrated predictive validities, it became evident that clarity and consistency in the dimension-performance relationships were somewhat lacking. Comparison of the research studies in detail made it clear that resolution of the apparent confusion and inconsistencies lie primarily in the answers to three questions:

1. What situational (e.g., task, environmental) variables influence the loadings of the sociopsychological dimensions on a particular test or task? In terms of a quantitative expression, the regression equation: if the size of loading β_i defines the contribution of ability x_i to performance measurement y, what parameters affect the size of β_i in the equation:

$$y = \beta_1 x_1 + \beta_2 x_2 + - - - + \beta_i x_i + - - - + \beta_{75} x_{75}?$$

   In other words, what terms belong in the functions that determine the beta values and what is the nature of the functions?

2. Were all the factors, or dimensions, contributing to performance on a particular test or task in the experimental environment really identified? And, is it possible to estimate what effect identification of all the factors contributing to a test or task performance would have had on the reported loadings for those factors that were identified?

3. Did there seem to exist any relationships between the dimensions or any dimensional structure? Or was orthogonality a justified assumption?

Factor analysis describes a variety of procedures developed for the purpose of determining the minimum number of independent dimensions needed to account for most of the variance in the original set of variables, or performance scores. It is basically an analysis of the intercorrelations between a large number of measurements, often including 20 to 40 tests in the reference test battery and sometimes an additional set of measures from a criterion task or tasks. The number of subjects must be large, usually between 50 and 500. The determined independent dimensions represent commonalities across the measurement set which can be included in a regression equation for the most efficient and effective prediction of performance on a criterion task.

Various factor analytic approaches have been the primary tools used in search of support for the abilities constructs, where rotations of the axes are performed until the reference axes are located in a position which gives a satisfactory psychological "ability" interpretation. This set of analysis techniques is a particularly powerful and effective tool and has repeatedly shown its usefulness both for deriving the minimum set of measures required to account for the maximum amount of performance variance and for the verification of hypothetical constructs of ability.

Difficulties arose, however, in the attempt to apply this very large body of research to the problem of a priori performance prediction as a result of the failure of certain initial assumptions to hold up under close examination. The questions presented above were the result of the following assumptions NOT being adequately met by the reviewed studies: 1) factor contribution to performance is consistent, 2) all the major factors contributing to the performances were identified, and 3) the performance could be satisfactorily described as resulting from orthogonally independent factors. Any knowledge of prediction techniques and of logic should make it clear that the development of a performance prediction methodology imposes the requirement that the three questions be answered as completely as possible.

Question 1. Situational variables affecting the regression equation. When a test battery is assembled, each test is considered independently and usually with the assumption that a particular test, A, will measure one or more particular abilities consistently. It should be recognized, however, that changes in the test environment or test structure can create a different measurement situation so that different aspects of the individuals are being measured. This can occur not only in purposely structured, stressed, or distorted physical and social environments but also more subtlely in environments within which the experimenter has tried to maintain constancy. Even in the carefully conducted studies of Guilford and Fleishman, minor factor loading variations are expected to occur with each repeated use of a test in comparatively similar test environments; at times, however, rather drastic variations appear. The development of a performance prediction methodology based on test measurements requires the development of procedures which allow the causes of the more drastic loading variations to be expected and their effect properly described.

One of the causes of variation which has been repeatedly demonstrated by measurement over a series of performances has been that of learning. The amount of previous training or practice on a particular test or task seems to determine to a rather large extent which dimensions will be required to perform the next time and what the relative contribution of those dimensions will be (19, 48, 137, 154, 161, 164, 179, 189). Examples which will serve to illustrate the effect of skill development may be found in factor analytic studies which have been conducted using the Complex Coordination Task (161) and the Discrimination Reaction Time Test (163).

COMPLEX COORDINATION TASK

Trials	Visual-ization	Spatial Orientation	Mechanical Experience	Control Precision	Speed of Arm Movement
1-5	.38	.39	.28	.48	.10
60-64	.10	.10	.18	.47	.37

DISCRIMINATION REACTION TIME TEST

Trials	Perceptual Speed	Spatial Orientation	Verbal Comprehension	Reaction Time	Speed of Arm Movement
1	.10	.60	.25	.11	.00
15	.23	.33	.07	.30	.41

TABLE C-3. The factor loading variations which occur as a result of learning are presented for the Complex Coordination Task and the Discrimination Reaction Time Test.

It will be noticed in the above examples that for the initial performances one set of dimensions is emphasized, but that a different set of dimensions is emphasized in the more thoroughly practiced and skilled performances. This change in dimension contribution to performance has been described as a shift of emphasis with respect to practice level from the cognitive functions to the motor functions. In the previous section (see Figures C-1 and C-2), the "Processing" category includes those dimensions more dominant in the initial performances, while the "Input" and "Output" categories include those dimensions more dominant in skilled performances.

Once the learning variable is recognized as having an effect on which dimensions are found to be of primary importance in performance on a test or task (i.e., which dimensions will have higher loadings), it can be dealt with in the human-task mapping procedures and in the assignment of beta weights to the selected factors. The assigned beta weights can be the result of beta weight functions where the parameters (e.g., skill level) affecting the beta weights and their behaviors are defined.

The effects of the social and physical environments (e.g., motivation, stress) and of task structure (e.g., difficulty, goal definition) on what dimensions the test or task performance may require will also be discussed in terms of possible beta weight functions in Chapters D and E. Again, the effects of the parameters will be considered to be expressible as changes in the beta weights of the regression prediction equation.

Question 2. The identification of contributing factors. As stated above, factor analysis may be briefly described as a set of methods for analyzing the intercorrelation matrix for a measurement set. As should be expected, the composition of the measurement set bears a complex relationship to the results of the analysis.

The inclusion of two or more covarying measures from one test will tend to create a factor which loads very highly on that one test (sometimes called a test-specific factor). The inclusion of measures from two or more tests which are very similar will allow a common factor to emerge if the tests are, in fact, very similar. This last statement (in combination with the earlier one that rotations are made to locations which make psychological sense) is an important one in that it seems to be basic to some of the more drastic variations in factor loadings which occur from study to study. This can best be shown by an example (based on information abstracted from Ref. 190). The information given below lists the factor loadings for the Speed of Identification test which have been found in six different psychomotor factor analytic studies.

Experimental Study	Verbal Comprehension	Finger Dexterity	Perceptual Speed	Spatial Orientation	Visual-ization
1	...	...	.46	.37	.38
2	...	...	.43	...	...
3	...	.33	.45	.32	...
4	...	...	.47	.35	.29
5	.37	...	.51	.16	...
6	.20	.10	.53	...	.06

TABLE C-4. The factor loading variations on the Speed of Identification Test which occurred across a set of six studies.

The review of a group of studies which have used a subset of tests in common makes an important reason for the loading variations on any one of the common tests (as in Table C-4) apparent. The variations are seen to be a function of the varying composition of the measurement sets between studies; the battery of reference measures used and the body of measurements taken on the criterion task if one is included. An introduction or deletion of highly similar tests, as are used in factor analytic studies, can cause the introduction or deletion of the major dimension(s) measured by those tests during the principal-component analysis as a function of the inter-correlational strengths that occur. Since the theoretically correct total of the factor loadings on one test remains 1.0 this implies a raising or lowering of at least some of the other factor loadings. As an example, note that in Study 5 above the Speed of Identification test loaded on Verbal Comprehension rather significantly. This did not occur because this was the very first time that the Verbal Comprehension factor had ever been used by subjects to solve the problems on this test, but rather because two (rather than one) decidedly verbal tests were included in the test battery (Word Knowledge and Background for Current Affairs). It was therefore possible for this sociopsychological dimension to be identified, in this study, as a contributor to performance on the Speed of Identification test.

It is entirely possible that yet other dimensions contribute to test performances, such as the Speed of Identification Test, but have not been properly identified because measurements on these other dimensions have not been included in the measurement set. Experimental evidence is available that this may indeed be the case for some spatial tests with respect to a visual discrimination dimension and personality characteristics.

An investigation of visual search performance conducted by Dorothy Johnston (330) demonstrated a relationship (-.5 correlation) between a measure of Peripheral Acuity and the Speed of Identification Test. Apparently, however, no factor analytic study of the spatial dimensions has yet included any measures of peripheral acuity or any other visual discrimination dimensions in their measurement set.

At least thirty years of research into the nature of perceptual behavior (the transformation relationships between visual stimuli and the response) indicate the complex involvement of personality characteristics in the transformation operation. One of the more extensive and clear cut set of investigations, initiated by H. A. Witkins and his associates, has been that using a verticality judgment measure on an instrument known as the Rod and Frame Test, or RFT (e.g., 78, 79, 80, 198). These studies have uncovered close interrelationships between spatial abilities, primarily Flexibility of Closure, personality measures and general behavior patterns. Again, personality measures have not been incorporated into factorial designs investigating spatial or other behaviors.

The change of factor contributions to psychomotor performance as a function of skill level was discussed previously under the first question. A question may also be raised, however, as to whether all the factors important to performance at the various skill levels have been adequately identified; the primary question concerns the possible contribution of the memory dimensions. A comprehensive study by Allison (48) collected a set of learning measures on 13 tasks which was subjected to an inter-battery analysis using 36 reference tests covering several behavioral dimensions. Allison's results indicate the major common performance factors to be a conceptual process factor, a rote memory process factor, a mechanical factor, and a psychomotor coordination factor. (The conceptual process factor was considered under the first question.) Another indication may be found in an annual report by Melton (71) of completed investigations into the human information handling processes. The comment is made (p. 18) that short term and associative memory was found to be involved in a far larger set of tasks than had been expected (e.g., information processing, reaction time). The point of these examples is that, again, there is evidence that additional dimensions (memory in this case) are important factors in test and task performance (psychomotor in this instance) but that no factor analytic studies have been conducted which will allow their contribution to be evaluated.

Perhaps the difficulty pointed up by the previous paragraphs can be said to have resulted from the assumption that persons can be made to do just one limited thing. The task or tests may place a heavy emphasis on one type of behavioral (e.g., paper and pencil, verbal or spatial problem tests as compared to the Two Plate Tapping Test) dimension, but rarely can they absolutely restrict the performance to only certain dimensions. The paper and pencil verbal test may emphasize verbal comprehension, but visual acuity, perceptual speed, and the psychomotor contributions to speedy handwriting (note appearance of Finger Dexterity factor on Speed of Identification Test) may also be expected to play a part in the output which constitutes a performance score. Whether the other dimensions which contribute to the final output have been identified or not will depend on whether measurements on performances which particularly emphasize these other dimensions have been included and repeated in the measurement set. The result of the difficulty in obtaining complete factor identification and correct factor loading data on test instruments will be less satisfactory predictions of performance from scores on test instruments than might have been achieved. Judgment will have to be exercised to a greater extent. For example, in setting down an a priori regression equation to predict visual search performance, what should the relative beta weights be for peripheral acuity and perceptual speed? Until the comparative importance of these two dimensions for visual search performance is empirically demonstrated, beta weights will have to be assigned on the basis of judgment.

Question 3: The orthogonal independence of the factors. The factor analytic procedures are such that "...the minimum number of independent dimensions needed to account for most of the variance in the original set of variables" (53, p. 151) is determined. The term "independent" indicates, of course, that a knowledge of an individual's standing with respect to one dimension, A, will not imply the person's standing on another dimension, B. If two tests are available, one of which measures A exclusively while the other measures B, then the correlation of scores from these two tests should yield a low correlation coefficient. If the correlation is relatively large then either the tests of A and B are not really exclusive measures of different, independent dimensions or else other causal factors are operating; such as the contribution of other, unidentified dimensions to the performance and an oblique, rather than an orthogonal factor structure. Which brings us again to the area of spatial abilities. These abilities seem to be involved in a wide spectrum of activities but their resolution into clearly orthogonal dimensions remains a problem.

Upon review it appears as if the difficulties investigators have experienced with these dimensions have indeed stemmed from the presence of a large amount of commonality (e.g., high correlations and covariances) among tests of the independent spatial abilities, especially Spatial Orientation and Visualization. A particularly explicit discussion of this phenomenon is presented by Frederiksen who, in presenting the analysis of a bimodal perceptual recognition study, reports: "...the large covariance between Visualization and Spatial Orientation (.80) indicates that tests of these two "abilities" have much in common." (166, p. 47) The effect this can have on identifying which spatial ability contributed to task performance is commented on in his discussion of the results: "The previous finding of a positive relationship between Visualization and late visual recognition was not replicated, despite the fact that the Visualization factor was clearly established in the factor analysis. Instead, the factor "Spatial Orientation" (included in our analysis in order to ensure that the Visualization factor would not be confounded with this ability) was related to visual recognition in the same manner as was Visualization in the previous study... Since Spatial Orientation and Visualization were more highly correlated in the present study than in the previous one, we suspect that the previous findings may have been due in part to a confounding of these two abilities." (p. 59). A further example of difficulty with these two factors in particular may be found by referring to Table C-4 which lists the varying factor contributions identified in performance on the Speed of Identification test in various studies.

Each dimension is assumed to operate independently of all other dimensions; in particular, each dimension is seen to be independent of any conditions imposed by other dimensions and to be unaffected by it's position within any sequence of dimensional operations. It does not, however, seem reasonable to expect that dimensions such as Spatial Orientation or Perceptual Speed can operate without some minimum level of, for example, visual acuity being in effect.

It has already been suggested (under Question 2) that the nature of performance in activities using visual information to deal with spatial relationships could be clarified through the use of more widely varied measurement sets in the factor analytic studies. The question of oblique vs. orthogonal factors is a special problem, however, which has a bearing on the organization of the factors into a usable conceptual structure.

The assumption of orthogonal independence (demonstrated by the particular analysis technique that is chosen) implies certain relationships between the dimensions. A high Peripheral Acuity score may not imply a high Perceptual Speed score, or vice versa, but it does seem reasonable to expect that a visual acuity standing could set an upper bound on, e.g., the attainable visual speed score.

And, the results of the perceptual investigations (e.g., 78, 79) suggest that the assumption of orthogonality would also not be appropriate for the spatial dimensions with respect to hypothesized personality dimensions. The nature of the relationships are yet to be defined by empirical evidence but a limiting or bounding action on the spatial dimensions by some personality dimensions does seem a possibility.

Not only may the operation of a dimension be bounded by limiting conditions imposed by other dimensions, but its operation may be serial in nature even though the action time span is very short. For example, a recent study (50) indicates evidence of a serial execution of a stimulus decision and a response decision in a two-choice reaction time test. Again, a relationship between the dimensions is indicated--the possible score on Response Orientation, the response decision dimension, will be bounded by the goodness of the previously made stimulus decision (also see 69).

The previous discussion has intended to point up the possible inappropriateness of the orthogonality assumption. It should be pointed out, however, that the composition of the subject population should be considered in determining whether the orthogonal assumption may be justified. The magnitudes of the intercorrelations which are subjected to factor analysis are affected by the characteristics of the population whose dimensions are being measured. If the entire subject population has, e.g., the same visual acuity and personality dimension scores then the bounds for the affected spatial dimension scores would be constant across the population allowing a decrease in commonality between tests of different spatial dimensions to occur. Or, in other terms, the spatial dimensions would appear to act in a more independent manner.

Problem 1: Summary

A close review was made of several factor analytic and experimental studies to resolve an initial set of questions based on three assumptions which appeared to be inadequately met: (1) factor contribution to performance is consistent, (2) all the major factors contributing to the performances were identified in the studies, and (3) the performance could be satisfactorily described as resulting from orthogonally independent factors.

It was found that the results of a factor analytic study (i.e., the dimensions identified and their loadings on each of the measurements) was a function of many parameters: (1) situational variables (e.g., training, stress, motivation) which impinge on the test or task performance, (2) the range of dimensions covered by the measurement set and the repetitive measurement of the same dimensions, and (3) a hypothesized bounding action and the dimensional score range within the subject population.

The analysis of the assumptions became necessary when efforts were made to generalize over a history of factor analytic and test research. These researches attempted to account for performance variance within limited activity realms through use of large test batteries consisting of highly similar tests. It should be recognized however, if it had not been for the volume of the factor analytic investigations and meticulousness with which they were conducted, a technical evaluation of the dimensions as a basis for a general prediction methodology would not have been possible. The fact that a definition of some of the variables and their effects on the results of these studies could be made is to the credit of the investigators. If the above assumptions had been consistently met by all the reviewed studies, then the dimension, or X_i, values, and use of an additive function in the simple regression equation:

$$y = \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_{74} X_{74}$$

would have been exactly right. And, given a person-task mapping procedure, the assignment of β_i values would have been much simpler and would have had a much greater likelihood of being accurate.

The immediate effect of the discovered parameters is the incorporation of these parameters into the person-task mapping procedure discussed in the next section. The effect of these and possible other parameters on future investigations should be to collect measurement sets and to perform analyses which will (1) define the terms and the operation of beta weight functions and (2) allow consideration of multiplicative or other functions for the combination of the dimensions. For the purposes of this report, however, the additive form of the regression equation will be used for demonstration purposes.

Problem 2. Evaluation of the dimensions as members of a necessary and sufficient set.

The Necessary Set. After the initial set of sixty dimensions had been formed, the collection of measurement data for these dimensions was initiated. The existence and general usefulness of the majority of the dimensions was evident throughout the literature; both from the repeated empirical evidence and from the conceptual sense they generated. The same comments do not hold for all the dimensions, however. Below are listed those dimensions whose existence and/or general usefulness have not been substantiated sufficiently to allow them to be used with complete confidence for prediction of the behavior of a subject population over a wide range of tasks. The basis for questioning the membership of each of these dimensions in a necessary set will be briefly discussed.

18. Meaningful memory ability
27. Symbol manipulation
29. Practical judgment
30. Intelligence
41. Movement analysis
42. Movement prediction
44. Acceleration control
46. Mirror tracing

Meaningful Memory Ability and Symbol Manipulation have appeared in one study each (140, 175). The studies were conducted to validate the existence of a small subset of the cells in Guilford's Structure-of-Intellect Model. These factors have been identified only by their loadings on two or three tests within a relatively restricted set of paper and pencil tests and, therefore, only these few tests are known to measure these factors. Further, an examination of the test instruments raises questions as to their true definition (i.e., how would they fare as independent factors if measurements for certain other dimensions had been included in the analysis) and of their relevance to more than a very specific type of task.

Movement Analysis and Movement Prediction have occurred in only one study (188) which was a second attempt to identify the dimensions responsible for performance on an acceleration tracking task (Tracking Task, criterion). Since measurements of neither cognitive nor spatial dimensions were included in this factor analytic study, a serious question can be raised as to the "real" definition of factors 41 and 42. The tests of these factors are visual displays which require an evaluation of the events displayed (Double Differentiation, Single Differentiation, and Double Differentiation/Integration tests). It may be that performance of an acceleration tracking task does require a unique, task-specific set of dimensions; but this will not be satisfactorily demonstrated until the performance is investigated with a larger measurement set which includes spatial and cognitive dimension measures.

Practical Judgment was identified in the factor analytic studies conducted during WWII using military personnel and is measured by a test developed during this period. Although it would be nice if a general Practical Judgment factor existed and could be measured, this factor, measured by this test, is apparently not it. One, the content of the sample questions for the test do not seem to fit the construct of practical judgment very well and two, further efforts to demonstrate the existence of 29 as a general factor have not been met by success (63).

Factor 30, Intelligence, can perhaps be best defined either as being that which is as of yet undefined or as a general category descriptor. The "intelligence" tests are usually collections of items which have been shown to variously tap conceptual, thinking, and perceptual-cognitive abilities (149). In research, measures of "intelligence" are often taken to better control the relatively undefined characteristics of the subject population. The fact remains, however, that no dimension has yet occurred in American studies which could not be defined in more exact terms than the word "intelligence".

There exists another set of factor analysis techniques, used primarily in England, which partials out the performance variance in a different manner and which serves to validate constructs like the "Spearman g Factor". The inclusion, however, of data and dimensions from that body of research would be difficult both in terms of data accessibility and in the conceptual and technical development of a prediction methology. Thus, although it may be possible to demonstrate an "intelligence" factor, it does not appear desirable to incorporate data from studies of this type.

Acceleration Control and Mirror Tracing are questioned because their existence has never been demonstrated. Apparently these dimensions were hypothesized to exist by Parker, et. al. (190) in an effort to account for and test activities described by a task analysis of the Gemini space mission. The terms, Acceleration Control and Mirror Tracing are really task descriptions and not the psychological ability definition of rotated principal-component axes.

If by Mirror Tracing is implied a "freedom from set" factor, an argument for its existence can possibly be constructed. For one thing performance on the two tests listed in Volume II for this dimension which have been included in factor analytic test batteries (Pursuit Confusion: Time-on-Target and Errors) was not completely accounted for by identified dimensions. They were included as measures of Mirror Tracing because the tests are just that - Mirror Tracing. Another body of research which suggests the possibility of a "freedom from set" factor is that using the Stroop Color-Word Test (272). This test has an annoying tendency to load only on a test-specific factor. It is sometimes described as measuring a tendency to "response interference" and tends to correlate with a wide range of behaviors, including psychomotor performance.

Acceleration Control does not, however, seem as easily supported. As indicated in the comments on 41 and 42, the research on acceleration tracking has not yet been adequate to justify the proposal of a task-specific dimension like Acceleration Control. First it must be demonstrated that a regression equation including cognitive and spatial dimensions, as well as psychomotor dimensions, will not account for a substantial amount of the performance variance.

The Sufficient Set Throughout the literature review, factor analytically derived or hypothesized dimensions other than those included in our initial set of 60 have appeared. Several of these dimensions have been included in the ability test tables of Volume II and are listed below:

Auditory Memory
Integration
Spatial Scanning
Length Estimation
Mechanical Knowledge
Aiming
Vigilance or Alertness
Time Estimation
Visual Feedback
Coriolis Reactivity
Motion Sickness Susceptibility
Spatial Disorientation

Most of these dimensions (except for Aiming, Spatial Scanning and Mechanical Knowledge) have not yet been demonstrated by large scale factor analytic studies to either exist or not to exist as independent dimensions. If, in the future, factor analytic studies are conducted using measures of these variables it will be possible to evaluate their independent existence or their dependent relationship to the initital set of dimensions. If their independent existence is demonstrated and if they represent commonalities across a range of tasks (i.e., if they are sufficiently general) then their membership into the dimensional set will be required. In the interim, they should be considered only if the performance to be predicted is not adequately described by the suggested set of dimensions; but the description is made substantially more complete by the inclusion of one or more of the above possible dimensions. For example, the introduction of rotationally-induced gravity to a MORL would necessitate the introduction of Coriolis Reactivity tests to the predictive measurement set. Coriolis Reactivity may not exist independently of the other 75 dimensions, or it may be eliminated through habitation, but until this is demonstrated empirically, it would have to be considered as a negative term in performance prediction equations for several of the MORL activities.

The question of the completeness of the final set of 75 dimensions to account for a very large subset of the behaviors from the human behavioral universe will be alluded to again within the specific contexts of stress and personality (Chapter D), and group behaviors (Chapter E). The MORL question above was a specific sample of the general question being asked: Is the suggested set of 75 dimensions sufficiently complete to account for an adequate amount of performance variance in most behavioral situations? This question cannot really be answered, of course, until the dimensional set and the attendent prediction methodology has been applied to a range of man-machine systems. If the methodology is found to be a sound one then the completeness of the dimensional set can be evaluated on the basis of empirical data and direction given to efforts to generate a more complete set.

It appears almost certain that additional dimensions may be needed to satisfactorily account for operator performance, especially in some special man-machine systems. The data at present, however, is not adequate to allow final decisions to be made on the completeness of or the required additions to the dimensional set.

To return to the variables whose dimensional existence has been demonstrated (Aiming, Spatial Scanning, and Mechanical Knowledge), Aiming was found to be a necessary one for mapping the command and control activities of the astronauts during Rendevous and Docking and, to a more limited extent, the behaviors during the Celestial and Space-Object Radiometry Experiments (see Appendix A).

Spatial Scanning is difficult to evaluate as nothing was found in the literature to clearly support it's independence from Perceptual Speed. If it is not distinctly separate from Perceptual Speed as a general factor then it is not needed to complete the set.

Although Mechanical Knowledge contributes to performance on paper and pencil tool and equipment tests, it does not appear to be involved in task performance to any extent. If it were to appear at all, it might be expected in the initiates' behavior in a new situation where past experience or knowledge might facilitate the processing activity (see data in Table C-3). This was apparently the case in one study (161) where Mechanical Experience loaded at .28 during the first five trials on the Complex Coordinator. It might therefore be suggested that the Mechanical Experience factor be considered when initial learning behavior is to be studied.

Mapping and Levels of Analysis

During the previous discussions, reference has been made to the use of prediction equations of the additive regression form. (It has also been pointed out that although the oblique structures make better conceptual sense, their forms are not sufficiently well developed to be immediately applied to the present problem.) The β weights for standard score prediction have been used since they directly represent the relative power of each of the dimensions in accounting for the performance variance. It has been emphasized that the beta weights may tend to change with respect to certain parameters, such that those performance dimensions which predominately contribute to immediate task output under normal conditions may tend to diminish slightly in importance while others gain. It has been suggested that if it is possible to construct beta weight functions then some combination of these parameters is expected to appear as terms in those functions. These parameters are given below with their expected effects on the beta weights listed.

Parameters affecting Beta Weights

1. Training, or skill level. The Processing dimensions (including the Processing half of the Perceptual category) tend to be emphasized, i.e., have larger beta weights, during initial performance. And further research on tasks like Acceleration Tracking may support a hypothesis that the Processing dimensions will continue to be predictive of performances even at high skill levels in those situations which are more variable or non-stable.

The Input and Output dimensions (including the Input half of the Perceptual category) tend to increasingly predominate as the skill level increases. The contribution of the Output Selection dimension of Response Orientation appears, however, to be relatively stable across skill levels.

2. Environmental stress factors, physical and social. As the physical and/or social environments become increasingly stressful, those dimensions often considered in personality research appear to account for increasingly greater portions of both the performance and the general behavioral variance. Selected dimensions of this type have been placed in the processing half of the Perceptual category, the Output Selection category, and the Interaction category of the matrix in Figure C-2.

3. Task factors. If the nature of the task or the required performance on the task implies a particular stress (e.g., fatigue, extreme demand) or motivational problem (e.g., boredom) for the subject

population then the individual and group dimensions identified in (2) above may be expected to account for an amount of the performance variance greater than zero.

4. What is to be predicted. Once the output has been identified by the task analysis, y needs to be defined with respect to at least two parameters: criteria and time. To select the proper dimensions, one must identify exactly which of the many possible behaviors (e.g., speed, interest, grade point average) related to the output one desires to predict and the context (e.g., the behavioral sequence) within which it occurs. After the criterion for the behavior to be predicted has been defined, consideration must be given to the time period involved. As the duration of time period covered by y increases, the personality and group compositional dimensions begin to account for a significantly larger amount of the variance (e.g., y = words/minute typing speed as measured for five minutes compared to y = words/minute as measured for an entire year where absences and non-productive periods are included in the measurement).

The Mapping Procedure

The Performance Descriptor X Physical and Interactional Categories matrix, in Figures C-1 and C-2, represent a conceptual framework intended for use as a human-task mapping guide. The columns, the Physical and Interactional categories, are to be considered in order, starting with the Receptor category, with respect to how the individual will interact with and meet the demands made by the task, the task configuration, and physical and social environments. Whether or not a particular column accounts for a significant portion of the performance variance should be decided in terms of the operational task requirements, modified as required by the beta weight parameters listed above. When a column is selected it is intended that the row headings, or performance descriptors, should facilitate the search for the small subset of the performance dimensions which describes the activity of the individual as defined by the selected column heading, again, in terms of the performance criteria. Application of the mapping procedure is demonstrated in Appendix A.

The Levels of Analysis

Several levels of system description are possible, the level being a function of the node and link constitutions. Three levels of description, system, group and individual, will be discussed here as a means of arriving at a set of performance dimensions and equations to predict human performance within a man-machine system. These same levels of description will again be used in a somewhat different manner in Chapter F to arrive at the subset of system performance criteria which are measured by man's performance, or outputs to the system (see Figures C-4 and F-1).

SYSTEM LEVEL ANALYSIS

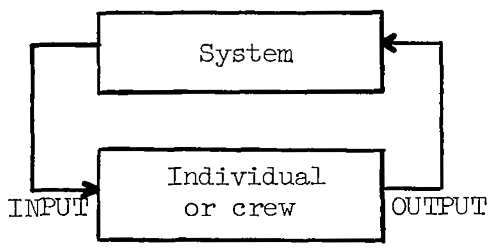


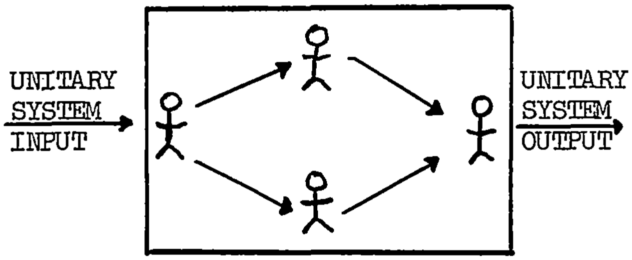
Figure C-4. System level analysis.

Inputs: the system inputs to the human(s) must be specified. Examples of system inputs might be visual displays such as gauges or CRTs, auditory signals, environmental changes if an environmental subsystem exists, or force dynamics in a control situation. They may or may not reflect the effects of crew outputs.

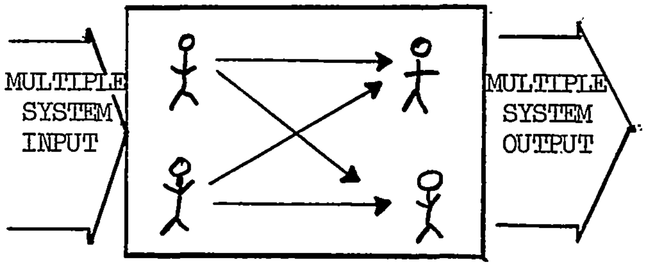
Outputs: the required outputs to the system would be defined in terms of the system performance measures and the boundary values that are established. Outputs to the system then would be only that subset of the crew actions which directly interfaces with and affects the system. Examples of measures of output to the system are time-on-target, frequency and amount of deviation from a target, errors, and response time.

Processing: at the system level processing would be contained in the black box. Analysis at the group and individual levels would investigate the crew's black box such that equations and values could be established for the output parameters, allowing system performance to be predicted and evaluated.

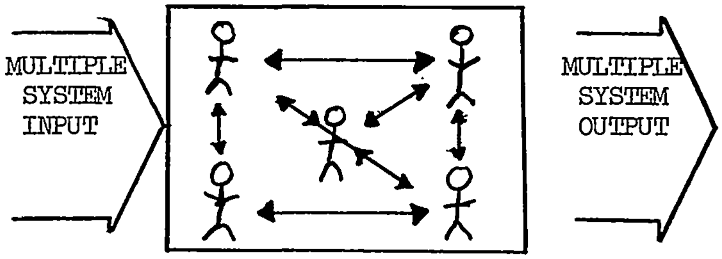
GROUP LEVEL ANALYSIS



GROUP PROCESSING (1)



GROUP PROCESSING (2)



GROUP PROCESSING (3)

Figure C-5. Three examples of group processing activity are given.

If a sequence of activities can be established for a group (Fig. C-5) and if not too many internal loops or interactions exist (Figure C-5(1) and C-5(2)) then it might be possible to identify a series of individual inputs and outputs such that the quality of the terminal performance will be dependent on the quality of a serial set of outputs, each of which, in turn, will be dependent on the levels of reception and processing of the preceding outputs(as defined by prediction equations at the individual level of analysis using selected performance dimensions). In other words, it might be possible to structure a set of predictor equations for individuals which would allow some answers to be generated by a model reflecting a group activity structure such as in Figure C-5(1)&(2). An example of one type of task description appropriate to this level is the man-man, man-machine interaction analyses in Appendix A (Table AA-2).

If, however, the processing black box of the system level assumes the interactional complexity of Fig.C-5(3) above, it is doubtful that any set of equations for the actions of individuals could either account for a substantial amount of the performance variance for the group output or do it efficiently. If group performance dimensions derived from group performance measures do exist as suggested in Section F, then system performance prediction and evaluation would best be done using this set of dimensions for the analysis. In this instance, inputs, processing and outputs would be defined in the same manner as at the individual level below. The difference would be the use of group performance dimensions rather than individual performance dimensions.

INDIVIDUAL LEVEL ANALYSIS

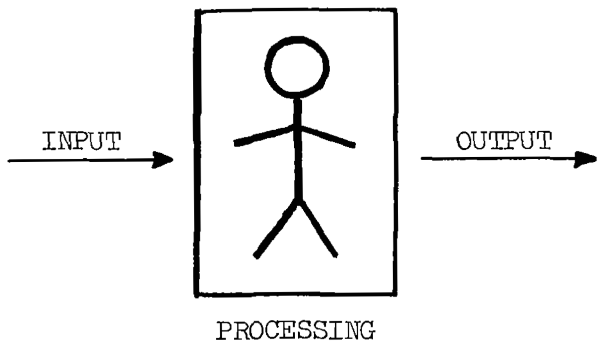


Figure C-6. The individual level of analysis.

Inputs: at this level inputs refer to those dimensions which are required by the human organism to receive the system or the interaction inputs. For example, Auditory Acuity and Static Visual Acuity are needed for accurate discrimination of auditory and visual stimuli.

Processing: those dimensions concerned with handling and transforming the input information such that the output is directed.

Outputs: the dimensions which are incorporated into the observable output activity as, for example, Explosive Strength or Manual Dexterity.

Summary

An attempt has been made to denote a set of comparatively objective procedures for selecting the subset of the sociopsychological dimensions required for prediction and evaluation of performance in situations ranging from simple to complex. Specified were the following: 1) the individual, group, and system levels of analysis, 2) the human-task mapping procedure, and 3) the parameters expected to influence the beta weights for the dimensions, i.e., the factor loadings on the operational performance. The above items were all discussed within the conceptual framework of the Performance Descriptor X Physical and Interactional Categories matrix developed earlier.

It is hoped that opportunities will arise which will allow the above selection procedures to be tested for their utility and reliability when used by mappers knowledgeable in the dimensional approach. The accuracy, however, of the beta weight assignments cannot help but be largely a function of subjective judgment at the present time. It has been possible to suggest what parameters belong in the beta weight function and their general effect. Extensive empirical research is needed, however, before they can be exactly defined in a manner which will allow them to be used entirely objectively.

D. MEASUREMENT: PERSONALITY AND STRESS RESPONSES

Introduction

As was indicated in Chapter C the ideal goal is to be able to predict any measure of performance under all conditions. Sociopsychological dimensions 1-60 appear to comprise a satisfactory initial set of dimensions for a priori prediction of performance in a wide number of tasks; as long as the predictions are short term with respect to time, under nonstressful operating conditions, not dependent on interaction with other persons and not dependent on the individual's perceptual or decision-making behavior. It is often desirable, however, to be able to predict and evaluate performances over long time periods, under non-optimal and, possibly, very stressful operating conditions, and where the final man input to the system is the result of or affected by interaction, perception and/or decision-making. It is expected that when performance is to be predicted for any or all of the latter conditions that individual differences will not be adequately accounted for until additional dimensions are considered. In other words, the prediction equation beta weights for these additional dimensions will increase to a value greater than zero under the latter conditions. The additional dimensions have been derived from those areas of research generally considered to cover the subject matter of "personality".

Personality, within the field of psychology, is supposed to refer to the uniqueness of an individual, i.e., anything that differentiates people into individuals. Generally, however, emotional and behavioral tendencies are the focus of attention. Although the research literature of this area is both extremely extensive and intensive, it is extremely disordered conceptually and rarely related to performance. In those instances where the emotional and behavioral tendencies are statistically related to performance measures, they sometimes relate closely, sometimes moderately and sometimes not at all. A review of these varying relationships has led to the conclusion that dimensions derived from the area of personality research would be needed to account for performances under the latter conditions stated above but not necessarily for the former set of conditions.

Deriving these dimensions was not an easy matter and it is not known at present whether independent dimensions of these exact descriptions will be empirically demonstrated to exist in the factorial sense. They are, however, real in the sense that they are measured, the measurements have been generated by conceptual constructs, and their relationships to various performances and behaviors have been demonstrated.

Derivation of Dimensions 61-75

The questions of: (1) the utility of the "personality" domain, from the performance standpoint, (2) whether it was possible to satisfactorily dimensionalize the domain, and (3) if such dimensions were measureable by an existing set of tools have been under continual consideration since the beginning of this project. Considerable effort has been expended searching both the experimental and the theoretical literatures for approaches which would provide answers to these questions. What was found was an extremely chaotic literature without any central concepts which afforded any direct means of organizing and integrating the results of this tremendous body of research into a human performance prediction methodology. Partial answers to questions 1 and 3 were evident, however. That is, (1) if performance variance was to be accounted for in more than a limited set of conditions then "personality" would have to be considered, and, with respect to item (3), certainly there existed a very large set of tests, of which some were well standardized.

An immediate and absolute answer to (2) is not available. The various dimensional structures from the literature seem to each cut the universe that is a person in a different direction in different size cuts, and, while implying the whole person is involved, actually consider limited and different portions of that person. For example, we have Cattell's U-I structure of 36 dimensions (e.g., U.I.26. Self-realization vs. homespunness, U.I.36. Strong self-sentiment vs. weak self-sentiment) (229), Guilford's five Primary Personality Traits (e.g., Sociability, Objectivity vs. Subjectivity) (63), Guilford's GZTS for ten factors (e.g., Thoughtfulness, Emotional Stability) (278), Borgatta's five dimensions (e.g., Assertiveness, Intelligence) (222, 223), Witkins' two dimensions, Field Dependence and Field Independence (78, 79), Bass's Task-orientation, Self-orientation and Interaction-orientation (214), Kugelmass's Worriers vs. Non-worriers (283), factor analytic efforts on the MMPI (cf., 274, 303, 315, 318), Freud's Ego, Id and Super-ego (92), Goldstein's Self-actualization (89), and Sheldon's Ecto-, Meso- and Endomorphs (109).

As the search continued, records were kept of the measurement tools described and especially those which were demonstrated to be predictive of performance. When a large set of tests had been accumulated they were sorted into a number of piles based on the similarity of the test contents and/or the similarity of the constructs they represented.

At a later date these initial groupings were evaluated in terms of some other things that had become apparent. These were: (1) several of the initial groups could be considered as more specific subcategories for more general dimensions, i.e., dimensions that would be predictive over a wider range of tasks; (2) the best way to cut or categorize the "personality" domain, to make it relatable to performance, was with reference to the situational impingement on the action, and (3) categories were also suggested by the particular positions which these dimensions seemed to occupy in the Performance Descriptor X Physical Interactional Matrix (see Figure C-2). The initial and final groupings are listed below in Figure D-1 with the effects of 1, 2 and 3 above indicated.

It will be noted that the very first item of the initial grouping, Adjustment Potential, has not been included in our dimensional set. This dimension was the result of a factor analytic study of rated adjustment to and rated general performance in FBM submarines (321). Although the resulting dimension is of interest and is included in the Ability-Test Tables in Volume II, it was both too general and derived from a measurement set including too few a priori measures to allow it to be included in a dimensional set for a priori prediction.

Dimensions 61-64 will be discussed in greater detail in Chapter E where the problems of group measurement and subsequent prediction are considered.

Measurement of Dimensions 61-75

The available measurement tools for dimensions 61-75 and information on these tools are given in Volumes II and III in the same manner as provided for dimensions 1-60. As indicated in the previous section, these dimensions have been derived from the measurement set and thus are primarily defined in terms of the tests for a dimension. It is also true, however, that the main orientation of this literature has not been in terms of performance prediction and, therefore, it is not expected that the measurement tools for these dimensions, defined in terms of performance characteristics, will be entirely satisfactory. It is expected that the dimensions with the best measurement tools will be those which have been factor analytically derived and by more than one researcher, as for example, Subjectivity vs. Objectivity, dimension 72.

Utility of Dimensions 61-75

The utility of and, therefore, the need for dimensions 61-75 is indicated by the relationships they bear with certain variables important to prediction. Some of the available references which cover these relationships and, therefore, the utility of the dimensions are listed in Table D-1. The following definition of the variables and their apparent relationships to the dimensions should afford an understanding of how these dimensions might provide more effective prediction.

Figure D-1. The development of the personality and group composition dimensions, 61-75, is demonstrated.

SITUATIONAL IMPINGEMENT	ASSIGNED DIMENSION NUMBER	INITIAL GROUPINGS	ASSIGNED DIMENSION NAME	MATRIX ASSIGNMENT
		Adjustment Potential, Optimal vs. Limited		
Group	61.	Similarity, perceived	Similarity, perceived	Group Composition
	62.	Group compatibility	Group compatibility	
	63.	Group cohesiveness	Group cohesiveness	
	64.	Leadership	Leadership	
Inter-individual, reactions to people	65.	Friendliness Sophistication, aloof Personal vs. counter-personal	Closeness of interactions	Interaction
	66	Introversion vs. Extroversion Withdrawal	Amount of interaction	
	67.	Assertiveness	Strength of interaction	
	68.	Agression Agressive nonconformity	Aggression reaction	
	69.	Dependency Power orientation Nonconformity Conformity Authoritarianism	Conformity and/or control reaction	Output Selection or Input Perception
Reactions to environment	70.	Flexibility Abstractness capability vs. integrative complexity Rigidity	Flexibility:rigidity reaction	
	71.	Self control	Self control reaction	
	72.	Self centeredness vs. objectivity	Subjectivity:objectivity reaction	
	73.	Nervous tension Anxiety Emotional maturity, defense mechanisms Stress responsitivity	Emotionality, sensitivity of reaction	
Values	74.	Activity Aspiration Motivation	Desired level of output	
	75	Conscientious vs. Expedient Esthetics vs. practicality Happy-go-lucky vs. Sober	Desired type of output	

Time Period: This refers to the length of time covered by the performance measure one wishes to predict. When it is desired to predict an output which is contingent on the comparative maintenance of a high level of effort for long periods of time then consideration of dimensions 1-60 often does not seem to adequately account for the individual differences in output. Grade point averages, production outputs measured on longer time spans, and cumulated errors for long term monitoring are examples of the type of measure which tends to correlate significantly with personality measures.

Non-optimal situational variables: When either the task or the physical and interactional environments surrounding the task introduces stressful and/or motivational elements into the situation, performances tend to correlate with "personality" factors. The tendency is a complex one, but the researches surveyed thus far appear to support the following hypothesis: the degree of relationship between dimensions 61-75 and the task output level is a function of the stressor and motivator intensity levels present in the task activities and the task environment. The more stressful and less motivating a situation becomes, the more important these dimensions will become in fully accounting for the individual differences in level of task performance.

Stress and motivation are usually defined in terms of individual response rather than external events. Knowledge of just the person's physiological response or anxiety level is not sufficient, however, to account for his performance. Stress and motivation from the standpoint of the individual's response will be considered further below.

The position to be taken here is that external events can be termed "stressful" or "motivational," if couched in terms of probable perception as stressful or motivational by the particular subject population under consideration (84, 116, 191 and 292 indicate that measured personality factors may or may not relate to performance as a function of whether or not the situation is motivating for all of the subject population). An example of such a stimulus definition for stress has been presented by Deese (87): "The properties of stressful stimuli are defined by a set of correlated responses. It will be useful, I think, to characterize as stressful those conditions which elicit reports of discomfort or which elicit correlates of discomfort."

Stressful and motivational (especially boredom) characteristics for the task or the interactional and/or physical environment are then considered to be continuous variables which determine the degree to which dimensions 61-75 are predictive of the performance output. Example stressors might be sleep deprivation, situation-induced illness, extreme temperatures, prolonged performance or severe pacing, social disapproval or condemation, or unusual hazards.

TABLE D-1. A listing of some of the researches found which indicated the relationships between "personality" and certain measurements, situational variables and behaviors.

TIME PERIOD	NON-OPTIMAL, STRESS	INTERACTION	PERCEPTION	DECISION-MAKING
	74 *		74	74
			78, 79	
	80		80	80
	85			
	98	98	98	98
	99	99	99	99
	110, 116			
119		119	119	119
	130			
	147			
	191			191
			198	
207, 208	207, 208	207, 208	207, 208	207, 208
238, 239	234	227		
242		242		242
	243	243		243
245			245	245
247	247	247	247	247
253	252, 254			
257	257		257	257
		258		258
	263, 268	259		
		271		271
275, 276	277			273
		280		280
292	292			
		297		
310		310		
312	312	312	312	312
320				313

* Numbers refer to citations appearing in Volume III, A Selected and Annotated Bibliography

Interaction: Whenever interaction between persons is part of the task situation, consideration must be given to the possibility of facilitation or inhibition of task output level as a result of personality characteristics. This is not to imply that group compatibility or cohesiveness is necessarily desirable. It may be that a higher level of group output will be maintained under the opposite condition, group incompatibility or incohesiveness. But if group interaction is a part of the system and the performance to be predicted is in any way affected by this interaction, then consideration should be given to these dimensions.

Perception and Decision-making: Whenever an analysis of the task requirements imposed on the human indicate the possibility of differential perception and/or output selection on the part of the individuals or groups which will have a bearing on the performance, dimensions 64-75 will again become important. The amount of importance and which dimensions are necessarily functions of the particular performance being predicted.

The utility of the above considerations rests on their connections with the basic prediction equation,

$$y = \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_{74} x_{74} + \beta_{75} x_{75}.$$

They are interrelated and may, singly or in combination, increase the relative importance, or contribution to y, of any one of the dimensions 61-75. For example, the first item, time period, represents one of the descriptors of y in the above equation. If the y covers an extended time period then the beta weights for one or more of these dimensions will probably increase.

The non-optimal situational variables are considered to be candidate terms for possible beta weight functions. In other words, the beta weight value is felt to be functionally related to the intensity levels of these variables.

The interactional, perceptual and decision-making variables all relate to the dimension-selection process, or the human-task mapping procedures discussed in Chapter C. As discussed there it is not felt that these dimensions should necessarily assume an additive form in the prediction equation; hopefully, research will be conducted which will allow the nature of their contribution to the prediction of y to be evaluated.

Optimum Performance Prediction: Evaluation of performance maintenance and decrement and pinpointing when changes may be expected to occur may be possible if the above items are considered in combination. For example, performance decrement under stress may be a function of: the nature of the stressor (e.g., degree of expected incapacitation), the internal stress response on the part of the individual (e.g., physiological measures, the SSS and the STAI tests for dimension No. 73), and the selection of output on the part of the individual (e.g., dimensions 71 and 74). The success of relating internal response alone, whether physiological measures or dimension No. 73 measures, to performance has been meager. The use of a larger framework may allow a greater amount of the variance to be accounted for.

Summary

A review of the personality literature made it apparent that a satisfactory conceptualization of this field, suitable for performance prediction in man-machine systems, was not available. It was also evident, however, that the test instruments developed within this field were predictive of performances where the conditions were long-term, non-optimal for the subject population, a function of various types of decision-making and perception, and/or a function of interaction variables. To place this information in a usable format, dimensions 61-75 were derived from the available "personality" measurement set. The purpose, then, of dimensions 61-75 is to increase the predictive power for those conditions where dimensions 1-60 may not account for an adequate amount of the performance variance. It is hoped that research will be conducted which will permit the existence and the definition of such factors to be demonstrated and which will allow the way in which they are predictive to be determined (e.g., multiplicative or additive, within what range of which boundary conditions, with what beta weight functions, etc.).

E. MEASUREMENT: SMALL GROUP PERFORMANCE

The Studies of Small Groups

The measurements popularly taken on small groups are almost entirely internally oriented and directed towards two considerations: the activity of and effects on the individual embedded within the group and the effects of group structure on internal activity. Examples of the internal measures taken on groups include: Bales Interaction Process Analysis which records twelve activities like "Gives opinion" and "Shows solidarity", Hemphill's Group Dimensions Description Questionnaire, various attitudinal scales, similarity measures like the Assumed Similarity Between Opposites (ASo), various choice-of-group leader and power structure forms, and the frequencies of certain communications within communication structures.

Measures of group output, when taken, are rarely task related. Satisfaction and enjoyment are often the accepted criteria. As Shaw reports in his review of experimental methods used for group study, "The task variable is one of the most neglected in social science research, and this is particularly true with regard to the group task variable " (123, 637). The most common task output measures are those taken on group discussion activities such as the number, goodness or originality of the answers.

Pre-experimental individual measures are often collected, but unfortunately, usually only a few are taken to serve as a basis for grouping the individuals with respect to one or two characteristics.

Little has been derived in the way of relationships between the variables mentioned above (individual characteristics, group output, internal group activity and group structure). The most effort has been directed towards demonstrating relationships between the measures of the individual and both group output and group internal activity (e.g., 98, 119). Much of this effort is reflected in the selected group compositional dimensions 61-64. Some researches have been located which attempt to discover interrelationships between individual measures, internal group activity and group structure. Currently, however, these researches do not appear to be applicable to the present problems as the relationships of group output to the internal group activity and structure do not appear to have been investigated.

In summary, the available research efforts on groups appear to have been almost entirely related to the internal activity and structure of groups. The concept of a priori group performance measures for prediction purposes has not been studied or applied (with one exception to be discussed below). The reviewed studies and the concepts with which they are concerned do not yield a good understanding of the relationship between task demands, physical environments, group dynamics and group composition; or, even more importantly, these studies have not defined the combined effects of these variables on group behavior, especially group task performance in man-machine systems.

In view of the group performance state-of-the-art, alternate approaches will be proposed and discussed below in terms of the complexity of the group task structure (as in Figure C-5). These approaches are amenable to quantitative prediction methods, given the research necessary to empirically demonstrate both their feasibility and the proper quantitative expressions. Reference is made to studies which support the feasibility and utility of these approaches.

Group Performance Dimensions

Suggested dimensions

If the group within a man-machine system has a very simple and well-defined structure with respect to the tasks to be performed, it may be possible to predict the group output as a function of the predicted outputs of the individuals within the group. Certainly some ground rules have been established if the task performances can be viewed as being either in series or in parallel with respect to a final criterion measure (124).

If, however, the group task activity is more complex as, for example, in Figure C-5 then an analysis which directly relates the activities of the individuals to the group's actual output to the system becomes an impossibility. If it is desirable to measure a group such that the performance of that group can be predicted for one or more complex group tasks, tasks which cannot be broken into completely disparate outputs for each individual with said outputs organizable into a simple structure, then a different approach is needed.

The approach to be suggested is congruous with the dimensional framework, consisting of primarily factor analytically derived dimensions. That is, if task performance measures were taken on a large number of groups, performing on a large number of varying tasks, and the data were subjected to factor analysis, then it would be expected that group performance dimensions would be obtained. These performance dimensions would load to varying extents on each of the tasks included in the measurement set; and, therefore, be useable in multiple regression equations which would account for some portion of the group performance variance on each of the reference and criterion tasks.

It is expected that some complex relationship should exist between the group composition (e.g., dimensions 61-64), the number of group members and the factor analytically derived performance dimensions. It is further expected that the particular combination of group performance dimensions and their respective loadings on any group task output will be a function of: (1) the demands made on the group as a result of what the group must do to produce an output, (2) the level of group practice on the task, and (3) various parameters such as the length of time the group has performed together and the stressors and motivators which arise from the task and physical environments.

At the outset it appears that the efforts of Shaw (29, 122) in establishing a dimensional scheme for group task structure and the efforts of Hackman (256) in organizing a set of group tasks with the available reference literature on each may provide an initial basis for research in this area.

With this approach in mind the Performance Descriptor X Physical and Interactional Categories matrix for the individual performer (Figure C-2) was reviewed and modified for use with group performance dimensions. Presented in Figure E-1, an X appears in those row x column intersections which seemed to describe performance dimensions which could reasonably be expected to account for group performance variance and which, further, seemed to describe recognizable differences between tasks.

Supportive background for the suggested dimensions

Only one study has been located which has taken both individual and group performance measures and then related these measures to the performances of these groups in later and varying situations. In this study by Torrance (312), both performances of the individual in the group setting and the performances of that group as a whole were initially measured in a series of three tests. The test measures consisted of performance ratings and scores and perceptual measures. The testing took place in the SAC Survival School and covered a sufficient number (133) of groups such that their operational group performance could be evaluated in one of the following situations: survival training, combat duty (where crew performance was rated by superior officers), or combat duty (where crew performance was rated by bombing missions failed).

This is an especially remarkable study in that (1) the individual and group test measures were related to group performance measures in two varying field environments and (2) these measures were unusually successful in discriminating significantly between good and poor group performances. The best overall predictive measures were the ratings of performance and the perceptual measures taken on a picture of a formal group setting (which, incidently, most closely simulated the operational environment). These measures are described as follows:

Group Performance Descriptors	INPUT	Perception	PROCESSING	Output Selection	OUTPUT
GROUP COMPOSITION DIMENSIONS	61. Similarity, perceived 62. Group compatibility 63. Group cohesiveness 64. Leadership				
SENSITIVITY or DISCRIMINATION	X	X		X	X
MANIPULATION			X		
SPEED		X	X	X	X
SELECTION		X		X	
FLEXIBILITY		X	X	X	
KNOWLEDGES*			X		
MEMORY			X		
GENERAL REASONING			X		
DEDUCTION, ANALYSIS					
INTEGRATION, COORDINATION			X		X
PREDICTION, FEEDBACK USAGE				X	X
STAMINA					X

*Some of the descriptors are more clearly a direct function of the group membership measures than others.

Figure E-1. Presents the hypothesized performance dimensions and selected compositional dimensions for the Group Performance Descriptor X System Performance categories matrix.

PERFORMANCE RATINGS	PERCEPTUAL MEASURES
Manpower utilization	Satisfactory outcomes
Participation	Someone leaving group
Coordination	Orderly functioning
Control	Productive
Flexibility	

These are at least three things of interest here. First, another group performance dimension was rated but, as would be expected in view of the nature of the criterion performance measures, did not discriminate between the groups. This dimension was Speed.

Another item of special interest is the fact that an individual verbal-intellectual score was predictive of group performance only in survival training. This suggests a possible parallel to the tendency of cognitive measures to be predictive of individual performance primarily during the initial learning phase.

The third item is important because it supports the suggested utility of using, as an initial set, those group performance dimensions suggested in the Performance Descriptor X System Performance Categories matrix of Figure E-1. The above performance ratings are ones that might be suggested to measure dimensions described by the row Performance Descriptors of Integration and Coordination, Flexibility, Speed, and Selection, and compositional dimensions such as Group Cohesiveness and Leadership.

Measurement and prediction of group performance

The approach selected (and, therefore, the measurement procedures used) as most effective for the prediction of group performance has been suggested to be a function of the level of complexity found to exist in the input, processing and output activities required of the group. If the procedures can be separated into relatively disparate sets of activities per person and if the input-processing-output flow is a simple one then prediction can probably be done primarily in terms of the outputs of the individual members. If, however, the group activities are more complex, but still must be predicted a priori without benefit of direct measurement on the tasks, then it is proposed that the x_i terms of a multiple regression prediction equation should be group performance dimensions. An initial set of group performance dimensions has been hypothesized to exist. Although it is felt that the group's standing on any of the group performance dimensions should be a function of the group composition, i.e., the characteristics of the individual members of the group, (in the same way, perhaps, that the individual's standing on an individual performance dimension may be a function of some transformation of internal native characteristics), there is no empirical basis, at present, on which to make decisions as to: 1) what compositional factors would be needed to comprise a necessary and sufficient set and 2) what functions would be needed to translate measurements on these factors to predictions of group performance. Referring to the Group Performance Descriptors appearing in Figure E-1, in terms of item (2), Knowledges could probably be measured through direct measurement of the individual group members. Whether or not Memory could be evaluated through measurement of the individual members would, in all probability, depend on the performance criterion to be predicted and the surrounding parameters. The remaining Performance Descriptors probably represent rather complex transformations of many compositional factors.

It does appear, however, that the suggested compositional dimensions 61-64, and possibly others, would be useful for the prediction of group performance under some conditions in somewhat the same way as are the personality characteristics on which these particular dimensions are based. That is, when stress or unusual demand occurs, these compositional dimensions are expected to play an increasingly important part in accounting for the behavioral and performance variance between the groups. The research literature indicates that at least two of them, Group Compatibility and Leadership, are useful for predicting the behavior and performance of the group under various stress conditions (e.g., confinement), task characteristics (e.g., goal path multiplicity) and group organizations (e.g., formal groups).

Summary

A review of the existing literature covering research activities and theoretical concepts within the area of group activities made it very clear that there was little available which was applicable to the problem of a priori prediction of group performance. A dimensional approach was suggested based on group performance dimensions similar in nature to those which have been defined in the investigations of individual task performance. It was hypothesized that a priori measurement of these dimensions and suggested group compositional dimensions would allow prediction of group performance in situations where the group activities were too complex to be evaluated in terms of individual performances. A research effort which had used a somewhat similar approach with unusual success was reported.

F. MEASUREMENT: SYSTEM PERFORMANCE MEASURES

System Performance Measurement Objectives

System performance measures are basically for the purpose of determining whether mission objectives are, can be, or will be, accomplished by a given man-machine system. A comprehensive set of system performance measures describes the status of a system in a manner which will provide a basis for the prediction of future system status if the environment and external forces (stressors) are specified. In control theory, the set of comprehensive descriptors is called the state variables. While it is not expected that the theory of man-machine systems has advanced to the point of the analytical power possible in control theory, the concept of a complete set of descriptors (state variables , or, system performance variables) should be quite useful. Therefore, it is this concept which will be used to define system performance measures.

For current purposes, system performance measurement provides information about (1) accomplishment of a specified mission, or the feasibility of attempting the mission with a given system, (2) the shortcomings of the system, subsystem, or components, and (3) the margin of operation within safe tolerances. In short, it is desired to obtain answers to such questions as: Will a system do what it is expected to, or hoped to? If something doesn't work correctly, will the designers know what is wrong, and how to fix it? Is the system working within safe tolerances? Or, what is the probability of failure?

In general it is possible to define measures of performance to answer all levels of such questions; however, it is all too often the case that practical measurement cannot be accomplished in the real-world environment. One must, therefore, fall back on predictions of the real-world quantities based on information collected in somewhat artificial environments. Even in this eventuality, the definition of performance measurement is not academic, for performance measurement provides a means for specifying prediction requirements.

The current section on performance measurement, then, has a two-fold purpose: (1) to define performance measurement which is feasible in the operational environment, and (2) to specify requirements for performance prediction, i.e., to directly answer the question, "to predict what?" Additionally, some implications to mechanisms for prediction may be derived.

For this discussion, human involvement will be treated with a strict systems engineering viewpoint. System performance measurement will deal only with the contribution of the human operators in the system to the system goals. Where the human contribution cannot be explicated, the smallest man-machine unit related to mission accomplishment will be identified. Therefore, the behavioral aspects involved in task performance by man will largely be ignored. Nevertheless, it is definitely intended to provide a system performance basis to which one may construct a connecting bridge from behavioral analysis of the human tasks. The behavioral dimensions and techniques for prediction of system performance were treated in Chapter C.

System Performance Dimensions

As indicated in the foregoing, a comprehensive system performance measure set must include one system performance measure (as a minimum) for each dimension of the system which may affect performance of the mission designated for the system. A full specification for system performance measurement can therefore only be accomplished when a specific case is given. However, system dimension classes may be identified which are believed to be inherent to all systems.

In the subsequent paragraphs, the following levels of system performance analysis are discussed: (1) system organization, (2) functional descriptors, and (3) performance criteria. System organization, functional description and criteria constitute adequate specifications for the generation of system performance measurement.

System organization. It is clear that there are performance characteristics of the entire system which may be directly related to mission requirements; also, there are performance characteristics related to the tasks performed by the human operator. However, depending on the complexity of the system there also may be many other divisions of the system which bear a relationship to system performance.

To be general, one must at least postulate a hierarchical system structure consisting of many levels of embedded functional units, eg., total system, subsystems/modules/etc...components, action elements. It may be uncommon to find a complex system with such a clear-cut hierarchical structure; many system functional units may depend upon, or influence, many others. Consequently, the system organization may require a complex block diagram to display, but such a block diagram will also be required for other system engineering purposes.

The system organization (block diagram) will show the flow of information and the chain of influence which will identify measurement points in the system. At each interconnection shown in a system block diagram something is happening which has impact on the total system. Measurement must be provided for each such point in the system in order to fully describe the system, and to allow diagnosis of the system. A gross description of the system organization will only permit gross diagnosis if corresponding measurement is implemented. To permit diagnosis to the level of the human operators in the system, and conversely to allow prediction of the effect of human operators on the total system performance, system description must be provided down to the level of the human operator tasks.

It is important, therefore, that the first level of analysis (system organization description) include all man and machine tasks, and man-machine, and man-man interactions to the degree of detail that one wishes to derive information through system performance measurement.

Functional description. Specification of the system organization may indicate where measurement should take place, but no information is provided about what to measure. To define the dimensions of system performance it is necessary to have information about the functions each system unit is to perform. Definition of system performance dimensions (the second level of analysis) involves explicitly stating the function performed by each system unit with regard to (1) the contribution made to the mission objectives, (2) the nature of the required output, and (3) the specific impact on other system units. In this manner a chain of functional relationships can be established in which the effect of a given unit can directly or indirectly be related to the total system output. In particular, it is desirable for the purposes of the current study to show the relationship of human operator tasks to subsystem and total system performance (the taxonomy of tasks is treated in a previous chapter).

To permit generation of system performance measures, the functional description of system units must be stated in operational terms. It is necessary to provide a description from which one can deduce the system variables affected and the manner in which the specified variables should change for proper system operation.

Criteria specification. To complete the minimum specification for system performance measurement, in addition to (1) where to measure, and (2) what to measure, one must also know (3) what is it that should be learned through measurement (e.g., what kind of measure?). In short, one could record all the system variables (state variables) from which all system related information could be derived, but specific transformations (the mathematical relationships which define performance measurement) must be created for each question to be asked about the performance of the system. The key to the final analysis level, which establishes the measures for the system performance dimensional set, is to establish criteria for system performance variables.

Total system output variables may be related directly to mission requirements to establish criteria of performance; for example, at injection into orbit, vehicle velocities must be within a specifiable range, the vehicle must be within an altitude range, oriented in a specific direction (X degrees) in each axis, etc. Further, for successful injection, each subsystem must be operating in a particular way; the astronauts must be performing certain duties, and ad infinitum.

Based on operationally specified criteria for each performance variable, performance measures may be designed to provide precisely the information necessary to full description of system performance in terms of system goals.

Performance Measurement Definition

The structure and procedures described above to specify system performance orgainzation, dimensions and criteria results in a skeletal system model. The model does not include the internal operation of any of the system units but it invites one to provide all possible information which may have a bearing on system performance measurement. For each system performance measure relatable to mission objectives, answers are given to: Where (measurement points in the system)? What (relevant system variables)? To know what (operation relative to established criteria)? Design of performance measurement is possible based on the system model, but there is, unfortunately, no direct procedure to obtain mathematical transformations of the system dimensions to result in performance measure definitions.

Often, system performance measurement is directly suggested by the performance criterion; for example, if one criterion is that less than X lbs. of fuel may be expended, then measurement of total fuel expended is an obvious choice. On the other hand, the choice is often far from obvious. For example, it may be desirable to exploit unforseeable opportunities to the benefit of ultimate mission goals; in such a case, it will be difficult to know what to measure and what sort of exploitation to expect. In short, to provide a solid basis for measurement one must be able to operationally define what it is that is to be found out through measurement, and to deal with phenomena which are reasonably well understood. The dilemma, of course, is that exploration and research efforts (where good measurement is vitally needed) are seldom directed at this sort of situation.

Further, even if measurement is defined, it is often impossible to measure in the operational environment. Frequently one is unable to get measurement equipment into the operational situation; to do so may even completely change the events to be measured. As is often the case, one may wish to measure errors; however, to measure errors requires knowledge of correctness. Knowledge of correct action may be difficult to obtain, and if available there may even be reason to use this information to drastically change system design. For these and many more reasons, measurement in the real-world environment under operational conditions is only possible for the grossest of system accomplishments, or when the system fortuitously provides the opportunity for measurement.

The result is that one must attempt to predict performance instead of direct measurement in the operational environment to obtain the information needed for design purposes.

System Performance Prediction

The prediction of the effect of out-of-tolerance performance, or various performance anomalies, on total system performance by any of the machine devices in the system is normally possible. The physical phenomena are sufficiently understood to permit development of a model which will permit direct prediction (calculation) of system performance. (Of course, the effect of unusual stresses, such as free-fall conditions, may not be tractable.) The prediction of human performance is seldom possible at the same level; but, if the effect on human task performance is known in terms of the effect on machine variables, calculation of the same sort is possible.

There is no need, therefore, to attempt to discover prediction equations which will directly predict the effects on the system of decrements in human performance. Prediction capabilities are available, in part, in the form of system models (mathematical models, or direct-analog simulation). If prediction techniques can be found which predict task performance (man or man-man) or man-machine subsystem performance, then these equations can be combined with the system model to provide a total prediction capability for predicting total system performance and the effect on the accomplishment of mission objectives. In taking this approach the validity of existing system prediction procedures must be accepted; even though imperfect validity is known, it is assumed that use of existing methods is the best short-term solution.

The implication to human performance prediction is clear: Bridge the gap, by building the capability to predict system performance measures closely related to human tasks (e.g., the system variables which are directly changed as a result of human behavior), then total system prediction is provided (at least to the same degree of prediction possible for other parts of the system). Figure F-1 represents these relationships diagramatically.

Measurement and Prediction Requirements for Selected Applications

To show the range of performance measurement requirements to be expected in the context of an extended orbital mission, Tables F1 - F4 show brief analyses of selected examples. Even though these examples occur as part of a system, for convenience the "system" is redefined in each case to constitute the smallest possible ensemble of operating elements. As may be seen from Tables F-1 through F-4 the procedure in each example is to: (1) define the system, (2) specify the system goals, i.e., mission requirements, (3) outline the performance measurement dimensions, (4) discuss the general characteristics of suitable performance measurement, and (5) identify implications for the prediction of human performance.

Extra-vehicular activity.* Extra-vehicular activity (Table F-1) provides one of the simplest examples in terms of system complexity. The astronaut is required to move around and use tools, encumbered, of course, by his protective suit and in an environment where the result of his actions is quite different from the same actions on the Earth. The questions to be answered through measurement are concerned with the accomplishment of simple activities. Task measurement, except by direct observation, is virtually impossible without further encumbering the astronaut (however, biomedical data is available). For purposes of design (e.g., the manner of constructing and repairing an orbital laboratory), it is necessary to predict the goal-oriented measurement which cannot be directly measured. Note, however, that it is not sufficient to predict that decrements in performance are to be expected; prediction must address the feasibility of specific task accomplishment.

Inflight exercise experiment. Table F-2 presents a system performance analysis of an inflight exercise experiment. This particular experiment was adapted from Gemini experiments in which the data were collected by means of a biomedical recorder. However, in the presumed shirt-sleeved environment of an extended orbital mission, such data may be collected by conventional means; in any case, an example is provided which demonstrates performance measurement requirements for an inflight experiment.

The experimenter is to take blood pressure and pulse rate measurements; the rationale of the experiment is presumed that any differences in these measurements which appear over time, or which appear when compared to similar measurements before or after the flight, can be attributable to only the subject, not the experimenter. The experimenter also must control the experiment which involves pacing the subject through exercise. The question is: can he take these measures and control the experiment in a standard fashion identical to that possible when not stressed by the space environment? Precise requirements for performance measurement are again clear; also, the prediction requirements are well-defined (Is there any bias in the data collected, and is the experimental error inflated due to space stresses?).

* Detailed task analyses, which were performed for all these examples, are shown in Appendix B.

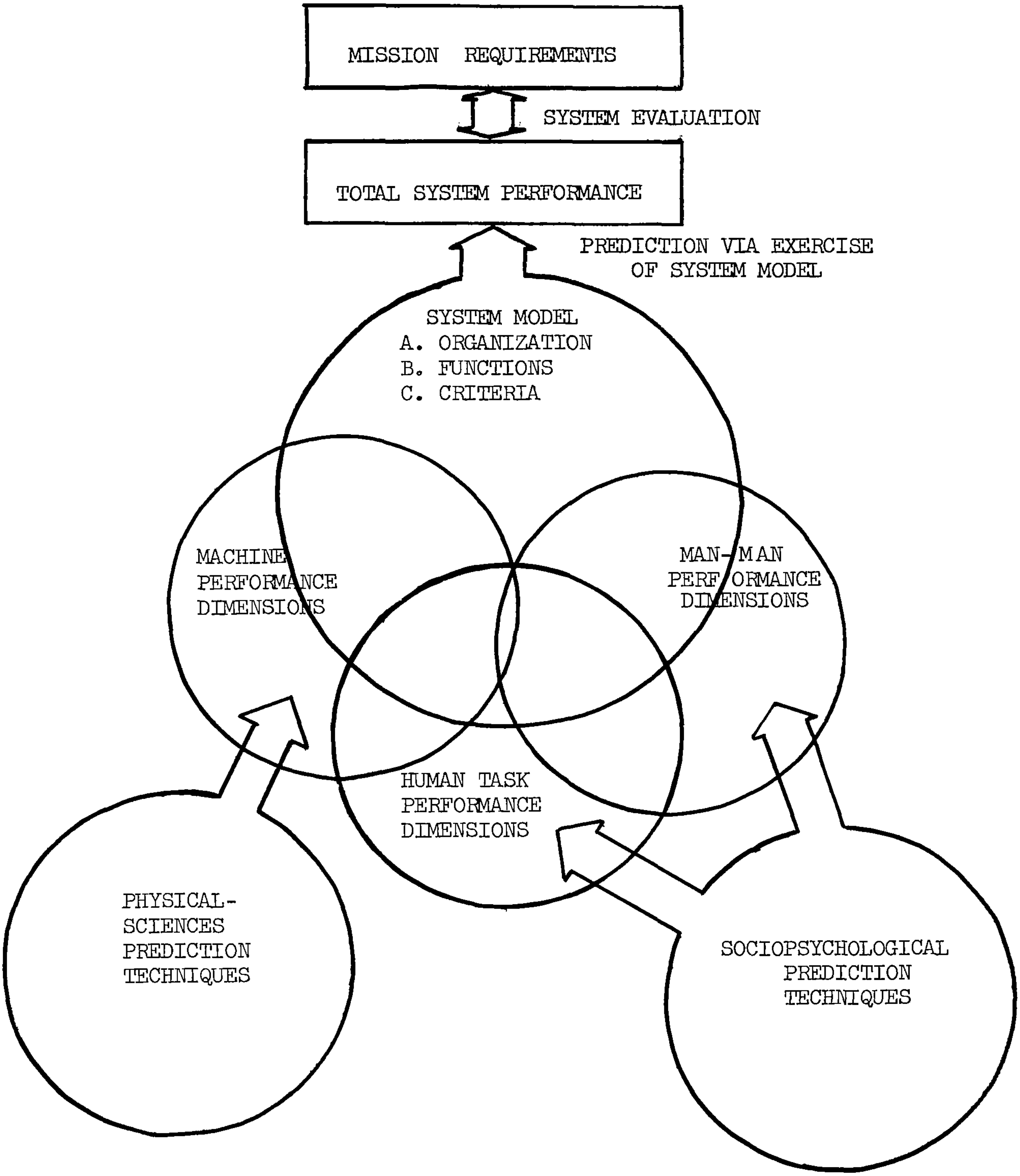


FIGURE F-1. SYSTEM PERFORMANCE IMPLICATIONS TO HUMAN PERFORMANCE PREDICTIONS

Synoptic terrain photography. As may be seen from Table F-3, the essential elements for the conduct of synoptic terrain photography are few, but human performance requirements are complex. The overall goal is the collection of photographic information for which definitive criteria are difficult to establish. Otherwise, the crew must coordinate in rolling the vehicle to provide the proper views, and in identifying land masses. Specific task requirements may be established for procedures in operating the camera effectively. Prediction needs are primarily in terms of yes-no answers to specific questions, ie: Can the crew identify land masses and select pictures of high information content? Orient and maintain necessary vehicle attitudes? Operate the camera?

Delta-V operation during rendezvous. Analysis of the change in velocity operation during rendezvous (Table F-4) indicates a highly complex system and performance measurement problem. Much more analysis than performed here is necessary to reveal the complete and detailed nature of the operation. Goals are easily established for the total system, but a systems analysis is necessary to show the relationship of specific subsystem and human performance to the accomplishment of system goals. Nevertheless, it is evident that accomplishment of the maneuver entails (1) small group activity, (2) sighting precision with optical devices to determine angles to particular celestial bodies, (3) orientation of the spacecraft, and (4) man-man, man-computer and man-machine interaction. Prediction needs include the determination of multi-man task accomplishment under visual and other stressors. Overall system performance is not only affected by human performance, but also by the performance of a number of subsystems; consequently, the prediction equation must include a number of machine performance variables as well as those of human performance.

Detailed example: Radiometry experiments. The last example is presented in more detail to illustrate specific performance measurement and prediction requirements in a complex man-machine system. To the extent that the literature permitted (e.g., 426), the analysis was accomplished according to the three levels of system performance analysis discussed earlier. The Tables may be found in Appendix A.

The basic overall objectives relate to the quality and quantity of radiometry data collected; but, these can be assessed only after the recorded data can be examined by specialists. Otherwise specific performance measurement and criteria can be established for other system functions and human tasks. Notice that the performance measures are quantitative and specific (e.g., time to rotate vehicle, fuel consumed, pounds of fuel per unit time while tracking a target, brightness and contrast ratio, means and standard deviations of system variables, within range to ground station, etc). Notice also that some measures such as probability of identification require repeated measurement to establish reliable estimates.

TABLE F-1

SYSTEM PERFORMANCE ANALYSIS
Extra-Vehicular Activity

System definition. The system to be considered for extra-vehicular activity is essentially the man, his suit, and whatever locomotion, tether, and tools which may be provided to him.

System goals. The goal is for the man to leave the vehicle, move from place to place and possibly perform some useful work, and return to either the original vehicle or some other.

System Performance dimensions. Measurement conducted in such setting would be for the purposes of (1) establish that the activity was performed safely without any physiological ramifications (safety dimensions), and (2) testing that any work performed according to requirements (work performance dimensions).

Performance measurement. While the ability to actually measure under such circumstances is practically limited, ideally one would desire to monitor performance of tasks to compare with established margins of safety and to measure work output. With regard to the former, measurement should address the questions: Can the astronaut reach the mirror which he is supposed to put out of the way? Does the umbilical get near anything which might foul it? On a more goal-oriented basis, does he exit from the hatch without mishap? Can he maneuver and return within acceptable mobility, time and fuel limitations? With regard to the latter, measurement may address the questions: Can he torque the bolts as required? Can he make repairs? What probability can be established for getting the job done properly? While the measures associated with these questions cannot be made specific at this time, it is clear that activity and goal-oriented measurement could be defined.

Performance prediction needs. Prediction is not greatly hampered by considerations of complex man-machine systems. One wishes to predict simply whether man can work in such an environment or not. However, note that the prediction to perform work is rather specific, eg., can he reach a given distance in a given direction?, can he use a given type of tool?

TABLE F-2

SYSTEM PERFORMANCE ANALYSIS
Inflight Exercise Experiment

System definition. Presumably the system consists of the experimenter, a subject, and simple apparatus (Sphygmomanometer, exercise cord, clock).

System goals. The goal is to conduct an experiment and to record the results whatever they might be. If the experiment is to be other than abortive, the experimenter must take periodic blood pressure and pulse rate measurements, while the subject must do paced leg-arm exercises with the exercise cord.

System performance dimensions. The basic question should be whether the experiment will produce the information for which it was designed. Presumably, this experiment is part of a larger experiment in which similar data are to be collected before and after exposure to space conditions (i.e., before launch and after splashdown). Consequently, the study is based on the assumption that the differences noted over time are solely attributable to the space environment (principally free-fall conditions). Specific dimensions of performance include blood pressure error, pulse rate error, errors in experiemntal procedures.

Performance measures. System performance measures include the following (assuming that any behavior on the part of the subject should be treated under the topic of experimental measurement): (1) Experimenter performance with the blood pressure instrument (possible comparisons with telemetered automatic recordings); (2) Experimenter pulse rate performance (again, possible comparisons with telemetered data); (3) Experimenter control of the experiment (was the experiment conducted in a standard way?).

Performance prediction needs. Predict blood pressure and pulse rate measurement errors by the experimenter under the stresses present. Unless the prediction is that no decrement in performance will result, the performance changes should be predicted quantitatively, as it is necessary to be able to estimate whether the difference will be practically significant (or whether a correction factor can be applied). Note that the task involves visual, aural, finger control, timing, and pacing of the subject.

TABLE F-3

SYSTEM PERFORMANCE ANALYSIS
Synoptic Terrain Photography

System definition. The system consists of a man and a camera, inside a space vehicle.

System goals. The objective is to obtain pictures of specific land masses. The camera, a fairly small and complex device must be operated in a free-fall environment. The space vehicle must be oriented to take pictures through a window. The land masses must be identified and maintained within the field of view while pictures are being taken.

System performance dimensions. System performance measurement relates primarily to the quality of the pictures taken and the information content of the pictures. The man must ensure that the window is clean, that the subject matter is appropriate, and that the shutter/lens settings are properly made in correspondence with settings that appear in the view finder.

Performance measures. Proper performance on window-cleaning and shutter/lens setting tasks should be evident when the film is developed. Measurement of the orientation of the space vehicle can be provided through recording of vehicle attitude angles and rates (mean and variability about each axis should be computed). Comprehensive measurement would also include shutter/lens settings and object viewed for each frame of film. General mission success will be judged from the film after development.

Performance prediction needs. The basic system performance prediction requirements are: (1) performance in identifying land masses and selecting pictures of maximum information content, (2) orientation of the vehicle, coordination between crew members, and maintenance of orientation, so that picture-taking is possible, and (3) performance of the visual and fine-movement tasks required to use the camera. Specific tolerances should be possible to define, so that the basic prediction task is the identification of deficiencies, if any, which would preclude satisfactory system performance, i.e., within tolerances.

TABLE F-4

SYSTEM PERFORMANCE ANALYSIS
Delta-V Operation During Rendezvous

System definition. The system is quite complex, consisting of the vehicle, three-man crew (Apollo), navigational optics, and computer. The human tasks are linked and embedded with other human and machine actions to result in a change in the vehicle velocity vector. To determine the net effect of human performance, therefore, one must consider the performance of several people and a hierarchy of equipment, incorporating a system model to calculate the total effect on vehicle motion.

System goals. The goal of the system is to produce a velocity change; a series of such changes, if adequately executed, will result in the rendezvous between two space vehicles. The system goals can be translated into goals for several subsystems; for example: (1) vehicle attitude must be controlled according to pre-determined programs within specific tolerances, (2) a computer subsystem must compute requirements for changes in thrust, based primarily on human sightings and man-sextant performance, and (3) thrusting must be controlled according to the computed program.

System performance dimensions. Performance dimensions can be listed for the total system, specific subsystems, or for human tasks; presumably, the mathematical basis exists for interrelating all of these. Without performing complex systems analysis, only two levels of measurement are convenient for discussion: (1) total system performance, and (2) human navigational tasks. Total system performance is obviously measured in terms of the velocity vector which resulted; while perhaps no reference data may be available for assessment of each velocity changes, the number of changes to effect rendezvous and the amount of fuel consumed, are possible indicators of system performance. The basic human navigational tasks are in terms of angular measurement precision and time.

Performance measurement. Several man-machine tasks can be taken as examples: (1) Vehicle control; (2) Sighting precision; and (3) Crew coordination. The vehicle must be pointed to portions of space permitting view of specific celestial objects, and held in that orientation with a reasonable degree of steadiness; this is measurable in terms of variability of orientation angles. Sighting precision may be described in terms of precision and variability of centering celestial objects in optical devices (the basic human task) or the accuracy of angles entered into the computer (a man-machine output). At least one possible measure of crew coordination is the total time to perform a delta-V operation.

TABLE F-4 (Cont'd)

Performance prediction needs. It is desirable to predict at the levels of system, subsystem, or human task performance. Quantitative prediction is necessary if total rendezvous performance prediction is to be attempted. The prediction equation would involve three-man crew performance, specific individual differences which have commonly been shown in sextant performance, the effect of irradiance from bright neighboring celestial bodies, and other space stressors.

Some measurement, such as the equipment set-up and operation, may seem trivial, but just the opposite may be true. For the Gemini V and VII missions, the operation of the recorder switch was apparently a matter of some concern. On the Gemini V mission an important measurement (on the rendezvous evaluation pod as it separated in space) was lost. The data transmitted to the ground was lost and the inflight recorder lacked data. Pilot error must have been suspected, as a switch guard on the recorder switch was added for the Gemini VII flight. However, further confusion was encountered as the experiment recorder operated intermittently during the first two revolutions of the Gemini VII flight. Was the loss of Gemini V dat due to improper human performance or equipment performance? One suspects that the answer will never be known.

The transformation from a specification of the performance variables and the criteria to the performance measures is not one for which rules can be clearly established. The manner in which the criteria are phrased may suggest, or even stipulate a particular measure of performance; however, the design of performance measures is often a function of the available mathematical tools. If the criteria are stated in terms of tolerance limits, then performance measures in terms of statistical parameters (from which one may infer the probability of exceeding the tolerances) seem to be a natural choice.

For better or worse, then, performance measures may be established; if required, the inventive individual with a mathematical background will come up with a mathematical relationship to yield quantitative measures. The task of implementing the resultant measures in the operational environment is another matter. Two problems occur regularly: (1) no measurement or recording devices can be installed, and (2) collection of measurement disrupts the mission (e.g., when repeated measures of the accomplishment of a maneuver are desired). To circumvent these difficulties, scientists have been required to substitute prediction for direct measurement.

Tools for System Performance Measurement

In view of the preceding discussion it should appear natural that investigators would wish to create an environment more suitable to their purposes than the operational environment. The basic tools that have been used for system performance prediction are simulation devices of many varieties. It is very important that all who use simulators, or the data collected from simulation, are aware that a simulation is an analog of the real-world, an operating imitation of a real process. Measurements are collected from the simulation, and inferences are made about the real world situation. However, since the measurements are made on an analog, or an imitation, extrapolations to the real world must be viewed with suspicion.

Simulation devices. Since a simulation is what it is, there are inherently some properties of the real world not possessed by the simulator. The lack of some real-world properties (such as danger) may even be considered advantageous; or, it is asserted that specific real-world properties are not necessary for the intended purposes. The degree to which a simulator possesses necessary real-world properties is termed fidelity of simulation. Another classification of simulators may be termed level of abstraction; the simulation (or model) may externally possess real-world properties (i.e., there is high fidelity of simulation), but it may take the form of a mathematical model rather than a form which looks like the real-world situation. It is frequently assumed (albeit, tacitly) that it is desirable to develop high fidelity, low abstraction, simulation devices.

Many simulators have been used in the space program for design purposes, as well as for training and other purposes. Among these are mission simulators, part-task simulators (translation and docking simulator), air-bearing simulator, linear-acceleration chair, aircraft flying zero-g parabolas, water immersion simulator, 1/6th-g simulator, and many others. For the most part, these are high fidelity simulators attempting to produce tasks which will look just like the tasks that the astronauts will perform during a mission.

Predictive validity. The majority of the simulators used in the space program are well-instrumented, permitting the measurement which would be desired in the operational environment. The degree of correlation between measures collected in the simulation and measures collected during operational flights is termed predictive validity. Since simulation is intended to be a substitute for measurement in the operational environment a basic prerequisite for the tool to be useful is for it to possess predictive validity. Fidelity of simulation relates to content validity (the extent to which real-world properties are included in the simulation) and does not necessarily imply predictive validity.

Even though predictive validity is a good theoretical concept, it is not necessarily very practical. It should be remembered from previous discussion that much measurement could not be practically achieved during operational missions. Therefore, if one wishes to correlate with the operational mission events, one must correlate at the level of gross mission accomplishments, or rely on the subjective judgment of astronauts. If it is possible to predict gross system performance measures, one may be tempted to infer that prediction of subsystem and task performance are also valid. However, this is equivalent to assuming that the ability to predict aircraft landing performance from simulator data allows one to assume that predictions of performance during the approach are also valid (experience indicates the contrary).

The space program has many instances where the characteristics of the simulator were changed after the mission was flown (e.g., changes in simulator noise and vibration after launch experience). In other cases, predictions from simulations were found to be invalid. The zero-g simulations did not predict the biomedical factors which brought about an early cessation of Astronaut Cernan's extravehicular task on Gemini IX. Correlation of water immersion simulation with Gemini EVA results (405) indicates (1) tasks in space were not performed in the same order, precluding comparison, (2) water immersion simulation may be inadequate for rapid motions, due to the presence of drag, (3) motions in real EVA resembled motions in the simulator, but time differences were noticeable, and (4) performance in orbit required a higher metabolic output than was required in the simulation, particularly for moderate or higher work tasks.

Consequently, our ability to simulate must be questioned. High fidelity of simulation may not result in predictive validity. Nor, should we really expect the simulation to have the same external appearances as the real-world. Where the phenomena are reasonably well understood (e.g., wind tunnel, model boat basin) distortions are delibertely introduced into the model to derive predictive validity (although, wind tunnel and model boat basin results have also occasionally been found to be invalid when structural failures dramatically proved them wrong). Perhaps the key problem is basic understanding of the problems for which simulation is used as a tool. Because there is ostensibly no other way, it is tempting to believe the results of measurement in a simulation in which everything looks just like we think it should.

Alternatives to high-fidelity simulation. It is really doubtful that any substitute for high-fidelity simulation will be found in the near future. A weighting of the successes and failures of simulation appear to overwhelmingly favor high-fidelity simulation for the design of complex systems.

The current study is primarily concerned with the problems of human performance prediction and the relation to system performance measures. In this context, emphasis is placed on the behavioral content of simulation. The current study includes the investigation of the development of tests for the prediction of human performance in operational tasks. Consequently, a possible alternative to full-mission, high-fidelity simulation, is the prediction of system performance based on tests with the appropriate behavioral components. In short, predictive validity may conceivably be accomplished in a much more abstract way (i.e., mathematical prediction) through the use of an abstract model which satisfactorially represents the characteristics of the real-world operation, i.e., content as well as predictive validity.

Summary: System Performance Measures

System performance measurement is expected to provide information about the accomplishment of a specified mission, the shortcomings of the system, and the margin of operation within safe tolerances. Analysis of system performance consists of three levels: (1) system organization, (2) functional description, and (3) performance criteria. The results of performing such an analysis is to provide information about the measurement points in the system, necessary and sufficient system variables for measurement, and required performance relative to established criteria.

Another result of such an analysis is to produce a system model appropriate for the specification of methods for system performance prediction. If prediction techniques can be found which will yield man, man-man, or man-machine performance, then these can be combined with the system model to permit a capability for total system performance prediction. Figure F-1 illustrates the relationships involved.

An examination of a number of representative system performance measurement problems indicates a design need for quantitative, precise prediction of man-machine subsystem, and total system performance in a way which will permit evaluation in terms of mission requirements. The examples show by means of illustration that mathematical definitions of system performance can be defined. Even though these may be somewhat arbitrary and are limited by how well one can define the nature of information which measurement is expected to provide, they present reasonable targets for system performance prediction. The task of implementing the resultant measures in the operational environment is another matter; often no measurement devices can be installed in the operational vehicle, or, collection of measurement is not possible without disruption or re-definition of the mission.

Simulation is a common form of system model which allows system performance measurement to be collected on an operating imitation of the real-world process. Inferences about the real-world situation are made from the simulator measurements; however, since the measures are collected on an analog, extrapolation to the real world must be done with care, e.g., some assurance that the measurement is valid.

A possible alternative to full-mission, high-fidelity simulation, is the prediction of system performance through the use of mathematical prediction techniques wherein the human impact on system performance is based on tests with the appropriate behavioral components. The point-of-view presented here is that the worth of a prediction method is best judged through tests of its predictive validity. An abstract model may conceivably exceed the predictive validity of a model which is a working imitation with a high degree of resemblance to the real world. That is, of course, a hypothesis which may be ultimately tested.

CHAPTER G. SELECTION OF TEST BATTERIES

The present program was not designed to extract either specific test application recommendations or to develop particular test batteries. However, a number of significant points may be made about the critical variables and the methodological approach to test battery development.

The Problem of Dimensions

In the practical sense, the number of testable dimensions implied by an application of the present methodology may become very large, so large in fact that feasible testing programs may be in serious doubt. In short, the complexity of the behavior and the number of dimensions involved in the behavior may be such that test batteries constructed to obtain precise information about each of the dimensions simply may not be within the range of any practical application.

For example, in Chapters C and D, the published literature was used to extract some 75 possible dimensions that may appear in human performance in man-machine systems. Precise test measurement of 75 dimensions would most probably- if they should occur in each specific application- present a testing program beyond any reasonable bounds of resources that could be allocated to a testing program per se.

A specific example may be found in Appendix A where the prediction methodology developed here has been applied to the celestial and radiometry experiments derived from the Gemini V and Gemini VII missions. For that relatively simple task, 19 dimensions are identified in the task performance of the commander pilot and copilot. A complete test battery sufficient for these dimensions would involve a set of 17 tests. That number alone brings into question feasibility of measurement; if the method was replicated across all the tasks involved in the Extended Earth Orbital Laboratory the number of test batteries each with multiple dimensions would clearly be beyond any practical scope.

Immediate relief, however, is found simply in the redundancy of dimensions that will occur across tasks. Analysis across tasks should show the relative frequency of the appearance of dimensions for all task components and imply the relative importance of the dimensions for the entire task set. Expert judgment, based on the specific problem at hand, is necessary to decide which parameters must be measured and which parameters simply do not constitute a significantly large portion of the variance to justify measurement.

The Bandwidth-Fidelity Dilemma

From the standpoint of test and measurement theory, Cronbach and

Gleser (125) have elaborated a testing program which seems very appropriate to the problem of multiple-dimensions and test battery design. They note that, within the bounds of feasible cost and testing time, there is inevitably a conflict between the variety of information desired (the test battery "bandwidth") and the thoroughness with which each dimension is measured (test "fidelity"). Traditional testing techniques would suggest that the maximum possible precision of measurement should be obtained for each dimension; practical consideration dictates that on this basis only a relatively few number of dimensions can be measured while the remainder will simply not be measured at all.

Cronbach and Gleser (125, pp. 97-107) clearly show that this is not the appropriate approach for complex multiple-decision test situations. For particular problems, the optimal strategy for testing is a compromise between the range of testing ("bandwidth") and the precision of testing ("fidelity"). While the test theory is complex, three of their general conclusions may be noted as guidelines for the present problem:

1. Within a finite limit of reasonable test time, several tests are better than a single test even at some cost in single dimension validity. The critical emphasis is not on the precision with which one test measures one dimension but rather the relative importance of each test to all the dimensions involved in the prediction problem. In practice, this implies a set of several tests each of which may have relatively low validity measures but which, in combination, provide far more useful overall information as compared with a single precise test that measures one dimension well but excludes any measurement on the rest of the dimensions in the problem.

In complex, multi-dimensional, decision situations, therefore, the traditional emphasis on single test validity coefficients is misguided. The cost of achieving high single dimension validity will probably be the loss of most of the pertinent information desired.

2. Not all dimensions must be measured. Again, within a finite practical limit of reasonable test time, equal testing time for all dimensions is not necessarily optimal. The range of the test battery ("bandwidth") may well be best limited particularly if the relative importance of the dimensions vary.

3. "For any given problem there is an optimal distribution of effort, both with respect to number of tests to be given and amount of time to be devoted to each test" (125, p. 106). The achievement of this "optimal distribution" for human performance prediction in man-machine systems is a very complex problem; no techniques exist in the present man-machine systems literature to solve this problem; indeed, it has been totally ignored.

Development of a Generalized Test Battery

There has been much interest over the past decade in this literature, and particularly over the past five years, in the development of general test batteries for a wide range of man-machine system applications within simulated and operational environments. It does not seem too much of an exaggeration to state that the "normal" procedure for test development has involved three steps: (1) select or invent some test or a small set of tests which have intrinsic interest for subject execution and superficially assumed face validity, (2) demonstrate that the test(s) are sensitive to (i.e., produce some performance changes) in the presence of stressors (any stressor is satisfactory), and (3) concentrate on the engineering characteristics of the test device or test panel to insure that a compact and portable piece of equipment is developed. While there are some few significant exceptions to this procedure, in general it seems to have been the mode of operation in the literature. It is little wonder that there has been increasing suspicion about the usefulness, validity, and meaning of the "test approach" in human performance prediction.

However, it seems very possible that effective test devices and methods can be developed for human performance prediction in man-machine systems provided certain basic steps are taken:

1. We must understand far more thoroughly the behavior we are attempting to measure. In classical applications, the degree of predictive success has been a direct function of the detailed understanding of the behavior being measured. Superficial estimates of face validity is simply not adequate. It is for this reason that so much attention has been given here (cf., Chapters B and C) to what corresponds to classical job analysis.

A generalized test battery must be particularly tuned to the most critical dimensions of the behavior involved. Yet, in only two cases in this entire literature has there been serious attempts to establish this relationship in developing a test battery, one in the case of manned space vehicle tasks (190) and one in the case of underwater tasks (372).

2. Certain basic steps of test development cannot be ignored. We must insist on quantitative measurement of test reliability. While in some cases this requirement is amply fulfilled in the majority of studies it is simply ignored.

3. We must be able to show how basic human properties are quantitatively related to human task performance and in turn to system performance. Much attention has been given here to this problem (cf., Chapters A and F), and there is little question as to the magnitude of this undertaking (and no question as to how far we are from significant achievements.)

4. The development of useful, precise, valid, reliable, and practical test batteries is not a simple, inexpensive, process. Those tests in the

general psychological literature which have approached these criteria (e.g., the MMPI) are the result of years of careful development.

Constraints on Test Development

The difficulty of developing tests and test batteries for human performance prediction in man-machine systems is further complicated by both familiar and unique constraints all of which seem to be accentuated relative to test application situations. Some of these are:

Predictive validity. The best technique of test validation remains the measurement of predictive validity. Yet, in many man-machine system problems, predictive validity measures are simply not possible.

"Face" validity. Far too much emphasis is placed on face validity. In far too many cases, "face" validity involves a superficial judgment that the test samples the task environment; in short, face validity is often used as a poor representation- or claim- of content validity. Yet, rarely are we told in detail the basis upon which this claim is made.

Training time. Minimization of training time for tests is a standard requirement in all testing applications. Yet, in the present literature this appears often to become an end in itself. Relative to the training requirements integral to most man-machine system tasks, minimum test training time can only be achieved by radical distortion and oversimplification of the test- in which case all validity may be lost.

Testing time. There would appear to be an overemphasis on minimization of testing time. The consequences of this trend are often to reduce test length to a point where validity is no longer possible. It is true that utility analysis (125) suggests tradeoffs between test length, test numbers, and range of decisions, but there is a point beyond which the test becomes useless in any context.

Repeated applications. For many man-machine systems applications, there is a requirement for repeated application of tests over extended periods of time introducing potential artifacts of learning and boredom. One classical solution- equivalent forms- has not been adequately exploited in the present literature.

Test motivation. There have been several recent cases where subjects in man-machine system experiments involving tests have simply refused to do the tests after a period of time. The requirement has been stated that tests must be made "interesting" and "motivating" to the subjects. That requirement is not easily achieved. One suspected difficulty is that subjects in these experiments are often required to perform tests without any understanding of why the tests are being given. Perhaps better instruction to subjects as to the relevance of the test program might alleviate many of the motivational problems.

Three major problems dominate the literature on human performance prediction tests in man-machine system performance: first, elementary and essential rules in test development have been frequently ignored; second, modern techniques for the development of cost-effective tests and test batteries through utility analysis have not been used; and, third, the basic issues in test validity have been avoided. So long as this "strategy" continues, the literature will be extremely suspect. However, all of these difficulties can be resolved.

APPENDIX A

An Application of the Human Performance Prediction Methodology

The purpose of the exercise of the human performance prediction methodology presented in this appendix was to provide demonstrations of how this methodology would be applied to a specific man-machine system activity: the celestial and radiometry experiments conducted during the Gemini V and Gemini VII missions. It will be seen that the series of events and the levels of analysis are such that they provide the necessary answers to the four questions which must be answered adequately if the performance of the man or the man-machine system is to be predicted with optimal effectiveness:

1. To predict what?
2. Upon what dimensions and measures?
3. With what tools?
4. For what purpose?

The sections following represent the actual output of efforts directed toward the above questions using the framework and methods specified in the text. Each of these sections is discussed below in terms of what particular purpose they serve and what aspect of the technical approach they illustrate.

Mission Task Analysis Detailed function and time-line analyses of a task-descriptive nature were performed for several mission segments to afford an overview from which initial selections for further analysis could be made. Figure AA-1 presents the analysis which had been performed for the celestial and space-object radiometry experiements. Although the overall task analysis may use a different format or level of detail than this particular example, it should serve to effectively guide the initial quest for gross-level answers to the question, "To predict what?" In this case, a review of the several analyses (see Appendix B) pointed to the radiometry experiments as being a particularly fruitful segment for methodology demonstration purposes.

Chapter B of the text discusses the use of task analysis in further detail, and the technique used in generating Figure AA-1.

Description of System Operation, or the Group Level Analysis A man-man, man-machine interaction form of task analysis was used to delineate the ongoing man and system activities during the radiometry experiments (Tables AA-1 & AA-2). This is an extremely important step as it is this level of analysis, system description at the level of human operator tasks, which:

1. Provides the basis for the establishment of the system organization, function description and the performance criteria and performance measures as listed in Table AA-3.

2. Sets the stage for the individual level analysis on tasks 1 through 19 in that:

   a. the man-man interactions are delineated and related to the operator input to the system, and

   b. the man-machine interactions and, therefore, interface are identified.

3. Identifies the behaviors in a manner which:

   a. facilitates the location of those points most sensitive to stressors due to the nature of the task and the task relationship to system performance.

   b. facilitates the identification of the task sets for and their functional relationship to (e.g., parallel, series, etc.) system performance measures.

The methodology which is represented by Tables AA-1 and AA-2 is discussed from the systems viewpoint in Chapter F and from the human operator viewpoint in Chapter B. What is obtained in Tables AA-1 and AA-2 is the description necessary to arrive at the system and human performance dimensions necessary to answer the question, "To predict what?" in full.

System Level Analysis As detailed in Chapter F of the text, Table AA-3 tabulates the results of three levels of system performance analysis: organization of the system into appropriate categories, description of the functions and the related tasks for each category, and definition of the performance criteria, or dimensions, to access the satisfactory fulfillment of the described functions. The contents of the criteria column represent the answers, in final form, to the question, "To predict what?", from the system performance standpoint as it concerns the human operator. The fourth column presents the end product of the analyses, a specified set of man-machine system performance measures. These performance measures provide an exact answer to the question, "Upon what measures?", from the system performance standpoint and identify the nature of the criteria and measures from the human performance standpoint. The fifth column contains a listing of alpha characters to allow reference to the performance measures in later tables.

FIGURE AA-1. The mission task analysis for the Celestial and Space-Object Radiometry Experiments presents a detailed function and time-line analysis for that mission segment.

BEHAVIOR: Conduct Celestial Radiometry and Space-Object Radiometry Experiments

RESPONSE REQUIREMENTS

Initiating Stimulus Type	Mechanism	Characteristics	Information Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
Visual Clock time matches event list	Written instruction to conduct experiment at specific time	Multiple - visual presentation on clock and auditory message from Grnd Control to conduct Radiometry experiments	Content Conduct Radiometry experiment	Short-lived 5 seconds	Multiple -2 Visual-List Auditory - Cmd	Jettison Protective doors	Tactile - Fine Motor - Push switch into "UP" position.	Discrete - Individual	High - other switches are in proximity to this switch and must be avoided.	2 - 5 Sec.	Performed in Zero-G
						Extend/ Erect Sensing Units	Tactile - Fine Motor Push Switch into "up" Position	Discrete - Individual	High- other switches are in proximity to this switch and must be avoided.	5 - 10 Sec.	Performed in Zero-G
						Rotate craft to optically align sensing units with target	Tactile - Visual Fine Motor- Pulse jets on proper side to rotate craft.	Serial - Multiple	High- rotation must be performed slowly in order to align vehicle properly	5 sec. - 5 min.	Performed in Zero-G while assistant is optically sighting on target.
						Turn Radiometer Power "ON"	Tactile - Fine Motor Push power switch into "UP" position	Discrete - Individual	High- other switches are in aproximity to this and must be avoided.	2 - 5 Sec.	Performed in Zero-G

FEEDBACK Criteria of Correct Performance	Modality	Content	Duration	TASK CONTEXT Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Visually observe doors blown off of Radiometry area.	Direct - Doors can be seen to explode from vehicle side.	Visual-Experimenter sees doors ejected.	Remains off throughout Mission	2 Observation by 2 personnel provides verification of ejection.	Part of Experiment Procedure	Part of Checklist	Celestial Radiometry Experiment could not be completed.	Voice Comm. with Grnd.
Visually observe sensing devices rising out of spacecraft.	Direct - Sensing devices can be observed extending out of side of spacecraft.	Visual - Experimenter can see sensing devices erect.	Remains in extended position for remainder of mission.	2	Part of experiment procedure	Part of Checklist	Celestial Radiometry experiment could not be completed.	Report to Grnd station when completed.
Optical sights aligned with proper target	Direct-, target appears in center of optical sight.	Visual-Experimenter sights target in center of sight.	Remains in this position until another experiment requires change.	2 Close coordination necessary for proper alignment.	Part of experiment procedure	Part of checklist	Celestial Radiometry experiment could not be completed.	Voice comm. with experimenter at optical sight.
Visually observe switch moved to "up" position.	Direct-experimenter can see switch is up.	Visual-Tactile Switch can be seen and felt to move into up position.	Remains in up position during this experiment.	1	Part of experiment procedure.	Part of checklist	Celestial Radiometry experiment could not be completed.	None

BEHAVIOR:						RESPONSE REQUIREMENTS					
Type	Mechanism	Charact-eristics	Infor-mation Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Check Ammeter for proper reading.	Visual	Dis-crete - In-divi-dual	High- if Ammeter reading not within bounds power should be turned off.	5 - 10 Sec.	Performed in Zero-G condition
						Turn on Recorder	Tac-tile - Fine Motor Lift Guard and put record-er switch in On posi-tion.	Ser-ial - mul-tiple	High	5 - 10 Sec.	Performed in Zero-G Condition
						Trans-mit Data to Ground Station (Turn on trans-mitter)	Tac-tile - Fine Motor Push XMITR button to up posi-tion.	Ser-ial - Mul-tiple	High- other switches are in proxi-mity to this switch and must be avoided.	2 - 5 Sec.	Performed in Zero-G Condition
						Realign craft to new target and continue recording & transmit-ting data.					

FEEDBACK	TASK CONTEXT							
Criteria of Correct Performance	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Visually observe the reading on the Ammeter dial to be within limits.	Direct-Ammeter dial rotates and settles within proper limits.	Visual-Experimenter views Ammeter dial setting within limits.	Ammeter dial registers proper reading throughout experiment.	1	Part of experiment procedure.	Part of Checklist.	Celestial Radiometry experiment could not be completed.	None
Visually observe recorder switch in On position.	Direct-Experimentor can see switch is up.	Visual-Tactile-Switch can be seen and felt to move into up position.	Throughout experiment.	1	Part of experiment procedure.	Part of Checklist	None- data will not be recorded in spacecraft but can still be transmitted to earth.	None
Visually observe XMITR switch moves to On position.	Direct-Experimenter can see switch is up.	Visual-Tactile-switch can be seen and felt to move into up' position.	Throughout experiment.	1	Part of experiment procedure.	Part of Checklist.	If recorder not working then data will be lost- if recorder is working no problem.	Voice comm. with grnd.

TABLE AA-1

SYSTEM PERFORMANCE ANALYSIS

Celestial and Space-Object Radiometry Experiments

Space definition: The system for these experiments consists of: the space vehicle, radiometry equipment, a vehicle-controller, and an experimenter.

System goals: The system objective is to acquire data from celestial objects through sensing units fixed to the vehicle and record/transmit data to ground stations. Data from a number of specific celestial objects are desired. The sensing units must be directed by rotating the vehicle; targets must be identified and aligned visually. One man rotates and aims the vehicle; the other operates radiometry equipment; both are involved in target engagement.

System performance dimensions: The basic measurement relates to the quality and quantity of the data collected. Were data collected on the desired targets? Was the vehicle sufficiently stable and within sighting tolerances for each target? Were all switches properly set, and all systems properly functioning?

Performance measures: Aside from proper experiment set-up and functioning of electronic devices, key performance factors are (1) the identification of desired targets, and (2) the two-man vehicle-orientation task. In short, it would be desirable to measure such parameters as the designation of the target sighted, and the accuracy of sighting (a sighting tolerance should be specifiable which will ensure data quality. It is not at all clear whether from such measures it can be shown that decrement will probably result in out-of-tolerance performance.

DESCRIPTION OF SYSTEM OPERATION

CELESTIAL & SPACE-OBJECT RADIOMETRY (GEMINI V & VII)

TASK	COMMANDER PILOT	PILOT	SYSTEM	PERFORMANCE MEASUREMENT COMMENTS
Begin			Spacecraft in orbit.	
Set up radiometry equipment	(4) Turn collimated window reticle light ON (5) Adjust brightness	(1) Jettison protective doors (2) Determine target from mission plan (3) Select IR sensor type (6) Radiometer power ON (7) Check ammeter	Doors opened pyrotechnically. Three sensing units swing out in boresight alignment with optical sight Either cryogenic IR or IR Sensors operating current flow indicated on meter	First revolution only. Operational readiness made on first revolution, not shown here Cryogenic IR measurements must be made during first 8 hours, measure smaller segment of JR spectrum. (Set up OK?)
Rotate vehicle and find target	(9) Use 3-axis hand controller to aim at approx. location Identify target by looking thru window	8 If target is star locate on charts; otherwise locate objects in space, on earth, moon. (10) Aid orientation Identify target by looking thru window	Reaction motors operate	(Find correct target?) (18) Should be alert for targets of opportunity (19) (Find any?)
Aim vehicle at target	(11) Accurately sight target with window reticle (for some tgts, vehicle is rotated at slow rate to scan across target area)	(12) Turn transmitter ON (photo coverage also possible) Verify reception by ground station	FM signals transmitted to tracking station	Sensor field-of-view $\approx 2^\circ$ Sensor misalignment $\approx \frac{1}{2}^\circ$ Aiming accuracy $\leq \frac{1}{2}^\circ$ (Aiming within tolerances?) (Amount of fuel used?)
Transmit and record data	(13) Hold aim (15) Voice commentary	(14) Turn recorder ON (16) Voice commentary (17) Turn recorder OFF	Signals recorded	Recording data important only when not transmitting to a ground station Voice to be related to data 56 minutes of recording possible (Judicious use of recording time?) (Were data collected?)

TABLE AA-2. The operation of the man-machine system immediately concerned with the radiometry experiments during the Gemini V and VII flights is described. The tasks are numbered for later reference.

CELESTIAL AND SPACE-ORBIT RADIOMETRY EXPERIMENTS

SYSTEM LEVEL ANALYSIS

SYSTEM ORGANIZATION	FUNCTION/TASK DESCRIPTION	CRITERIA	PERFORMANCE MEASURES	ALPHA CODE
I. VEHICLE GUIDANCE AND CONTROL A. Command-pilot B. G & C System C. Optical sight	Functions: I. Rotate vehicle to assist scanning for target object (and scanning of target with sensors)	Time (target within reticle) $\leq T_L$	Time Between: (1) start scan, (2) tgt within reticle	a_1
		Fuel (target within reticle) $\leq F_L$	Lbs. Fuel consumed	a_2
	II. Maintain alignment of target with window reticle	Angular error $\leq \frac{1}{2}^o$	Mean & std. dev. of misalignment error	b
	Tasks: 1. Rotate vehicle with reaction motors using 3-axis hand controller	Angular velocity: $V_{Min.} \leq V_{Rot.} < V_{Max.}$	Mean & std. Dev. of $V_{Rot.}$	c
		Minimum control actuations	No. control inputs	d
	2. Small adjustments of vehicle orientation with hand controller	For each adjustment: ΔFuel $< F_A$	Lbs. Fuel / Unit time for Tracking	e_1
		Stick Movement $< \theta s$, Minimum stick movement	Mean & std. Dev. of controlled displacement	e_2
			$\int$ |stick deflections| dt	f
	3. Control reticle: on/off brightness	For tgt loc. & ident. $B_{ret} \cong B_{optimum}$	$\frac{B_{ret}-B_{bkgrnd}}{B_{bkgrnd}}$ = Contrast Ratio	g
II. RADIOMETRY DATA COLLECTION	Functions: I. Set-up & checkout of radiometry equip.	Data transmitted and/or recorded (as appropriate) for all tgts.	Examination of data by radiometry specialist	h
A. Pilot B. Sensors C. Transmitters D. Tape Recorders E. Control Panel	II. Collect data appropriate to each tgt.	Appropriate data collection for all tgts.	Examination of data by radiometry specialist	i
	Tasks: 1. Deploy equipment	Equip. deployed	Verbal report of	j
	2. Select equip. configuration	Cryogenic for first 8 hours	Cryogenic power on (recording)	k
	3. Operate transmitter	Transmit in range of grnd. station	Transmitter power vs. Range of time (recordings)	l
	4. Operate tape recorder	Tape all data, < 56 min.	Tape examination by specialists. Tape power on (recording).	m
	5. Detect equipment malfunction		No. min. of data collected	

SYSTEM LEVEL ANALYSIS (Continued)

SYSTEM ORGANIZATION	FUNCTION/TASK DESCRIPTION	CRITERIA	PERFORMANCE MEASURES	ALPHA CODE
III. TARGET LOCATION AND IDENTI-FICATION	Functions: I. Visually locate tgts according to mission plan	Required sequence: tgt_1, tgt2, tgt_3...., tgt_N	Verbal recording analysis of data	n
A. Both pilots B. Windows C. Charts	II. Find tgts. of opportunity	No. tgts. opportunity ≥ 0	Count based on verbal recording, analysis of data	o
	Tasks: 1. Locate on charts 2. Control reticle brightness	scan time (tgt. in reticle) $\leq T_L$	Time from (1) start scan, to (2) tgt within reticle	p
	3. Scan (rotate vehicle) for selected targets 4. Identify targets of opportunity	$\text{Prob.}_{\text{ident.}} \geq P\%$	$\frac{\text{No. tgts detected}}{\text{No. possible tgts}} \times 100$	q

TABLE AA-3. A system level analysis is performed to identify the system performance measurement set. The performance measures are given alpha designations for later reference.

System-Task Performance Relationship Table AA-4 presents a listing of the system performance measures with the associated task sets. An associated operator task was defined as one the performance of which had a determining influence on whether, or how well, the system criterion was met. Table AA-4 is of special importance as it represents the establishment of the relationships between system performance and operator performance; for example:

Let t_i be task performance i, and

y_i be system performance measure i.

If y_g = Contrast ratio, a system performance measure from Table AA-3.

t_4 = Turn collimated window reticle light on, task 4 from Table AA-2.

and t_5 = Adjust brightness of the reticle light, task 5 from Table AA-2.

(1) then $y_g = f(t_4, t_5)$

The nature of the transformation of the task performances to the system performances is rarely defined easily; although in the above example it can be seen that the measure Y_g is dependent on t_4 if it is to be met at all and is dependent on t_5 for the "goodness" with which it is met. The success of the transformation definition will be largely determined by the clarity and adequacy of the definition of the system and task performance criteria. What is being demonstrated here, however, is the essential first step: the specification of the existing functional relationships.

Individual Operator Level of Analysis The individual level analysis represented by Table AA-5 is discussed in detail in Chapters C and D of the text. The table presents the mapping of human performance dimension to the enumerated tasks of Table AA-2, using the input-processing-output paradigm.

During the early development stages of advanced systems, the adequacy of the mapping activity may be limited by the lack of detailed information. Any information that can be obtained pertinent to the items below should, however, be collected. The information collected or generated for the radiometry experiments pertinent to these items was as follows:

1) The nature of the task performance measure. The task performance measures were, in this case, considered to be primarily defined in terms of the system performance measures as listed in Table AA-3. Additional dimensions were selected in some cases for possible other criteria, such as speed.

2) The background characteristics of the operators. The men were described as mature with pilot backgrounds.

3) The surrounding conditions. A review of the static, physical task environment may suggest that certain dimensions will be emphasized in the performance (e.g., panel layout, display characteristics, etc.). The task environment within Gemini V and VII was well described (cf. 426) and is presented in Figure AA-2. For the variable parameters, two conditions were considered: a) normal, standard operating conditions and b) stress conditions, a variety of which were evaluated. The primary dimensional set was identified under condition (a) with additional dimensions selected for (b).

4) The skill level of the operators. Two levels were considered: a) skilled and b) relatively unskilled. (a) was evaluated in conjunction with 3(a) above. Additional dimensions were selected for level (b) items.

The mapping for (b) of the skill and surrounding conditions above was done on tasks 9 and 10 only. Although the beta loadings on the other tasks would also be affected, tasks 9 and 10 were pinpointed for the following reasons: 1) the effective use of fuel is critical to the overall mission success, 2) the measure on task 9, in particular, would be relatively sensitive to performance variations and is known to be differentially predicted by dimensions as a function of learning, and 3) it appeared to be the most critical point with respect to team interaction and, therefore, possibly more stress and learning sensitive.

The purpose of the above activities was to provide answers to the question, "Upon what measures?" from the human behavioral standpoint, in the form of sociopsychological dimensions, here called human performance dimensions. Once these have abeen listed, then: 1) an overall predictive relationship is established and 2) it is possible to proceed to the third question from the man standpoint, "With what tools?". The overall predictive relationship concerns system performance and is as follows:

Let x_i be human performance dimension i.

If $t_i = f(x_1, x_2, \ldots, x_i, \ldots, x_n)$

or $t_4 = f(6, 36, \text{Aiming})$ (See Table AA-5)

and $t_5 = f[47 \text{ (brightness discrimination)}]$ (See Table AA-5)

then from (1):

$$y_g = f[56, 36, \text{Aiming}, 47 \text{ (brightness discrimination)}]$$

MATCHING SYSTEM PERFORMANCE MEASURES TO THE TASK ANALYSIS SUCH THAT:
$\text{SYSTEM PERFORMANCE}_{human} = f(\text{MAN-MAN, MAN-MACHINE INTERACTIONS})$

SYSTEM PERFORMANCE MEASURES (alphas from Table AA-3)	MAN-MAN, MAN-MACHINE INTERACTIONS (numbers from Table AA-2)
I. Guidance and Control	
a, c, d	4, 5, 9, 10
b, e, f	11 (target scanning only), 13
g	4, 5
II. Radiometry Data Collections	
h	1, 6, 7, 12, 14, 17
i	1, 2, 3, 6, 7, 12, 14, 15, 16
j	1
k	3
l	12, 14
m	14, 15, 16, 17
III. Target location	
n	2
o	18, 19
p	4, 5, 9, 10
q	4, 5, 8, 9, 10

TABLE AA-4. System performance measures which are a function of human activity are matched to specific task performances by the crew members.

CELESTIAL AND SPACE-OBJECT RADIOMETRY EXPERIMENTS

INDIVIDUAL OPERATOR LEVEL OF ANALYSIS

TABLE AA-5 (a)

SKILLED PERSONNEL, STANDARD OPERATING PROCEDURE

COMMANDER PILOT		PILOT	
Tasks	Human Performance Dimensions	Tasks	Human Performance Dimensions
4.	56, 36, aiming	1.	56, 36, aiming
5.	47 (brightness discrimination)	2.	48, 19, 75 (conscientious)
		3.	57
		6.	56, 36
		7.	57, 75 (carefulness)
9.	47 (dynamic visual acuity), 49, 60, 50, 54, 36, 37, 71 (Hand controller assumed to allow continuous Δv operation with automatic null in neutral position)	8.	48, 55
		10.	47 (dynamic visual acuity), 60, 50, 54, 20
11.	54, 36, 37, 71	12.	57, 36, aiming
13.	54, 36, 37, 71	14.	57, 36, aiming
15.	49, 20, 28, 75 (conscientious, practical)	16.	20, 28, 75 (conscientious, practical)
		17.	57, 36, aiming
18.	70, 74, 75	19.	70, 74, 75

TABLE AA-5(b). STRESSFUL CONDITIONS

(low fuel or other condition creating doubt as to advisibility or feasibility of completion or continuance; fatigue; monotony)

COMMANDER PILOT		PILOT	
Tasks	Human Performance Dimensions	Tasks	Human Performance Dimensions
9.	70, 71, 74, 75, 24, 73 The specific dimensions selected would be a function of the specific situation. Other tasks, for example task no. 14, may also be affected.	10.	57, 75 (carefulness)

TABLE AA-5(c)

RELATIVELY UNSKILLED PERSONNEL, INITIAL PERFORMANCES

COMMANDER PILOT		PILOT	
Tasks	Human Performance Dimensions	Tasks	Human Performance Dimensions
9.	28, 23, 56, 59, 72, 74, 75	10.	57, 28, 23, 20, 72, 74, 75 (59 may be in effect throughout the entire task sequence)

TABLE AA-5. Human performance dimensions (numerically identified in the same manner as presented in Chapters C and D) are mapped to the crew member activities (numerically identified in the same manner as in Table AA-2), for three man-man, man-machine interaction states as defined by skill and stress levels.

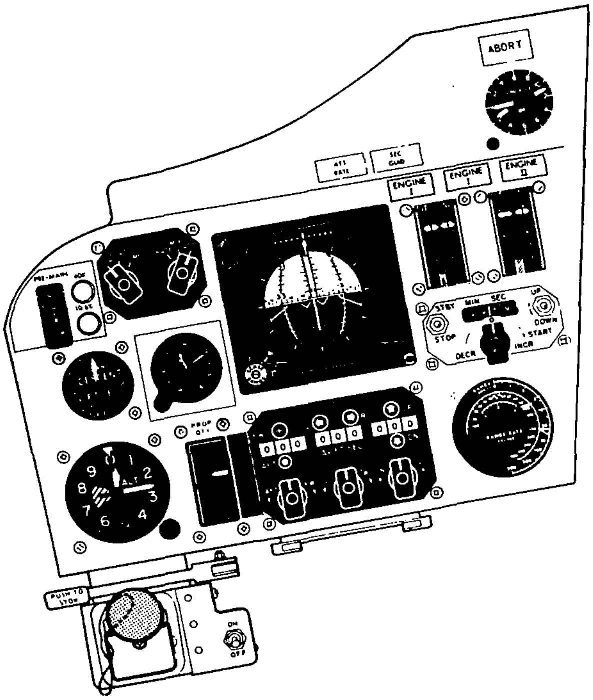


Fig. AA-2(a). Command pilot's panel.

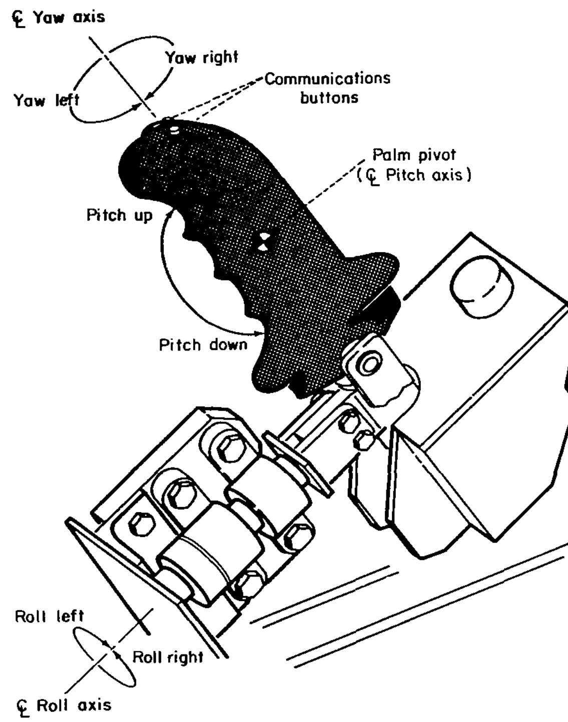


Fig. AA-2(b). Altitude hand control operated by command pilot.

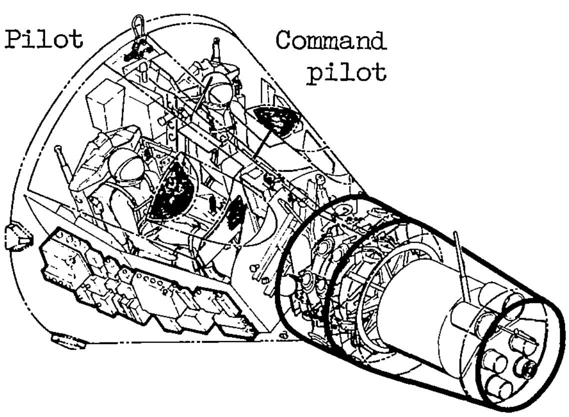


Fig. AA-2(c). Crew station arrangement. The critical interfaces are shaded.

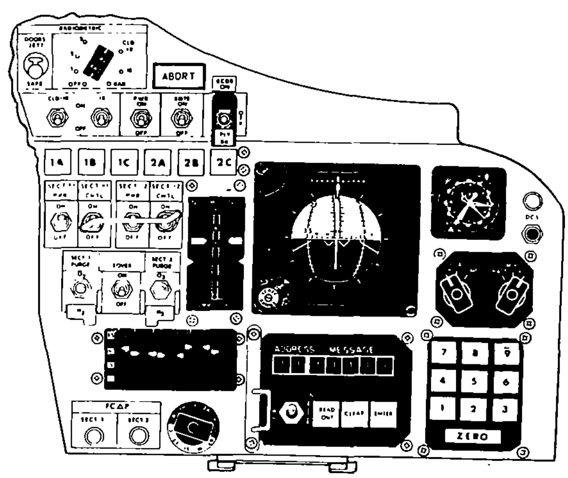


Fig. AA-2(d). Pilot's panel.

FIGURE AA-2. Man-machine interface for the radiometry experiments conducted in Gemini V and Gemini VII. (Figures taken from reference 426.)

However, since the definition of y_g does not emphasize the possible time or accuracy requirements for t_4, the relationship then becomes:

(2) $y_g = f(56, 47(\text{Brightness discrimination}))$

As mentioned above, the selection of the sociopsychological dimensions predictive of operator and, therefore, system performance is a major step towards deriving an answer to the third question, "With what tools?" Which tools are selected will, of course, also be contingent on the purpose (the fourth question) the tools must serve: human performance prediction

Test Battery Development. Prior to the selection of any test or test battery for human performance prediction, a basic decision must be made as to the appropriate test strategy. In the case of a single scientific experiment such as celestial and space-object radiometry and with the system equipment (Figure AA-2) available and tasks and system performance requirements specified (Tables AA-2 and AA-3), the logical test strategy is a direct test in an operationally simulated environment.

However, this example serves as an illustrative case of the selection of tests and test batteries once the sociopsychological dimensions have been related to system and task performance. From Table AA-5, it may be seen that some 19 dimensions have been identified*. These have been re-grouped and named in Table AA-6, and associated with the commander pilot and copilot.

Table AA-7 shows that 11 of the dimensions are common to both crew members; and four each are unique. It is obvious that a separate test battery is not required for each crew member.

From the tabulation of Table AA-7, it is possible to identify test candidates. Here, Volume II is indispensible for the appropriate selection of a dimensional test for each dimension. Several criteria have been used to select the test candidates in Table AA-7. They include: (1) validity of measurement, (2) simplicity of test, (3) ease of administration, (4) demonstrated use with operational personnel comparable to those in this example, (5) sensitivity to stressors based on the existing literature, and (6) tests which measure multiple dimensions. Wherever possible, potential interest was considered; for example, "Spatial Orientation II" involves the use of aerial navigation maps.

* For those who advocate simplistic task taxonomies the multi-dimensionality of this relatively simple operational task will be abhorent. Be that as it may, detailed analysis of man-machine systems tasks (cf., 190, 372) invariably results in one conclusion: human performance in man-machine system tasks is complex.

TABLE AA-6

CELESTIAL AND SPACE-OBJECT RADIOMETRY:

SOCIOPSYCHOLOGICAL DIMENSIONS

DIMENSION	COMMANDER	PILOT	NAME
19		X	Verbal Knowledge
20	X	X	Word Fluency
28	X	X	Logical Evaluation
36	X	X	Response Orientation
37	X		Control Precision
47	X	X	Dynamic Visual Acuity
47	X		Brightness Discrimination
48		X	Perceptual Speed
49	X		Time Sharing
50	X	X	Closure Abilities
54	X	X	Spatial Orientation
55		X	Spatial Visualization
56	X	X	Associate Memory: Rote
57		X	Associate Memory: Meaningful
60	X	X	Visual Memory
70	X	X	Flexibility: Rigidity Reaction
71	X		Self Control Reaction
74	X	X	Desired Level of Output
75	X	X	Desired Type of Output
Aiming	X	X	Aiming

TABLE AA-7

CELESTIAL AND SPACE-OBJECT RADIOMETRY:

SOCIOPSYCHOLOGICAL DIMENSIONS AND TEST CANDIDATES

COMMON DIMENSIONS Commander & Pilot		DIMENSION NAME	TEST CANDIDATE
20		Word Fluency	Word Arrangements
28		Logical Evaluation	Logical Reasoning
36		Response Orientation	Dial Setting *
47		Dynamic Visual Acuity	Landolt C Ring Apparatus II
50		Closure Abilities	Object Identification Test
54		Spatial Orientation	Form Board Test **
56		Associate Memory: Rote	Memory for Syllables (I)
60		Visual Memory	Sentence Span Test ***
74		Desired Level of Output	Behavior Interpretation Inventory
75		Desired Type Of Output	Counting Accuracy
Aiming		Aiming	"Aiming" Test
INDIVIDUAL DIMENSIONS		**NAME**	**TEST CANDIDATE**
Commander	**Pilot**		
	19	Verbal Knowledge	Sentence Span Test
37		Control Precision	Dial Setting
47		Brightness Discrimination	Braunstein & White Apparatus
	48	Perceptual Speed	Spatial Orientation II
49		Time Sharing	Time Sharing Test (Mechanical)
	55	Spatial Visualization	Form Board Test
	57	Assoc. Mem.: Meaningful	Sentence Completion Test
71		Self Control: Reaction	GZTS: Restraint Scale

* Also measures (37) Control Precision
** Also measures (55) Spatial Visualization
*** Also measures (19) Verbal Knowledge

TABLE AA-8

CELESTIAL AND SPACE-OBJECT RADIOMETRY:
A POTENTIAL TEST BATTERY

	Word Arrangements (20)
	Logical Reasoning (28)
	Dial Setting (36, 37)
	Landolt C Ring Apparatus II (47)
	Object Identification Test (50)
	Form Board Test (54, 55)
	Memory For Syllables (I) (56)
	Sentence Span Test (60, 19)
	Behavior Interpretation Inventory (74)
	Counting Accuracy (75)
	"Aiming" Test (Aiming)
*	Dial Setting (37)
*	Braunstein and White Apparatus (47)
**	Spatial Orientation II (48)
*	Time Sharing Test (Mechanical) (49)
**	Sentence Completion Test (57)
*	GETZ: Restraint Scale (71)

* Commander Pilot Only

** Copilot Only

An exhaustive test battery, therefore, for this application would require a set of 17 tests as shown in Table AA-8. Eleven of these tests would be common; four additional tests would be required for the commander pilot; and two additional tests would be specific to the copilot. To return briefly to the specific example of y_g, Contrast Ratio, it can be seen that the setting of the Contrast Ratio by the commander pilot would be predicted from test measures as follows:

(3) y_g = f (Memory for Syllables (I), Braunstein and White Apparatus)

It is obviously very doubtful that such an exhaustive test battery would be justified for the specific case of the scientific experiment, celestial and space-object radiometry. The cost of such a battery would probably only be justified in an extreme case where the entire mission success depended upon the specific task.

However, this example sets the stage for the generation of a generalized test battery for the entire Extended Earth Orbital Laboratory. The following steps would be necessary:

1. The type of analysis identifying the sociopsychological dimensions would have to be completed for all of the tasks executed by the crew in the mission.

2. Across all tasks, the relative frequencies of sociopsychological dimensions can be established. This information immediately provides an indication of the relative priority and importance of the individual dimensions.

3. A technical decision would have to be made as to those dimensions upon which information was necessary and those upon which expert judgment would suffice. This step involves the Cronbach and Gleser (125) bandwidth-fidelity dilemma problem and the strategy that must be developed (through utility analysis) to resolve this dilemma in constructing a cost-effective test battery. (See Chapter G)

4. The utility analysis results in the selection of critical dimensions that must be measured in the generalized test battery. At this point, candidates for specific test instruments are assigned to the dimensions. Based on a number of criteria, an optimal set of tests will be derived comprising the generalized test battery for the entire context of the Earth Orbital Laboratory mission

	SYSTEM	SYSTEM-MAN	MAN
	Group and System Level of Analysis	System-Task Relationship and Individual Level of Analysis	Test Battery Development
System Criteria	TABLE AA-3 Q_{1s} To Predict What?		
System Performance Measures	TABLE AA-3 Q_{2s} Upon What Measures? (1)	TABLE AA-3 Q_{1s-m} To Predict What?	
Operator Tasks	TABLE AA-4 Q_{3s} With What Tools?	TABLE AA-4 Q_{2s-m} Upon What Measures? (2)	TABLE AA-4 Q_{1m} To Predict What?
Human Performance Dimensions		TABLE AA-5 Q_{3s-m} With What Tools?	TABLE AA-5 Q_{2m} Upon What Measures? (3)
Tests			TABLE AA-8 Q_{3m} With What Tools?

* (1), (2) and (3) refer to equations in Appendix A text.

FIGURE AA-3. The outputs resulting from the human performance prediction methodology are represented within the generalized methodological model.

APPENDIX A

Summary

The human performance prediction methodology presented in Chapter A through G was demonstrated in detail through application to a specific man-machine system activity: the conduction of celestial and radiometry experiments. Several detailed analyses were performed at several levels to provide answers to the first three of four basic and essential questions:

1. To predict what?
2. Upon what dimensions and measures?
3. With what tools?
4. For what purpose?

The efforts expended to answer questions 1, 2 and 3 were directed by the answer to the fourth question: "To predict human performance." It should be realized that if the purpose had instead been selection, classification or placement, the outputs of the efforts would not have been quite the same.

The relationship of the first three questions to (1) the system, system-man, and man levels of analysis and (2) the end products of the analytic efforts is represented in Figure AA-3. Three points should be made concerning Figure AA-3:

1. An analytic output may provide answers to different questions, depending on what level is under discussion (note Table AA-4 entry).

2. Equations 1, 2 and 3 represent the functional relationships between analytic outputs and, if quantitative, require transformations of the test measurement data. Since established and validated functions and rules for transformations 1 and 2 are not presently available, careful and thorough evaluation of data is called for; such evaluations, done with adequate initial and validation measurement sets on man-machine systems, would be invaluable.

3. The fact that the analytical steps (the validity, of course, remains to be demonstrated) from $Q1_s$ to $Q3_m$ could be executed for a test case to such a level of detail is remarkable; and provides strong support for the contention that the generalized methodological model is a conceptually meaningful one, well worth further examination.

APPENDIX B

Mission and Task Analysis Examples

Basic to the methodology used in this program, the functional process begins with the question: To Predict What? Thus, one must turn directly to the man-machine system performance which is to be predicted. For methodological purposes, a behavior sample had to be selected. As has been noted in Chapter B, a 180-day circular earth orbit mission was used for behavior analysis. Detailed task analyses were required at the microlevel. From these task analyses, the following subset has been selected as the most critical for present pruposes:

1. The gross mission analysis, as shown on the following pages, from which the examples of rendezvous, docking and EVA are shown.

2. Based on the Meister taxonomy, several portions of the mission were further analyzed with particular emphasis on space experiments, e.g., conduct synoptic terrain photography, conduct inflight exercise, and so forth. The importance of this kind of information has been illustrated in Appendix A where the specific case of celestial and space-object radiometry experiments have been used to illustrate some of the methods recommended here.

3. Because of the interest in group performance, analyses had to be made of the man-man-system problem. To illustrate the analyses completed in this area, the example of rendezvous and docking is given within this Appendix.

It would appear that meaningful prediction programs for applications context must be based on this kind of detailed performance analysis. The magnitude of this step, however, is apparent to anyone who has ever performed it.

FIGURE BB-1. Examples of the Gross Mission Analysis

Task	Sub-Task	Vehicle Equipment	Support Equip & Personnel	Feedback	Stressor	Reference
Check environmental control system status	Verity all systems Go	Environmental control system	MSC GTS	All systems Go Condition		
Receive Rendezvous command	Acknowledge	Communications	MSC	Auditory Msg.	Auditory	FDL TDR 64-94
Receive Tracking data on rendezvous & target vehicle	Read computer readout Check radar Assure all systems Go Verify message and content	Computer Radar System Communications	MSC Tracking Stations	Computer Readout Pip on radar All systems in limit Verification	Visual Auditory	
Receive stored plan for rendezvous maneuver sequence	Check mission plan for sequence	Stored mission plan communications	MSC TS	Mission sequence Verification by MSC & TS		
Assess guidelines for choice of rendezvous type	Initiate sequence for computer calculation	Computer		Readout of selected rendezvous type	Decision making	FDL TDR 64-94
Determine rendezvous maneuver sequence & time of arrival of first thrust point	Feed appropriate data into computer Communicate info to MSC	Computer Communications	MSC	Verification of computed data	Decision making	
Orient vehicle for firing to start altitude correction	Check data in tgt. location. Apply appropriate thrust to orient vehicle Check fuel supply	Computer printout Thrust control Fuel supply gauges	MSC	Reorientation of vehicle	Physiological	

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Engage altitude hold	Check altimeter for steady state	Altitude hold control Communications	MSC TS	Altimeter steady Verification by MSC		
Set boost control for 1st thrust magnitude		Boost control		Boost control in thrust position		
Set timer for boost start and stop	Rotate timer to predetermined position	Timer Communications	MSC	Verification of time by MSC		FDL TDR 64-94
Check restraints Fire thrust	Physically pull restraint. Read computer printout Observe radar Communicate	Restraint Computer Radar Communications	MSC	New computer readout Position moves on radar Verification by MSC	Physiological Psychological Visual	
Monitor reaction control system thrust	Check clock for amount of thrust Monitor target on radar Communicate change of position	Clock Radar Communications	MSC verification GTS verification	Change in orbit position	Auditory	FDL TDR 64-86
Check results of reaction control system thrusting	Check new computer readout. Check radar position Readjust boresight scan for target	Computer Radar Communications Boresight	MSC GTS	New orbital data change in radar position	Visual	FDL TDR 64-86

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Determine initial conditions for 2nd rendezvous correction	Check computer Verify position with GTS. Check radar position	Computer Radar Communications	MSC GTS	Computer readout Verification MSC Radar position	Decision making Visual Communication Visual	FDL TDR 64-86
Determine AV required to accomplish 2nd rendezvous correction	Check computer readout Discuss with MSC-GTS. Check radar position. Acquire lock on manual control OFF Boresight Target	Computer Communications Radar	MSC GTS	Computer readout Verification MSC Pip on Radar	Visual Communication Visual	FDL TDR 64-86
Check auxiliary power supply status	Scan auxiliary power supply panel check switch positions	Auxiliary power supply	MSC	All dials within limits All switches in proper position	Visual	FDL TDR 64-86
Check new velocity & direction of motion	Read computer printout Check target on radar Communicate	Computer Radar Communications	MSC	Altimeter Computer Readout Radar MSC	Visual Auditory	FDL TDR 64-94
Repeat above steps as necessary to be in position for terminal maneuver (3000 feet)						
Receives rendezvous command	Acknowledge	Communications	MSC	Auditory Message	Auditory	FDL TDR 64-94

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Receive tracking data on rendezvous & target vehicle	Read computer readout Check radar Assure all systems Go Verify message & content	Computer radar communications	MSC TS	Computer readout on radar All systems in limits Verification	Visual Visual Communications Visual	FDL TDR 64-94
Continual monitoring of spacecraft condition	Check status lights Check instruments Check computer calculations	Instrument panel communications	MSC GTS	Go condition Instruments within safe zones Ground station verification		FDL TDR 64-86
Check subsystem warning lights	Visual scan	Master warning light panel	MSC GTS	All warning lights out	Visual	FDL TDR 64-86
Check electrical power supply	Visual scan of panel and switches	Electrical panel Communications	MSC GTS	All dials within proper limits All breakers in same position	Visual	FDL TDR 64-86
Received stored plan for rendezvous maneuver sequence	Check mission plan for sequence	Stored mission plan Communications	MSC TS	Mission sequence Verification by MSC-TS		FDL TDR 64-94
Determine relative motion of vehicle & target	Check computer readout Check homing sig Check visual sighting Communicate	Computer Radar Auditory homing signal Communications	MSC TS	Computer data Position on Radar Auditory signal Visual sight of tgt Verification of position by MSC	Decision making Visual Auditory	FDL TDR 64-94

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Compute cross-course increment required to produce collision course	Feed data to computer Check radar position Observe target visually Communicate	Computer Radar Communications	MSC	Pip on radar Position of target Verification by MSC	Visual Visual Auditory	FDL TDR 64-94
Monitor spacecraft system status	Scan panels	All dials and switches	MSC GTS	All systems in Go condition		FDL TDR 64-86
Check subsystem master warning lights	Visual scan of master warning light panel	Master warning light panel	MSC GTS	All lights out	Visual	FDL TDR 64-86
Check electrical power supply status	Visual scan of panel & switches	Electrical panel Communications	MSC GTS	All dials within proper limits All switches in same position	Visual	FDL TDR 64-86
Check environmental control system status	Verify all systems Go	Environmental control system panel Communications	MSC GTS	All systems in Go condition	Visual	FDL TDR 64-86
Check auxiliary power supply status	Scan auxiliary power supply panel Check switch position	Auxiliary power supply panel Communications	MSC GTS	All dials within limits All switches in proper position	Visual	FDL TDR 64-86
Check reaction control system status	Scan dials Check switch positions Communicate	Reaction control panel Communications	MSC GTS	Verify all systems Go Verification by MSC	Visual	FDL TDR 64-86

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Check stabilization Control system status	Check fuel quantity Check instrument panel Visual verify target position	Fuel gauges Stabilization instrument Communications	MSC GTS	Fuel quantity sufficient Control system in Go condition Target sighted	Visual	
Turn on docking lights	Verify lights on Check electrical panel	Parking light switch Electrical dials		Electrical dial discharge Visual search light on	Visual	FDL TDR 64-86
Compute along-course increment required to produce desired closing rate as function of range	Feed data to computer Recheck radar position Observe target visually	Computer Radar		Verification by MSC	Decision making	FDL TDR 64-94
	Communicate	Communications	MSC			
Combine cross-course & along-course increments into a single vector	Feed data to computer Recheck radar position Recheck target visually	Computer Radar		Computer calculations Pip on scope	Decision making	FDL TDR 64-84
	Communicate	Communications	MSC	Verification by MSC		
Set in required altitude for boost	Feed data to computer	Computer		Computer read-out		FDL TDR 64-94
	Communicate	Communications	MSC	Verification by MSC		
Engage Altitude hold		Altitude hold		Altitude remains stable		FDL TDR 64-94

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Fire boost until range-rate relationship is achieved	Depress & hold boost thrust Monitor instruments Check Radar Communicate	Boost thrust button Range-rate readout panel Radar Communications	MSC - TS	Altitude change Orbit change Relationship to Target change Verification by MSC	Acceleration	FDL TDR 64-94
Reorient vehicle for deceleration firing along line of sight to target	Adjust vehicle position Fire thrust in opposite direction for slow down Monitor radar position & range of target Communicate	Boost thrust Radar Communications	MSC	Slow down of movement Close in radar range & position Verification of range & position by MSC	Deceleration	FDL TDR 64-94
Modify direction of fire to provide collision course	Monitor radar Visually check target Communicate Fire thrust in direction required to line up target	Radar Communications Thurst Control	MSC	Target in line with vehicle Verification by MSC	Acceleration	FDL TDR 64-94
Decrease range-rate to 2 ft. per second	Monitor target visually Fire thrust as needed	Thurst control		Slow down of forward equip		FDL TDR 64-94

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
DOCKING						
Set up altitude control systems as fine vernier propulsion unit for docking maneuver	Orient craft to complete docking Maintain visual contact	Altitude Control		Visual orientation	Visual	FDL TDR 64-94
Deploy aligning docking probe		Docking probe		Visually observe docking probe extended	Visual	FDL TDR 64-94
Check static electrical equalization achieved	Scan electrical panel for fluctuation	Electrical panel		No fluctuation of electrical dials	Visual	FDL TDR 64-86
(2) Confirm docking	Communicate with MSC	Communications	MSC	Verification of docking	Auditory	FDL TDR 64-86
Follow same procedures from (1) to (2)						
Accomplish docking	Ease vehicles into dock position		MSC	Vehicles locked	Psychological	
Begin shutdown of spacecraft systems	Check subsystem master warning lights	Master warning panel	MSC TS	All warning lights out	Visual	FDL TDR 64-86
	Check electrical power supply status	Electric power panel	MSC TS	All dials within limits		
	Check environmental control system status	Environmental panel	MSC TS	All dials within limits		

Task	Sub-task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
Prepare for EVA	Hold umbilical in lap	Umbilical				SP 149 NASA-S-67-463 and 4640
	Remove it from container	Umbilical		Umbilical now free		
	Check cabin recirc valve closed	Cabin Recirculation valve		Valve in down position	Visual	
	Check cabin vent check valve open	Cabin vent valve		Cabin vent in up position	Visual	
	Open cabin vent valve to depressurize cabin	Cabin vent valve		Airflow		
	Check system integrity			Visually inspect cabin	Visual	
	Complete cabin depressurization					
	Hold hatch closing device to preclude explosive opening	Hatch latch				
	Start event timer	Clock			Physiological	
Start EVA	Unlatch hatch	Hatch latch		Move latch to open		
	Open hatch	Hatch		Push hatch up		
	Position gain & drive selector to lock	Gain & drive selector				
	Stow hatch handle	Hatch handle		Place in compartment		
	Check all fittings			Visually inspect fittings	Visual	
	Stand in seat					
	Jettison waste pouch	Waste pouch		Release pouch		NASA-S-67-4640

	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
	Fasten restraints on leg	Restraints		Leg locked in position		
	Rest for 2 minutes					
Prepare to leave spacecraft	Check for ELSS out-flow & float out tendencies				Physiolog-ical	
	Evaluate standup dynamics			Move within confines		
	Check EVA camera tethered in cockpit untethered in cockpit From outside cockpit	Camera		Visually and manually check		
	Check camera setting	Camera		Visually check	Visual	
	Rest 2 minutes					
	Pull umbilical out of container	Umbilical		Unfold		
	Release leg restraint			Unlock legs		
	Move to nose on handrail			Pull body out of capsule		
	Attach waist tether to handrail	Waist Tether		Hook tether to handrail		
	Rest					
	Hook up lab tether	Lab tether		Hook up lab tether		
	Attach docking bar clamp	Clamp		Hook on clamp		
	Evaluate waist tether dynamics	Waist tether		Check tether		

Task	Sub-task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
	Rest					
	Move to docked lab sections	Handrail		Physically move to lab sections	Physiological Psychological	
Begin fastening sections together	Hook feet in restraints	Restraints		Lock feet		
	Open pouch & remove wrench	Pouch		Undo snap		
	Perform torqueing operation on all bolts	Wrench		Tighten nuts	Physiological Psychological	
	Make necessary connections of cables & hoses between lab sections	Cables & hoses		Physically tighten all clamps and hoses		
	Rest					
	Inspect all seals	Seals		Visually inspect		
Prepare to ingress in lab	Open external airlock hatch	Airlock		Lift hatch	Physiological Psychological	
	Enter airlock and disconnect tether & umbilical	Airlock		Ingress into airlock		
	Close hatch & pressurize airlock	Hatch		Pull hatch closed		
	Open internal door and enter lab	Door		Undo latch & push open door		

Task	Sub-task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
	Initiate communications with spacecraft	Communications	Spacecraft MSC-TS	Establish communications	Auditory	
Prepare to transfer crew to lab	Prepare records & equipment for transfer	Documents				
	Check consummables & report to MSC		MSC TS	Report quantities	Auditory	
	Shut down spacecraft systems	All systems except standby		All systems Off		
	Release seat restraints	Restraints		Face floating	Physiological	
	Enter airlock	Airlock			Psychological	
	Seal Hatches	Hatch				
	Pressurize airlock	Airlock				
	Open hatch	Hatch				
	Move into lab					
	Close hatch	Hatch				
	Check seals	Seals		Visual check		
Prepare laboratory for operation	Check seals in lab	Seals		Visual check		
	Turn on lights	Lights		Lights on		
	Pressurize lab	Valves				
	Recheck for leaks	Test seals				
	Remove helmet	Helmet			Physiological	
	Extend Antenna	Activate antenna switch		Visually check extension	Psychological	
	Initiate communications with MSC & TS	Communications	MSC TS	Verity condition	Auditory	

Task	Sub-Task	Vehicle Equipment	Support Equip. & Personnel	Feedback	Stressor	Reference
	Check orientation of laboratory	Bore sight		Visually sight orientation star	Visual	
	Activate station keeping equipment:	Guidance & Navigation Equipment		Turn on		
	Turn on transmitters	Transmitters				
	Turn on thermal control system	Thermal control system		Switches and lights on		
	Check temperature	Thermometer		within range		
	Check oxygen flow	Oxygen		Normal reading		
	Check lab for visible damage					

FIGURE BB-2. Examples of the Detailed Task Analyses which were Performed

BEHAVIOR: Conduct Inflight Exercise - Work Tolerance (Heart Rate)

RESPONSE REQUIREMENTS

Type	Mechanism	Characteristics	Information Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
Visual-Check time matches event list.	Written-Instructions to conduct experiment at specified time.	Multiple-Visual-presentation on clock and auditory message from grnd control to conduct inflight exercise.	Content-Conduct inflight exercise.	Short-Lived 5 Sec.	Multiple 2 Visual - List Auditory-Ground Station Command	Attach blood pressure cuff.	Tactile Visual - Gross Motor Cuff is Wrapped around bicep.	Serial Multiple	High - Accuracy of positioning properly important	5-10 Sec.	Zero-G
						Pump-up(Inflate cuff.	Tactile Visual - Gross Motor, Bulb is squeezed and released continuously until meter reading is higher than normal blood pressure rating.	Serial Multiple	High-Otherwise accurate reading will not be obtained	5-10 sec.	Zero-G
						Position ear pieces of sthethescope into ear channels.	Tactile Fine Motor Experimentor can feel ear pieces positioned within ear channels.	Serial Multiple	High-Inaccurate reading will be obtained if ear pieces are not fitted properly.	5-10 sec.	Zero-G

FEEDBACK Criteria of Correct Performance	Modality	Content	TASK CONTEXT Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Visually observe cuff is in correct position on bicep.	Direct - Experimentor can see and subject can feel cuff in proper position.	Visual for Experimentor - Tactile for subject	Until blood pressure reading is complete.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained.	Coordination between 2 crew members.
Visually observe meter reading is higher than subjects normal blood pressure reading.	Direct - Experimentor observes meter reading.	Visual	Until pressure is released to obtain blood pressure reading.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained.	Coordination between 2 crew members.
Tactilly-Feel ear pieces seated properly in ear.	Direct - Experimentor can feel ear pieces fit properly.	Tactile	Until reading of blood pressure is complete.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained	Coordination between 2 crew members.

BEHAVIOR: RESPONSE REQUIREMENTS

Type	Mechanism	Characteristics	Information Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Place diaphragm on subjects brachial artery just below cuff.	Tactile - Visual	Discrete - Individual	High - inaccurate reading will be obtained if diaphragm is not directly on artery.	2 - 5 sec.	Zero-G
						Release screw at base of bulb very slowly.	Tactile - Fine Motor	Discrete - Individual	High-Too quick a release will cause cuff to deflate rapidly and recording cannot be made.	10 - 30 sec.	Zero-G
						Listen for 1st beat or pulse and mentally record meter reading at that moment.	Aurally - Mental concentration reqd.	Discrete-Individual	High- 1st beat records diastolic pressure.	5 - 10 sec.	Zero-G
						Continue to release screw slowly and listen for pulse beats.					

FEEDBACK			TASK CONTEXT					
Criteria of Correct Performance	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Visual on Experimentors part - he can see position of diaphragm on artery.	Direct - Experimentor can see swollen artery.	Visual	Until reading of blood pressure is completed.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained.	Coordination between 2 crew members.
Aurally-Experimentor can hear air being expended. Tactilly - Subject can feel deflation of cuff.	Direct	Aurally	Until reading of blood pressure is completed.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained.	Coordination between 2 crew members.
First pulse of blood through Brachial artery is heard by experimentor.	Direct - Experimentor hears 1st beat.	Aurally	Until reading of blood pressure is completed.	2	Part of experiment procedure.	Part of checklist.	No blood pressure reading will be made - incomplete medical data will be obtained.	Coordination between 2 crew members.

BEHAVIOR: RESPONSE REQUIREMENTS

Type	Mechanism	Charact-eristics	Infor-mation Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Remove cuff and repack instru-ment in container	Tac-tile - Gross Motor	Ser-ial/ Mul-ti-ple	Low.	30 sec. 2 min.	Zero-G
						Two minutes before exercise experi-mentor should now place 2nd & 3rd finger of his hand on pulse of subjects wrist.	Tac-tile - Fine Motor	Dis-crete Indi-vidual	High- must accu-rately locate pulse for correct reading.	5-10 sec.	Zero-G
						Count pulde beat for next 15 seconds.	Tac-tile - Mental Visual	Ser-ial/ Mul-tiple	High - Experi-mentor must concen-trate on watching clock and counting beats.	15 sec.	Zero-G
						Subject places both feet in nylon foot strap.	Tac-tile - Gross and Fine Motor	Ser-ial/ Mul-tiple	High - strap must be positioned so it is across shoe just in front of heel	10-15 sec.	Zero-G

FEEDBACK			TASK CONTEXT					
Criteria of Correct Performance	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Equipment is properly removed and stored in container.	Direct	Tactile	Until reading of blood pressure is complete.	2	Part of experiment procedure.	Part of checklist.	Equipment may be damaged and not usable in future examinations.	Coordination between 2 crew members.
Pulse beat can be felt in experimentor's fingers.	Direct	Tactile	Until reading of blood pressure is complete.	2	Part of experiment procedure.	Part of checklist.	Inaccurate placement will cause poor reading of pulse.	Coordination between 2 crew members.
A count of the number of pulse beats in 15 seconds is obtained.	Direct	Tactile Mental	Until reading of blood pressure is complete.	2	Part of experiment procedure	Part of checklist	Inattention will cause inaccurate recording of beats.	Coordination between 2 crew members.
Nylon foot strap is across bottom of shoes just in front of heel.	Direct	Tactile	Until reading of blood pressure is complete.	2	Part of experiment procedure.	Part of checklist.	Strap may slip and cause injury to subject or damage to equipment.	Coordination between 2 crew members.

BEHAVIOR:						RESPONSE REQUIREMENTS					
Type	Mechanism	Characteristics	Information Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						With legs extended grasp handle in both hands.	Tactile Gross Motor	Serial/ Multiple	High- correct grip important for proper manipulation of equipment.	10-15 sec.	Zero-G
						Experimentor record pulse for next 15 seconds (See # # above)					
						Subject pull handles toward face with legs extended so that rubber bunger cord is stretched to full length.	Tactile/ Gross Motor	Serial Multiple	High- in order for exercise to be beneficial it must be done correctly.	$\frac{1}{2}$ sec.	Zero-G
						Subject slowly releases tension on rubber bunger cord so it returns to original, unstretched position.	Tactile Gross Motor	Serial/ Multiple	High- In order for exercise to be beneficial it must be done correctly.	$\frac{1}{2}$ sec.	Zero-G

FEEDBACK			TASK CONTEXT					
Criteria of Correct Performance	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Both hands are gripping handle in over hand position.	Direct	Tactile	Until reading of blood pressure is complete.	1	Part of experiment procedure.	Part of checklist.	Hands may slip off handle causing injury to subject or damage to equipment.	Coordin- ation between 2 crew members.
Rubber bungee cord is stretched to its full length.	Direct	Tactile-Visual	Until reading of blood pressure is com- pleted.	1	Part of experiment procedure.	Part of checklist.	No benefit will be derived from exercise.	Coordin- ation between 2 crew members
Rubber bungee cord returns to its natural unstretched state.	Direct	Tactile-Visual	Until reading of blood pressure is completed.	1	Part of experiment procedure.	Part of checklist.	No benefit will be derived from exercise.	Coordin- ation between 2 crew members.

BEHAVIOR: RESPONSE REQUIREMENTS

Type	Mechanism	Charact-eristics	Infor-mation Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Subject continues stretching and releasing cord at rate of once every second for next 29 seconds.					
						Experimentor records pulse rate for last 15 seconds of exercise # #					
						Experimentor records pulse rate for 2 minutes at 15 second intervals following exercise # #.					
						Experimentor takes subject blood pressure following completion of exercise #.					

BEHAVIOR: Conduct Synoptic Terrain Photography

RESPONSE REQUIREMENTS

Type	Mechanism	Characteristics	Information Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
Visual - clock time matches event list.	Written - Instructions to conduct experiment at specific time.	Single - Visual presentation.	Content - Conduct synoptic terrain photography.	Short-lived 5 sec.	Single	Unpack camera	Tactile Visual Fine - Gross Motor	Serial - Multiple	High- avoid banging or hitting camera on portions of spacecraft.	10-20 sec.	Zero-G
						Clean interior surface of window.	Tactile - Visual Gross fine motor.	Serial/ Multiple	High- clean window necessary for good pictures.	5-10 sec.	Zero-G
						Orient craft to land mass is below window to be used.	Tactile - Visual Fine Motor pulse jets on proper side to rotate craft.	Serial/ Multiple	High- rotation must be performed slowly in order to align vehicle properly.	5 sec. - 5 min.	Zero-G
					#	Hold camera so that lens is flat against window and land mass appears in camera viewer.	Tactile - Fine Motor	Serial/ Multiple	High - proper position of camera will insure clear pictures.	5 - 10 sec.	Zero-G

FEEDBACK Criteria of Correct Performance	Modality	Content	Duration	TASK CONTEXT Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Camera removed from protective container and held in hand.	Direct	Tactile-Visual	Through-out Photo-graphic portion of mission.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	In voice comm. with grnd station.
Window appears visually clean.	Direct	Visual	Once - unless window fogs.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	In voice comm. with ground control.
Window view is of land mass.	Direct-land mass is within window view.	Visual	Remains in this position until experimentor requires change.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be complete.	Coordin-ation between crewmen.
Camera lens flat against craft's window.	Direct-land mass is within window view.	Visual	Remains in this position until experimentor requires change.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	Cordin-ation between crewmen.

BEHAVIOR: RESPONSE REQUIREMENTS

Type	Mechanism	Charact-eristics	Infor-mation Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Place eye against camera view finder and read lens settings that appear in finder.	Visual - Tac-tile - Mental	Ser-ial - Mul-tiple	High-proper reading and memori-zation necessary to set lens properly.	5-10 sec.	Zero-G
						Remove camera from window and set lens opening and speed setting just viewed in view finder.	Visual - Tac-tile - Mental Fine Motor to Gross Motor	Ser-ial - Mul-tiple	High-proper setting will insure good photos.	2-5 sec.	Zero-G
						Replace camera as in #1 above.					
						Place eye against view finder and watch for appro-priate targets.	Tactile Visual Mental	Ser-ial - Mul-tiple	Low-High Most land masses viewed would present some data for study.	5-10 sec.	Zero-G

FEEDBACK Criteria of Correct Performance	Modality	Content	Duration	TASK CONTEXT Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
View finder will contain an "F" stop reading and a "speed" setting.	Direct-Experimenter will see these numbers within view finder.	Visual	Will remain there as long as camera is held in position.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	Coordination between crewmen.
Experimentor will set lens and it will be within previously established limits.	Direct	Tactile - Visual	Until new setting is indicated by camera.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	Coordination between crewmen.
Land masses will appear in view finder as craft orbits earth.	Direct	Tactile Visual	Until photography is completed.	1	Part of experiment procedure.	Part of Checklist.	Experiment will not be completed.	Orally report each photo taken.

BEHAVIOR: RESPONSE REQUIREMENTS

Type	Mechanism	Charact-eristics	Infor-mation Presented	Duration	No.	Content	Type	No.	Accuracy Req.	Time Req.	Stress Factors
						Depress camera trigger to take photo of land mass.	Tactile - Fine Motor	Dis-crete - Indi-vidu-al	High-must be done smoothly so as not to move camera.	2 sec.	Zero-G
						Continue photographing land masses until film in magazine is expended.					
						Remove camera from window and dis-connect magazine.	Tac-tile - Gross Fine Motor	Ser-ial/ Mul-tiple	Low-care must be taken but task is simple.	10-20 sec.	Zero-G
						Receive new magazine from partner and attach it to camera.	Tac-tile - Fine-Gross Motor	Ser-ial/ Mul-tiple	Low-care must be taken but task is simple.	10-20 sec.	Zero-G
						Continue as in #2 above.					

FEEDBACK Criteria of Correct Performance	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Camera shutter click will be heard and film will automatically advance.	Direct	Tactile - Visual	Until photo-graphy is completed.	1	Part of experiment procedure.	Bart of checklist.	Experiment will not be completed.	Orally report each photo taken.
Magazine comes off camera.	Direct	Tactile - Visual	Until magazine is removed.	1	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	Coordin-ation with other crewmen.
New magazine is attached to camera and locked on.	Direct	Tactile - Visual	Until magazine film is expended.	2	Part of experiment procedure.	Part of checklist.	Experiment will not be completed.	Coordin-ation with other crewmen.

(TASK CONTEXT spans Modality through Time Sharing.)

BEHAVIOR: Prepare for Scheduled EVA

Initiating Stimulus Characteristics

Type	Mechanism	Characteristics	Information Presented	Duration	Number
Visual- Clock time matches event list.	Written Material Instructions to prepare for EVA at specified time.	Multiple-Visual Presentation on clock and auditory message from ground station to prepare for EVA.	Content - Prepare for EVA.	Short-Lived- 5 Seconds	Multiple-2 Visual-List Auditory- Commun.

Response Requirements

Content	Type	Number	Accuracy Requirements	Time Requirements	Stress Factors
Insure S/C mirror is out of way.	Perceptual-Visually insure mirror stowed.	Discrete/Indiv	High-Mirror cld foul umbilical.	Instantaneous	Performed in Zero with full pressurized suit.
Position waste pouch for jettisoning	Fine motor-lift pouch	Discrete/Indiv	High-Damage to pouch could be dangerous.	10 sec.	Performed in Zero with full pressurized suit.
Record to CONT	Fine motor-turn switch	Discrete/Indiv	High- Loss of record could result	Instantaneous	Performed in Zero with full pressurized suit
Keying to VOX	Fine motor-move switch	Discrete/Indiv	High- No communication.	Instantaneous	Performed in Zero with full pressurized suit
Hold Umbilical in lap (Remove bag)	Gross physical-lift umbilical from bag	Serial multiple- Hold bag, pull umbil. out of bag	High-Umbil must be kept from unraveling into cabin.	2-5 Min.	Gloved hand
(1) Verify cabin Recirc. valve dwn (closed) (2) Verify cabin check valve open	Perceptual-visually insure valves in correct position	Discrete/Indiv	High- Pressurization loss(?) Unable to open hatch	5-10 Sec.	Performed in Zero with full pressurized suit

Criteria of Correct Pref.	Modality	Content	Duration	Number Personnel	Embedding	Task Structuring	Failure Consequence	Time Sharing
Mirror out of way	Direct-Visually pilot can see mirror is stowed	Visually -Pilot sees mirror in stowed position.	Until moved into another position	2	Part of proc for EVA	Part of EVA checklist	Mirror could damage umbilical and cancel EVA	
Pouch in position and not broken	Direct-Visually Pilot can see position and no leakage.	Visually pouch in position No leaks	Until disposed of	1	Part of proc for EVA	Part of EVA checklist	Damaged pouch could cause danger to crew and vehicle.	
Recorder ON	Direct-Visually	Recorder ON	Until EVA is over	1	Part of proc for EVA	Part of EVA checklist	Recorder not on or operating - loss of info.	Voice comm with grnd station
Voice comm is established	Direct-Visually and Auditory comm est.	Key on VOX position grnd. station audible	Until EVA is over	1	Part of proc for EVA	Part of EVA checklist	Loss of voice comm.	Voice comm with grnd station

RESPONSE REQUIREMENTS

CONTENT	TYPE	NUMBER	ACCURACY REQUIREMENTS	TIME REQUIREMENTS	STRESS FACTORS
Determine Initial Condition for First Rendezvous Correction	Perceptual-Motor	Serial-Multiple	High	1 - 5 min.	Zero G
Monitor Spacecraft System Status	Perceptual	Serial-Multiple	High	30 seconds-1 minute	Zero G
Check Subsystems Master Warning Lights	Perceptual	Serial-Multiple	High	30 seconds-1 minute	Zero G
Check Electrical Power Supply	Perceptual	Serial-Multiple	High	30 seconds-1 minute	Zero G
Determine V Required to accomplish First Rendezvous Maneuver	Mediational-Perceptual	Serial-Multiple	High	4 min.	Zero G
Synchronize Event Timer	Motor-Perceptual	Serial-Multiple	High	15-30 sec.	Zero G
Switch Computer to Rendezvous Mode	Motor-Perceptual	Discrete-Individual	High	10-15 sec.	Zero G
#1 Boresight on Target Vehicle	Motor-Perceptual	Serial-Multiple	High	1-5 min.	Zero G
Verify Perpinent Computer Constants	Visual-Mediational (Computational)	Serial-Multiple	High	1-5 min.	Zero G
Record Elevation and Range to Target Vehicle	Motor-Visual Mediational (Computational)	Serial-Multiple	High	1-5 min.	Zero G
Determine when Initation Point is Reached	Visual-Mediational (Decision-Making)	Serial-Multiple	High	1-5 min.	Zero G
Lock on Radar	Visual-Tactile	Serial-Multiple	High	30 sec. 1 min.	Zero G
Depress START COMP button	Visual-Tactile	Discrete	High	1-5 sec.	Zero G

FEEDBACK				TASK CONTEXT				
CRITERIA OF CORRECT PERFORMANCE	MODALITY	CONTENT	DURATION	NO. PERS-ONNEL	EMBEDDING	TASK STRUCTURING	FAILURE CONSEQUENCES	TIME SHARING
Initial Conditions will provide correct info for Rendez-vous Correct-ion.	Computer Display-Auditory	MSC Voice Message Verifies Initial Condi-tion	Until thrust is com-plete.	2	Part of R & D Procedure	Performed according to check list.	R & D cannot be completed.	Auditory Voice Commun.
System is GO	Visual-Status Lights	All system lights Green	Periodic	2	Normal procedure to scan system status periodic-ally.	Routine	May not see warning light.	Auditory Voice Commun.
All warning lights are extinguished	Visual-Master warning lights.	All Master Warning Lights Out.	Periodic	2	Normal procedure to scan system status periodic-ally.	Routine	May not see warning light.	Auditory Voice Commun.
All elec-trical power within limits.	Visual-Power Gauges	Power Supply Gauges within proper limits	Periodic	2	Normal Procedure to scan system status periodic-ally.	Routine	May not see warning light.	Auditory Voice Commun.
Calcula-tion permit success of ren-dezvous maneuver	Visually	Computer readout-Bore-sight on agena	During change in orbit.	2	Discrete maneuver.	Routine	Failure to rendezvous.	Auditory Voice Commun.
Event timer agrees with MSC report	Visually	Event Timer reads 00:00	During change in orbit.	2	Part of R & D procedure.	Routine	Can be repeated no ser-ious conse-quences.	

FIGURE BB-3. A Man-Man, Man-Machine Analysis for Rendezvous and Docking is given.

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
Determine required to accomplish first rendezvous maneuver				
	Look at display		Secure tape recorder	Continuous update of range (six digit numeric readout)
	Look at FDAI	Look at FDAI	Disconnect batteries from main busses	Continuous attitude information displayed in pitch, yay and roll
	Reach out and push AGC switch UP		Charge batteries, if necessary	Activates guidance computer to determine attitude error
	Look at AGC display			Display of attitude error and orbit parameters
	Key microphone			Opens communication circuit
	Report to MSFN earth orbit parameters from AGC display		Transmit real time T/M	
	Reach out and push C/M propellant jet logic switch down (OFF)		Transmit recorded T/M	
	Reach out and push EOS power switch down (OFF)		Record real time T/M	C/M propellant jet logic system OFF

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
	Reach out and push master events sequence pyro switch down (OFF)			Pyro switch is in safe position and unarmed
	Reach out and push master events logic switch down (OFF)			Master events logic off
	Reach over and pull out all EOS circuit breakers			
	Reach over and pull out all ELS circuit breakers			Disconnects d-e power from battery to APEX cover jett switch - Drogue delay switch- and main deploy switch
	Reach over and pull out all master events control circuit breakers			
	Set controls and displays for earth orbit phase	Set controls and displays for earth orbit phase	Set ECS for orbital operation	
		Key microphone	Key microphone	Voice circuit open
		Acknowledge communications acquisition	Transmit real time	
			Transmit recorded T/M	
	Perform G + C System check			
			Check ECS pressure displays	Display within limits
			Check ECS temperature displays	Display within limits

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
			Check ECS quantity displays	Display within limits
			Check oxygen flow rate displays	Display within limits
			Check both cabin air fans	Switches on
			Check cabin temperature control	Display within limits
			Check both suit compressors	Display within limits
			Check both glycol pumps	Switches on Manual
			Check water accumulators	Switches on Manual
			Check emergency coolant loop	Switches Off
			Check ECS Radiators	Switches Off
			Record real time T/M	
			Check DC voltage and ampere displays	Display within limits
			Check AC voltage and frequency displays	Display within limits
			Check pressure and quantity of cryogenic oxygen and hydrogen tanks	Display within limits
			Check AC inverters	Switch controls d-c power to a-c inverter

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
			Check AC busses	Switch controls a-c output of Inverter No. 1
			Check each fuel cell	Switch indicator-flow-radiators-heater
			Check Cryogenics H_2 heaters	Check switch position
			Check cryogenics H_2 fans	Check switch position
			Check cryogenics O_2 heaters	Check switch position
			Check cryogenics O_2 fans	Check switch position
	Test .05 G light	Check SM-RCS sub-system A pressure-temp-Quan meter indicator		Switch select "A" Observe-display within limits
	Test G increase and skipout lights	Check SM-RES Sub-system B Press-Temp-Quan meter indicator		Switch select "B" observe-display within limits
	Check scripe on mylar scroll	Check SM-RCS sub-system C Press-Temp-Quant meter indicator		Switch select "C" Observe-display within limits
		CheckSM-RES subsystem D Press-Temp-Quant meter indicators		Switch Select "D" Observe-display within limits
		Check SM-RCS helium and propellant valve event indicators		Observe indicator

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Check CM-RCS subsystem A, Press-Temp meter indications	Check SPS Press-Temp and Quan. meter indications	Switch select "A" Observe-display within limits
		Check CM-RCS subsystem B Press-Temp meter indications	Check SPS event display indications	Switch select "B"- Observe-display within limits
		Check CM-RCS event display indications	Log results of checks	Switch select "C"- Observe/Write display within limits
		Check CM-SM caution and warning lights		All OFF
		Check CM caution and warning lights		All OFF
			Prepare and ingest food	
	Turn on and run IMU accelerameters			Initializes the inertial subsystem
			Transmit real time T/M	
			Transmit recorded T/M	
			Record real time T/M	
	Interrupt S-IVB attitude control and roll C/M to bisect two reference stars with C/M optics	Turn on map and data viewer		Turning of rotation control causes thrust vectors to fine and roll spacecraft in direction of rotation
Prepare for IMU fine alignment	Maintain roll attitude	Display fine alignment sequence and data on M & DV		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Determine desired inertial attitude reference		
		Determine bisector of two reference stars		
Perform IMU fine alignment		Slave telescope to star LOS	Optics power ON	Navigator manually sights stars
		Optics control on appropriate speed		Switch action to Hi-Med or Low regulates voltage
		Optics mode on resolved		Coupling (switch) with hand controller
		Enter fine alignment program into AGC (AGC will point telescope and sextant optics at reference star)		Push buttons on computer
		Determine first star in M & DV		
		Enter first star code number into AGC		Push buttons on computer
		Optics control to manual		Switch action - hand controller Output direct to sextant
		Identify first star in M & DV and telescope		
		Center first star in telescope with optic hand controller		Hand crank operation to slow telescope
		Verify first star in sextant		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
		Center first star in sextant with optic hand controller		Handcrank
		Turn minimum impulse enable switch ON		Switch ON
		Push mark button when star is centered		Push button - computer input
		Push mark reject button if mark is unsat. and repeat work		
		Turn minimum impulse enable switch OFF		Switch OFF
		Optics control to computer		Computer reads angles, time and computes position of space-craft
		Determine second star in M & DV		
		Enter second star code number into AGC		Push buttons on computer
		AGC will point tele-scope and sextant optics at reference star		Automatic slew
		Optics control to manual		Switch down
		Identify second star in telescope		
		Center second star in telescope with optics hand controller		Hand crank

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
		Verify second star in sextant		
		Center second star in sextant with optics hand controller		Hand crank
		Turn minimum impulse enable switch ON		Switch ON
		Push mark button when star is centered		Push button
		Push mark reject button if mark is unsat. and repeat work		
		Turn minimum impulse enable switch OFF		Switch OFF
		Verify completion of fine alignment program by AGC display		Calculations complete
IMU alignment Check sequence		Display alignment check sequence and data on M & DV		
		Enter alignment check program into AGC		Push buttons
		Optics control to computer		Repeat above
		Determine reference star in M & DV		↓
		Enter reference star code number into AGC		↓
		AGC will point telescope and sextant optics at reference star		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
		Optics control to manual		
		Identify reference star in M & DV and telescope		
		Center reference star in telescope with optics hand controller		
		Verify reference star in sextant		
		Center reference star in sextant with optics hand controller		
		Turn minimum impulse enable switch ON		
		Push mark button when star is centered		
		Push mark reject button if mark is unsat. and repeat work		
		Turn minimum impulse enable switch OFF		
		Verify completion of IMU alignment and check and alignment accuracy by AGC display		
	Roll S/C to S-IVB desired attitude and return attitude control to S-IVB instrumentation unit			Turning of rotation control causes thrust vectors to fire and roll spacecraft in direction of rotation

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
Perform landmark navigational sighting	Interrupt S-IVB attitude control and maintain appropriate roll control			
		Display navigation sighting sequence and data on M & DV		
		Determine pertinent data on next landmark		
		Slave telescope to star LOS		Repeat of previous guidance information
		Optics control on appropriate speed		
		Enter earth orbit navigation sighting program into AGC		
		Optics control to computer		
		AGC will point telescope and sextant optics at reference point		
		Optics control to manual		
		Verify landmark in M& DV and telescope		
		Center landmark in telescope with optics hand controller		
		Turn minimum impulse enable switch ON		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
		Push mark button when landmark is centered		
		Push mark reject button if mark was unsatis- factory and repeat mark		
		Maintain landmark in telescope field of view with optics hand controller for several seconds		
		Center landmark in tele- scope with minimum impulse control		
		Push mark button when landmark is centered		
		Push mark reject button if mark was unsat. and repeat mark		
		Turn minimum impulse enable switch OFF		
		Obtain comparison of actual trajectory para- meters and the desired or nominal trajectory by AGC display		
		Turn off M & DV		
			Transmit real time T/M	
			Record real time T/M	
	Perform SM-RCS status check		Perform ECS status check	Switch positions checked

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEM ENG)	MACHINE
			Perform operational check of ECS, normal, alternate and backup modes	
	Perform operational check of caution and warning lights			View C & W panel - All lights off
			Perform EPS status check	Switches and meters within limits
			Perform operational check of EPS, normal, alternate and backup modes	Switches and meters within limits
			Perform SPS status check	Switches and meters within limits
End Navigation sighting period				
	Secure navigation sighting controls and displays	Secure navigation sighting controls and displays	Secure navigation sighting controls and displays	Stow telescope and sextant
	Roll C/M to S-IVB desired attitude and return attitude control to S-IVB instrumentation unit		Optics power OFF	See previous ROLL operation
Present trajector computation	Preparation and ingestion of food	Compute and display present trajectory error and uncertainty factors using land-mark sighting data		Computer operation
		Compute and display ephemeris miss distance and uncertainty factors		Computer operation

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Compute and display on board determination of rendezvous parameters		Computer operation
Prepare for IMU alignment		Turn on map and data viewer		See previous similar area starting on page
		Display course alignment sequence and data on M & DV		
		Determine desired inertial attitude reference		
		Determine bisector of two reference stars		
		Interrupt S-IVB attitude control and roll C/M to bisect two reference stars with C/M optics		
		Maintain roll attitude		
			Transmit real time T/M	
			Transmit Recorded T/M	
Compare trajectory and ephemeris	Compare trajectory ephemeris and uncertainty factor data with MSFN			Communications

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
	Obtain rendezvous parameter data from MSFN and compare with on board generated data			Computer output check against MSFN data
			Record real time T/M	
		Slave telescope to LOS		
		Optics control on appropriate speed		
		Enter course alignment program into AGC		
		Optics control to computer		
		Determine first star in M & DV		
		Enter first star code number into AGC		
		AGC will point telescope and sextant optics at reference star		
		Optics control to manual		
		Identify first star in M & DV and telescope		
		Center first star in telescope with optics hand controller		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Turn minimum impulse enable switch ON		
		Push mark button when star is centered		
		Push mark reject button if mark is unsatisfactory and repeat mark		
		Turn minimum impulse enable switch ON		
		Optics mode to computer		
		Determine second star in M & DV		
		Enter second star code number into AGC		
		AGC will point telescope and sextant optics to reference star		
		Optics control to manual		
		Identify second star in M & DV and telescope		
		Center second star in telescope with optics hand controller		
		Turn minimum impulse enable switch ON		
		Push mark button when star is centered		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Push mark reject button if mark is unsatisfactory and repeat mark		
		Turn minimum impulse enable switch OFF		
		Verify completion of course alignment program by AGC display		
			Secure earth orbit controls and displays	
				Button pushing operation
				Thumbwheel operation
	A S B E F O R E			
Perform IMU fine alignment check				
	Roll C/M to S-IVB desired attitude and return attitude control to S-IVB instrumentation unit		Optics power OFF	SEE PREVIOUS ROLL DATA
		Secure navigation station for orbit change		

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
	Obtain IMU attitude data from AGC			Computer readout
	Insert data in attitude set display			Push button operation
	Push GDA align button			Push button-Aligns GDC to given reference
Prepare AGC for orbit change		Enter program	Set SPS switches and controls for quick abort contingency capability	
		Enter CG offset angle		
		Enter programmed thrust vector	Connect batteries to main busses	
		Enter programmed Delta V minus SPS tailoff		
	Secure center couch for orbit change		Secure engineer station for orbit change	
			Secure recorder	
	Count down to insertion		Count down to insertion	
	Review preparations for insertion		Review preparations for insertion	
	Adjust couch restraints		Adjust couch restraints	

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
S/C preparation for insertion	Set SPS switches, controls and gimbal motors for quick abort contingency capability			Switches
	Set elapse time clock			Switch operation
			Transmit real time T/M	
			Transmit recorded T/M	
	Secure commander station for insertion			
	Observe elapse time clock			Observe timer
	Countdown to insertion			Observe timer
	Adjust couch restraints			Tighten restraints
Start S-IVB Vllage acceleration	Monitor progress of vllage sequence	Monitor progress of vllage sequence	Monitor progress of vllage sequence	Observe meters operating within limits
			Record real time T/M	
Start of Propulsion system ignition	Monitor program			
	Observe elapse time clock	Observe master timer		Timer operating
	Observe caution and warning indicator	Observe caution and warning indicator	Observe caution and warning indicator	All lights OFF
	Observe FDAI display	Observe AGC display	Observe crew safety indicators	Attitude correct

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
	Observe V remaining display	Observe FOS display	Observe critical system indicators	V display
	Observe EOS display	Observe crew safety indicators	Countdown thru insertion sequence of events	EOS within limits
	Countdown thru insertion sequence of events	Observe critical systems indicators		Clock moving
		Countdown thru insertion sequence of events		
			Record real time T/M	
			Transmit real time T/M	
			Transmit selected comments on progress	
S-IVB propulsion cutoff				
Post injection check				
	Set controls for coast		Disconnect batteries from main busses	Electrical Power
	Release couch restraints	Set control panel for coast	Check DC voltage and amperage	Meters within limits
		Release couch restraints	Check AC voltage amperage and frequency	Meters within limits
			Check cryogenic quality, pressure and temperature	Meters within limits

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
			Check fuel cell displays	Meters within limits
			Release couch restraints	
Confirm safe coast trajectory	Compute V state vectors			
	Check actual V parameters with programmed V parameters			
	Compare on board V data with MSFN			Communications
		Check subsystem "A" pressure, temperature, quantity and event displays		SEE PAGE
		Check subsystem "B" pressure, temp, quantity and event displays		
		Check subsystem "C" pressure, temp, quantity and event displays		
		Check subsystem "D" pressure, temp, quantity and event displays		
Post V SPS gimbal operation	Turn off gimbal motors		Adjust PV valve	Switch off
	Turn off quick abort capability			Switch off

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
	Orient S/C to specified attitude for transposition and docking			Attitude control activated S/C changes attitude
ECS check		Check pressure, temp., quantity, event and flow displays		All within limits
SCS attitude alignment		Obtain IMU attitude data from AGC		Computer readout
		Insert data into attitude set display		Push buttons
		Push GDC align button		Push botton
	Place G & N in attitude control mode			Switch
		Confirm S/C status with MSFN		Communications
	Verify S-IVB in attitude hold	Program AGC for V mode		Switch
	Arm pyro circuit	AGC automatically orients S/C to V attitude		Switch
		Enter GC offset into AGC		Computer (pushbutton operation)
		Enter V direction vector into AGC		Computer (pushbutton operation)
		Enter programmed V minus tailoff into AGC		Computer (pushbutton operation)
		Enter CG offset angles into gimbal position display		Thumbwheel

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
		Insert time to V in elapse time clock		Switch activation-clock set
SCS preparation for V	Insert programmed V including tailoff into V remaining display			Pushbutton
	Monitor elapse time clock		Connect entry batteries to main buss	
	Verify programmed attitude hold			
			Observe critical EPS displays	
T	Turn on gimbal motors			Switch ON
	Check gimbal position displays		Re	Readout - within limits
	AGC initiates SM-RCS vllage			Computer operation
		Observe master timer		Activated and cycling
	Monitor FDAI	Monitor FDAI		Attitude holding steady
	Monitor V remaining display			Numbers decreasing
	Observe displays on G and N panel	Observe displays on G & N panel		All within limits

TASK DESCRIPTOR	MAN (COMMANDER)	MAN (NAVIGATOR)	MAN (SYSTEMS ENG)	MACHINE
Monitor V Maneuver	Stop SM-RCS vllage	Observe master timer	Monitor SPS fuel and oxidizer quantify displays	Switch off Display within limits
	Monitor V remaining display		Observe SPS pressure and temperature displays	All within limits
	Monitor FDAI	Monitor FDAI		Attitude steady
	Observe displays on G & N panel	Observe displays on G & N panel		All within limits

R E P E A T W H O L E S E Q U E N C E F O R E A C H O R B I T A L

C H A N G E U N T I L R E N D E Z V O U S I S A C C O M P L I S H E D

APPENDIX C: PRELIMINARY ANALYSIS OF THREE CURRENT TASK TAXONOMIES

Introduction

As demonstrated by the examples presented in Appendix B (Figure BB-2), several of the activities which might occur during a space flight or an extended stay in a manned orbiting research laboratory were described at a micro level of detail using Meister's Task Dimensional Taxonomy. In light of the project goal, human performance prediction in man-machine systems, it was desirable to evaluate various existing analytic and descriptive behavioral taxonomies to (1) discover what they might offer in terms of a procedure for mapping the detailed task descriptions into behavioral categories and (2) to determine how to measure the usefulness and effectiveness of a taxonomy for any particular purpose this effort took place prior to the development of the mapping and analysis procedures outlined

It was decided to try out three quite different behavioral taxonomies, two analytic (Miller and Alluisi) and one descriptive (Meister), as a heuristic exercise which might provide insight and, possibly, answers to the following set of questions:

1. Could the mapping activity be performed? If so, how satisfactory was the mapping performance?

2. Did the taxonomic categories serve to adequately describe, define and differentiate between the behaviors?

3. Did the taxonomies appear to offer any obvious advantages or disadvantages?

It should be recognized that the critical evaluations made of these taxonomies will necessarily tend to cover either the analytic (generally applicable behavioral interpretations) or the more activity-specific descriptive taxonomies. The two types of taxonomies are not directly comparable even through discussed with respect to the same criteria. Further discussions of the three taxonomies appear in Chapters B and C.

Method

The micro level task descriptions for two activities provided the items to be categorized according to the three taxonomies. These activities were: the Rendezvous and Docking mission (description of this activity at the Man-Man, Man-Machine Interaction level is provided in Appendix B, Figure BB-3) and one of the scientific experiments, Inflight Exercise-Work Tolerance (micro level description example appears in Appendix B, Figure BB-2). Since both of these activities involve considerable repetition, a subset of nonrepeated items was selected for each. As a result, the list of task descriptions for Rendezvous and Docking consisted of 58 items while the Inflight Exercise-Work Tolerance list consisted of 24 items. These two lists each provided an axis for separate matrices.

The other axis for both matrices consisted of the categories provided by each of the three taxonomies. A brief description and the set of categories is given below for each taxonomy. Further discussion is provided in the text in Chapters B and C.

(1) The Alluisi Taxonomy. The six category system of Alluisi is said to be a sufficient set of functions to interpret all described task behaviors.

Categories: Watchkeeping
Sensory-perceptual functions
Memory functions (short and long)
Communications functions
Intellectual functions
Perceptual-motor functions

(2) The Miller Taxonomy. This list is an eight-step sequential categorization; i.e., each item must be considered in order for each task description. This system, again, is said to be sufficient to categorize all task behaviors.

Categories: Concept of purpose
Scanning function
Identification of relevant cues function
Interpretation of cues
Short-term memory
Long-term memory
Decision making and problem solving
Effector response

(3) The Meister Taxonomy. Level 2 of Meister's Descriptive Behavioral Taxonomy was selected. It is specifically oriented towards space flight activities.

Categories: Perform control-display operations
Tracking
Record data received
Communicate
Observe external vehicle events
Perform quantitative computations
Perform preventive maintenance
Make decisions
Put on/remove personal equipment

Open/close doors, hatches, access covers, etc.
Move from one vehicle location to another
Read written material
Precise control manipulations

Two members of the project staff independently performed the exercise of mapping each one of the task descriptors to those taxonomic categories which seemed either to provide an appropriate behavioral interpretation (Alluisi and Miller) or behavioral description (Meister). A match was indicated by checking the appropriate matrix cell. Evaluation of the mapping efforts proceeded along two lines: (1) the responses of the personnel to the questions posed above and (2) the relative inter-analyst agreement as indicated by checked cells of the matrices.

Evaluation Results

The mapping efforts proved to be very beneficial heuristically in that several difficulties became evident in the attempt to apply the taxonomies, particularly those of Alluisi and Miller. Specific problems will be discussed prior to consideration of the three questions presented above.

The Alluisi Taxonomy. Several criticisms were expressed concerning this taxonomy: the categories were so broad and general as to afford little definition (as, e.g., "intellectual functions"), the categories did not cover sufficient domain (no gross body movement categories provided), interaction processes not covered except by "communications" , and, as a result of both overlap and unclear separation, the categories of sensory-perceptual, perceptual-motor and watchkeeping were made unnecessarily difficult to use. Further, it appeared that if the other categories were defined more the nature adequately that "watchkeeping" would either be dropped or redefined. In comparison, however, the set of categories in this taxonomy were apparently relatively easy to use objectively. The project members indicated that the definitions were comparatively clear-cut except for the "intellectual functions" category; the reality of this was indicated by the high degree of inter-analyst agreement on the mappings except for the aforementioned category.

The Miller Taxonomy. The use of this taxonomy resulted in several expressions of dissatisfaction on the part of the analysts. The taxonomic categories, or steps, were found to be terribly general, vaguely defined, and provided little discrimination between or adequate definition of the task items. It was felt that the usefulness of the taxonomy, due to and definition of the categories, would necessarily be a function of the goodness of the intuition and depth of experience held by the individual analyst.

In applying the taxonomy the analysts found that sequential consideration of categories like "Concept of Purpose," "Interpretation of Cues," and "Effector Response" imposed the essentially analogous requirements of either checking every matrix cell for each task item (because they describe the execution process for much of human task behavior; i.e., the checking of one step implied the checking of one or more prior steps) or checking practically no cells (because they did not discriminate between the task items). It was felt that the procedure of sequential steps might be useful in another context, but not at this level with these categories. The analysts differed radically in their task item assignments to categories as a result of (1) adopting alternate checking procedures (every cell vs. no cells for the above mentioned categories) and (2) interpreting the definitions of some of the other categories somewhat differently.

The Meister Taxonomy. As stated above, the level 2 taxonomy was developed to provide a more general set of descriptive behavioral categories particularly suitable for active space flight tasks. As a result, the Rendezvous and Docking task items were easily mapped according to the analysts and their category assignments were in close agreement. The only criticism seemed to be a feeling that the category, "Perform Control-Display Operations" included a much wider range of behaviors than the other categories (e.g., "Read Written Material") and would have been more satisfactory if separated into two or more categories (e.g., active and passive control-display operations categories).

As would be expected of a taxonomy suitable for description of flight tasks, the categories were not adequate for the Inflight Exercise-Work Tolerance task items either with respect to completeness or with respect to the appropriateness of the category definitions for the task items.

As a result of the mapping exercise (mapping micro-level task descriptions into general-level analytic and descriptive behavioral taxonomies) considerable insight was gained with respect to the initial set of three questions. The evaluations made by the participating analysts of the mapping performance and the results of their activity formed the following answers to the questions:

Question 1. Could the mapping activity be performed? How satisfactory was the mapping performance? The answer to the first question seems to be "yes". The main question then appears to be, "How satisfactorily can the activity be performed in terms of analyst understanding and inter-analyst agreement?" As indicated by the taxonomy-specific review above, the analysts evidenced fairly close agreement when using the Alluisi and Meister taxonomies. Apparently this was a function of the comparatively clearcut definitions and examples given by these authors and the relevance of these sets of categories to the Rendezvous and Docking activity in particular.

Question 2. Did the categories serve to adequately describe or define and to differentiate between the behaviors? The Alluisi and Meister taxonomies seemed to provide the best definition and to allow the most discrimination (although limited in the Alluisi case due to the broadness of his categories) between the task behaviors; although both inadequate coverages of the behavioral domain and a possible need for redefinitions of the categories were noted for each. The Miller Taxonomy seemed to offer very little in the way of description, definition or differentiation in the form used.

Question 3. Did the taxonomies appear to offer any obvious advantages or disadvantages? The advantages or disadvantages of a taxonomy are most appropriately evaluated by a measure of how well it served the purpose for which it was designed. It should, therefore, be realized that responses to this question were made primarily with reference to the requirements of this project. As has already been pointed out, the taxonomies of both Alluisi and Miller were felt to be at too gross a level to be particularly useful. In the final evaluation of these two taxonomies and the needs of this project it was determined that a taxonomy at a greater level of detail would be needed.

Considering the taxonomies with respect to what advantages they might offer, Miller and Alluisi were both viewed with interest as they each contained a subset of categories which could be related to the test literature, given further detail. Level 2 of the Meister Taxonomy offered a level of detail that appeared to collect the task descriptions into units that might, e.g., serve certain system analysis, design or evaluation purposes.

Summary

In summary, the use of each of the three selected taxonomies appeared to offer certain benefits. In the process of actually applying these taxonomies to a set of task descriptions, however, both strong and weak aspects were noted for each. It became clear that the effectiveness and usefulness of a taxonomy is a function of at least these things: (1) how appropriate the level of detail is to the purpose of the taxonomy, (2) how cleanly separated and appropriate the categories are, (3) how objectively and thoroughly the categories are defined, and (4) in the case of the analytic behavioral categories, how completely the taxonomy covers the behavioral domain.

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