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AIR FORCE FLIGHT CONTROL AND FLIGHT DISPLAY INTEGRATION PROGRAM

AF 33(657)-8600: Martin Human Engineering Group Final Summary Report, 1962

C. A. Gainer

Engineering Report Number 12,905

Contract: AF 33(657)-8600
Baltimore, Maryland
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FOREWORD

This report is a final summary report of contract activities under United States Air Force Contract AF 33(657)-8600 from 1 March 1962 to 28 February 1963, as required by contractual agreement.

Work covered in this report was initiated under contract by the Human Engineering Branch, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. The work upon which this report is based was completed at the facilities of and in support of the activities of the Control Elements Research Branch and the Control Synthesis Branch of the Flight Control Laboratory, Directorate of Aeromechanics, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. Contract AF 33(657)-8600 "Human Engineering Support to the Air Force Flight Control and Flight Display Integration Program," supports Task 619007 and 71573 both part of Project 6190.

Mr. J. H. Kearns II (ASRMCE) was the Air Force Project Engineer for the Flight Control Laboratory. Technical work was under the direct supervision of Aerospace Medical Research Laboratory representatives, Capt. C. E. Waggoner and Dr. D. P. Hunt. Capt. Waggoner is the current Task Scientist as Dr. Hunt has left the employment of the Air Force. Mr. R. W. Obermayer and Mr. C. A. Gainer served successively as Principal Investigator for the Martin Company.

Particular thanks is extended to Mr. R. R. Davis (ASRMCS-3) whose Section fabricated and supported all equipment which was used for the experimental investigations conducted during the term of the contract.

ABSTRACT

The Martin Company provided human engineering support to a number of Air Force programs being conducted under Project 6190. This report is a final summary report of the activities from 1 March 1962 to 28 February 1963.

The extent of task activities were broad in scope and quite deverse in subject matter. Members of the group were involved in research projects, consulting activities, reviews of literature and methodological development. Each of these kinds of tasks are briefly reviewed and the topics investigated are discussed.

The subject matter of these tasks in part consisted of controller studies, display evaluations, display development, performance and opinion measurement, and program planning.

TABLE OF CONTENTS

LIST OF TABLES

I. INTRODUCTION

This paper is a summary report of the activities of Air Force Contract AF 33(657)-8600 from 1 March 1962 to 28 February 1963. Based on experience from previous contracts in support of the Air Force Flight Control and Flight Display Integration Program, four kinds of human engineering activities are required to provide sufficient support. These are:

1. Consulting and System Team Efforts
2. Research and Man-Machine Systems Evaluations
3. Analytical Study and Methodological Tasks
4. Technical Presentations

A monthly progress report was issued which described the activities being conducted under each of the above. This progress report is separated into four major sections which parallel the above categories. This report will deal with the consulting activities, the analytical tasks, and the evaluations in Section II. Section III will show the relationship of the type of task to the program phasing. All technical details of the tasks will be omitted. For this kind of information the reader is referred to the appropriate report which was issued as a result of each effort. The reports which are issued from this contract group fall into five categories:

1. Human Engineering Memorandum Reports
2. Engineering Reports
3. Aeronautical Systems Division Technical Notes and Reports
4. Journal Publications
5. Conference Reports

A list of the reports issued will appear in Section V categorized by the first four of the above. The one exception is the conference report which is only for the purpose of reporting daily activities and meetings of consequence which need to be documented. There is no technical information contained in the conference reports, but are for the purpose of recording significant events for the transmission of this information to involved personnel.

II. CONTRACT TASKS

Task numbers were assigned to tasks of sufficient magnitude and importance to warrant a major effort. The formal task number could be assigned as an outgrowth of any one of the four categories listed in Section I. There were a number of ways in which task assignments can be derived. The first and most frequent was by direct request of support from the Flight Control Laboratory and by agreement of the project engineer, the task scientist and the principal investigator. A second method of task number assignment comes from the internally generated hypotheses which were the result of the analytical tasks. A third method of number assignment was through the consulting and/or system team. In all cases agreement by the project engineer, task scientist and principal investigator was needed before number assignment. An example of consulting was Task No. 12, Pilot Opinion. Examples of the system team were Task Numbers 13, Mark IV-B Controller Study, and 16, Profile Measurement. During the normal working cycle a certain amount of effort is expended in support of programs that are too brief to be considered for a task number. These will be summarized under Consulting.

The tasks so assigned are listed below and will be described briefly on the following pages of this Section. By virtue of the method of assignment, these tasks coupled with the consulting are considered to be the fulfillments of the contractual requirements and the requirement specified under Project 6190. The items in Table 2 list the tasks by number and their title. It should be noted that some of these efforts are carry-overs from the preceding contract, AF 33(616)-7752. Table 1 lists the tasks completed during the previous contract year 1 January 61 through 31 December 1962. These carry-over efforts were of sufficient magnitude that they could not be completed within the confines of a single contract span and in some cases, by necessity will be carried into the next contract period.

Table 1

List of Tasks Completed During the Previous Contract Years 1 January 1961 - 31 December 1962

Task No. 1	Procedures for Inflight Instrument Evaluation
Task No. 2	Eye Movement Study
Task No. 3	Operator Controls Research
Task No. 4	Display Assessment - A Tool for Instrument Design
Task No. 5.I	Human Engineering Support to Display Design of the Modified Phase II-A Altimeter

Table 1 - continued

Task No. 5.II.0	Lear Vertical Velocity Radar Altimeter Landing Instrument
Task No. 5.II.1	Automatic Lateral Control System for ILS Approaches Using the T-33
Task No. 5.II.2	James Connally: Automatic Compensation for Crosswind During ILS Approaches Using the T-33
Task No. 5.II.3	Feasible Control Display Techniques for use in Event of Automatic Landing System Failure
Task No. 5.III	Cockpit Displays for All-Weather Landings
Task No. 6	Simulator Test, Kollsman Drum-Pointer, Counter-Drum-Pointer, and Specialties Altimeters.
Task No. 9	Design of Digits and Coding for Flight Displays

Table 2

List of Active Tasks, Analytical Tasks and Consulting Tasks for the Contract Year from 1 March 1962 - 28 February 1963

Active Tasks

Task No. 7: Mark IV-B Development
Task No. 8: Reference File for Control-Display Engineers
Task No. 10: Three-Dimension, Volumetric Display Investigation
Task No. 11: Transition from IFR to VFR During the Approach for Landing
Task No. 12: Pilot Opinion
Task No. 13: Mark IV-B Development Program, 3-Axis Controller
Task No. 14: Vehicle Attitude Controller Problems
Task No. 15: Scale Factors for Moving Tape Instruments
Task No. 16: Profile Measurement
Task No. 17: 3-Axis Controller: An Investigation of the Effects of Location and Position Variables upon Tracking Performance using the 3-Axis Controller
Task No. 18: Phase III Airspeed Indicator and Altimeter Investigation

Analytical Tasks

1. Levels of Automation
2. Pictorial Displays
3. Color Coding
4. All Attitude Indicators and Attitude Director Indicators

Table 2 - continued

Consulting Tasks

1. Planetarium and Compact Simulator
2. Micro-Vision Display System Investigation
3. Photochromic Display
4. Tracking Research
5. Pilot Factors Program
6. Dyna Soar Simulation Program
7. Straight Scale Bibliography

Task No. 5.III. Cockpit Displays for All-Weather Landings

Purpose: To conduct an evaluation for an in-house study of three methods for the display of absolute altitude information.

Discussion: As a result of common interest in all-weather landings, there was established a project agreement between FAA/BRD and AFSC. This agreement provides for simulator testing of three panel configurations which are designed to augment landing phase instrumentation. This program is limited to state-of-the-art equipment, and, is designed to evaluate the performance of three available instrument configurations. These instruments will present in different display forms: (1) absolute altitude, (2) instantaneous rate of sink, (3) altitude, (4) rate of descent, and (5) a landing flare shield.

Status: This task has been completed in the form of an Engineering Report, Number 12,446, "Cockpit Displays for All-Weather Landings", by C. A. Gainer, W. L. Welde (Martin Company) and R. Monroe (Link Division, GPI), May 1962.

Task No. 7: Mark IV-B Development

Purpose: To participate in a team effort for the design and development of an advanced aerospace vehicle control-display system.

Discussion: This will be a program requiring participation in a team effort. Effort under this project will consist of planning the human factors activities for the Mark IV Program, and defining and outlining human factors problem areas which require analytical and/or experimental effort. As problem areas are defined, they will be given a separate task title and further work will be conducted under the assigned task title.

Status: A study of the 3-axis piezoelectric controller has been completed (Task 13: Mark IV-B Development Program, 3-Axis Controller). This activity is being followed by a more extensive study as to the best location of the controller. Three positions will be studied and for further detail refer to Task No. 17: 3-Axis Controller: An Investigation of the Effects of Location and Position Variables upon Tracking Performance using the 3-Axis Controller.

Additional effort has been spent in the display requirements associated with the cockpit layout. Of primary concern was the photochromic display. The other display has not been specified in detail and there will be an emphasis on the displays during the next contract year.

Reports issued that are directly assocated with this task: Memorandum Report 62-1.

Task No. [illegible]: Reference File for Control-Display Engineers

Purpose: To define, to study and, to implement a system providing ready access to information necessary for all phases of control-display engineering.

Discussion. It is necessary to first specify the categories of information desired, the scope, form and desired accessibility, etc. Having this degree of definition, one may logically proceed to a method of implementation.

Status: One complete set of cards has been made up for 231 reports. These cards are filed in seven different categories:

1. Accession
2. Author
3. Contract
4. Project
5. Contractor
6. Government Agency
7. Title

A subject file which is the ultimate objective of this task has not been specified. Work will continue on the categorization of reports and when the subject file has been settled upon this will be incorporated into the file.

Task No. 10: <u>Three-Dimension, Volumetric Display Investigation</u>

Purpose: To plan and conduct an analytical and empirical investigation of a three-dimension volumetric display in order to point up the limitations, design parameters, and potential uses of the display technique.

Discussion: Making the assumption that a three-dimensional volumetric display developed by ITT is representative of the class, an investigation will be conducted to derive useful information about three-dimensional displays. By means of a combined analytical and empirical approach, it is hoped to derive information relevant to: (1) types of broad classes of information amenable to three-dimension display; (2) effect of two-dimension display principles with a three-dimension display; (3) special characteristics of the display elements of a three-dimension display; (4) the integration of a three-dimension display with other information displays. While an extremely long research program is usually necessary to accomplish such ambitious goals, it is hoped to design a comparatively compact investigation which will yield exploratory but useful information.

Status: Approximately 80% of the literature relative to the 3-D volumetric display has been reviewed; the remaining reference material has been requested from ASTIA. Pertinent psychophysical variables have been studied, and their physical limits, as they relate to this display, have been ascertained. Consideration has been given to the application of this instrument with respect to air traffic control, aircraft and space vehicle missions. Moreover, some of the required research problems associated with the use and application of the 3-D display have been scrutinized. A written report will be initiated after the final research literature is received.

Task No. 11: <u>Transition from IFR to VFR During the Approach for Landing</u>

Purpose: To investigate what should be done to solve some of the problems associated with IFR-VFR transition.

Discussion: Since little is known about the problem area it will be necessary to conduct an analytical search of the literature. In addition, the methodology for analysis and synthesis of the vast body of literature must be developed and necessary areas for future research pointed out. This would lay the foundation for an ongoing program of research.

Status: This task has lain dorment for most of the contract year awaiting manpower availability.

Task No. 12: Pilot Opinion

Purpose: To improve current evaluation measurement by exploring and developing techniques for eliciting valid and reliable pilot assertions.

Discussion: This task is an expression of the hope that the set of evaluation criterion possible through system performance measurement may be augmented by measurement through the human operator. For example, one might expect that the following items of valuable information might be obtained from experienced operators:

1. User acceptance
2. Design advice
3. Operator task analysis
4. System performance evaluation
5. Fidelity of the system test
6. Recording of unexpected events

The problem is -- as is often the case with tests involving the human operator -- to obtain data which are related to the desired measurement. In short, it is desired to achieve valid measurements. A program in the area of pilot opinion measurement must necessarily be based primarily on (a) the ability to recognize 'valid' measurement, and (b) development of appropriate measurement techniques to collect valid measurements in a stable and reliable way.

Thus, the program under Task 12 consists of two parts:

A. Pilot Opinion and Validity
B. Pilot Opinion Questionnaire Development

Status: This task will continue to command time, some promising questionnaire techniques have been uncovered and are being developed. For more specific detail the reader is referred to Martin Engineering Report 12,446, Cockpit Displays for All-Weather Landings, Memorandum

Report No. 62-2, Revision of Work Statement Concerning the Investigation of the High Angle Letdown, Omni-Angle Technique, Memorandum Report No. 62-8, Results of Semantic Differential and Questionnaire used in the Investigation of Micro-Vision, Memorandum Report No. 62-10, Summary of the Results of the Questionnaire used during the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver).

The validity part of "A" is in the form of a paper which is in preparation and is awaiting editorial comment from a number of journals.

Task No. 13: <u>Mark IV-B Development Program 3-Axis Controller</u>

Purpose: (1) to provide data for the further design and development of a 3-axis controller for the Mark IV vehicle. (2) To provide information for the design and fabrication of a control system for the Mark IV vehicle.

Disucssion: Initially, it was conceived that an evaluation of the 3-axis controller in comparison to the standard control stick would be undertaken. However, due to difficulties in the controller itself, this study was not begun. Instead, it has been decided that more information concerning gains for pitch and roll, and other properties of the controller need to be known before any evaluation can be undertaken. The present controller study is intended to furnish data concerning (1) preferred gains and control ranges, (2) cross-coupling effects, (3) the effects of subject body dimensions and the seating arrangement. It is hoped that information from this study will be of value in the design and fabrication of a control system for the Mark IV-B vehicle. Further, it is anticipated that this study will be the first step in a continuing program for the investigation, study, and development of force stick controllers. For further information concerning this, the present study, see MR 61-24, dated 30 November 1961.

Status: Since the completion of data collection, favorable progress has been made in statistically analyzing the performance data. To date, six partial hierarchical analysis of variance procedures have been completed for the error (e) and error squared (e^2) data. In the analysis, tracking performance has been assessed as a function of method of choosing gains, method-derived gains, magnitudes of gains, and single versus dual axis tracking. Further analyses are currently being undertaken to asses apparent interactions found in the preliminary analyses. No analysis of cross-coupling or anthropometric factors has been attempted.

Steps have also been taken toward completing the engineering report for Task 13. To date, a search of pertinent literature has been undertaken. The method section of the report has been completed in first draft form, and those portions of the results section pertaining to subject-derived gains have been completed. It is anticipated that with the completion of statistical treatment of the performance data close at hand, that an engineering report will follow.

Task No. 14: Vehicle Attitude Controller Problems

Purpose: (1) Identify meaningful problems related to vehicle controllers and to establish their relative importance. (2) Establish boundaries and constraints defining where meaningful work can be accomplished. (3) Determine suitable approaches to these problems. (4) Compare the required program thus determined to the state-of-the-art to determine what must be done.

Discussion: Since the human operator in a man-machine system is obviously limited by the controls through which he is required to respond, there is little reason to doubt that this area is one which could profitably stand attention. Further, since evidence exists that the effects of controller parameters are a function of the information displayed and the manner of display, the vehicle dynamic parameters, and the environment, especially g's and vibrations, it is strongly suspected that this problem area may be one of the most complicated of those involved in man-machine systems. An abundance of jusitification exists for the conduct of a well-thought-out program, however, to the best of our knowledge no such program exists. The following, therefore, are some recommendations for the establishment of the essential characteristics of the needed program.

As the task title indicates, to channel efforts one can profitably concentrate on the difficult problem of vehicle attitude control; it is hoped that a suitable adaptation will be possible to other controller areas.

In the following is indicated an approach to the problem, but as in most problem-solving tactics, one must allow considerable freedom to take advantage of problem specifics as they become known, and also, the following procedure may be one which allows successful interaction.

1. Conduct a review of the available literature. This could be a huge task, but it is intended here only to prepare the individual for the following steps. Some good reviews are in existence (Muckler, 1960; Bell Aerospace, 1961) and it should be possible to efficiently use these as a starting point.

2. Formulate a tentative program outline and program goals. This should include fruitful controller principles for exploration, controllers for development and evaluation, establishment of criteria and techniques for subsequent measurement. Possibly at this time an adequate case can be presented to justify immediate work on the development of methodology.

3. Update, and by visitation, summarize current nation-wide activities. Possibly, vists may be made to: Bell-Aerospace, Chance-Vought, Boeing, Ames, NASA, McDonnell, North American, Martin, and others.

4. With the guidance of FCL, design a program which will lead to the goals of FCL, and indicate which of the proposed programs have been done, is being done, and remains to be done.

5. Sample from the accepted program those pieces of work which can most appropriately be accomplished by the Martin Human Engineering Group.

Status: The importance of this task is obvious, but due to it's nature and the lack of immediate application to our current priority work, it has remained inactive awaiting manpower availability.

Task No. 15: Scale Factors for Moving Tape Instruments

Purpose: To define, study, and implement a program on scale factors for moving tape instruments.

Discussion: It is proposed to conduct a study on scale factors (major interval markings per inch) for moving tape instruments. The study would be carried out in two phases: (A) Static Display and (B) Dynamic Tracking Situation. It is expected that the results will yield a family of curves depicting (1) reading error vs. scale length, (2) reading error vs. rate of tape movement, and (3) reading error vs. scale length and rate of tape movement.

Experimental scales will be constructed, 3 types with vertical orientation, and 3 with horizontal orientation. Variables to be investigated will include scale factors, spacing of minor graduation marks, number of digits, rate of tape movement, instrument orientation, and instructions to the subject, however, these are subject to change when the experimental design is completed.

Status: A work statement for Scale Factors for Moving Tape Instruments was issued as MR 62-9. A program has been laid out in 2 phases -- (A) Static Legibility Investigation, and (B) Dynamic Tracking Situation, for the purposes of identifying those scale variables that affect the speed and accuracy of reading moving tape instruments. The work statement provides in detail the experimental design for Phase A. At present, equipment fabrication is approximately 70% completed for the Static Legibility Investigation. Photographing of the tapes is in the final stages, and work will begin on the binding of the 750 slides required.

One hundred and fifty college students are being secured as subjects. It is anticipated that the data collected from Phase A will be available in June, 1963 for the writing of the final report.

Task No. 16: Profile Measurement

Purpose: To provide data concerning a proposed descent and land profile after re-entry of the Mark IV-B vehicle utilizing the Hypersonic ME-1 space simulator.

Discussion: From this task will evolve an experimental study for purposes of investigating the following problems:

1. Can the descent profile be flown as it presently exists to permit the space vehicle to reliably effect a safe approach and landing?

2. If the existing profile does not result in consistent performance of the flight task, what alterations should be instituted to achieve the optimum descent profile?

3. What additional cockpit instrumentation and controls are essential to simplify the pilot's task of information integration and, thus, enhance the probability of a safe approach and landing?

4. In flying the profile, what are the quantitative values of the more important flight parameters during each phase?

Data from this task will be used to update the vehicle characteristics section of the Mission-Equipment-Functions-Task (MEFT) analysis shown in Martin Memoranda Reports 61-20 dated 31 October 1961, and 62-1 dated 12 January 1962.

Status: Installation of the required equipment items in the Hypersonic ME-1 simulator and checkout of all associated systems for the study continues.

Pre-experimental work is realistically judged to commence in the first week of March, 1963 with the actual experimental sessions to follow approximately three weeks later. A description of the profile under investigation and the manner in which the study will be conducted to evaluate this task is contained in Martin Memorandum Report Number 63-2, Work Statement for Mark IV-B Profile Measurement Task.

Task No. 17: Three-Axis Controller: An Investigation of the Effects of Location and Position Variables upon Tracking Performance Using the Three-Axis Controller

Purpose: To provide data concerning the effects of position and location variables upon tracking performance using the three-axis controller. Information obtained from this task will aid in determining what the optimum mounting location and the vertical angle for the controller should be. Also, it is anticipated that this study will provide more basic data concerning the influence of these variables upon performance.

Discussion: Under this task, the three-axis controller will be mounted in three or four locations in combination with three or four vertical angles. Using a standard gain setting for all subjects, the subjects will perform a tracking task consisting of tracking ILS needles on a standard ADI for all possible combinations of vertical angles and locations. Measures of display error (e and e^2) and stick output will be taken for purposes of data analysis.

Status: A work statement (Martin Memorandum Report 63-3) is in preparation. Essentially the same basic equipment which was used in performing Task No. 13 will be utilized with modifications being required. In order to expedite equipment fabrication a preliminary working document was published for use by the engineers concerned with the study. A time schedule showing the events and time required to accomplish these events will be included in the work statement.

Task No. 18: Phase III Airspeed and Altimeter Investigation

Purpose: To evaluate the new developments in the Phase III Airspeed and Phase III Altimeter as to how they affect pilot performance in flying instruments.

Discussion: The development of the Phase III vertical tape airspeed indicator and altimeter has evolved from the Phase II vertical tape instruments. The new developments are proposed to improve pilot control of the parameters displayed on these instruments. Since both the Phase II and Phase III instruments are available, it would be highly desirable to investigate the capabilities of the Phase III instrument using the Phase II instruments as a standard. Utilizing a simulator and a scoring system, a rigorous full mission profile may be flown by a sample of pilots and then performance using the Phase II and Phase III instruments may be analyzed. Such a procedure would provide information regarding pilot performance using those instruments and provide an opportunity to gather subjective data (questionnaires) concerning pilot attitude toward the new instruments.

Status: A detailed work statement describing the method of evaluation has been published (Memorandum Report 63-4). The initial contacts have been made for the planning of the program and it is understood that the instruments will be available shortly. It is anticipated that the ME-1 simulator will be used as the test equipment and the analog computers will be used as the measurement equipment.

III. CONTRACT PROGRAM PHASES

As has been done in the past, the Martin Human Engineering Support Group has participated in four distinct kinds of activities in support of the Flight Control Laboratory. These are as previously stated:

1. Consulting and System Teams
2. Research and Evaluation Activities
3. Analytical Study and Methdological Tasks
4. Technical Presentations

It has been our experience that the best program should consist of proper proportions of each of the above. These phases do not occur in temporal sequence rather they run concurrently as part of an integrated program. This section will be devoted to show how each of the tasks described in the previous section fit into the four activities.

Consulting and System Teams

The amount of consulting activity was limited due to the emphasis of the direct research activity, the participating in design teams and the amount of analytical work.

Consulting

While there were a limited number of consulting activities *per se*, the topics covered were broad. Almost all the consulting activity was limited to support of Project 6190 and the Flight Control Laboratory. In general consulting tasks performed were short in duration and were performed within tight time restraints. A list of the topics which were covered by our consulting activities were:

1. Bibliographies
2. Questionnaires
3. Control Evaluations
4. Display Evaluations
5. Program Planning

System Team

This activity was not as apparent in the types of reports issued but still played an emphatic role in the overall program. The presence of human factors engineers as part of the development team was apparent in:

1. Task No. 7: Mark IV-B Development Program
2. Task No. 13: Mark IV-B Development Program, 3-Axis Controller
3. Task No. 16: Profile Measurement
4. MR 62-10: Summary of the Results of the Questionnaire used during the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver).
5. MR 62-11: Scoring System Requirements

Within each of these efforts, a considerable range and type of support was provided. For specific problems that were encountered the Human Factors team member did the following types of tasks:

1. Literature review
2. Questionnaire development
3. Instrument design recommendations
4. Experimental design
5. Data analysis

During the course of a system team project, human engineers contribute to the problem solution through a close association with system engineers, control system engineers, maintenance and installation personnel, display engineers, measurement and calibration personnel, simulation engineers, and flight test engineers and project pilots.

Research and Evaluation Activities

Perhaps the most important function of a human engineering group in the support of a design and development effort, is the ability to apply experimental techniques to the solution of practical problems. In a problem area where little is usually known and generalization is always hazardous, the experimental approach frequently appears to be the only safe approach. On the other hand, the complexities introduced by the human subjects in an experimental system are such that bias and distortion of experimental results is quite possible. Conclusions which are a direct result of the system parameters under study can be obtained only through careful experimental design. It is for these reasons that the conduct of an experimental program is considered extremely critical.

During the course of the contract year, 8 research programs and evaluations were initiated, and are now in various stages of completion:

1. Task No. 13: Mark IV-B Development Program 3-Axis Controller
2. Task No. 15: Scale Factors for Moving Tape Instruments
3. Task No. 16: Profile Measurement
4. Task No. 17: Three-Axis Controller: An Investigation of the Effects of Location and Position Variables upon Tracking Performance Using the Three-Axis Controller.
5. Task No. 18: Phase III Airspeed Indicator and Phase III Altimeter Investigation.
6. MR 62-2: Revision of Work Statement Concerning the Investigation of the High Angle Letdown, Omni-Angle Technique
7. MR 62-5: Work Statement: Investigation of the Relationship between Split-Axis Control and Task Load for the High Angle Letdown, ILS Approach to Touchdown.
8. MR 62-10: Summary of the Results of the Questionnaire used During the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver).

It is evident that these programs represent a wide scope of research items. Simulator, inflight, questionnaire, and static display techniques are represented.

Analytical Study and Methodological Tasks

During the contract period, a number of tasks were attempted on a non-empirical basis. These included literature surveys, establishment and extrapolation of state-of-the-art, attempts to predict requirements and the development of methodology.

Inflight Evaluation. Based on a great deal of experience with inflight evaluation, two of these were undertaken and completed during the contract period (Memorandum Report 62-8, Results of Semantic Differential and Questionnaire used in the Investigation of Micro-Vision, and Memorandum Report 62-10, Summary of the Results of the Questionnaire used during the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver).

Questionnaire Development. This is Task No. 12 and was for the purpose of the development of techniques for the extraction of reliable pilot opinion. The task was defined in detail in Section II.

Other analytical and methodological tasks being conducted were previously defined in Section II and will not be repeated. However, it should be pointed out that this type of task was one of the most important performed. In every case a great deal of knowledge was derived and this activity also provided information concerning many kinds of future research requirements. Continued emphasis will be placed in the development of methods and the analysis of problem areas.

Technical Presentations

One of the prime responsibilities of a Human Engineering Technical Group should be the education of their engineering counterparts in the methods and techniques of their specialty. Formal technical presentations were one way for this activity to be conducted. Although there were a limited number of the formal presentations, the day to day and week to week interaction was a more informal method in providing this support.

The following are the formal presentations given:

1. Mr. James E. Brown presented a paper entitled, "Familiarity and Novelty of Stimulus and Response Terms in Paired-Associate Learning", to the Southeastern Psychological Association at Louisville, Kentucky.

2. An informal briefing was given to members of the FAA/BRD and FAA/NAFEC 10 May 1962 on "Cockpit Displays for All-Weather Landings", by C. A. Gainer.

3. A presentation was given on 27 July 1962 to Mr. Claus G. Spindler and Dr. Helmuth Hunger of Minneapolis-Honeywell, Doernigheim/Hanau, Germany concerning the Mark IV-B Program. Primary purpose of the briefing was to present the visitors with information concerning the 3-Axis Controller study although the discussion was not limited to this topic.

4. On 18 October 1962, at the request of Mr. E. Warren, Messrs. William Knowles, William Elkins, and Stan Roscoe (Hughes Aircraft) were briefed on the 3-Axis Controller study now being conducted by the Martin Group. Immediately following the briefing, the visitors were given a tour of the simulation facility where other aspects of the Mark IV-B Program were discussed.

5. At the request of Mr. Mel Snyder (ASBSTP), a tour of the simulation facility was given to Dr. Don Haines (ASBSTP) on 3 October 1962. The purpose of the tour was to familiarize Dr. Haines with the types of projects that are currently being performed at the facility.

6. A presentation was made to nine members of the Edwards Aerospace Flight School. The presentation was on the activities of our group and how we fit into the Flight Control Laboratory Program. The following people participated in this briefing. Messrs. C. Semple, W. Welde, J. Brown and C. A. Gainer of the Martin Company, and Major D. M. Sorlie, Major B. F. Knolle, Lt/Cdr. C. Birdwell, Major C. C. Bock, Major J. F. Currie, Capt. W. T. Twinting, Capt. R. W. Smith and Major R. H. McIntosh of AFFTC-FTTA.

Analytical Tasks

1. Levels of Automation: Frequently in the past, the pilot's control mode has been considered to be one of two modes -- manual control or autopilot flight. Techniques have developed so that today virtually a continuum exists from manual to full automatic control, and in vehicle control, the extremes are usually considered inferior alternatives. In this era of super and hypersonic complex weapon systems, and today's missile Air Force, the roles of men and machines are extremely varied and intertwined.

Obviously, a frequent question is, "What is the optimum man-machine combination?" A great deal of heated debate has taken place, but it seems that really quite little is known about the answer to this question. In practice, it seems usually easy to provide a multi-mode system -- making it easy for one to assert his preference. While this seems sensible and abvisable, the system's modes that are conveniently provided are probably only a few of the infinity that could come under consideration. It is usually, however, only in terms of available system modes that one is able to define the term "levels of automation".

Status: A working paper has been drafted which deals with this problem analytically. There are some obvious research projects which will be an outgrowth of this effort. The report is being edited and will be re-written.

2. Pictorial Displays: At the present time, a great deal of interest is being shown in the development of pictorial navigation displays. Several of these instruments already exist, and it is, therefore, felt that an examination of this form of navigation information is warranted. Some of the potential uses of such displays are in enroute navigation, alternate re-entry sites, terminal navigation, re-entry profile and since a display screen is usually provided, the possibility exists to time-share other information, e.g., checklists. While it seems highly desirable to obtain a display capable of many uses, the most apparent need for pictorial navigation rests in the complex traffic control problem and the definite need for an accurate position indicator.

Some preliminary work concerning pictorial navigation displays has been performed and the area certainly appears worth further study.

Status: A collection of pertinent material has been completed.

3. Color Coding: With the increasing complexity of displays and controls with which pilots must cope, the use of color deserves consideration as a means of task simplification and subsequent promotion of performance and accuracy increases. However, the use of color as a means of facilitating the stimulus discriminations and response differentiations imposed upon pilots has not been treated extensively in the literature. Several studies have undertaken the determination of the maximum number of colors discriminable on an absolute basis, however. The number appears to be somewhere between five and nine, a surprisingly small number.

Some of the pertinent variables influencing color discrimination are:

(1) Number and hues of colors employed
(2) Chromatic composition of light source
(3) Intensity of light source
(4) Saturation of hues
(5) Type of illumination employed, i.e., ambient as opposed to self generating
(6) Distance of viewer from colored area
(7) Size of colored area
(8) Visual angle subtended by the colored area

Any of the variables mentioned above could adversely affect the use of color as a coding device in aircraft instruments or on aircraft controls. It is suggested, however, that with the discovery of photochromatic phosphors which will make possible colored radar presentations and in light of the increasing potential need for further facilitation of discrimination among controls and displays, that a review of the available literature on color discrimination and color coding be undertaken. The purpose of the review would be twofold. First, the review would result in the compilation of an annotated bibliography of the available literature pertinent to color coding in general. Second, such a review of the literature should result in the development of generalizations and specific "do's" and "don'ts" in the area of color coding. The review could attempt, therefore, to establish the state-of-the-art of color coding. The results of the review should also prove highly useful as a general guide for the preliminary assessment of new innovations regarding the color coding of instruments and controls.

A review of the literature in this area for large-board display systems will soon be available.

Status: The collection of review material has been completed and the write-up is awaiting manpower availability.

4. All-Attitude Indicators and Attitude Director Indicators. The purpose is to determine what are the design features of all-attitude indicators (AAI) and attitude director indicators (ADI) which optimize man-machine performance.

(1) To evaluate, summarize, and report the adequacy of the empirical research which has indicated some of the optimal design features.

(2) If no empirical determinations have been made with regard to whether certain design features are optimal -- (a) To compile empirical evidence from related research areas so as to generalize to the particular features as optimal design, and to summarize in report form. (b) To suggest research evaluation methodology on particular design features, and to carryout and report these studies which can aid in determining the design.

Eight major topic areas have been delineated each concerning different design features of AAI and ADI displays and in which various amounts of empirical knowledge have accumulated with respect to the design. These are:

(1) Dial size, shape, lighting, warning signals, aircraft symbols, rates of needle displacement, direction of needle movement, and size of lines, letters, and numbers are but a few of the basic features which shall be considered.

(2) The background design is another feature to be considered.

(3) Cluttering or how much other information should be displayed, within limits shall be considered.

(4) Whether qualitative or quantitative information should be displayed.

(5) Different modes of attitudinal information display, such as the Peripheral Command Indicator (PCI), shall be considered.

(6) Considerations of the methods to represent the three dimensions of attitude shall be made.

(7) The problem of pilot reference, i.e., "fly-to" or "fly-from", shall be considered.

(8) The overall efficiency of presently manufactured displays as far as precession error, ease of adjusting the display, etc., shall be considered.

Status: A literature search and review covering all eight topics has been planned and is in progress. An outline of these eight topics in more detail than presented here has been prepared.

(1) A brief literature review concerning the basic problem of the optimal size of these displays has been prepared.

(2) Indications from this brief review are that an optimal size has not been empirically investigated and is unknown.

<u>Consulting Tasks</u>

1. <u>Planetarium and Compact Simulator</u>: The simulation facility is interested in determining the best use for the compact simulator and planetarium as a research tool. A preliminary literature search has been accomplished to determine what has been done using such devices. The

conventional human engineering literature sources, journals, ASTIA publications, etc., produced no applicable papers for the novel combination of a simulator and planetarium. Several preliminary ideas have been considered:

(1) Investigating the use of the star pattern as cues of attitude.

(2) Investigating effects of a conflict between cockpit displays (attitude ball) and the extra-cockpit cues (star pattern).

(3) Investigating pilot ability to detect targets in a star field.

(4) IFR-VFR Transition.

The above are the first thoughts and need much more refining and are all subject to change. A rough draft of a research program for the compact simulator and planetarium will be avilable by 15 March 1963.

2. Micro-Vision Display System Investigation. The Flight Control Laboratory investigated a developmental night landing display by Bendix. The system, using micro-wave transmitter placed beside a runway, like runway lights, displayed dots on a CRT in the cockpit that corresponded to the runway lights as seen at night. The pattern of these dots changed as the pattern of runway lights during a night landing. This display was proposed to aid instrument approaches.

The Micro-Vision display system was installed in a C-131 for inflight investigation. Pilot subjects were selected from Cargo Operation. It was the Martin Company's responsibility to develop a briefing for pilot subjects to standardize the investigation procedure and to develope meaningful questionnaires to access pilot attitude toward the system. This was accomplished (MR 62-8). The results of the investigation suggested that the Micro-Vision System has potential and should be further developed.

3. Photochromic Display. At the request of ASRMCE-3 a study was made of the applications and research required for the Photochromic Display which is to be used in the Mark IV-B. The results of this are reported in MR 63-1.

4. Tracking Research. Pulse Modulation: At the request of Dr. D. Hunt, MRPEP, consideration was given to problem areas in vehicle control systems where the operator is in control of some parameters in

a pulse modulated system; for example, the thrust output of a reaction control system might take the form of a series of thrust bursts where the operator controls the amplitude, or frequency, or pulse width, etc. Further consideration shall be given to define potential work areas of the Martin Human Engineering Group.

5. Pilot Factors Program. This task is now a contract in itself and was carried during the early months of Contract AF 33(657)-8600 as a consulting task. This was the planning stages of the study of the split-axis-forced-wheel control system which is being investigated in detail at Instrument Pilot Instructor's School, San Antonio, Texas, by the Martin Company. Related reports are Memorandum Report 62-2, Revision of Work Statement Concerning the Investigation of the High Angle Letdown, Omni-Angle Technique, and Memorandum Report 62-5, Work Statement: Investigation of the Relationship between Split-Axis Control and Task Load for the High Angle Letdown, ILS Approach to Touchdown.

6. Dyna Soar Simulation Program. Consulting services were rendered to provide preliminary recommendations for the Dyna Soar Dynamic Simulation program concerning (1) response measures for magnetic tape storage, (2) phase I of data reduction, (3) suggested minimal dynamic simulation run conditions, and (4) preliminary suggestions for the procedure of the actual run sequence.

7. Straight Scale Bibliography. A bibliography of straight scale instrumentation, including both horizontal and vertical instrumentation, was prepared. For comparative purposes, a selected list of reports concerning circular scaling also was included. (See MR 62-3)

IV. PERSONNEL

The general success of the programs and the fulfillment of contractors commitments is based upon the degree to which qualified personnel are available. During the contract year the following personnel have been employed by Martin and have been directly associated with the contract activity.

Table 3

Table of Personnel

Part-Time	Associated with Contract But Not for Present	Current Staff
W. Dalhamer	R. W. Obermayer	J. E. Brown
W. Duncan	W. F. Swartz	C. Crisp (Secretary)
C. Malkin		G. Ervin
M. Young		C. A. Gainer
		B. J. Kelso
		W. K. McCoy
		M. McMillen (Part-Time)
		F. Mullen
		M. Narva
		C. A. Semple
		W. L. Welde
		R. Yoelin

Malkin, Young, and Duncan were temporary employees. Secretarial support was provided by Mrs. Crisp and Miss McMillen. All other personnel with the exception of Mr. Obermayer are presently employed in a technical capacity, although Mr. Dalhamer and Mr. Swartz are employed in another capacity in support of the Flight Control Laboratory.

V. REPORTS ISSUED

Memorandum Reports

MR 62-1: Mark IV-B Development: Preliminary Landing Phase Profile: Results of Additional Effort on the Mission-Equipment-Function-Task (MEFT) Analysis. (J. E. Brown and R. W. Obermayer)

MR 62-2: Revision of Work Statement Concerning the Investigation of the High Angle Letdown, Omni-Angle Technique. (W. F. Swartz)

MR 62-3: Bibliography: Straight Scale Instrumentation: Straight Scales for Horizontal and Vertical Instrumentation; Selected References Pertaining to Scaling of Dial-Type Displays. (J. E. Brown)

MR 62-4: Pre-Experimental Results: Cockpit Displays for All-Weather Landing. (C. A. Gainer and W. L. Welde)

MR 62-5: Work Statement: Investigation of the Relationship between Split-Axis Control and Task Load for the High Angle Letdown, ILS Approach to Touchdown. (W. F. Swartz)

MR 62-6: Mark IV-B Development: Work Statement: Equipment Requirement for Preliminary Measurement of Mark IV-B Profile. (J. E. Brown)

MR 62-7: Pilot Opinion vs. Validity. A Presentation given to the Flight Control Laboratory, 13 June 1962. (W. K. McCoy)

MR 62-8: Results of Semantic Differential and Questionnaire used in the Investigation of Micro-Vision. (W. K. McCoy)

MR 62-9: Work Statement for Scale Factors for Moving Tape Instruments. (B. J. Kelso)

MR 62-10: Summary of the Results of the Questionnaire used during the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver). (C. A. Gainer)

MR 62-11: Scoring System Requirements. (W. K. McCoy)

MR 63-1: Working Paper - Application of and Research Requirements of Photochromic Display Device. (F. G. Mullens)

MR 63-2: Work Statement for Mark IV-B Profile Measurement Task (W. L. Welde)

MR 63-3: Three-Axis Controller: An Investigation of the Effects of Position and Location Variables Upon Tracking Performance. (J. E. Brown)

Engineering Reports

ER 12,446 Cockpit Displays for All-Weather Landings. (C. A. Gainer, W. L. Welde, Martin Company, and R. Monroe, Link Division, GPI) May 1962.

ER 12,128 The Study of Pilot Eye Fixations while Flying Selected Maneuvers using Two Instrument Panels. (C. A. Gainer and M. L. Rosinia) Revised and Issued July 1962.

ER 12,905 Air Force Flight Control and Flight Display Integration Program: AF 33(657)-8600: Martin Human Engineering Group Final Summary Report, 1962. (C. A. Gainer) March 1963.

Journal Articles

"Preferred Panel Viewing Distance" by R. W. Obermayer accepted by Journal of Engineering Psychology.

"Interaction of Information Displays with Control System Dynamics and Course Frequency in Continuous Tracking." Perceptual and Motor Skills, 1962, 15, 199-215. R. W. Obermayer, W. F. Swartz, and F. A. Muckler.

"Familiarity and Novelty of Stimulus and Response Terms in Paired Associate Learning." Accepted by Psychology Reports, J. E. Brown (Martin) and J. O. Cook (North Carolina State College)

"A Test of the Accuracy of Crossman's Confusion-Function." submitted to British Quarterly Journal of Experimental Psychology, by W. K. McCoy.

"Problems of Validity of Measures Used in Investigating Man-Machine Systems." submitted to Human Factors Journal, by W. K. McCoy.

Theses

Resistance of Extinction of a Running Response as a Joint Function of Number of Acquisition Trials and Schedule of Reinforcement. Submitted by C. A. Semple to Ohio University in partial fulfillment of the requirements for the Master's Degree.

The Relationship of Statistical Self-Rating Variables to Inventoried Variables. Submitted by R. W. Yoelin to the Illinois Institute of Technology in partial fulfillment of the requirements for the Master's Degree.

APPENDIX

This Appendix contains all of the Martin Memorandum Reports issued during the contract period. The reports in other forms are not reproduced here but can be obtained upon request to Aeronautical Systems Division, Flight Control Laboratory, Attention: ASRMCE (Capt. C. E. Waggoner), Wright-Patterson Air Force Base, Ohio

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(616)-7752

MEMORANDUM REPORT: 62-1 12 January 1962

To: E. L. Warren

cc: Mr. William Austin, Mr. E. Bobbet, Mr. J. Charlton, Mr. R. R. Davis, Mr. T. J. Emerson, Mr. S. G. Hasler, Dr. D. P. Hunt, Mr. J. H. Kearns, Mr. N. MacGregor, Mr. E. Vinson, and Capt. C. E. Waggoner, and all members of the Martin Human Engineering Group.

From: J. E. Brown and R. W. Obermayer

Subject: Mark IV-B Development: Preliminary Landing Phase Profile: Results of additional effort on the Mission-Equipment-Functions-Task (MEFT) Analysis.

One of the primary purposes of the initial mission-equipment-functions-task (MEFT) analysis (MR 61-20) was to indicate the type of format to be used in specifying the important aspects of the Mark IV-B flight profile. As such, the purpose of that analysis was to demonstrate the technique to be used to study the man-machine relationships in the development of the Mark IV-B System. At the time of publication of the initial MEFT Analysis, it was intended that the MEFT analysis would be revised continually as additional information became available.

The purpose of this report is to supply supplemental information to the original MEFT analysis. The information presented herein represents further efforts in attempting to more precisely define the operator functions and the display-control tasks of the operator. The information presented in this report utilizes the same time-base as the original MEFT analysis (MR 61-20) and, therefore, may be substituted in place of the operator functions and display-control tasks presented in the initial MEFT analysis.

The information given in this report is essentially a refined and more detailed description of the functions that the operator performs and the manner in which he performs his tasks. The description of operator functions presented is not considered to be complete by these writers. However, a more detailed description might well be erroneous as well as misleading. A more detailed description of the operator behavior must await empirical evidence. The same can be said for the specification of the display-control tasks since these tasks are dependent upon the description of the operator functions.

Although the coding system used for specifying the displays and controls employed by the operator in performing his tasks has been described in MR 61-20, nevertheless, it should be defined again. For the purposes of this report, a glossary of the code terms is included. To cite an example, examine the designation of the altimeter. The designation is D_1-8. The letter D indicates that the display is located in panel D, which is the panel containing the primary flight displays. The $_1$ indicates that the display is from subsystem 1 as shown in the panel allocation charts and the control-display parameter charts of the Mark IV reports (1,2). The number 8 is the display within subsystem 1. Thus, it can be determined that the code D_1-8 refers to display number eight, which is the altimeter; subsystem one, which is the vehicle situation subsystem; and panel D, which is the primary flight group panel.

Finally, it should be stated that in specifying the operator functions and the display-control tasks, no claims of accuracy can be made. In many instances, the operator functions and display-control tasks are fairly obvious; in others, they appear somewhat arbitrary; and in others, they can not be specified. However, attempts will continue to be made throughout the Mark IV program to completely identify and redefine these components of the Mark IV system. As has been previously stated, many of the operator functions and display-control tasks must await further empirical work with the Mark IV system before they can be specified.

Some of the areas of the MEFT analysis which require further effort are as follows:

1. Vehicle Information

At present, this information needs to be checked to determine whether the present flight profile of the Mark IV-B is indeed realistic; that is, can the vehicle actually follow the flight profile as it is presently outlined or, will changes have to be made in either or both the time-base and the vehicle information of the MEFT analysis.

Currently, it is anticipated that this information will be supplied by the modified ME-1 which is now being installed and checked out.

2. Measurement

It is currently thought that the specification of the required measurement and the procedures for measurement of operator performance will not require a great amount of effort. Work in this area will be initiated and it is thought that results of these efforts will be forthcoming in the very near future.

3. Equipment Functions

The equipment functions for the Mark IV-B system will be specified in more detail when the equipment becomes available. Presently, information concerning the equipment function is not considered to be as important as information concerning measurement and vehicle information. Efforts toward gaining more information in this area probably will not be undertaken in the near future.

List of References

1. Lear, Incorporated Whole Panel Control-Display Study - Summary Report July 1958 - July 1960. Volume II The Mark IV Control-Display System. Lear Engineering Report GR-1364 (II), Lear, Incorporated, Grand Rapids Advance Engineering Division, July 1960.

2. Lear, Incorporated Whole Panel Control-Display Study - Volume II. The Mark IV Control-Display System. ASD TR 61-91, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, July 1960.

3. Lear, Incorporated Whole Panel Control-Display Study - A Display and System Integration Study for a Flight Data Display System. Lear Engineering Report GR-1370, Lear, Incorporated, Grand Rapids Advance Engineering Division, November, 1960.

James E. Brown
J. E. Brown

Richard W. Obermayer
R. W. Obermayer

GLOSSARY OF MAJOR CONTROL-DISPLAY

Panel A - Viewer and Projection Controls

Display/Control	Designation
1. Viewer Display selection control	A_4-2
2. Field of view control	A_4-3
3. Brightness control	A_4-4
4. Display slew switch	A_4-5

Panel B - Vehicle Configuration Display

Display/Control	Designation
1. Drag Chute	
Control	B_8-24
Display	B_8-25
2. Speed Brake	
Control	B8-15
Display	B8-16
3. Skids	
Control	B_8-22
Display	B_8-23
4. Missile Bay Doors (fore and aft)	
Control	B8-20
Display	B8-19
5. Antenna	
Control	B_8-27
Display	B_8-28
6. Ram Air Turbine	
Control	B_8-13
Display	B_8-14
7. Control Surface Position Indicator	
Elerions	B_8-17
Rudder	B_8-18

Panel C - Standby Panel

Display/Control	Designation
1. Altitude	C_1-9
2. Temperature (nose, body, wing)	C_2-27
3. Airspeed	C_1-7

Panel D - Primary Flight Panel

Display/Control	Designation
1. Indicated Airspeed	D_1-6
2. Altitude	D_1-8
3. Angle of Attack	D_1-10
4. Flight Path Angle	D_1-11
5. Attitude and Flight Director Display	D_2-1, 2, 3,
6. Body Axis Rate	D_2-8, 9, 10
7. Wing Temperature	D_2-26 Wing
8. Nose Temperature	D_2-26 Nose
9. Body Temperature	D_2-26 Body
10. ILS/VOR Mode Control	D_3-20

Panel E - External Viewing and Projected Displays

Control/Display	Designation
1. Display Screen	E_4-1

Panel F - Arm Rest Controls

Display/Control	Designation
1. Three-Axis Controller	F_2-16, 17, 18
2. Thrust/Drag Control	F_2-Thrust/Drag

Panel N - Communication Displays and Controls

Display/Control	Designation
1. UHF	
Receive	N_3-2
Transmit	N_3-3
Frequency	N_3-4
Volume	N_3-5
2. VHF	
Receive	N_3-6
Transmit	N_3-7
Frequency	N_3-8
Volume	N_3-9
3. VLF	
Receive	N_3-10
Transmit	N_3-11
Frequency	N_3-12
Volume	N_3-13

Panel O - Switches and Circuit Breakers

Displays/Controls	Designation
1. Left Panel Knob	O_2-15 left panel
2. Ambient Light Control	O_9-24, 25
3. Right Panel	O_2-15 right panel
4. Auto Pilot	O_2-24

Time Min/Sec	Operator Functions Description	LH*	RH**	Eyes
0:00	1. Canned Auto Flight			
	2. Check List			
	A. External Viewing and Projected Display Panel Landing Checklist ON	A_4-2		(1) A_4-2 (2) E_4-1
	B. Center Console control -- uses display slew switch to perform checklist of center console control.	A_4-5		(1) A_4-5 (2) E_4-1
	1. Left Panel Knob ON		O_2-15	(1) O_2-15 Left Panel (2) E_4-1
	2. Ambient light knob ADJUST TO DESIRED BRIGHTNESS		O_9-24,25	(1) O_9-24,25 (2) E_4-1
	3. Right Panel OFF		O_2-15	(1) O_2-15 Right Panel (2) E_4-1
	4. Purge PSI		O_9-7	(1) O_9-7 (2) E_4-1
	5. Air Composition NORM		O_9-3	(1) O_9-3 (2) E_4-1
	6. Master switches of lower four rows ON		O_3-25	(1) O_3-25 (2) E_4-1
	7. Mode SPU		O_7- 22	(1) O_7-22 (2) E_4-1
	8. SPU START		O_7-8	(1) O_7-8 (2) E_4-1
	9. Fore Bay doors CLOSED		O_8-20	(1) O_8-20 (2) B_8-19 (3) E_4-1
	10. Aft Bay Doors CLOSED		O_8-20	(1) O_8-20 (2) B_8-19 (3) E_4-1
	11. Blower ON		O_9-5	(1) O_9-5 (2) E_4-1
	12. Antenna ATMOS		O_8-27	(1) O_8-27 (2) E_4-1

* Except when otherwise indicated, the LH will normally be on the thrust/drag control. (F_2-DT)

** Except when otherwise indicated, the RH will normally be on the 3-axis controller (F_2-16,17,18)

Time	Operator Functions Description	LH	RH	EYES
0:00	2.B. 13. Retro ______			
	14. UHF Transmitter ON		0_3-3	(1) 0_3-3 (2) E_4-1
	15. VHF Transmitter ON		0_3-7	(1) 0_3-7 (2) E_4-1
	16. VLF Transmitter ON		0_3-11	(1) 0_3-11 (2) E_4-1
	17. Security Transmitter ______			
	18. Command Link Transmitter ______			
	19. IFF Air/Air ______			
	20. IFF Air/Ground ______			
	21. Recovery Beacon ______			
	22. UHF Receiver ON		0_3-2	(1) 0_3-2 (2) E_4-1
	23. VHF Receiver ON		0_3-6	(1) 0_3-6 (2) E_4-1
	24. VLF Receiver ON		0_3-10	(1) 0_3-10 (2) E_4-1
	25. Security Receiver ______			
	26. Command Link Receiver ______			
	27. ICS Amplifier ______			
	28. TACAN ______			
	29. ILS/VOR ON		0_3-20	(1) 0_3-20 (2) E_4-1

Time	Operator Functions Description	LH	RH	EYES
0:00	2.B . 30. Inertial Reference ON		O_1-5	(1) O_1-5 (2) E_4-1
	31. Standby Attitude Reference OFF		O_2-1,2,3	(1) O_2-1,2,3 (2) E_4-1
	32. Digital Computer			
	33. Auto Pilot			
	34. Reaction Controls OFF		O_2-12,13,14	(1) O_2-12,13,14 (2) E_4-1
	35. Retro-thrust Align OFF		O_6-20	(1) O_6-20 (2) E_4-1
	36. Hydraulic System ON		O_7-25	(1) O_7-25 (2) E_4-1
	37. Secondary Power ON		O_7-	(1) O_7- (2) E_4-1
	38. Orientation Display ON		O_2-	(1) O_2- (2) E_4-1
	39. Launching-Reentry Displays OFF		O - L & R	(1) O - L & R (2) E_4-1
	40. Environmental Displays ON		O_9-	(1) O_9- (2) E_4-1
	41. Secondary Power Unit Displays ON		O_7-	(1) C_7- (2) E_4-1
	42. Rocket Displays OFF		O_6-	(1) O_6- (2) E_4-1
	43. Weapons Displays OFF		O_5-	(1) O_5- (2) E_4-1
	44. Pilot Viewer ON		O_4-(1-9)PV	(1) O_4-(1-9) PV (2) E_4-1
	45. Co-Pilot Viewer OFF		O_4-(1-9)CPV	(1) O_4-(1-9) CPV (2) E_4-1
	C. Checks Primary Flight Displays 1. Angle of Attack-Temperature-Airspeed			(1) D_1-10;D_2-26; D_1-6
	2. Attitude and Flight Director Display			(2) D_2-1,2,3,
	3. Wing Temperature			(3) D_2-26
	4. Flight Path Angle and Altitude Display			(4) D_1-11; D_1-8
	5. Body Axis Rate Display			(5) D_2-9,10,11 (6) E_4-1

Time	Operator Functions Description	LH	RH	EYES
0:00	2. D. Checks Standby Flight Displays 1. Airspeed 2. Temperature Displays 3. Altimeter			(1) C_1-7 (2) C_2-27 (3) C_1-9 (4) E_4-1
	E. Checks External Vehicle Configuration Displays 1. Antenna 2. Missile Door (nose) (tail) 3. Speed Brake 4. Control surface position indicator 5. Ram air turbine 6. Landing gear 7. Drag Chute			(1) B_8-27,28 (2) B_8-19,20 (3) B_8-15,16 (4) B_8-17,18 (5) B_8-13,14 (6) B_8-22,23 (7) B_8-24,25 (8) E_4-1
	F. Checks out External Viewing and Projected Display			
	1. Pre-landing checklist OFF	A_4-2		(1) A_4-2 (2) E_4-1
	2. External Viewing Down ON	A_4-2		(1) A_4-2 (2) E_4-1
	a. Uses viewing field knob to adjust size of field	A_4-3		(1) A_4-3 (2) E_4-1
	b. Uses brightness knob to adjust brightness	A_4-4		(1) A_4-4 (2) E_4-1
	3. External viewing down OFF	A_4-2		(1) A_4-2
	4. External viewing oblique ON	A_4-2		(1) A_4-2 E_4-1
	5. External viewing oblique OFF	A_4-2		(1) A_4-2
	6. Navigation Display ON	A_4-2		(1) A_4-2 (2) E_4-1
	7. Navigation Display OFF	A_4-2		(1) A_4-2
	8. Navigation Display magnification ON	A_4-2		(1) A_4-2 (2) E_4-4
	9. Navigation Display magnification OFF	A_4-2		(1) A_4-2
	10. Landing Checklist ON	A_4-2		(1) A_4-2 (2) E_4-1

Time	Operator Functions Description	LH	RH	EYES
0:00	G. Checks use of three-axis controller			
	1. neutralize trim		F_2-16,17,18	(1) F_2-16,17,18
	2. check use of thrust-drag control	F_2- DT*		(1) F_2- DT*
	H. Establishes Communications			
	1. Tunes UHF radio station		N_3-4	(1) N_3-4 (2) E_4-1
	2. Tunes VHF radio station		N_3-8	(1) N_3-8 (2) E_4-1
	3. Tunes VLF radio station		N_3- 12	(1) N_3-12 (2) E_4-1
	4. Check UHF communications by transmitting on UHF radio		N_3-3	(1) N_3-3 (2) E_4-1
	5. Receives verification of communication from UHF operator on ground		N_3-2	(1) N_3-2 (2) E_4-1
	6. Adjusts volume using volume control		N_3-5	(1) N_3-5 (2) E_4-1
	7. Checks VHF communications by transmitting on VHF radio		N_3-7	(1) N_3-7 (2) E_4-1
	8. Receives verification of communication from VHF operator on ground		N_3-6	(1) N_3-6 (2) E_4-1
	9. Adjusts volume using volume control		N_3-9	(1) N_3-9 (2) E_4-1
	10. Checks VLF communications by transmitting on VLF radio		N_3-11	(1) N_3-11 (2) E_4-1
	11. Receives verification of communications from VLF operator on ground		N_3-10	(1) N_3-10 (2) E_4-1
	12. Adjusts volume using volume control		N_3-13	(1) N_3-13 (2) E_4-1
	I. Switches Pre-landing checklist OFF	A_4-2		(1) A_4-2
	J. Select Gross Navigation Display	A_4-2		(1) A_4-2 (2) E_4-1
0:00	3. Ready to accept control--right hand on controller, left hand on thrust-drag control	F_2- DT*	F_2-16,17,18	(1) F_2-16,17,18 (2) F_2- DT*
0:00	4. Switches Auto-pilot OFF Switches to mode that is not completely automatic	O_2-24		(1) O_2-24 (2) D_2-1,2,3 (3) D_2-26

* DT = drag/thrust

Time	Operator Functions Description	LH	RH	[illegible]
0:00			F_2-16, 17, [illegible] ↓	(4) D_1-1 (5) D_1-[illegible] (6) E_4-1
0:20	5. Decelerate to 290 knots and hold 0° heading A. Gain control of vehicle			(1) D_2-1, 2, [illegible] (2) D_2-8, 9, 10
	B. Introduce fixed amount of speed brakes and trim attitude	B_8-15		(1) B_8-15 (2) B_8-16
	C. Pitch up to α°, angle of attack			(1) D_2-[illegible] 3 (2) D_1-10 (3) D_2-26 [illegible]
	D. Hold α° angle of attack until 290 knots is reached			(1) D_1-10 (2) D_2-1, [illegible] 3 (3) D_1-6 (ti[illegible] shared w/ [illegible] term)
1:50	6. Neutralize acceleration at 290 knots, flight path angle of $\gamma_1°$, and a heading of 0°. A. Take out speed brakes and put in trim	B_8-15		(1) B_8-15 (2) B_8-16 (3) D_1-6
	B. Trim vehicle at flight path angle of $\gamma_1°$			(1) D_2-1, 2, 3 (2) D_1-11
2:00	7. Maintain flight path angle of $\gamma_1°$, and 0° heading			(1) D_2-1, 2, 3 (2) D_1-11
2:00	8. Using the navigation display, the operator controls laterally to intercept high key at 35,000 feet and 0° heading			(1) E_4-1 (2) D_1-8 (3) D_2-1, 2, 3 (4) D_1-11
2:20	9. At altitude of n_1, put out full speed brakes and maintain $\gamma_1°$, of flight path angle.	B_8-15		(1) D_1-8 (2) D_1-1, 2, 3 (3) B_8-15 (4) B_8-16 (5) D_1-11

* n, b, w = nose, body, wing

Time	Operator Functions Description	LH	RH	EYES
2:30	10. Checks intercept of high key		F_2-16,17,18 (↓ continues to item 14)	
	A. Removes P% speed brakes and trims to 180 knots and γ_2^* flight path angle.	B_8-15		(1) B_8-15 (2) B_8-16 (3) D_1-6 (4) D_1-11
	B. Intercepts high key with 0° heading, 180 knots and flight path angle of γ_2^*			(1) D_2-1,2,3 (2) D_1-6 (3) D_1-11 (4) E_4-1
	C. Reports in via UHF radio communications to ground based operator	N_3-3		(1) N_3-3
	D. Receives verification of intercept of high key from ground based operator	N_3-2		(1) N_3-2
2:30	*11. Compensates for inaccuracies at high key			(1) E_4-1 (2) D_1-6 (3) D_2-1,2,3 (4) D_1-11 (5) D_1-8 (6) D_2-8,9,10 (7) D_1-10
2:40	12. Selects terminal area display	A_4-2		(1) A_4-2 (2) E_4-1
2:40	13. At 33,000 ft. initiates left turn using 20° nominal bank angle.			(1) D_1-8 (2) D_2-1,2,3 (3) D_2-8,9,10 (4) D_1-11 (5) E_4-1
2:50	14. Notes position with respect to runway			(1) E_4-1 (2) D_1-8

* From this point in the flight profile until the completion of the flight, alternative ways of using the controls and displays become increasingly important. If any one flight parameter varies more than is acceptable according to the pre-determined flight profile, then other corresponding flight parameters must be altered to bring the deviating parameter back to within acceptable limits. To say the least, the alternatives for the pilot are numerous. He can alter the flight path angle to pick up needed airspeed.

Time	Operator Functions Descriptions	LH	RH	EYES
2:50	15. Adjusts bank angle and holds A/S equal to 180 knots.		F_2-16,17,18 ↓	(1) D_2-1,2,3 (2) D_2-8,9,10 (3) D_1-6 (4) D_1-11
3:20	16. Notes halfway through turn, alignment with runway.		↓	(1) E_4-1 (2) D_1-8
4:20	17. Initiates roll out at 20,000 ft. approximately adjacent to far end of runway.		↓	(1) D_2-1,2,3 (2) D_2-8,9,10 (3) E_4-1 (4) D_1-8
4:30	18. Steers to arrive at low key at 18,000 ft.		↓	(1) E_4-1 (2) D_1-8 (3) D_2-1,2,3
4:40	19. Checks to proper conditions at low key A. Intercepts low key at 18,000 feet at heading of 180°, 180 knots A/S and γ_2^{o} of flight path angle		↓	(1) D_2-1,2,3 (2) D_1-8 (3) D_1-6 (4) D_1-11 (5) E_4-1
	B. Reports in via UHF radio communications to ground based operator	N_3-3	↓	N_3-3
	C. Receives verification of intercept of low key from ground based operator	N_3-2	↓	N_3-2
5:30	20. Initiates left turn at 15,000 feet, using a 30 degree nominal bank angle and γ_3^{o} flight path angle		↓	(1) D_2-1,2,3 (2) D_1-8 (3) D_2-8,9,10 (4) D_1-11 (5) D_1-6 (6) E_4-1

Time	Operator Functions Descriptions	LH	RH	EYES
5:40	21. Adjusts turn to roll out diving on aiming point		F_2-16,17,18	(1) E_4-1 (2) D_2-1,2,3 (3) D_1-11 (4) D_1-6 (5) D_1-8
5:40	22. Selects speed brake setting (none is nominal)	B_8-15		(1) B_8-15 (2) B_6-16
5:40	23. Watches A/S = 290 knots and flight path angle of γ_3°			(1) D_1-6 (2) D_1-11 (3) D_1-8 (4) D_2-1,2,3 (5) E_4-1
6:40	24. Switches in ILS mode	D_3-20		(1) E_4-1 (2) D_3-20 ILS/VOR (3) D_2-1,2,3
6:48	25. Select oblique view	A_4-2		(1) A_4-2 (2) E_4-1 (3) D_1-8 (4) D_2-1,2,3 (5) D_1-6
6:48	26. Roll out in alignment with runway: continues to dive on aiming point using flight path angle of γ_3°. Heading of 0° degrees.			(1) D_2-1,2,3 (2) D_1-6 (3) D_1-8 (4) D_1-11 (5) D_1-10 (6) E_4-1
7:20	27. Transition to 3 degree glide slope			(1) D_2-1,2,3 (2) E_4-1 (3) D_1-6 (4) D_1-8
7:30	28. Skids down and trim	B_8-22		(1) B_8-22 (2) B_8-23 (3) D_2-1,2,3 (4) E_4-1 (5) D_1-8 (6) D_1-6 (7) D_2-8,9,10

Time	Operator Functions Description	LH	RH	EYES
7:40	29. Begin terminal flare		F_2-16,17,18 ↓	(1) E_4-1 (2) D_1-8 (3) D_1-6 (4) D_2-1,2,3 (5) D_2-8,9,10 (6) D_1-11
7:48	30. Touchdown with rate of sink at less than 10 fps and A/S = 175 knots			(1) E_4-1 (2) D_1-8 (3) D_2-1,2,3 (4) D_1-11 (5) D_1-6
7:50	31. Drag chute deployed	B_8-24		(1) B_8-24 (2) B_8-25 (3) E_4-1

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(616)-7752

MEMORANDUM REPORT: 62-2 22 January 1962

Task: Consulting

To: Mr. R. R. Davis

cc: Mr. W. Austin, Mr. S. G. Hasler, Dr. D. P. Hunt, Mr. J. H. Kearns, Mr. S. Knemeyer, Mr. A. L. Longiaru, Mr. N. MacGregor, 1/Lt. J. Stone, Mr. E. Vinson, Capt. C. Waggoner, Mr. E. L. Warren, Mr. R. Wible, Maj. W. E. Wilvert, Mr. G. L. Yingling, and all members of the Martin Human Engineering Group.

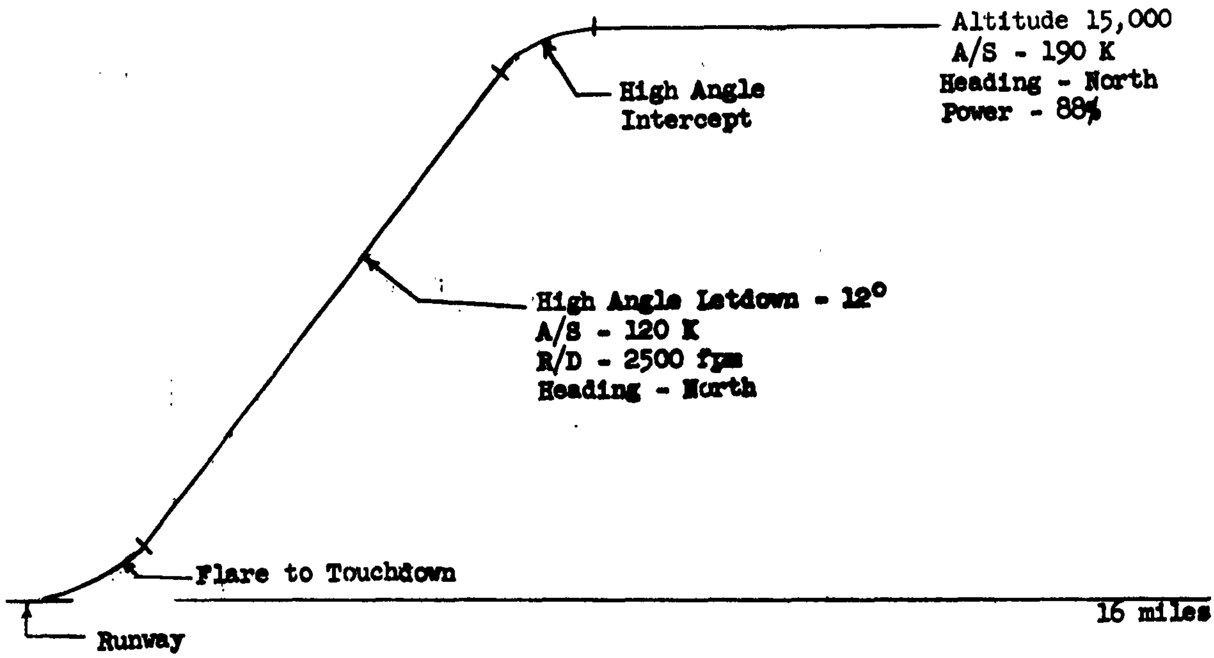
From: W. F. Swartz

Subject: Revision of Work Statement Concerning the Investigation of the High Angle Letdown, Omni-Angle Approach Technique.

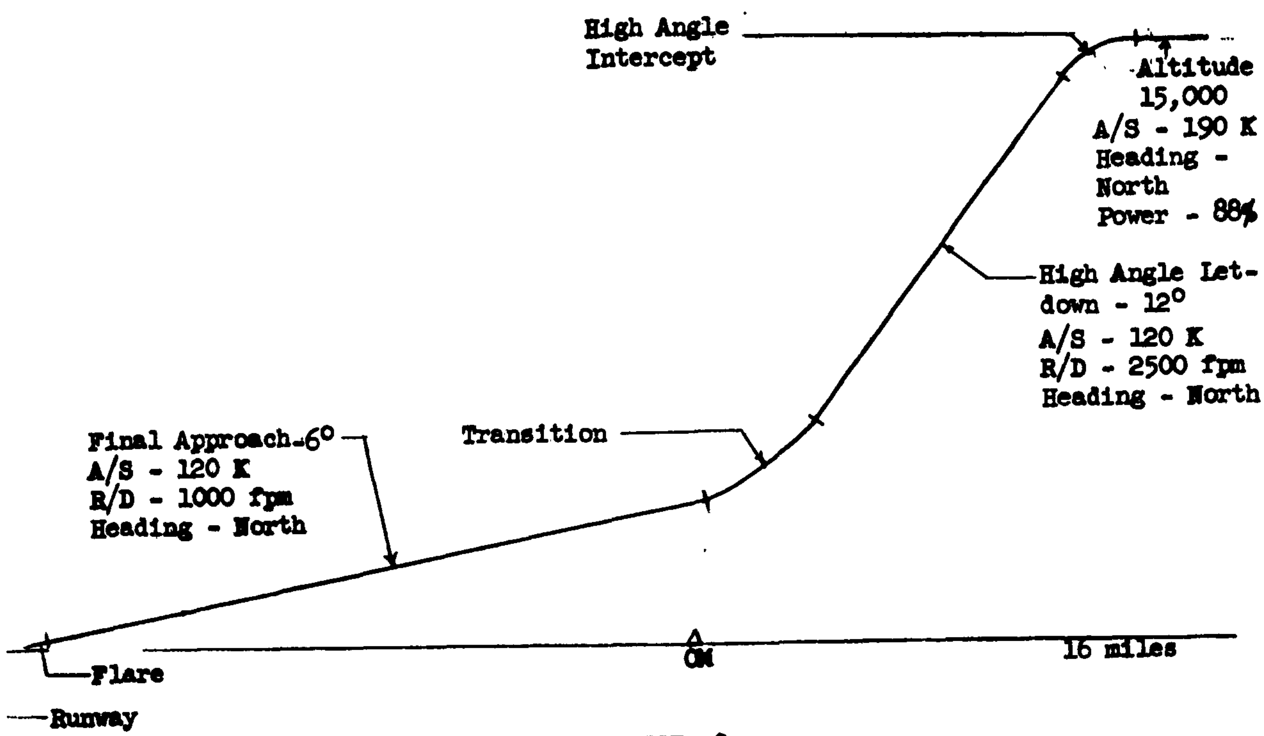
The same pilot-subjects are being used in the investigation of the high angle letdown, omni-angle approach technique that are being used in the study of all-weather landings. As the study of all-weather landings is of primary importance, some rather fundamental changes have been made in the investigation of the high angle letdown, omni-angle approach technique in order to use the same subjects. Essentially, the major change from the approach described in MR 61-26 is the reduction in the number of parameters for investigation so that the time required of each subject could be made compatible with demands of the all-weather landing program. The purpose of this memorandum is to report the current status of the investigation of the high angle letdown, omni-angle approach technique in the ME-1 simulator.

Selection of Parameters

The parameter, Profiles, is being considered in the study. As shown on the following page by Figure 1, two profiles are being used. The difference between the two is that Profile 1 has no final approach component while Profile 2 does have this component. Profile 1 is of



PROFILE 1



PROFILE 2

Figure 1. The profiles being used in the study.

interest because it represents the profile which offers the best in fuel management and minimum time to touchdown. Profile 2 is of interest for comparative purposes in terms of system performance. It is noted that the final approach angle is 6° which will permit the simulator to remain airborne for the power off engine condition. The engine failure condition has been retained as a parameter for investigation because of the hypothesized value of the letdown technique in event of such an occurance.

The parameters of Variable Approach Angle, Full Manual-Split Axis, and Flare Command-No Flare Command have not been included in the study because of time limitations. The subjects are available for only 3 hours each; thus, in order to properly familiarize them with the simulator and obtain an adequate number of trials for those conditions which are being investigated, a number of parameters had to be excluded. In the study, the final approach angle has been fixed at 6°, full manual control is used for each approach in conjunction with flare command information. It is anticipated that a study examining the effects of split axis control will be initiated shortly using different subjects.

Method

Apparatus

Display. The display aspects are the same as described in MR 61-26. Command steering information is being presented on the pitch command bar of the ADI throughout the entire profile. A light has been added which indicates when the speed brakes are out. The ADI which is being used displays the angle to the station rather than the flight path angle as described in the earlier memorandum.

Control. As was mentioned previously, only full manual control is being used in the study. During pre-experimental, the subjects complained about the force-displacement ratio of the control stick; it was much too low (light). This has been corrected. In addition, Link personnel have eliminated the transient pitch condition which would occur when the simulator was unfrozen. In short, many small deficiencies of the simulator have been corrected, thus making it even more acceptable for use in this type of endeavor.

Profiles. Figure 1 represents the profiles that are being used in the investigation. The task of the subjects is to fly the simulator from

15,000 feet along the profile to touchdown maintaining 120 knots airspeed once the high angle letdown has been obtained; this results in a rate of descent approximating 2500 feet per minute for the high angle letdown of 12 degrees and 1000 feet per minute for the final approach in Profile 2. The technique of flying these profiles is certainly only one of several alternatives. For example, flying the profile in minimum time might well prove to be more feasible. However, the technique of flying the profiles at a relatively slow airspeed of 120 knots in the study is being used for several reasons. Primarily, this technique has been demonstrated at airspeeds of 120 knots by facility personnel and we were directed to use the same profile. In addition, the apparatus which generates the profile as displayed on the pitch command bar has been set for this type of airspeed. The flying of the transitions is particularly affected by the higher airspeeds and greater rates of descent; this would make the task more difficult than it already is, particularly for the commercial pilots who are not familiar with one single display in the simulator.

Scoring. All measurement requirements specified in MR 61-26 have been satisfied. The RMS values are computed for each component of each profile and displayed on a digital voltmeter. Deviation from flight path angle is computed for the linear components of the profiles and deviation from steering command is computed for the transitions and flares to touchdown. Airspeed, rate of descent, G's, and angle of attack are being obtained by means of oscillographic recordings. Values of A/S and R/D will be obtained at each half mile and recorded for every approach. Average curves may then be plotted at the conclusion of the study for each of the experimental conditions. In addition, the terminal values of A/S, R/D, G's, and angle of attack will be recorded and statistically analyzed. Distance down the runway and lateral displacement from centerline are being obtained from Brush recordings for greater accuracy. X-Y plots of lateral displacement vs. range and altitude vs. range are being obtained for each approach.

Subjective data are being obtained by means of the semantic differential, a positive-negative set questionnaire, and a general comment section. It is hoped that the first two means will aid in bettering the questionnaire technique as well as furnishing data concerning the high angle letdown, omni-angle technique.

Subjects. A total of 20 subjects will be used in the experiment. Ten subjects will be military pilots assigned to MATS and currently assigned to fly C-135 aircraft. The remaining ten subjects will be commercial pilots currently flying 707 or DC-8 aircraft.

Experimental Design. Since time was so seriously restricted, a Lindquist Type III design is being used. In this design, each subject will receive both profiles but will fly only one engine condition- power on or power off. Subjects are randomly assigned to the power conditions and the experimental treatments are randomly presented to each subject. Each subject will perform six trials, three for each profile. The design will be used to statistically examine the terminal conditions as well as the total RMS measure. Because of the difference in the profiles, a Lindquist Type I design will be used to statistically examine the RMS measure for each component of the profiles.

Procedure. In pre-experimental, it was found that practice was needed in order to familiarize the subjects with the simulator as well as the task. As a result, the first of two periods for each subject is devoted to a standardized briefing, twenty minutes of flying the simulator through the various fundamental maneuvers and then practicing each profile two times with the appropriate engine condition. The briefing includes what is being done and why, a thorough explanation of the subject's task and operational procedures as well as a cockpit checkout. The cockpit checkout is rather long as all new displays, at least to the subjects, are being used including the Flight Director System. The experimentor must be in the simulator during the practice of the trials as well as at the time of actual data collection. This is not desirable but the switching requirements demand his presence as well as the requirement to reposition the simulator at 20 miles and 15,000 feet after each approach. The subject is told that the "co-pilot" will not judge or grade him in any way. Riding along in the practice session does assist in that the experimentor can explain things to look for in performance of the task, how to correct various errors in flying the profile, etc. After each trial, the subject takes the simulator off, and the experimentor re-positions the simulator with respect to range and altitude. Then the simulator is frozen and the profile to be flown on the next trial explained. The simulator is then unfrozen and the subject proceeds to fly the profile. The technique of flying each component is read aloud by the experimentor until the subject has the task memorized. In the second period, a brief cockpit check is made. Two practice approaches are then made, one for each profile. Six approaches for record then are performed in random order. A five minute rest period is given between the fourth and fifth trials. The questionnaire is administered at the completion of the trials.

W. F. Swartz

W. F. Swartz

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM
Martin Human Engineering Group
AF 33(616)-7752

MEMORANDUM REPORT: 62-3 26 January 1962

To: Mr. J. H. Kearns

cc: Mr. S. G. Hasler, Dr. D. P. Hunt, Mr. N. MacGregor, Capt. C. E. Waggoner, and all members of the Martin Human Engineering Group.

From: J. E. Brown

Subject: Bibliography: Straight Scale Instrumentation; Straight Scales for Horizontal and Vertical Instrumentation; Selected References Pertaining to Scaling of Dial-Type Displays.

This bibliography was prepared at the request of Mr. J. H. Kearns. The purpose of the present bibliography is to indicate those reports which relate to straight scale instrumentation and to provide, for comparative purposes, a selected list of reports concerning circular scales. The list of references has been selected to provide the information requested and to supply additional sources of literature.

James E. Brown

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AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(616)-7752

MEMORANDUM REPORT: 62-4 31 January 1962

Task: FAA/BRD Project 114-15-2D

cc: Mr. R. R. Davis, Mr. S. G. Hasler, Dr. D. P. Hunt, Mr. N. MacGregor, Mr. R. Monroe, 1/Lt. J. Stone, Capt. Waggoner, and all members of the Martin Human Engineering Group.

From: C. A. Gainer and W. L. Welde

Subject: Pre-Experimental Results: Cockpit Display for All-Weather Landings.

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In Martin Memorandum Report No. 61-25, it was specified that the pre-experimental work would be used for investigating the following aspects of the experiment.

1. Task Definition
2. Practice Trials Required
3. Procedure Refinement
4. Questionnaire Development
5. Digital Computer Program

A certain degree of success was achieved in each of the above tasks. The pre-experimental work provided, to adequate satisfaction, results on items 1, 2, and 3 above; however, limited value was achieved for the latter two items under consideration in the per-experimental work.

The questionnaire development is an ongoing task and there is a continual effort to sophisticate and improve these techniques. There were a number of preliminary efforts conducted prior to the question-naire which was developed for this study. The results of only one of these was completed prior to the beginning of the present study. The results of the questionnaire are reported in Martin Memorandum 61-21. A second memo which is applicable for this questionnaire development is MR 61-23. The results described in that memo were not received before the beginning of this study, therefore, the questionnaire was founded on one summarized study, one unfinished study, and a careful consideration by a panel of judges.

There is tabulated data available on four subjects which will be used for the purpose of checking the computer program. This data is expected to be made available by 31 January and at that time a program check will be initiated.

Task Definition

During the pre-experimental work numerous approaches were made in an attempt to develop the most efficient way to make the transition and touchdown. MR 61-25 showed a non-scale graph which showed two points of inflection as is shown here in figure 1.

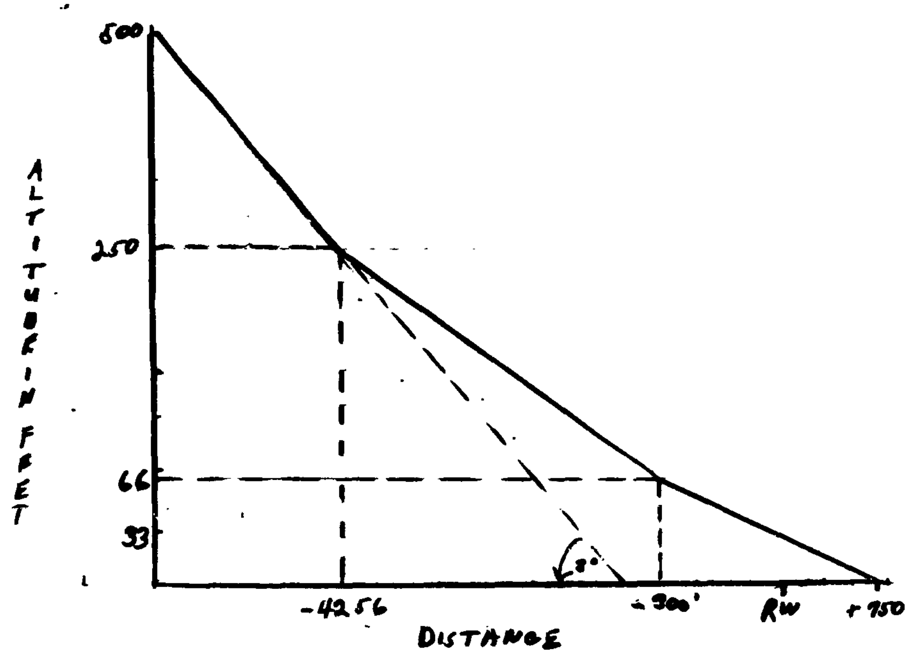


Figure 1. A non-scale graph of the final 500: a minus shows distance from runway; a plus shows distance down runway; RW is the end of the runway.

Values have been assigned to these points 250' for the reduction to 500'/min rate of sink and 66' for the reduction to 200'/min. rate of sink which is held until touchdown occurs.

It should be pointed out that the first thing each morning a complete equipment check and calibration was completed prior to the arrival of any subjects. After the final subject each day another check was accomplished while getting the instrument panel set up for the next day's sessions. During the days when the experimental panels were being used the absolute altitude tapes were checked between each session. The detailed description of the procedure and the task are as follows:

Experimental Procedure

Upon arrival at the simulator facility on Monday, each subject is individually briefed by the experimenter concerning the simulator characteristics, a general description of the flight task to be performed, the specific manner in which the task is to be flown using the practice panel and the procedure to be utilized for conducting each day's session, which consists of ten approaches per subject. Any questions presented by the subject dealing with the task itself or the experimental procedure are answered. However, if the subject's querries extend to the basic experiment and if answered would be too revealing, he is requested to reserve the question until he has completed the entire week of simulator runs and questionnaires. At the end of one half the days trials or the end of the 5th run a 5 minute break is given where the canopy is opened and any questions are answered.

This briefing takes approximately 15 minutes and occurs prior to the subject entering the simulator cockpit. Also, at this time, a detailed account of the pilot's flying experience is recorded.

A verbatum account of these experimental instructions follows:

General Description

"The task to be performed will be only the terminal phase of a flight - from the approach to a field to actual touchdown of the aircraft on the runway. Assuming control of the aircraft prior to interception of the IIS outer marker, the subject pilot will be asked to maintain the glide path to the middle marker, at which point either of two methods, depending on the instrument panel installed, will be utilized in transitioning from the IIS glide path to the flare-out point and, finally, to touchdown.

The first of these two methods will be with a practice panel whereby the rate of descent is decreased at specific altitudes, thus approximating the flare-out maneuver for touchdown. The second method employs a flare shield displaying aircraft absolute altitude in which the rate of descent is reduced as the flare shield passes certain index points on the vertical velocity instrument. The latter method will be utilized with each of the three experimental panel configurations.

The task will be performed under the hood to simulate IFR flight conditions. A detailed description of the flight task and instrument panel display will be presented prior to flying the simulator each day."

Simulator Characteristics

"The characteristics of the MB-5 simulator have been altered somewhat in order to achieve a resemblance to the flight performance of a multi-engine jet transport at a gross weight of approximately 180,000 pounds. In addition, a split-axis control system has been incorporated into the simulator whereby pitch attitude is controlled manually by the pilot, but roll and yaw is controlled automatically. Thus, there is no lateral displacement from the ILS heading displayed by either the Attitude Director (ADI) course bar or the Horizontal Situation Indicator (HSI). Another prominent characteristic of the MB-5 simulator concerns the trim. After a pitch correction has been applied, a slight delay precedes the actual reaction of the controls; therefore, the pilot should be aware of this inherent system lag."

Flight Task Description

"The subject pilot will assume control of the aircraft for each run at an altitude of 2850 feet and 8.2 miles from the runway. The aircraft configuration will consist of the landing gear remaining down through all' maneuvers and speed brakes (which act as the sole drag device due to the absence of flaps on the F-102) up initially and then lowered upon glide slope interception. A constant heading of 360 degrees will be maintained during the entire test run by the automatic lateral controller. Prior to commencing with the experimental run, level flight and an approach speed of 150 knots, requiring 92-93% rpm, will be established. The pilot will fly at this altitude for about 45 seconds before intercepting the ILS glide path 6.5 miles from the field. As the aircraft nears one bar width of the ILS glide path, simultaneously initiate a 1-1/2 bar nose down pitch adjustment on the ADI, lower full speed brakes and reduce the engine rpm to 92%. This pitch change will produce 650-700 fpm on the vertical velocity which will, in turn, sustain the aircraft on the glide path providing the airspeed remains constant at 150 knots. Approximately twenty seconds after glide path interception, the marker beacon will indicate the aircraft has passed over the outer marker located 5.5 miles from the field.

While descending on the glide path, an rpm of 91-92% will maintain the 150 knots airspeed and, because of the extremely rapid acceleration and deceleration rates of the simulator in relation to the amount of throttle movement, any power setting varying in excess of 2% from this range will create major deviations from the desired airspeed. Also, only very minor corrections in pitch attitude should be made while descending on the glide path for rates of descent greater than 1000 fpm or less than 400 fpm are to be considered as approaching a tendency to over-control the aircraft."

Practice Panel

"Passage of the middle marker, occurring at 1000 feet MSL and .7 of a mile from the runway, will again be signified by the marker beacon. This, consequently, is the pilot's cue to disregard the ILS glide path needle and fly only specific rates of descent to touchdown. Reduce the rate of descent to 500 fpm and, accordingly, this pitch change necessitates a slight increase in rpm to uphold the airspeed at 150 knots. At 820 feet MSL, which is 70 feet above touchdown, begin a final flare-out maneuver by establishing a 200 fpm rate of descent until touchdown. After the flare attitude is established and the aircraft is approximately 30 feet from touchdown or 780 feet MSL, slowly retard the throttle to the idle position. Touchdowns will occur at 750 feet MSL and, ideally, all touchdowns should be accomplished at a rate of descent between 100-300 fpm and an airspeed of 140-145 knots.

To assure the pilot that the aircraft is over the end of the runway, a red flag will appear in the ADI at the nine o'clock position whenever the aircraft is above or actually on the runway.

Upon touchdown, advance the throttle to 100% rpm and permit the airspeed to build up to 170 knots for takeoff. At liftoff, the nose of the aircraft will pitch up because of a large amount of back trim on the elevators. This pitch up tendency can be alleviated by the immediate application of nose down trim and the reduction of the engine rpm to 93%. At approximately 1000 feet MSL, initiate leveloff procedures. When the airspeed approaches 150 knots, raise the speed brakes, adjust the throttle to maintain 150 knots, and retrim the aircraft for level flight. While leveling off, disregard the indications displayed by the altimeter and glide path needle since the aircraft will be in the process of being repositioned by the experimenter.

The pilot will have two minutes to get 'squared away' before commencing with the next experimental run."

At the conclusion of this briefing by the experimenter, the subject enters the simulator cockpit and is given a cockpit checkout on the items listed below:

1. Altimeter
2. Vertical Velocity
3. Attitude Director Indicator - ADI
   ILS Glide Slope Needle
   Runway Indicator
4. Horizontal Situation Indicator - HSI
5. Airspeed Indicator
6. Engine Instruments
7. Speed Brake Indicator
8. Throttle - Speed Brake Switch
9. Control Stick
   Trim (Slow reacting)
   Avoid Depressing Pilot-Assist Button
10. Marker Beacon
11. Temperature Control
12. Canopy Switch
13. Seat Adjustment Switch
14. Rudder Adjustment Switch
15. Ash Tray
16. Headset -- click mike to acknowledge instructions

At the end of this first practice session, the subject pilot is advised as to his next appointment.

The procedure on Tuesday is the same except a refresher briefing on the flight task and simulator cockpit is given rather than the detailed one received on the first day.

The following three days, Wednesday, Thursday, and Friday, consist of the subject flying the experimental panels. Each day that particular experimental panel to be flown is described to the subject as he is seated in the cockpit of the simulator. A detailed schedule is presented in Table 1.

<u>One-Inch Module</u>

"This instrument panel insert contains the standard round dial altimeter. An instantaneous vertical velocity with the capability of displaying absolute altitude below 300 feet has been included in the insert.

This one-inch module instrument is an instantaneous vertical rate instrument, consequently there is no lag in its presentation. The scale is graduated into increments from 1,000 fpm ascent to 2,000 fpm descent with an expansion of this scale existing from 1,000 fpm ascent to 1,000

Table 1

Schedule for Instruments to be Used by Date

	SUN	MON	TUES	WED	THUR	FRI	SAT	
JAN	28	29 PP	30 PP	31 II-A	Feb 1 MOD	2 SUM	3	Completed Order 1
FEB	4	5 PP	6 PP	7 MOD	8 II-A	9 SUM	10	Order 2
FEB	11	12 PP	13 PP	14 SUM	15 MOD	16 II-A	17	Order 3
FEB	18	19 PP	20 PP	21 II-A	22 SUM	23 MOD	24	Order 4
FEB	25	26 PP	27 PP	28 MOD	Mar 1 SUM	2 II-A	3	Order 5
MAR	4	5 PP	6 PP	7 SUM	8 II-A	9 MOD	10	Order 6

fpm descent to provide more precise rate information. If the aircraft vertical rate of climb exceeds 1,000 fpm, the pointer will move opposite the window and the vertical rate will be displayed by a digit appearing in the window. For example, if the aircraft was climbing at 4,000 fpm the figure "4" would be visible. The same digital readout applies to any rate of descent greater than 2,000 fpm.

The flare shield, displaying aircraft absolute altitude, is an orange colored tape which ascends from the bottom of the case to the zero index and covers the right side of the rate of descent scale. The tape will come into view at 300 feet altitude and will travel in a constant movement if the aircraft rates of descent are reduced as prescribed by the instructions. As the flare shield ascends, the points along the rate of descent scale only approximate absolute altitude below 300 feet with the exception that the 1,000 fpm index on the scale represents 66 feet absolute altitude and the 500 fpm mark represents 33 feet of altitude."

Summers

"This instrument panel insert contains the standard round dial altimeter. An instantaneous vertical velocity with the capability of displaying absolute altitude below 270 feet has been included in the insert.

This is the Summers instantaneous vertical rate instrument which has no lag in its presentation. The scale is graduated into increments from 4,000 fpm ascent to 4,000 fpm descent with an expansion of this scale existing from 1,000 fpm ascent to 1,000 fpm descent to provide more precise rate information.

The flare shield, displaying aircraft absolute altitude, is an orange-red colored ring which rotates about the lower perimeter of the vertical velocity dial face. The tape will come into view at 270 feet altitude and will travel in a constant movement if the aircraft rate of descent is reduced as prescribed by the instructions. As the flare shield rotates to the zero index on the vertical velocity, the points along the rate of descent scale only approximate absolute altitude below 270 feet with the exception that the 1,000 fpm index on the scale represents 66 feet absolute altitude and the 500 fpm mark represents 33 feet of altitude."

Phase II-A

"This instrument panel insert contains the Phase II-A altimeter, which is a vertical scale altimeter and an instantaneous vertical velocity in the same instrument. In addition, a flare shield with the capability of displaying absolute altitude below 240 feet has been included in the vertical velocity scale.

The vertical velocity indicator of the Phase II-A altimeter is an instantaneous vertical rate instrument, consequently there is no lag in its presentation. The scale is graduated into 100 foot increments to 500 feet ascent-descent. If the aircraft vertical rate exceeds this 1,500 fpm, the pointer will move opposite the appropriate window and the vertical rate will be displayed by a digit appearing in the window. For example, if the aircraft was climbing at 2,000 fpm the figure "2" would be visible.

The grey scale on the right of the instrument is the altitude tape representing aircraft altitude in thousands of feet with the scale graduated into 500 foot increments and numbered every 1,000 feet. The tape moves and the altitude is read under the fixed reference line.

Aircraft altitude is presented in hundreds of feet by the black vernier tape. The scale is graduated into 50 foot increments and numbered every 100 feet. Therefore, precise aircraft altitude can be determined by first obtaining thousand foot information from the altitude tape and then obtaining the hundreds of feet from the vernier tape.

The flare shield, displaying aircraft absolute altitude, is a red colored tape which ascends from the bottom of the vertical velocity scale to the zero index and covers the left side of the rate of descent scale. The tape will come into view at 240 feet altitude and will travel in a constant movement if the aircraft rates of descent are reduced as prescribed by the instructions. As the flare shield ascends, the points along the rate of descent scale only approximate absolute altitude below 240 feet with the exception that the 1,000 fpm index on the scale represents 66 feet absolute altitude and the 500 fpm mark represents 33 feet of altitude."

When the subject pilot fully understands the various functions of the experimental panel, he is instructed how to fly the flight task with regard to that specific experimental display.

Experimental Panels

"Upon passage of the middle marker, a flare shield depicting aircraft absolute altitude will come into view. This absolute altitude display is introduced at ___feet* above the terrain or ____feet MSL*, and this consequently, is the pilot's cue to reduce his rate of descent to 500 fpm. And again, from the initial appearance of the flare shield to touchdown, the ILS glide path needle should be ignored and only the specific rates of descent are to be flown.

As the flare shield passes the 1,000 fpm rate of descent index, which represents an aircraft absolute altitude of 66 feet, the pilot begins a final flare-out maneuver by establishing a 200 fpm rate of descent until touchdown. Also, as the flare attitude is assumed and the absolute altitude flare shield passes the 500 fpm rate of descent point, which indicates an altitude of 33 feet, slowly retard the throttle to the idle position."

The first half of a two-part questionnaire is administered to the subject by the assistant experimenter prior to being released from the simulator facility. The second section of the questionnaire is answered by the subject preceeding the following day's simulator flight. A detail layout for the order of questionnaire presentation is presented below.

After each daily session, the subject is requested not to discuss the study with anyone until its conclusion.

<u>Practice Trials</u>

Means

The measurement of the learning effect is not apparent when the means of the various parameters are plotted. For example, the mean of the airspeed at touchdown for trial one is 142.2 and for trial twenty the airspeed at touchdown is 141.3. The other trials had an inconsistent scattering of the touchdown airspeeds from 138.9 on trial 13 to 143.9 on trial 5. This tendency to be inconsistent in terms of the mean was apparent for all the measurements recorded during the practice trials. There is no particular reason to expect a general decrease in the size of the means as in every case there is a desired value to be held. It is expected that the groups of subjects as they learn control of the simulator to decrease in their dispersion about the expected value. For example, it was

* Values are inserted which are appropriate for the instrument being used.

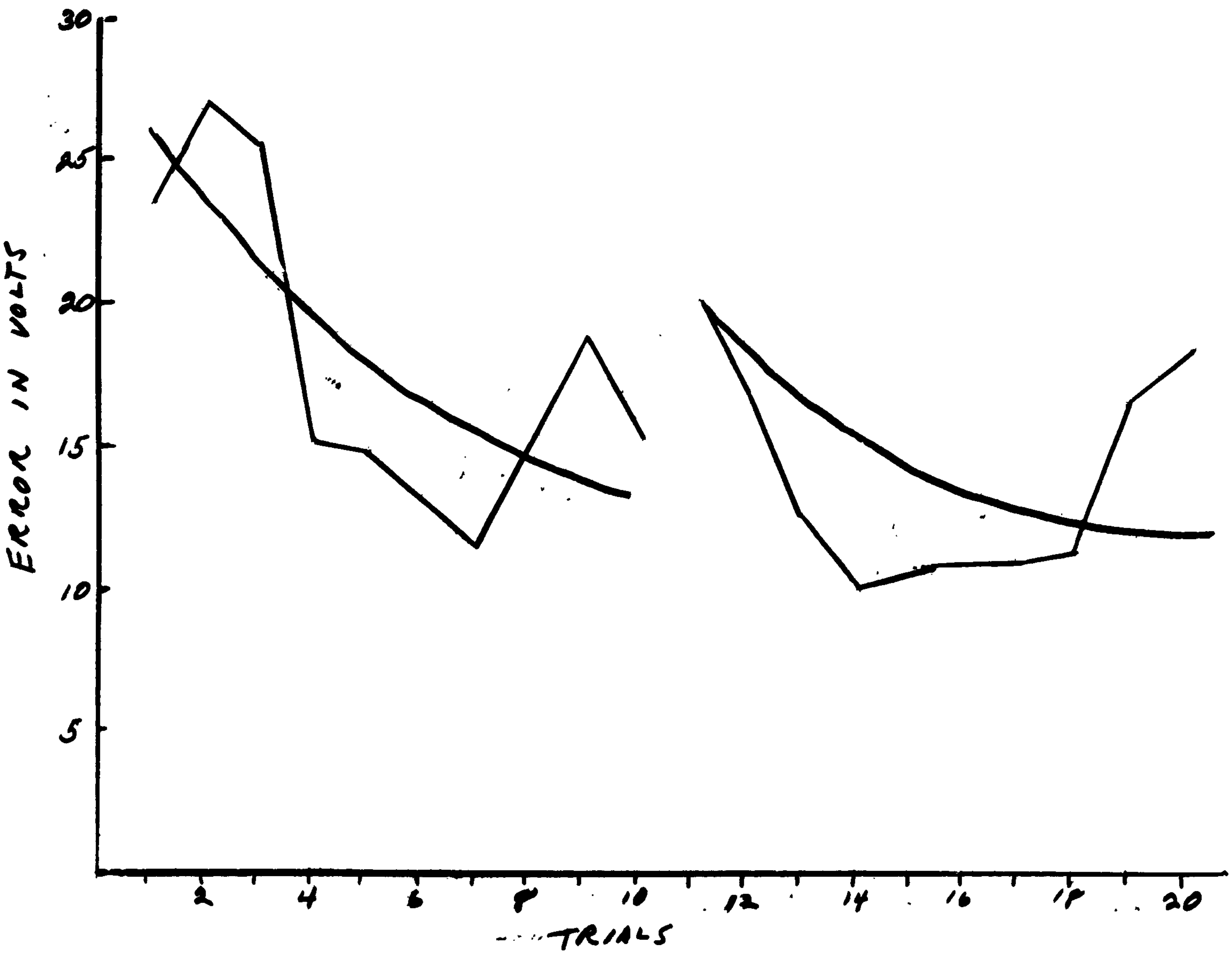


Figure 5. Plot of distance down runway with a smooth hypothetical curve drawn on same graph showing what is expected with a large sample.

anticipated that touchdown would occur at about 145 knots. When the touchdown speeds were computed it was noted that some were much higher and some were lower but when averaged together the scores were as stated above and, thus, left some doubt as to whether learning had taken place. Since the dispersion of the scores about the fixed value generally decreases as a function of trials, it can be assumed that there was learning occurring.

Standard Deviation

Figure 2, 3, 4, are plots of the standard deviations of the subjects as a function of trials. It should be pointed out that the ordinate in each graph is in error voltage and thus, all three parameters are plotted on the same ordinate scale even though the converted values would be quite different. Each of the curves must be considered as independent.

Trials 1-10 represent the first practice session. Trials 11-20 represent the second practice session. As can be seen by the plots of the airspeed, vertical velocity, and range, there is a trend for a gradual decrease in the magnitude of the standard deviation from trial 1 of the first session to trial 10 of that session. Figure 2 shows an increase in the error voltage on trial 11 or the first trial of the second day. Apparently this is due to the intervening time period which ranged from 20 hours to 26 hours.

It might be noted from figures 2, 3, and 4 that there is not a continual decrease in the size of the standard deviations rather the trend is to decrease with scattered points along the trend line. Figure 5 shows the actual plot with the hypothetical plot that would be expected providing there were adequate subjects to stablize the data points. From these four figures it can be concluded that learning in terms of the control of the simulator occurred.

There is some additional learning which takes place in the second session as is demonstrated, trials 11-20 of figures 2, 3, 4, and 5, but there is a primary trend of scattering about the level achieved in the first session suggesting the fact that the performance asymtote has been approached. By trial 17 or 18 they are relatively stable with very little improvement occurring after these trials. The deteriation in the final trials could possibly be explained by fatigue or motivation. It is not unusual to observe a slight deteriation in performance in a repeated task which is learned.

It is felt that the increase in the standard deviation in trials 19 and 20 are not motivationally associated with the program because of the general improvement on day three, the third experimental session and first with absolute altitude.

As a confirmation of the general improvement in the subject handling capability of the simulator figure 6 is presented with a curve of the error voltage for airspeed and vertical velocity Once again the means do not demonstrate learning taking place while the variability about the mean does show a definite decrease. This curve is plotted from the integrated error square scores from Outer Marker to Middle Marker.

Experimental Design

The basic design has not changed as this is still a four dimensional design. The variables have been changed as well as the effects of primary concern. The variables for this study are:

1. Order (a control variable)
2. Subject Groups
3. Instruments
4. Trials

The interaction of prime interest are pilots by instrument, trial by instrument, pilots by instrument by trials. All other effects are important but are not of primary importance and will be utilized for control purposes only.

The final design to be used is described in the following paragraphs.

The design used in this study was a four dimensional, mixed design similar to those described in Lindquist (Ref. 1). The 24 subjects were assigned to one of the six orders of instrument presentation in accordance with their appearance. Within each of the orders all other treatment combinations were administered to each subject except for the dimension of pilot background which by definition was the second between effect. In other words within each pilot group, two subjects, received one of the six orders in combination with instruments and trials.

There were six possible orders by which the three instruments were presented to each subject group. All six of these orders were used and two military and two civilians were assigned to each order. The following orders were used:

Order	1	II-A, Mod, Sum*	
	2	Mod, II-A, Sum	
	3	Sum, Mod, II-A	*Sum - Summer IVVI
	4	II-A, Sum, Mod	Mod - 1"Module IVVI
	5	Mod, Sum, II-A	II-A - Phase II-A Altimeter
	6	Sum, II-A, Mod	

With this arrangement all instruments occurred twice in the first position twice in the second position and twice third. For example, the 1" module occurred first in orders 2 and 5, second in orders 1 and 4, and last in orders 4 and 6. By this arrangement, practice and fatigue effects which might cause differences were subject to control. The arrangement also minimizes any systematic influence resulting from one instrument always preceeding or following another. Thus, in this experiment order is not an effect of primary importance, but is included as a control variable so that the variance attributable to order can be extracted from the error term. It is not anticipated that there will be a significant effect of order but this technique 'purifies' the remaining tests.

Table 2

Analysis of Variance Summary Table for the Sources and the Degrees of Freedom*

Source	Degrees of Freedom	
Between Subjects	opn-1	23
Order (O)	o-1	1
Pilots (P)	p-1	5
O X P	(o-1)(p-1)	5
Error (b)	op(n-1)	12
Within Subject	opn(ri-1)	408
Instruments (I)	(i-1)	2
Trials (R)	(r-1)	5
I X R	(i+1)(r+1)	10
I X O	(i-1)(o-1)	10
I X P	(i-1)(p-1)	2
R X O	(r-1)(o-1)	25
R X P	(r-1)(p-1)	5
O X P X I	(o-1)(p-1)(i-1)	10
O X P X R	(o-1)(p-1)(r-1)	25
I X R X O	(i-1)(r-1)(o-1)	50
I X R X P	(i-1)(r-1)(p-1)	10
O X P X R X I	(o-1)(p-1)(r-1)(i-1)	50
Error (W)	op(ir-1)(n-1)	204
Total	opirn-1	431

*There were 6 orders, 2 pilot groups, 3 instruments, and 6 trials. o=6, p=2, n=2, i=3, r=6.

Items to be Accomplished

The only things left to be accomplished is the conduct of the experiment, the analysis of the data, and the preparation of the Martin Engineering Report which will be used by the technical writers for preparing the final two sections of the report to be issued to FAA. It is anticipated that the time limitations at the terminal end of this experiment are even more critical than before. The data analysis at its best will not be completed until 30 March 1962 which leaves four weeks for the completing and issuing of the report.

Reference

Lindquist, E. F. Design and Analysis of Experiments in Psychology and Education. Boston: Houghton Mifflin Company, 1953.

C. A. Gainer

W. L. Welde

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin-Human Engineering Group
AF 33(616)-7752

MEMORANDUM REPORT: 62-5 9 February 1962

Task: Consulting

To: Mr. R. B. Davis

cc: Mr. S. G. Basler, Dr. D. P. Hunt, Mr. J. H. Kearns, Mr. S. Knemeyer, Mr. A. L. Longiaru, Mr. N. MacGregor, Capt. C. Waggoner, Mr. Warren, Mr. R. Wible, Major W. E. Wilvert, and Mr. G. L. Yingling, and all members of the Martin Human Engineering Group.

From: W. F. Swartz

Subject: Work Statement: Investigation of the Relationship between Split-Axis Control and Task Load for the High Angle Letdown, ILS Approach to Touchdown.

In the T-33 inflight investigation of split-axis control for the landing maneuver, a significant improvement of localizer performance by the introduction of automatic lateral control did not result in a subsequent improvement of glide slope performance. This finding is contrary to the hypothesis that unburdening the pilot from having to maintain control of the aircraft in roll and yaw, while performing the landing maneuver, will result in better glide slope (pitch) performance. The explanation advanced for the neutral finding was based upon the fact that the task load was relatively low for the inflight study. The T-33 aircraft had excellent handling qualities, rather slow airspeeds, and never flew in 90 degree cross-winds of greater than 10 knots or gusts of greater than 5 knots; any one of these factors, either singly or in combination, could have increased the task load of the pilots in the study. Based on this, a hypothesis was made which stated that the split-axis control would have improved glide slope performance if the task load had been higher. A primary purpose of the study described in this memorandum is to examine that hypothesis. The ME-1 Simulator is being utilized. This study is being conducted in conjunction with high angle letdown, omni-angle approach study.

Selection of Parameters

The two parameters selected for investigation are Controls and Task Load. Two levels within each parameter are being studied. Within the parameter, Controls, the standard Full Manual control and the experimental, Split-Axis Control, are being utilized. Full Manual Control is incorporated into the study to furnish baseline data for comparative purposes with the split-axis control condition. Task Load will have the levels of high and low. High task load will be introduced by means of having rough air and having the subjects maintain airspeed within plus or minus four knots of the desired. Rough air is not of interest *per se*, but is being used as a means of increasing course complexity which in turn increases the task load of the subject; maintaining strict airspeed control increases the task load even more. Low task load consists of no rough air and no limits with respect to airspeed.

Method

Apparatus

Display. The following instrument displays will be used in the study:

- a. Flight Director System
  - (1) Attitude Director Indicator
    - (a) Pitch Command Bar
    - (d) Bank Command Bar
    - (c) Depression Angle to the Station
  - (2) Horizontal Situation Indicator
    - (a) Lateral Displacement Bar
- b. Phase III Altimeter
  - (1) Altitude Tape
  - (2) Vernier Altitude Tape
  - (3) Instantaneous Vertical Rate
- c. Horizontal Drum Airspeed Indicator

Command bank attitude and command pitch attitude information are placed upon the command bars of the ADI for the entire profile from altitude to touchdown. The lateral displacement bar of the HSI displays the incurred angular error to the center of the localizer beam.

Control. Full Manual control (standard) will be availabe for use as well as split-axis. Split-axis control will consist of automatic control of roll and yaw with manual control of pitch; the simulator will be flown along the localizer beam automatically when the split-axis condition is being employed.

Profile. Figure 1 presents the profile to be used in the investigation. The task of the subject is to fly the simulator from 15,000 feet, down the high angle letdown of 12 degrees, transition into the ILS approach of 3 degrees, and on to touchdown. The profile is flown by maintaining the null of the command bars on the ADI. It is noted that the angle of 12 degrees is being used to maintain the compatibility of this investigation with the high angle letdown, omni-angle approach study. By having a profile such as shown in Figure 1, both the high angle letdown and the ILS approach segments may be used to examine the parameters of Controls and Task Load.

Scoring. The scoring apparatus is the same by necessity for this study as for the omni-angle approach investigation since the studies are being conducted con-currently. Airspeed, vertical rate, Gs, and angle of attack are being recorded by a Sanborn oscillographic recorder for the entire profile. The terminal performance scores for each of these parameters are also obtained by means of the oscillographic recordings. Brush recordings of distance down the runway and lateral displacement upon touchdown are being made of each approach. Measurement of the Mean Square is being obtained for (1) the high angle intercept, (2) the high angle letdown, (3) the transition to the ILS, (4) the ILS approach, and (5) the flare to touchdown. The Mean Square estimates of deviation from the desired flight path angle are being obtained for the linear portions of the profile and estimates of deviation from the command pitch attitude are being obtained for the non-linear portions of the profile. X-Y plots of lateral displacement vs. range and altitude vs range are also being made of each approach.

Subjective data are being obtained by means of the questionnaire technique. The semantic differential is being utilized in conjunction with the questionnaire.

Subjects

It would be desirable to have a minimum of 20 subjects for the study. Due to the difficulty in obtaining subjects, 20 may be somewhat ambitious, however. An absolute minimum will be 15. Since the difficulty does exist in obtaining subjects, the subject qualifications must be somewhat lower than optimum in order to obtain the required number. Therefore, jet time is not required of the subjects. The major qualification is that they must be currently rated pilots.

Experimental Design

By reducing the qualification requirements, there can be little doubt but that the between subject differences would significantly contribute to the experimental error term, thus, resulting in conservative estimates of F. Therefore, a design is required which will compensate for the hypothesized

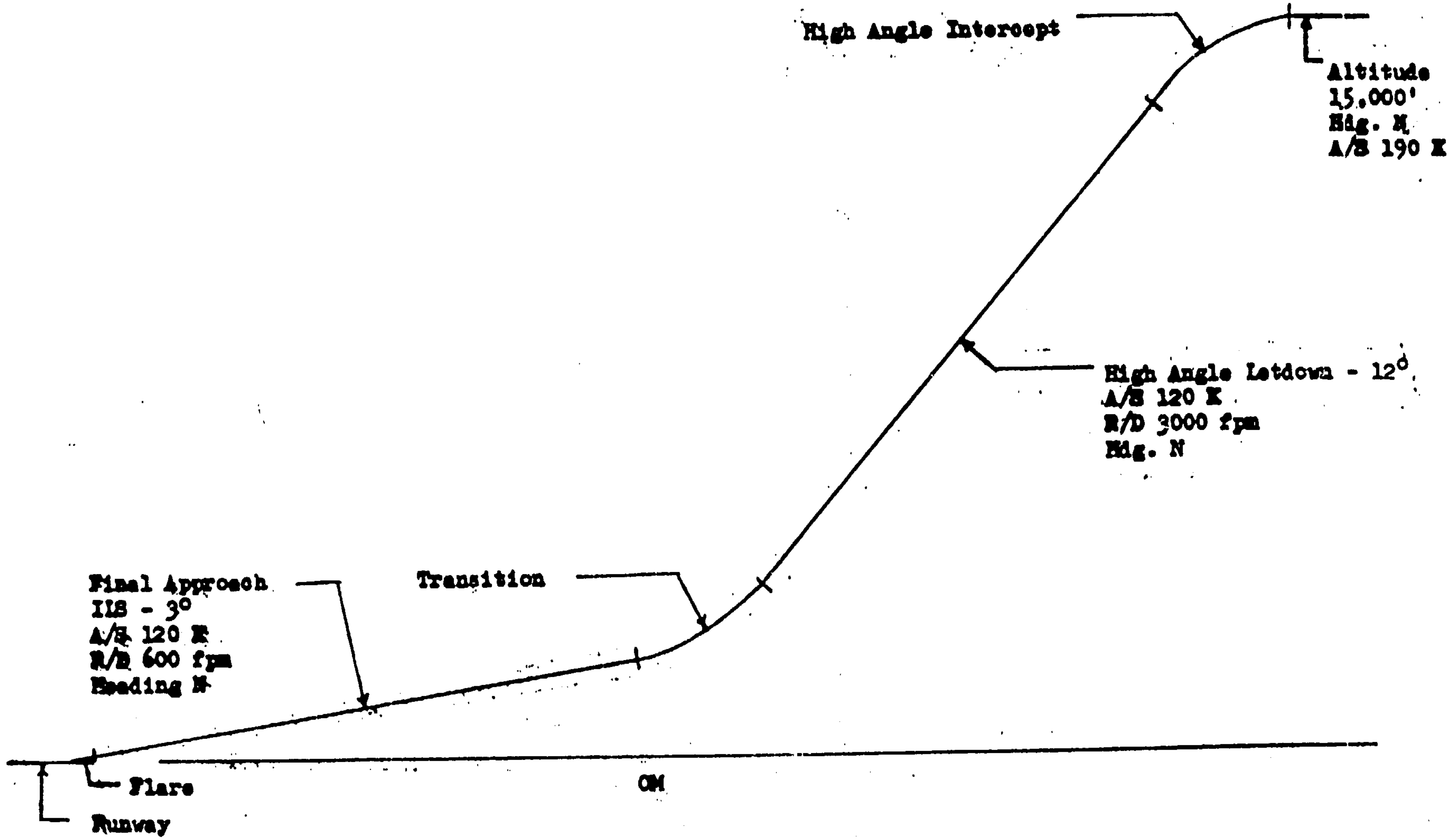


Figure 1. The Profile

difference between subjects. The Treatment X Treatment X Subjects design satisfies this requirement. Using this design requires that each subject receive each combination of Controls (Full Manual and Split-Axis) and Task Load (High and Low). The combinations are administered in random order. Each subject will receive each combination two times for a total of 8 trials. In addition, each subject receives one practice trial for each condition.

Procedure

Upon appearance, each subject is given a standardized briefing. This briefing includes background information concerning the study, the purpose of the investigation and a thorough explanation of the profile. Following is a thorough cockpit check. Most of the subjects are not familiar with the Flight Director System and none of the subjects has never seen the Phase III altimeter. Following the briefing, each subject is permitted to fly the simulator for 10 minutes in order to become accustomed to the sensitive control system. Upon completion, each of the conditions is practiced one time. The experimenter must be in the simulator at this time in addition to all subsequent trials in order to make the proper mode selection changes and to reposition the simulator upon completion of each trial. The subject is told that the experimenter will not judge or grade him in any way. Upon completion of the practice trials, the subject is given a 10 minute break. The experimental trials for purposes of data collection are then performed. A ten minute break is given between the fourth and fifth trials. All trials are made under the canopy. The overall time consumed by each subject is four hours. Actual running time is two hours. A questionnaire is administered at the completion of the trials.

W. F. Swartz

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

MEMORANDUM REPORT: 62-6 27 April 1962

Task No.: 7

To: Mr. E. L. Warren

CC: Mr. William Austin, Mr. E. Bobbet, Mr. J. Charlton, Mr. R. R. Davis, Mr. T. J. Emerson, Mr. S. G. Hasler, Dr. D. P. Hunt, Mr. J. H. Kearns, Mr. N. MacGregor, Mr. E. Vinson, and Capt. C. E. Waggoner, and all members of the Martin Human Engineering Group.

From: J. E. Brown

Subject: Mark IV-B Development: Work Statement: Equipment Requirements for Preliminary Measurement of Mark IV-B Profile.

The purpose of this work statement is to set forth the requirements for measurement equipment for the purpose of obtaining some preliminary measurement of the flight profile of the Mark IV-B vehicle. This profile is the same one used in the Mission-Equipment-Functions-Task Analysis (MEFT) and is shown in MR 61-20 dated 31 October 1961. However, the profile indicated in MR 61-20 has not been empirically verified. In fact, data which would furnish a more complete description of the vehicle performance is still lacking. It is felt that some information could now be supplied by use of the Hypersonic ME-1 which utilizes the same analog computers as will the Mark IV-B. Data gathered from the Hypersonic ME-1 will not only be used to describe the vehicle performance characteristics but will also allow further description of the operator's tasks.

Perhaps the most important question which can be most readily answered by the simulation data is, "Can the profile be flown?" At present, this question can not be answered without data from the simulator.

In order to gather as much information as possible about the flight profile, the following measurement and measurement equipment are requested:

Measures	Equipment
A. Profile Measurement 1. Altitude vs. Range 2. Ground Path or a. $range_x$ vs. time b. $range_y$ vs. time 3. Path Angle a. Heading = ψ b. Flight Path Angle = γ	X-Y Plotters (preferably with two different gains) and/or 1 X-Y Plotter and one 5-Channel Oscillographic Recorder
B. Attitude 1. Angle of Attack = α 2. Roll Angle = β 3. Yaw Angle = ϕ = Side Slip 4. Pitch Angle = θ = Angle of Attack (α) + Path Elevation Angle (γ)	5-Channel Oscillographic Recorder
C. Motion Along Path (all vs. Time) 1. Altitude = h 2. Rate of Change of Altitude (R/C or R/D) = $\dot{h}$ 3. Indicated Velocity (ft/sec) = V_i 4. Mach (True Velocity/Velocity of Sound) = M 5. G-Load = n a. A_n = accelerations in vertical axis b. A_t = acceleration in transverse axis c. A_l = acceleration in lateral axis	5-Channel Oscillographic Recorder

Miscellaneous

In addition to the above measurements it will be necessary to measure:

1. Ground Path
2. Heading vs. Range
3. *Free Channel Key for Coding Events

*If more free channels are available, it would be desirable to measure flap position, skid position, speed brake position, etc. for the purpose of looking at the effects of each.

Apparatus

The apparatus will be the Hypersonic ME-1. In addition to the primary flight instrumentation which will be installed, it will be necessary to have a Horizontal Situation Indicator to furnish navigation information. The HSI should be of the type having concentric rings and should have DME and bearing information.

Subjects

Because of time limitations, it is thought that the number of subjects required should be no more than ten but not less than two. To obtain the maximum value from the subjects, repeated measures will be utilized. The subjects will be qualified pilots (prefereably with jet time) and will be drawn on the basis of availability.

Procedure

The subjects will be briefed on the profile shown in MR 61-20. They will then be given ample practice time to learn the flight characteristics of the vehicle and to practice the profile. After sufficient practice, the subjects will then fly the profile a number of times for the purpose of measurement.

Results

The results will be analyzed only with respect to answering the following questions:

1. Can the profile be flown?
2. In flying the profile, what are the quantitative values of the important flight parameters during each phase?
3. What are some alternative methods of flying the profile?
4. If the profile can not be flown, how should it be changed?

James E. Brown

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

MEMORANDUM REPORT: 62-7 — 20 June 1962

Task No.: 12

To: Mr. R. W. Obermayer

cc: Mr. Basham, Mr. Bryan, Mr. Davis, Mr. Frost, Mr. Hasler, Dr. Hunt, Mr. Kearns, Mr. Knemeyer, Mr. Lemon, Mr. Lippscomb, Mr. Longiaru, Mr. McGregor, Dr. Muckler, Mr. Ostgaard, Mr. Purcell, Mr. Rosenbaum, Mr. Ruth, Major Sumerich, Capt. Waggoner, Mr. Warren, and Mr. Yingling, and all members of the Martin Human Engineering Group.

From: W. K. McCoy, Jr.

Subject: Pilot Opinion vs. Validity. A Presentation given to the Flight Control Laboratory, 13 June 1962.

The logical starting place for this problem is to determine what is wanted from a man-machine system evaluation, or an investigation of an element of such a system. There are perhaps four major objectives. These are: (1) to predict the ultimate system or element capability, (2) to predict the ultimate user acceptance of the system or element, (3) to elicit design information. That is, to elicit specific information concerning particular elements of the system. This information could be used to improve the system, and (4) to determine the potential of a system. That is, to get indications from the prospective users of a system, pilots, as to what direction the development of a system might take. Of course all such studies might contribute to our general understanding of man-machine systems.

The current techniques for conducting such evaluations usually involve taking "overall" system performance measures while systematically varying the elements, both man and machine, to determine which elements produce the best overall system performance. By "overall" system performance, I mean the total system output. The measures include the man's output plus the output of the machine. Figure 1 shows such a system. Measure are usually taken from the vehicle performance. The system is either simulated or "flight tested" and a sample of pilots is selected and used to operate the system while measures are taken.

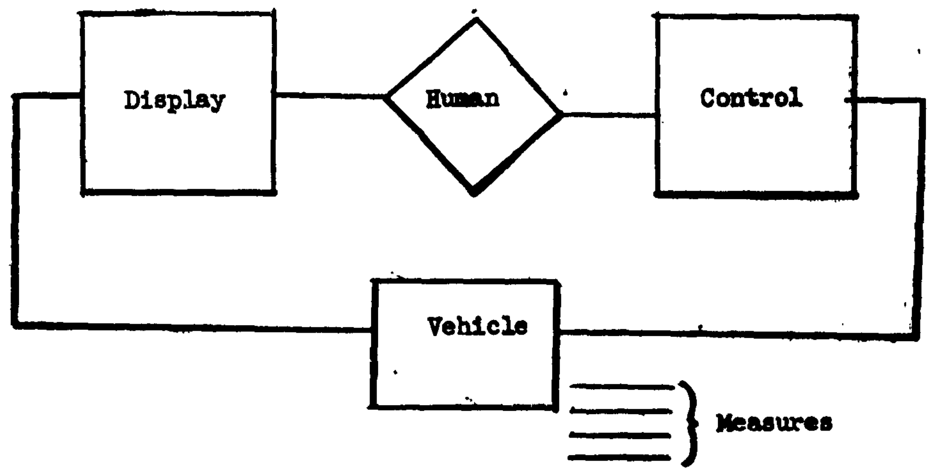


Figure 1

Interest may be in either investigating particular elements of a system or in comparing two or more systems. In either case it is desirable to obtain information concerning the characteristics and capabilities of the individual elements, so that the system might be improved. The "overall" system performance measures do give us the variability of the total system output, but very little information concerning the individual elements can be extracted from such data. The complicated interactions between the man and the elements of the systems and between the elements themselves make interpretation of the measures in terms of any particular element impossible, at least in the present state of the art.

Ideally for the most effective investigations of a system, the functional relationships between "what the man does", all his outputs, and "what the machine does", all the responses of the machine, should be determined. Such functional relationships would permit the optimum design of a system so that each element would provide maximum positive contribution to total system output without compromising the other elements.

As in the case with most ideals, this is as yet not possible to achieve. We could conceivably measure everything the man does while performing the tasks necessary to control the system, but we can not measure "what he was responding to". For example, in a recent "eye movement" study, the experimenter was able to record accurately where on the panel the pilot was fixating, but could not precisely determine "what the pilot saw". That is, he could not determine with precision what the pilot was responding to. This shows clearly why we cannot tie down the pilot's responses to specific characteristics of the machine. That is, we cannot yet determine functional relationships.

The lack of information in "overall" system performance measures concerning the specific elements makes questioning the pilot not only desirable but necessary. Also, information concerning the ultimate acceptance of the system by the user should probably come from the user.

The information to be elicited from pilots could be divided into six categories, these are as follows:

(1) Pilot's self analysis of his tasks:
   A. Status information (Did he know the status of the system at all times).
   B. Did he know what to do at all times?
   C. Did he know when to do it?

(2) Pilot's judgment of system performance:

(3) Design information:
   A. Specific questions concerning the elements of the system (control and display).

(4) Acceptance information:
   A. Willingness to use the system.
   B. Need
   C. Preference

(5) Fidelity of simulation:
   A. Questions to enable the investigator to determine whether or not he has achieved a reasonable degree of representativeness in simulating the environment to which predictions will be made.

(6) Equipment operation:

A. Questions to enable the investigator to determine whether or not the equipment used in the study functioned as was assumed during the "evaluation."

With these information requirements in mind we can consider some problems involved in obtaining a "valid" technique for eliciting such information.

First, we might consider the pilot's task in making the "design judgments" we call for. Traditionally in flight testing the pilot's task was relatively simple. He was told to fly various profiles and determine, usually on a check-list basis, whether or not the various elements of the system functioned properly. The judgments were simply "it worked" or "it didn't". Now we ask considerably more from the pilot. He is asked to make subtle judgments such as those concerning number size, panel arrangement, lighting, control pressures, gain settings and many others. These are many times very subtle judgments, and to complicate things we ask him to do it while performing the tasks necessary to control the system. Possibly we expect too much. At present we must assume that the pilot can make the judgments we ask for but the assumption is certainly questionable.

Assuming that the pilot is a "valid" source of information still leaves problems in obtaining valid measurement of his responses.

Validity has a number of meanings and has proved to be a difficult concept to tie down to our measurement problem. The most general concept of validity which asks, "Does this test measure what we suppose it to measure?", does not seem to have much utility for our problem. Concerning pilot opinion, we must assume that we are measuring pilot opinion. Thus, we would need some "true scale" of pilot opinion against which we could check our measures. We have no such scale, so generally we use some other independent measure of opinion to check our experimental measure. If the two measures agree, the best we can assume is that we have consistent results, because the possibility exists that both measures could make the same type of errors. If the measures do not agree we cannot tell which, if either, is valid and which is not. Validation of our measures under this criterion does not seem promising at all.

Test and measurement psychology cites four types of validity in the literature. These are more or less operational definitions which differ in the aspect of validity that is of major concern. The first two types are statistical validities. That is, there are statistical procedures for determining the degree of validity achieved.

1. Predictive Validity. Predictive validity is evaluated by showing how well predictions made from the test are confirmed by subsequent observation. The most common way to check predictive validity is by correlating test scores with some subsequent criterion measures.

2. Concurrent Validity. Concurrent validity is evaluated by showing how well test scores correlate with some concurrent status or performance. This is similar to predictive validity except for the point in time at which validating criteria are selected. Usually the measures are obtained simultaneously, or at least about the same time. The most common reason for seeking concurrent validity is to substitute one measure for another.

The second two types of validity are logical validities. That is, there are no statistical methods to determine the degree of validity obtained.

3. Content Validity. Content validity is evaluated by showing how well the test samples the class of situations or subject matter about which conclusions will be drawn. This must be decided on a logical basis, usually by expert opinion.

4. Construct Validity. Construct validity is evaluated by investigating what "psychological qualities" a test measures by demonstrating that certain explanatory constructs or theories account for, in some degree, the performance on the test. This concept is used when interest is in validating theories or constructs. Defining the "psychological qualities" assumed to be measured by a test is done on a logical basis.

For our problem of eliciting "valid" pilot opinion, two of these types of validity seem most crucial. To obtain design information from questionnaires, the questions for this purpose would need to have high content validity. That is, the responses of the pilots to such questions must have precise meanings in terms of design parameters. We can only rely on the opinions of experts to decide whether or not we have content valid questions.

For predicting the ultimate user acceptance of a system or element of a system the questions for this purpose would need to have high predictive validity. As pointed out above we can statistically check the predictive validity by correlating our measure with some subsequent criterion measure. But, determing such "criterion measures" is no small task. Many of the problems we encounter in constructing some measure of opinion are involved also in determining the criterion for validation.

We suppose we are measuring pilot opinion. Before we can attempt any sort of validation, we must be sure that our measure is reliable. By reliable, I mean that our measure will produce consistent results if applied to the same sample again and again, provided that our sample has received no new information about the system or element about which they have expressed opinions. This implies that opinion is a relatively stable quantity. Is it? Can we assume that pilot opinion will vary only with the systems or elements being investigated? Or, are there other factors not controlled by our measure that have a significant effect on opinion? What about the biases and motives of the pilot? As psychologists we know that these things do affect opinion, but we do not know the degree or direction of the effect since our measures do not control for such variables.

The major concern of this paper is the validity of pilot opinion measures, but it is clear that validation under any concept is not feasible until we have achieved reliable measures. Perhaps C. A. Gainer's work with a device called the "Semantic Differential" shows the most promise in terms of stable, or consistent results. It has been used only three times at present but the results have been encouraging. More effort with this device is now in progress. If it can be shown to be a reliable measure, validation attempts will probably be made.

William K. McCoy, Jr.

William K. McCoy, Jr.

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

MEMORANDUM REPORT: 62-8 26 July 1962

Task No.: Consulting

To: Major J. D. King

cc: Mr. Basham, Mr. Bryan, Mr. Davis, Mr. Foret, Mr. Hasler Dr. Hunt, Mr. Kearns, Mr. Kenemeyer, Mr. Lemon, Mr. Lippscomb, Mr. Longiaru, Mr. McGregor, Dr. Muckler, Mr. Ostgaard, Mr. Purcell, Mr. Rosenbaum, Mr. Ruth, Major Sumerich, Capt. Waggoner, Mr. Warren, and Mr. Yingling, and all members of the Martin Human Engineering Group.

From: W. K. McCoy, Jr.

Subject: Results of Semantic Differential and Questionnaire Used in the Investigation of Micro-Vision.

Semantic Differential

The Semantic Differential is a combination of word association and scaling techniques designed to elicit inherent feelings or attitudes. This device, as used for instrument evaluation is fully described by C. A. Gainer in Memorandum Number 61-23.

In the investigation of the Micro-Vision display, the five subject pilots received the Semantic Differential three times during the investigation. The first one was administered before the pilots received any first hand experience with the Micro-Vision display and only limited information concerning its use (pre-briefing). The second differential was given after the pilot's orientation flight. That is, after the pilot had had a detailed briefing on Micro-Vision and actually flown several approach profiles using the Micro-Vision display (post-orientation). The final semantic differential was given after the pilots had flown all flights in the investigation (post-test). Obtaining data at these three points in the progress of the investigation served to indicate any changes in the pilot's feelings or attitudes toward the Micro-Vision display as they received more information about the display and more experience using it.

Results

Figure 1 shows the mean profiles for all five pilots on all three semantic differentials (pre-briefing, post-orientation, and post-test). It is apparent that there was little change in the profiles along the negative-positive dimension as the investigation progressed.

Mr. Gainer points out three possible interpretations of such a result. These are as follows:

1. The pilots confirmed their initial attitudes.
2. The pilots were hesitant to change their initial attitudes.
3. The system (Micro-Vision Display) performed as they thought it would.

Since there were only five subjects used in this investigation, this result must be interpreted with caution. Since the mean profiles represent the average of all five pilots, one pilot's data could conceivably distort the "mean profiles". In this investigation, three pilots were fairly consistent in showing a "positive shift" while the two remaining pilots were fairly consistent in showing a "negative shift". The individual profiles for each subject are shown in Figures 2 through 6. When the five profiles are "averaged" the result is mean profiles that show little change. The inconsistancy, the 3-2 split in attitude, suggests that a larger sample of pilots is needed to better estimate the attitude of the pilot population. No such estimate can be made from this series of differentials.

Further, using such a device as the semantic differential requires that the subjects "evaluate" the system under uniform conditions. That is, all subjects should have the same or approximately the same "experience" with the system. In this investigation, the pilots flew approach profiles using the system while several factors varied (runway used, number of functional beacons, and weather or wind conditions). Thus, the pilots actually "evaluated" different systems depending upon the conditions prevailing during their particular flights. This would contribute to the variance in the individual profiles on the differential. If it is desired to evaluate the system under a large variety of conditions. Many more observations (i.e. more subjects) are needed to obtain stable estimates for the parameters of interest (pilot-performance and pilot-preference).

Questionnaire

A thirty-eight item questionnaire was constructed to elicit information concerning the manner in which the pilots used the display and their ideas for improving the display. The questionnaire was divided into three parts: I, questions pertaining to the first part of the approach profile (from the outer marker to the middle marker). II, questions pertaining to the second part of the approach profile (from the middle marker to the breakoff point from micro-vision to outside VFR) and III, questions of a general nature concerning improvements that might be made in the display system, the valuable characteristics of the display system and the shortcomings of the display system. The questionnaire has been duplicated in the Appendix along with the responses of the pilots.

The pilots found that the micro-vision display system was most valuable during the second half of the approach profile and that its most valuable characteristic was its use as a localizer for "lining up" on the runway. (see questions 1 and 6, part I; question 1, part II; questions 20 and 23, part III).

Apparently, the pilots felt that the display system, in its present stage of development was no better than the currently operational "approach to land" systems (see question 22, part III). This was indicated by the "limitations" placed on the use of the display by the pilots.

The first six questions of part III indicated what additions the pilots thought would improve the display system. Question 13, part III, indicated that practice using the display system did increase the pilot's confidence in it.

Summary

In order to determine the pilot's attitude toward the micro-vision display system and to elicit comments concerning the valuable characteristics and shortcomings of the display system, in its present stage of development, two techniques were used. The Semantic Differential was used to indicate any changes in attitude toward the display during the progress of the investigation, as the pilot subjects obtained more information about the system and more experience using it. Also, a thirty-eight item questionnaire was constructed to determine how pilots used the display system and to elicit comments that would provide information that would facilitate "improvement" of the display system.

The results of the Semantic Differential indicated that a larger sample of pilots is needed to adequately estimate the "attitude" of the pilot population.

The questionnaire data indicated that pilots felt that the display system was most valuable during the last part of an approach to land profile (from the middle marker to the breakoff point from micro-vision to outside VFR), and that the most valuable characteristic of the display system was its use as a localizer. Although, the pilots felt that the system, in its present stage of development, was no better than currently operational "approach to land" systems, the fact that they were able to use the system to obtain information for "flying the approach profile" and that they indicated some additions that would improve the performance of the system suggests that the micro-vision display system does have possibilities.

W. K. McCoy, Jr.

W. K. McCoy, Jr.

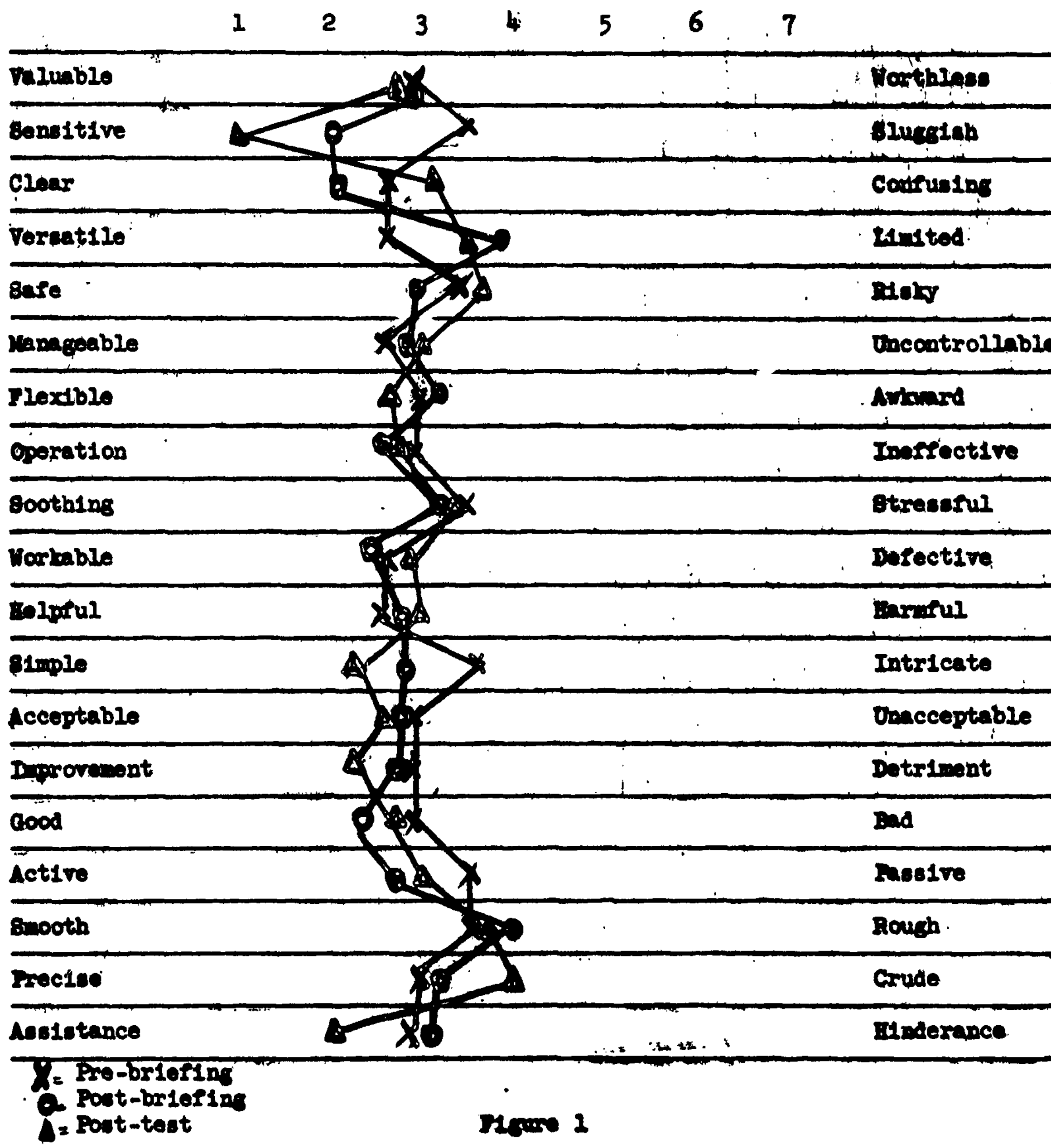
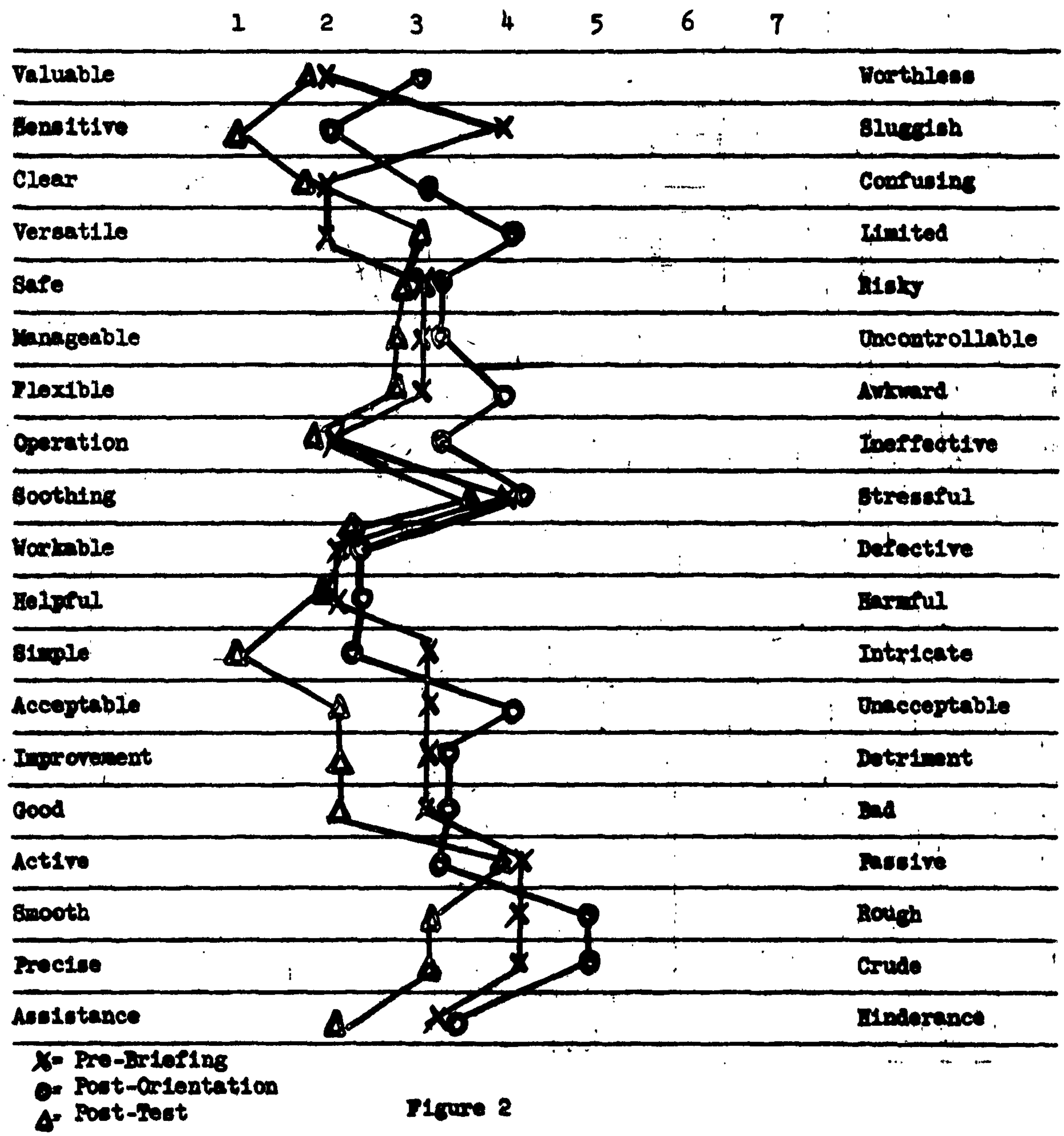


Figure 1
Group Profiles



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X= Pre-Briefing
o= Post-Orientation
Δ= Post-Test

Figure 2

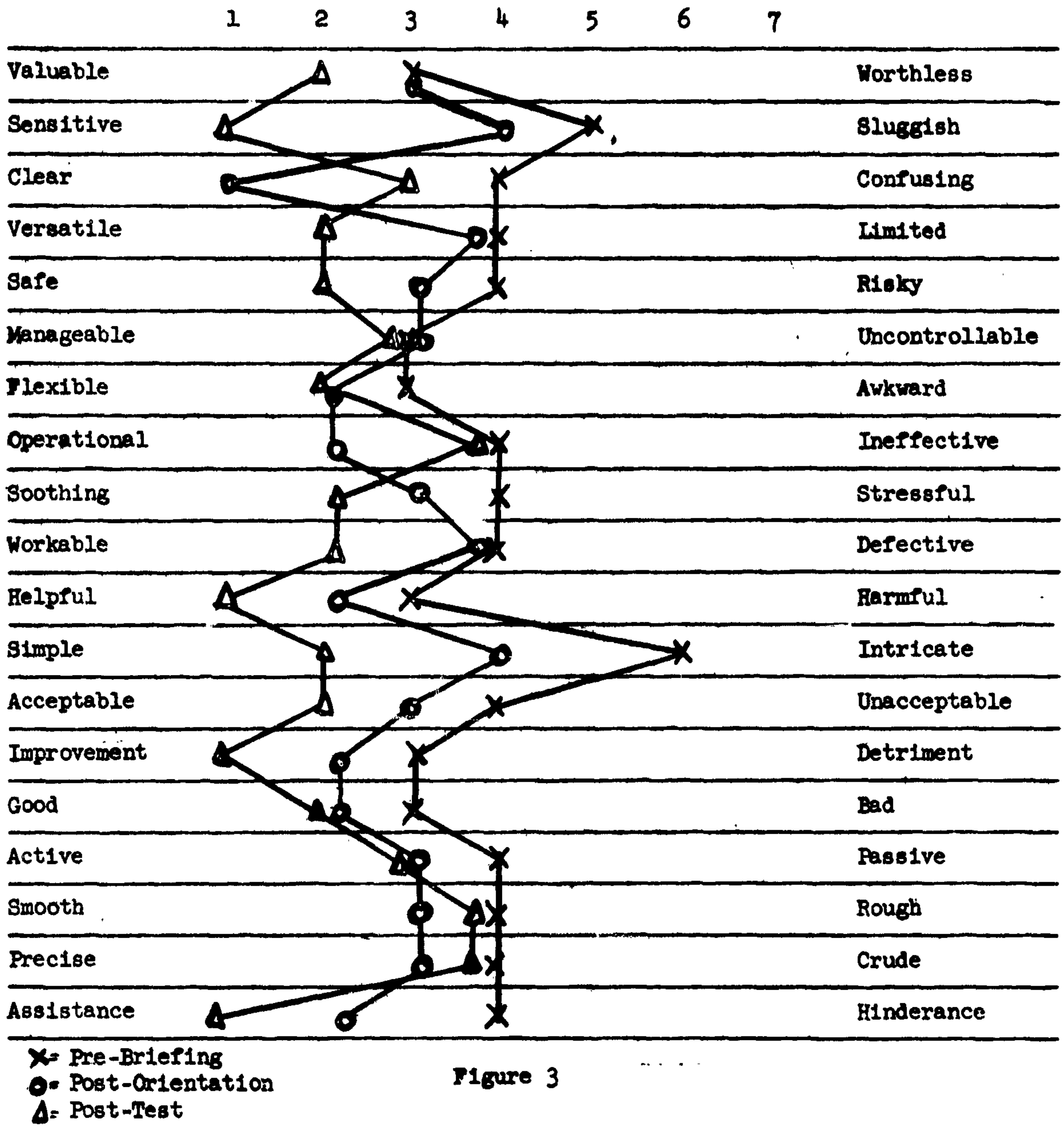
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Figure 3

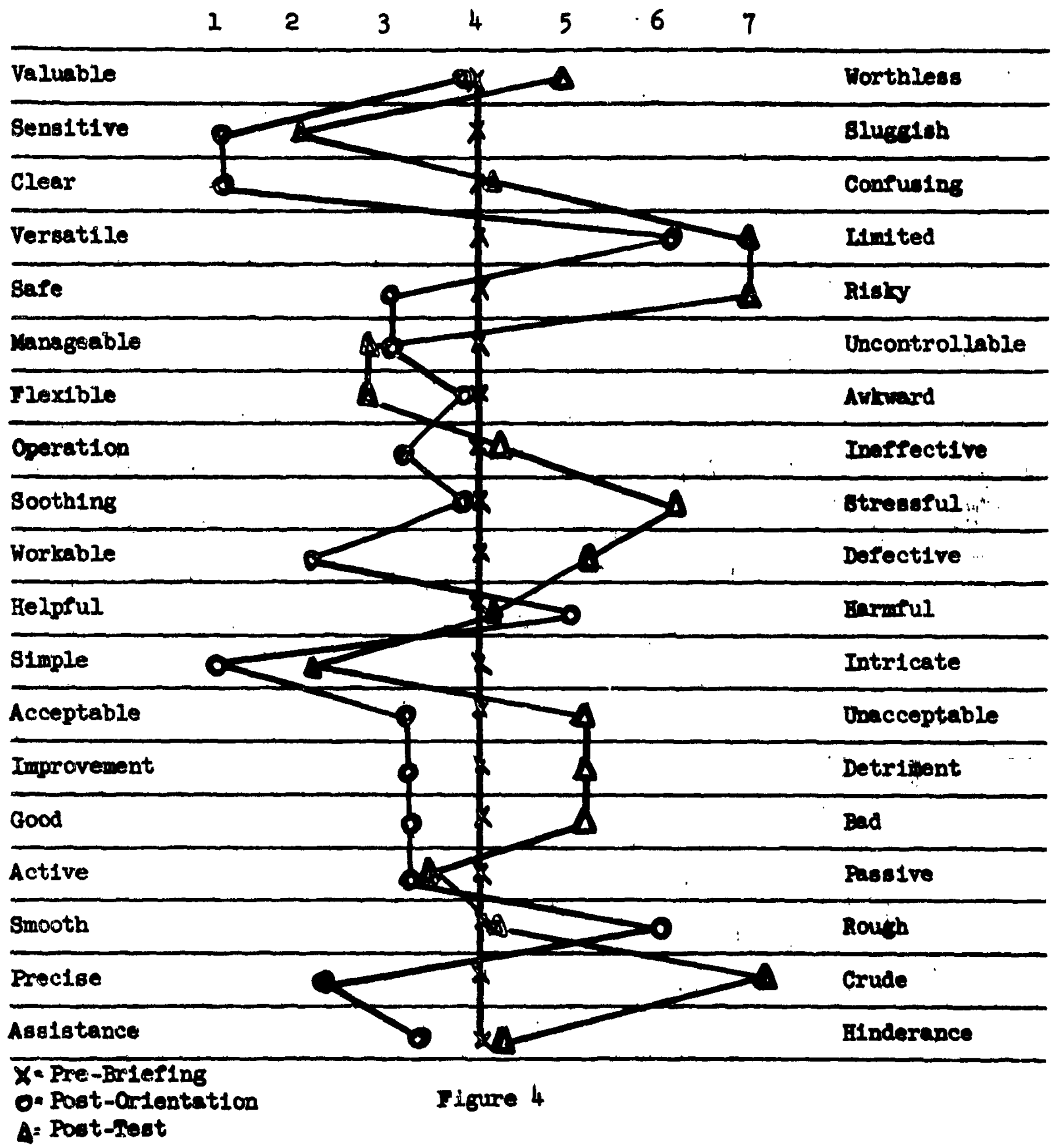
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Figure 4

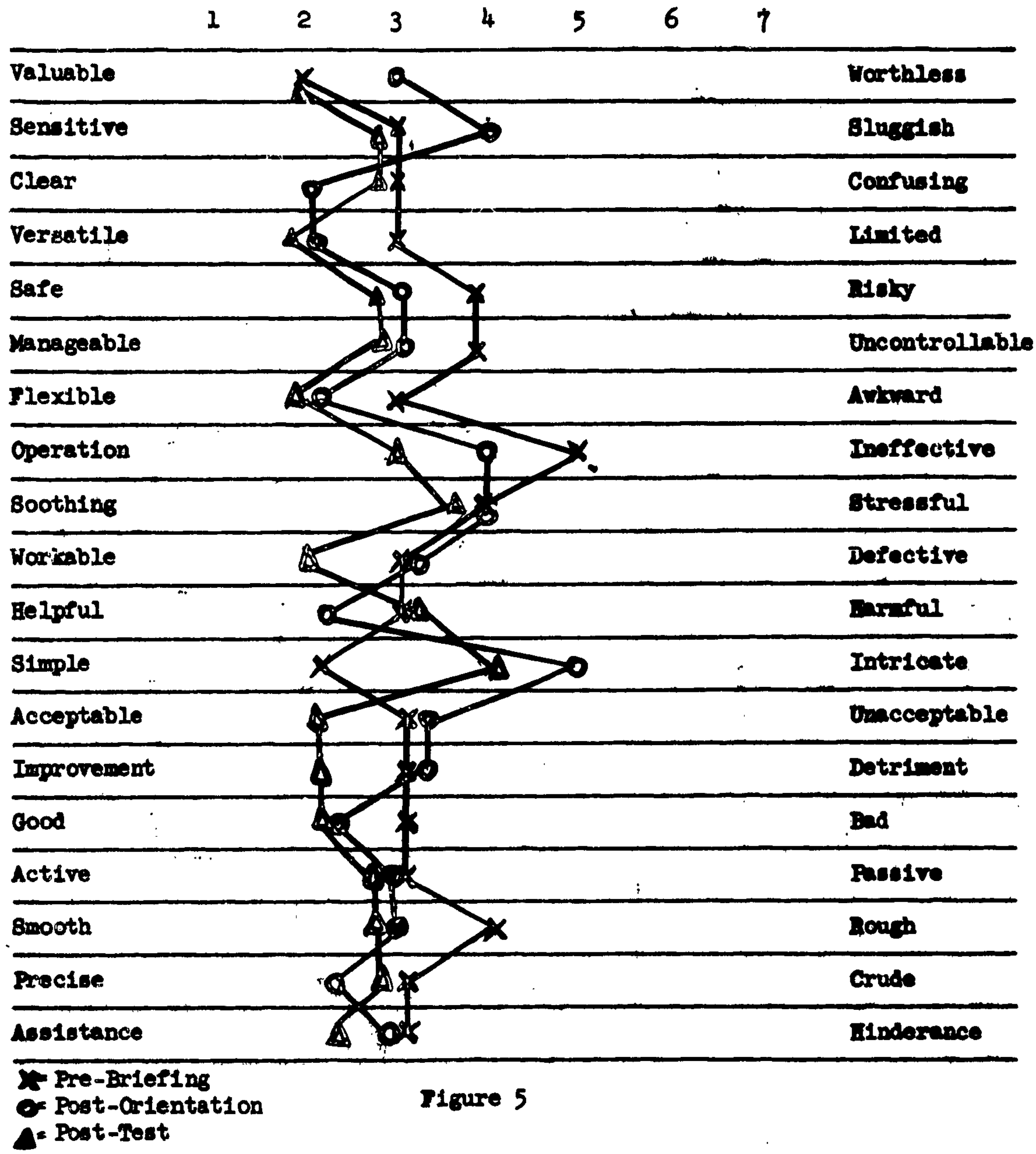

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Figure 5

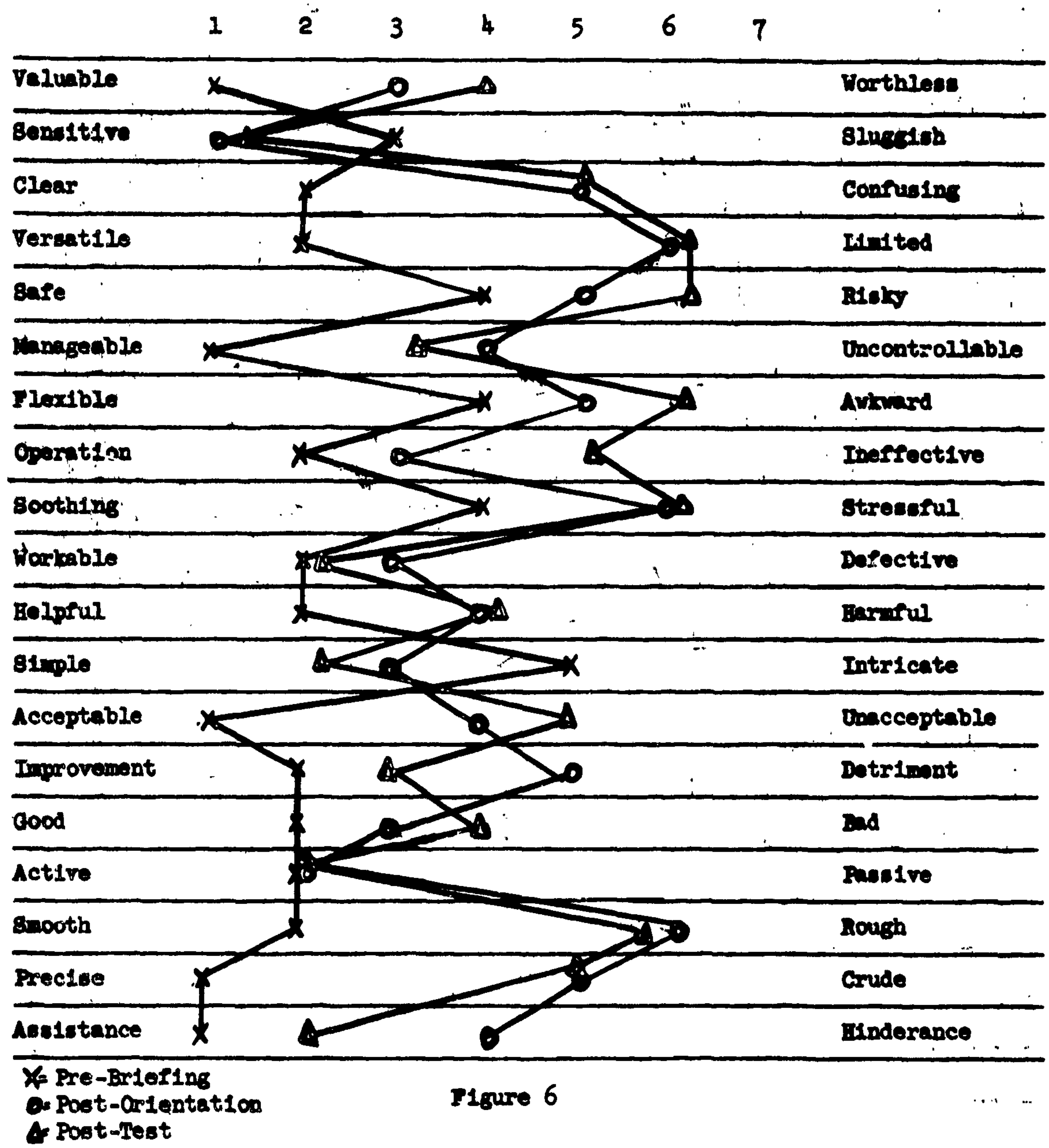
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Figure 6

APPENDIX

FINAL QUESTIONNAIRE

Now that you have completed all of the flights for this investigation we want you to answer the following questions. Answer every question.

I. The first group of questions concern the first part of your "approach", from the outer marker to the middle marker.

	YES	NO
1. Was the display an aid in checking your alignment on centerline?	4	1
2. Could you estimate your altitude from the display?	2	3
3. Were you able to estimate "distance to go" from the display?	1	4
4. Was the image on the display stable enough?	0	5
5. Could you estimate your approach angle from the display?	3	2

6. What about the display was most useful to you during the first part of your approach?
   1. Parallel lights (for alignment with runway)
   2. Use as a localizer
   3. Aid in lining up with runway
   4. Position aircraft on line with the runway
   5. Not useful during first part of approach

II. The next group of questions concern the last part of your approach, from the middle marker to the breakoff point, from micro-vision to VFR.

	YES	NO
1. Was the display an aid to holding centerline?	5	0
2. Were you able to estimate your altitude from the display?	3	2
3. Could you estimate your approach angle from the display?	2	3
4. Could you estimate your airspeed from the display?	0	5

	YES	NO
5. Were you able to estimate your rate of descent from the display?	4	1
6. Did the display provide cues for determining		
Pitch?	5	0
Roll?	0	5
Yaw?	5	0
7. Could you estimate rate of closure with the runway from the display?	2	3

III. The following group of questions are of general interest concerning the display.

	YES	NO
1. Would the addition of more runway beacons significantly improve the display?	5	0
2. Would the addition of approach beacons improve the display?	4	1
3. Would you like a horizon reference on the display?	5	0
4. Would a touchdown point on the display improve it?	5	0
5. Would the addition of a glide slope reference improve the display?	4	1

6. List any other improvements you see that might be made?

   1. Range information
   2. Place display on windscreen - use display with ILS
   3. Center light on approach end of runway
   4. -----
   5. Beacons perpendicular to approach end of runway for indicating position relative to centerline.

	YES	NO
7. Could you easily see the display at all times during your approach?	3	2

	Question	YES	NO
8.	Was it easy to interpret the information given on the display?	3	2
9.	Did you like the position of the display on the panel?	3	2
10.	Were you able to incorporate the display into your normal cross-check pattern easily?	3	2

11. What instrument did you most often cross-check with the display?

    1. HSI
    2. HSI
    3. Heading
    4. Airspeed
    5. Airspeed

	Question	YES	NO
12.	Did you look at the display as often as you look outside during a normal VFR approach?	4	1
13.	Did practice using the display increase your confidence in it?	5	0
14.	Was the display adequately explained to you before you used it?	5	0
15.	Did any function of the display surprise you?	1	4
16.	Did you have adequate practice using the display?	5	0
17.	After practice did you have to work as hard to approach as when on outside VFR?	4	1
	Harder?	4	1
18.	Did the equipment operate as you were told it would?	5	0
19.	Could most pilots adapt easily to the Micro-Vision display?	3	2

20. Where, or at what point of your approach was the display most valuable?
   1. Outer marker to middle marker
   2. Last 300 feet of altitude
   3. During last stages of approach
   4. Last 1/2 mile
   5. Final mile

   Why?
   1. Manageable rate of change
   2. Best use as localizer with less cross-check of heading
   3. It functioned as I expected and was easiest to interpret
   4. Information "broke out" and was easier to interpret
   5. Sufficient size and clear enough to tell position, drift, etc.

21. Could you suggest a better panel arrangement than the one used in this investigation? Explain.
   1. No
   2. Yes, center it (CRT Tube)
   3. Yes, project it on windscreen
   4. Yes, place HSI and vertical velocity indicator on same elevation
   5. Yes

A/S	ADI	Alt
MV	HSI	R/C

22. What limitations, if any, would you place on the use of this display?
   1. Should not be used for low approach until display is proved
   2. Do not recommend it be used for landing minimum less than ILS or in strong crosswinds.
   3. Would not fly without other approach system
   4. Use as transition aid in approaches from IFR minimums to VFR T.D.'s.
   5. 300' 1 mile

23. What were the most valuable characteristics of the system?
   1. The diverging characteristic of the times when near T.D.
   2. Runway alignment the last 1/4 mile.
   3. Runway alignment
   4. Getting closer to zero-zero capability.
   5. Final approach from minimums to over T.D.

24. What other use might be made of this sytem?

1. ?
2. Don't know
3. ?
4. Use for approach to small field and at night
5. Possibly establish and present glide slope

25. What was the major difficulty you encountered using the system?

1. Shaking of dots
2. Over correcting -- very poor altitude vs. range control
3. Hitting the runway
4. Altitude determination as I approached end of runway and confusion over runway presentation after over T.D.
5. Trying to estimate shift correction needed and vertical descent to establish.

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

MEMORANDUM REPORT: 62-9. 20 September 1962

Task No.: 15

To: C. A. Gainer

cc: Mr. S. G. Hasler, Mr. J. H. Kearns, Mr. N. McGregor, Capt. C. E. Waggoner, and all members of the Martin Human Engineering Group.

From: Barbara J. Kelso

Subject: Workstatement for Scale Factors for Moving Tape Instruments

---

Introduction

It is often the case that flight demands require aircraft instruments to be installed before experimental evidence can confirm the selection of certain design parameters. (i.e. size of graduation marks, spacing of numbered units, etc.) Past research on instrument design has yielded a wealth of information concerning the effect of physical design variables on the reading of instruments. Readers are herein referred to 8, 15, and 28 for excellent summaries of work done in this area. As evidenced, the research has been confined to studies on circular instruments. Time and flight requirements however, have necessitated generalizations of results of these studies (from circular instruments) to vertical instruments without the endorsement of experimental evidence.

Since the favorable results of the USAF Vertical Instrument Program (2), more consideration has been given to development of vertical displays with moving tapes. Research in this realm, however, has been confined to analytical or experimental work (on vertical displays) for specific flight parameters, such as altitude, or mach. (see 7, 9, 10, 11, 21, 22, 23, 26, 27) In the search for more efficient means of displaying information in high performance aircraft, increasing use has been made of vertical instruments; yet little experimental work has been done on identifying those scale variables that effect speed and accuracy of reading moving tape instruments. Work of this nature, in addition to simplifying pilots' task of interpreting information, would facilitate the screening of preliminary display designs for vertical instruments.

It is the purpose of this paper to outline an experimental approach of identifying those scale characteristics that contribute to reading speed and accuracy. Mr. Charles A. Gainer of Martin Human Engineering Group initiated direction of the proposed study on scale factors. His analytical works on scaling of vertical displays can be found in Martin Memoranda Numbers 36, 101, and 155 (ref. No. 9, 10, and 11 respectively).

Statement of the Problem

In order to secure data on scale characteristics that will provide known degrees of reading accuracy, it is proposed to conduct a study on scale factors -- defined as size of the interval between numbered units -- for moving tape instruments. The study will be carried out in two phases; (a) Static Legibility Investigation, and (b) Dynamic Tracking Situation. Details of Phase B will be specified at a later date since they will be directed by the results of Phase A.

The purpose of Phase A will be to identify those scale characteristics that contribute the greatest -- either singly, or in combination -- to scale resolution (legibility). Resolution will be determined by amount of error occurring -- error being the absolute magnitude of deviation of a subject's reading from the "true" reading. More will be said of this measure further in the memo.

Typically aircraft instruments are read by 10, 100 or 1000. For example, the aircraft heading is numbered 3, 6, E, 12, etc., when in fact it is read as 30, 60, E, 120, etc. The altimeter is numbered 1, 2, 3, 4, etc., and actually is read 1000, 2000, 3000, 4000, etc. Therefore, provisions have been made to give prime consideration to the effect of scale factors on the accuracy to which the scales can be read by 10, 100, or 1000. For the purpose of this experiment, these will be labelled powers of 10; 10^1, 10^2, and 10^3.

It is expected that results from the static legibility investigation will yield curve information of reading error vs. scale length depicting an increase in error associated with increasingly smaller scale factors. At the other end of the continuum, if the scale factor is large enough so that only one number could be seen, it is expected that errors would again increase because of lack of "directional" cues to the reader. This latter expectation, however, will not be investigated in the present study. Thus, given a specified error tolerance, the scale factor that is "best", or stated in another manner, the scale factor (of those under investigation) that results in the greatest resolution or least error, can be selected directly from the curve.

FIG I.

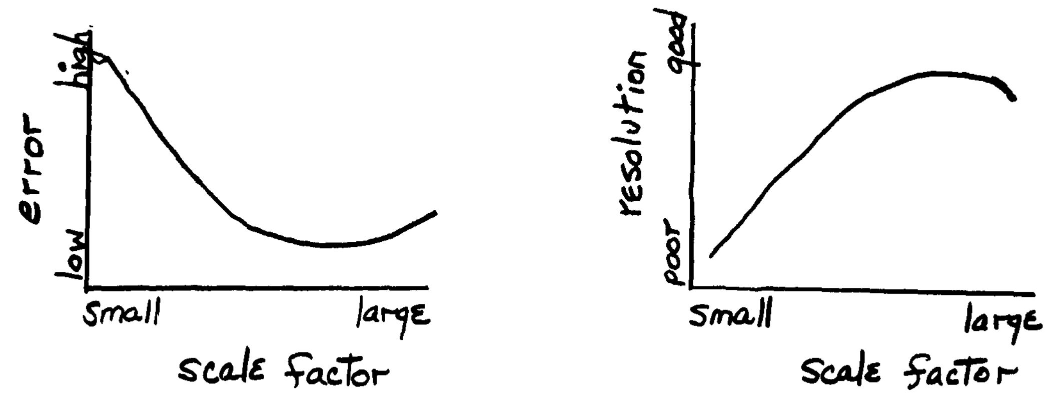

Figure 1. Note that the curve on the right is the reciprocal of the curve on the left. Results of the study will be expressed in one of these forms.

W. F. Grether (13) reports essentially the same type of curve information, although his results were a function of dial diameter, along with spacing of scale divisions. The expectation that expansion of a scale tends to improve performance is given further credence by results of the following studies (12, 21, 22, 23, 24). On examining their reported performance differences on circular displays vs. vertical displays, those displays -- whether circular or vertical -- having the greater scale factor, resulted in better performance scores.

After delineation of the scale variables that contribute the greatest to resolution, it would be operationally valuable to test them in a dynamic tracking situation -- Phase B. In this phase, moving tapes instead of static pictures of scales, will be used. Rates of tape movement will be specified at a later date. Using the same variables as in Phase A, the information derived from Phase B will presumably allow construction of two additional curves; reading error vs. rate of tape movement, and reading error vs. scale length.

This first curve should show an increase in errors as the tape movement becomes more rapid, so as to eventually cause "running together", or blurring of the numbers.

The second curve resulting from Phase B would not be separate and distinct from the reading error vs. scale length curve in the static study. Rather, it should yield data comparable with this latter curve, provided the following assumptions are borne out; (1) results from Phase A conform to previously established expectations, (2) addition of rate of tape movement variable does not change the main effects and interactions of the experimental variables reported in Phase A.

From the static and dynamic studies, the ingredients necessary to fulfill the prupose of the scale factors program will have been established. Given a specified numerical range to be covered and the reading accuracy required in the use of the instrument, it would now be possible to specify, with a known statistical probability, the degree of accuracy that can be achieved with a given scale factor and also a given rate of tape movement.

Readers may wonder at this point why it is necessary to do a static display study first, rather than incorporating the program into one dynamic experiment. Several considerations entered in the decision to utilize two phases. In a research program, such as this, it is important to assess the relative effects of the scale variables to get a base line measure of their contributions. Incorporating a movement variable in the same study would serve to confound the effects of the scale variables. It would demand inclusion of other variables to consider, such as motor skill, type of control stick to use, etc., such that isolation of the effects of the scale variables would be difficult. Secondly, since the static study will allow us to isolate the variables considered to be important, we will be in the position to determine the effects of these variables and their interactions. It may be that scale factors, assumed in this experiment to be a major contributor to scale reading accuracy, turns out to have a minimal effect. Although there is a small possibility of such an occurrence, there has been far too little research done on the contributions of various markings enhancing readability of vertical scales, to warrant an inclusive dynamic study. Finally, overall cost of the program can be kept down. The proposed static study requires simple and inexpensive equipment. But more important, any changes needed to continue the study, due to results from the static investigation, can be done without retrofit of equipment, or repeating the entire experiment.

The remainder of this paper will be devoted to detailing the experiment for Phase A -- Static Legibility Investigation. A memo specifying experimental design for Phase B will appear later.

Variables under Investigation -- Phase A

Scale reading is affected by so many display, environmental, and reader characteristics that it would be difficult to study all but a few of those related to the experimental task. Below are listed the independent variables expected to contribute significantly to legibility of straight scale instruments.

(1) Scale Factors -- Defined as size of the interval between numbered units.

The three experimental interval sizes will be 1-3/8 inches, 1-7/8 inches, and 2-3/8 inches. Using these values, the maximum number of numbered units showing at any scale position (read line is fixed) will be 5, and the minimum number, 2. More than 5 numbers viewed on the scale would tend to clutter the display. Fewer than 2 numbers would hinder anchoring of the read line setting, so that readers would have difficulty in determining either direction or progression of the scale numbering system.

Loucks (20) and Grether (13) studied to some extent, the spacing of numbered divisions on circular instruments. Although these studies differed in purpose and experimental design, they concurred that closely spaced marks tends to reduce reading accuracy. Of particular interest are Grether's specifications in fractions of an inch for spacing of marks and the corresponding reading accuracy obtained. Hopefully, this study will result in quantitative specifications for straight scales.

(2) Number of Graduation Marks -- Graduation marks defined here as minor unit marks between the scale factors.

Accuracy of scale reading is also a function of the graduation scheme employed. Experimental conditions for this variable will be one, three, four, nine, and "no" graduation marks. The first four conditions are consistent with "preferred" graduation schemes, (1) and represent the ranges of minimum and maximum graduation aids currently in use. The last condition -- "no" marks -- will help to determine the relative importance of graduation aids, and will point up subjects' characteristic ways of interpolating between numbered units.

(3) Powers of 10 -- As used in this study, powers of 10 will refer to the factor of 10 by which the scales will be read.

The three experimental conditions (or attitudes) by which subjects will read the scales are by (x) 10, (x) 100, and (x) 1000. Number of digits for all numbered units will be constant at 2.

To illustrate, let us suppose the read line is positioned exactly midway between 37 and 38. Those subjects reading a scale x 10 would read 375; x 100, the read line value is 3,750; and x 1000, read line value is 37,500. This attitude of reading is no different from scale reading demands of current instruments. For example, the altitude scale is read x 1000, airspeed is read x 100, and the heading indicator is x 10.

(4) Orientation -- Refers to the plane in which the scales will be presented.

The 2 conditions here will be vertical, and horizontal. Up to this point, experimental conditions have been described in reference to vertical scales. Some horizontal scales have been incorporated in experimental aircraft as an alternative means of displaying information. Inclusion of this variable for investigation will permit a direct comparison with vertical scales on the legibility and accuracy that can be achieved with such scales.

The manner in which these four independent variables will be studied is described under Experimental Design.

Equipment

Stimulus materials will be presented by a tachistoscope equipped with a sliding carriage with the capacity to hold 150 slides. Rates of exposure and intervals between exposures will be automatically controlled by two electric timers. Pre-exposure and exposure fields will be a homogeneous white screen 20.5 inches high and 22.5 inches wide. Brightness of both fields will be held constant as will the background illumination.

Tachistoscope and screen will be mounted on a table. An adjustable chair will be provided for subjects, and also for the experimenter. A control button with a lead wire to the tachistoscope will be mounted on the edge of the table in front of the subjects within easy access. Upon determining a reading, subjects will depress the button which will automate the electric timers that are wired to control stimulus exposures at appropriate intervals. This is described further under Procedures.

Stimulus Materials

Thirty tape segments, each 7" x 1", will be constructed, one for each of the graduation mark conditions per scale factor in each orientation. (see figures 2 and 3) Permanent design features on the tapes will be the numbered unit marks, and graduation marks, the dimensions of which are specified further in the memo.

So that additional tape segments will not have to be constructed, the numbers will be printed on clear plastic strips 1-1/2" x 1/2". The strips will be hung from pins that are located on each side of the tape at the positions required according to the numbered unit marks. Ninety-two plastic strips will be needed for the vertical tapes to represent consecutively the numbers 9 through 102. For the horizontal tapes also, 92 strips will be needed giving a total of 184 plastic strips.

Figure 2

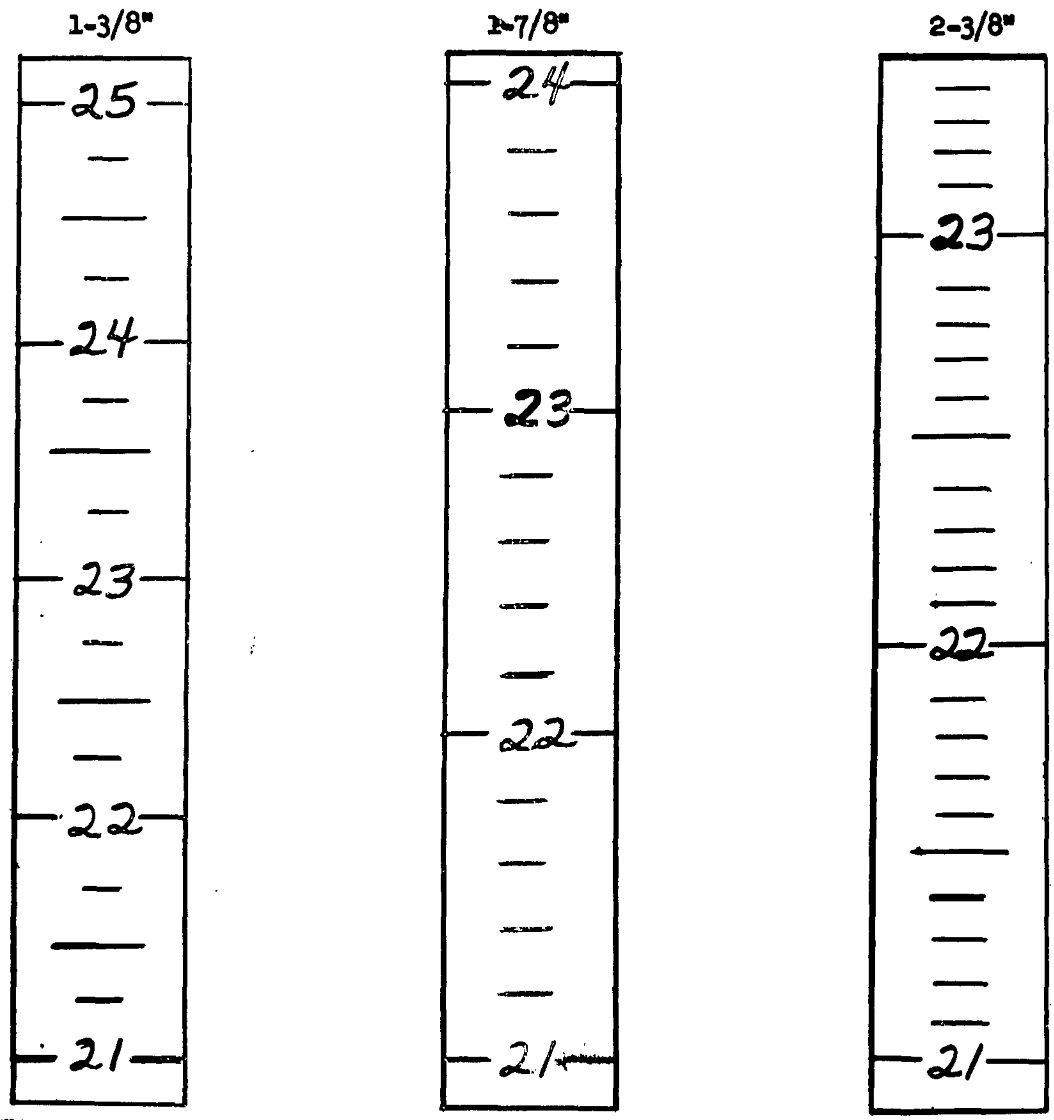

Figure 2. Sample of Vertical Scales Depicting the 3 Scale Factors, and 3 of the 5 Graduation Mark Conditions.

Figure 3

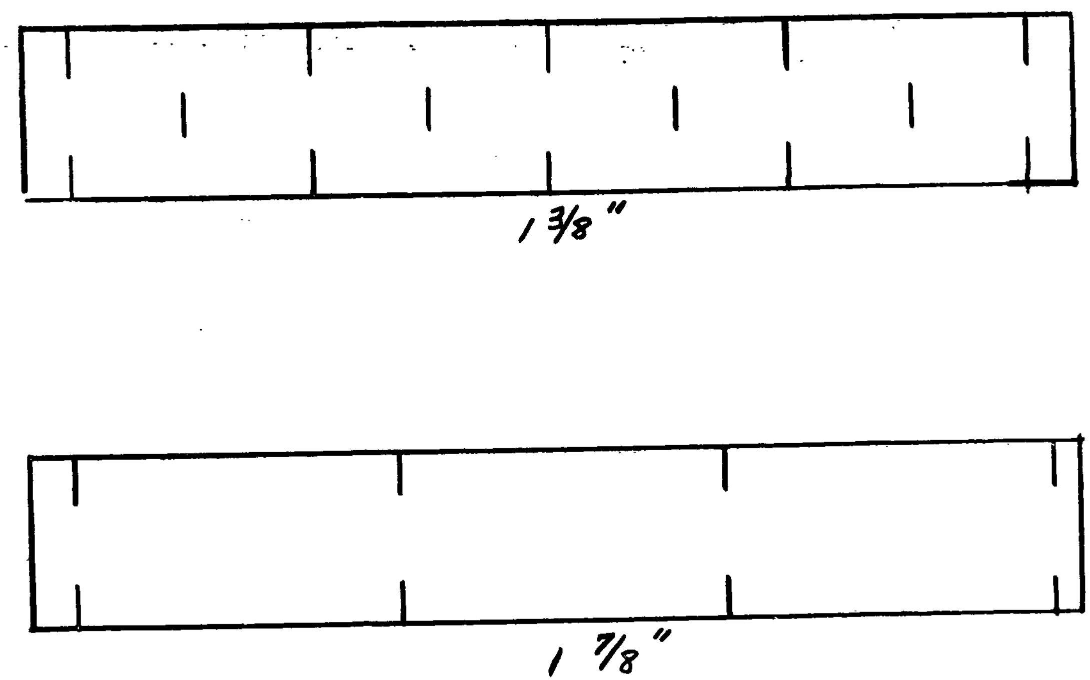

Figure 3. Sample of horizontal scales depicting the 1-3/8" scale factor with 1 graduation mark, and the 1-7/8" scale factor with no graduation marks.

Two black instrument cases with the permanent read line drawn on the glass window in the proper orientation, will be properly aligned and fastened over each tape segment in turn. Dimensions of the cases will be such as to allow the viewing of a 6" x 1" tape.

Individual pictures for each read line setting will be taken, and slides made from the negatives, which will consequently project black markings on a white background. To eliminate "shuffling around" of the slides during the testing period, two or three slides will be made of each read line setting, for a total of 150 slides.

In order to insure accuracy of read line settings, drawings of the scales will be tripled in size so that the tape segments will actually be 21" x 3". Pictures to be taken will then be photographically reduced such that projection size of the tapes will be 7" x 1" at a 28" viewing distance.

The specifications for scale markings given below are in reference to a 7" x 1" tape segment.

Specifications for Scale Markings (see Figure 4)

Digits

1. Digits will be located in the center of the tapes, progressing low to high from left to right on the horizontal scales, and from bottom to top on the vertical scale.

2. Recommended numeral style is MILSPEC (25) (MS 33558 ASE)

3. Height of the digits will be .25 inches.

4. Combined width of the digits is not to exceed .40 inches except - for 1-3/8" horizontal scale with 9 graduation marks digit width is not to exceed 0.25". Height of digits in this latter case will be in the same width - height ratio as used for the other numbers.

Graduation Marks

1. Graduation marks will be located in the center of the tapes in a horizontal orientation for vertical tapes, and in a vertical orientation for horizontal tapes.

2. They will be equally spaced throughout a particular scale factor, although size of the spaces will be different across graduation mark conditions.

Figure 4

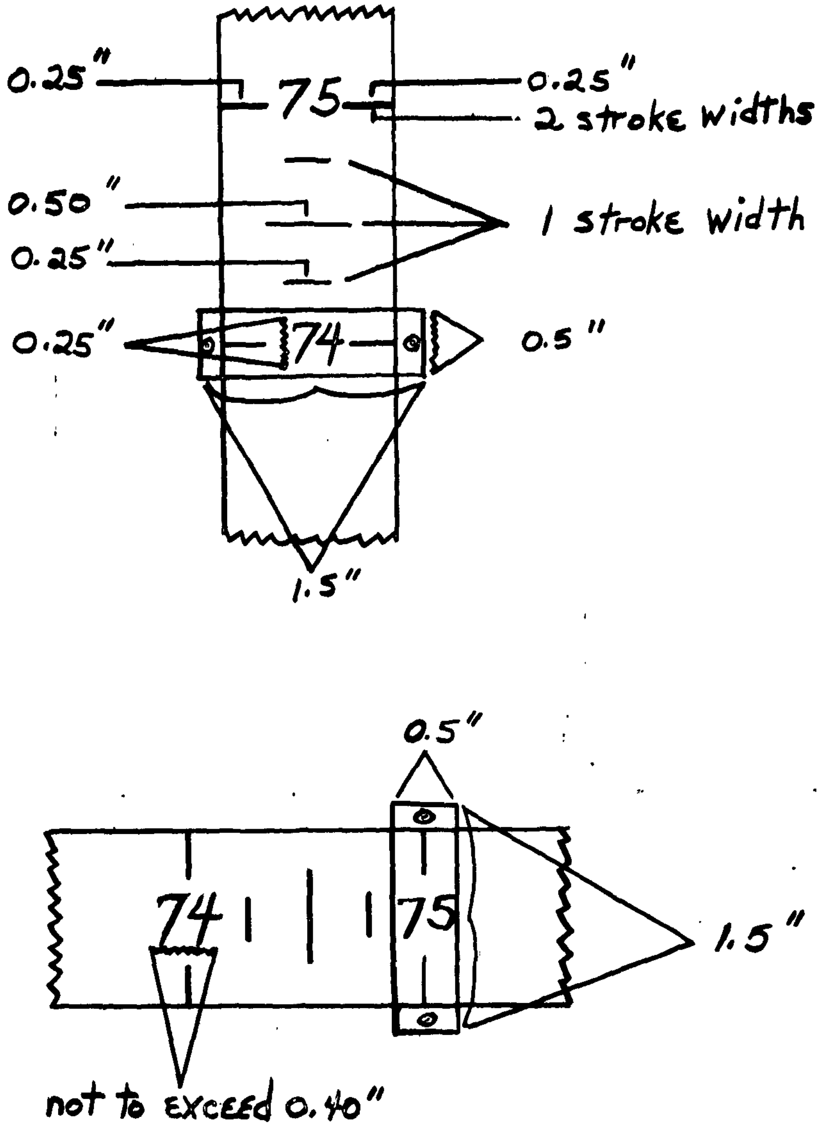

Figure 4. Portions of a vertical and a horizontal tape depicting scale marking dimensions to be used. Dimensions of the graduation marks, numbers, and major numbered units will be the same for both the vertical and the horizontal scales, with the one exception noted in the context of the workstatement.

3. Length of the graduation marks will be .25 inches, except for the middle mark when 3 or 9 graduation marks are used. The middle graduation mark will be emphasized in length -- .50 inches -- to enhance readability of the scales.

Numbered Unit Marks

1. Numbered unit marks will be located on each side of the digits and will be slightly wider than the one stroke width graduation marks -- again to enhance readability.

2. On vertical scales, they will be perpendicular to the digits and centered according to height of the digits. On horizontal scales they will be perpendicular to the digits and centered according to the combined width of the digits.

3. Numbered unit marks will extend from the edge of the tapes to a length of .25 inches on each side of the digits.

Read line indicator will be one stroke width.

Subjects

Since there are reportedly no differences between naive and experienced subjects for this type of task, (6) it would be more practical to secure naive subjects. It is currently planned to use 150 male ROTC students with 20/20 vision -- corrected or uncorrected. Subjects will be secured from the local colleges.

Experimental Design

Partial Hierarchical -- Fifteen groups of 10 subjects each will be used. Each group will represent one of the 15 possible combinations of graduation marks (M) and scale reading conditions (P). Thus:

	Number of Grad. Marks	Scale Read X
Group 1 M_1P_1	1	10
Group 2 M_1P_2	1	100
Group 3 M_1P_3	1	1000
Group 4 M_3P_1	3	10
Group 5 M_3P_2	3	100
Group 6 M_3P_3	3	1000
Group 7 M_4P_1	4	10
Group 8 M_4P_2	4	100
Group 9 M_4I_3	4	1000
Group 10 M_9P_1	9	10
Group 11 M_9P_2	9	100
Group 12 M_9P_3	9	1000
Group 13 M_0P_1	0	10
Group 14 M_0P_2	0	100
Group 15 M_0P_3	0	1000

All subjects within all groups will receive in combination, all other treatments, namely the three scale factor (S) conditions; S_1 1-3/8", S_2 1-7/8", S_3 2-3/8", within each orientation -- vertical (O_v) and horizontal (O_h).

Time and error scores will be made on all readings for each subject. Reaction time is defined as the time elapsed from the exposure of a scale, to subject's depressing the button. Error is defined as any deviation of a subject's verbalized reading from the "true" reading, and (after a subject completes the task) will be expressed as the absolute magnitude of this deviation. During the test trials, experimenter will only record subject's verbalized reading and reaction time.

Both time scores and error scores will be subjected to analysis of variance. In terms of main effects, the interest is in determining if there are significant performance differences among the scale factors, graduation marks, scale orientation, and factors of 10. The analysis used will also provide information as to the significance of the interactions. Subjects scores will be treated to assess the relative effects of differences across groups.

Graphs will be drawn up depicting frequency and percentage of errors against scale factors and corresponding design features. Reaction times will also be plotted against the scale variables.

Analysis of variance summary table, and model of the experimental design appear below.

Model

AB CD S/CD
A Scale Factor
B Orientation
C Graduation Marks
D Factor of 10
S Subjects

Source		df
C (5)	C-1	4
D (3)	D-1	2
C x D	(C-1)(D-1)	8
S/CD	(S-1)(CD)	285
A (3)	(A-1)	2
A x C	(A-1)(C-1)	8
A x D	(A-1)(D-1)	4
A x S/CD	(A-1)(S-1)(CD)	570
A x C x D	(A-1)(C-1)(D-1)	16
B (2)	(B-1)	1
A x B	(A-1)(B-1)	2
B x C	(B-1)(C-1)	4
B x D	(B-1)(D-1)	2
A x B x C	(A-1)(B-1)(C-1)	8
A x B x D	(A-1)(B-1)(D-1)	4
B x C x D	(B-1)(C-1)(D-1)	8
B x S/CD	(B-1)(S-1)(CD)	285
A x B x S/CD	(A-1)(B-1)(S-1)(CD)	570
A x B x C x D	(A-1)(B-1)(C-1)(D-1)	16
A x B x C x D x S	90 x 20	(1800-1)
	Total Degrees of Freedom	1799

The tests for significance of the main effects and the interactions are accomplished by the term that represents the interaction of that effect with subjects. For example:

$C/s|CD$ $D/s|CD$ $A/A\ s|CD$

$B/B\ s|CD$ $AB/AB\ s|CD$

$AD/A\ s|CD$ $AC/A\ s|CD$ etc.

Procedure

Subjects will be randomly assigned to one of the 15 groups. Standardized instructions will be given to all subjects on general procedures and operation of the equipment. Additional instructions, standardized within groups, will point out particular features of the scales, including the graduation scheme and 10's factor by which the scale is to be read.

Subjects will be told to read the scales as accurately as possible. Accuracy will be stressed since it is essential to determine the degree of accuracy to which the different scales can be read. To ease the interpolation task, subjects will be permitted to view the scales for as long as it takes them to determine the read line setting. This is in accordance with natural dial reading situations.

Knowledge of results will be given after each practice trial, (but not after the test trials) and subjects will be invited to re-examine any readings that are missed. A five minute rest period will be provided between practice and test trials to answer any questions about the task.

Each subject will make 150 readings, equally divided among the six scales in his group. Read line settings were chosen to sample nine different areas within an interval, and to systematically represent the tape ranges from 11 to 99. Read line settings involving the zero digit were intentionally omitted because of reported confusion of interpolation associated with this digit (ref. 18).

Of the 54 settings listed, each of 42 settings will be presented three times during the test trials to insure stability of subject responses. For practice trials, the remaining 12 settings will be presented twice. It is assumed that subjects will have learned the task within the 24 practice trials, however, this is subject to pre-experimental verification.

Read Line Settings

Vertical Orientation

1-3/8"	1-7/8"	2-3/8"
34.7415 (P)*	21.7415 (P)	98.7415(P)
93.5681 (P)	44.5681 (P)	37.5681(P)
86.1573	62.1573	71.1573
22.2327	85.2327	13.2327
47.8244	77.8244	89.8244
65.9856	38.9856	54.9856
51.3939	99.3939	66.3939
78.4768	16.4768	25.4768
19.6192	53.6192	42.6192

Horizontal Orientation

1-3/8"	1-7/8"	2-3/8"
11.7415 (P)	63.7415 (P)	83.7415 (P)
69.5681 (P)	27.5681 (P)	74.5681 (P)
28.1573	94.1573	49.1573
92.2327	56.2327	68.2327
57.8244	35.8244	15.8244
43.9856	81.9856	97.9856
76.3939	12.3939	31.3939
84.4768	48.4768	52.4768
36.6192	79.6192	26.6192

*Practice

Scales will be presented in alternating series based on orientation i.e., in sets of 6 vertical, 6 horizontal, etc., for the practice trials, and in sets of 21 for the test trials. This breaking up of the task should help reduce monotony and fatigue effects for the subjects. The series will be counterbalanced within groups such that 5 subjects in a group will start with a V series, then H. The other 5 will start with an H series, followed by a V series. Order of presentation within a series will be randomized to eliminate systematic effects of scale factors, orientation, or read line settings. Two five-minute rest periods -- one after each group of 42 readings, will be provided.

The experiment will be conducted in the following manner. A subject will be seated in an adjustable chair at a 28 inch viewing distance from a projection screen. The experimenter will describe the task and demonstrate operation of the equipment. Between scale exposures, subjects will fixate on the crosshairs projected on the center of the screen. This is necessary to keep subjects variations in eye movements to a minimum. Christensen (5) reports significant effects on results -- both quantitatively and qualitatively -- with small changes in directed point of fixation. Upon scale exposure, the read line indicator will appear in the same location as the crosshairs.

When the subject is ready, the experimenter will slide a scale in place and an electric timer will automatically start. The subject will press a button on determination of a reading, and simultaneously call out his answer. Activation of this button will remove the scale from the screen thus stopping the electric timer, and will start up another electric timer which will run for a specified and adequate time interval, during which the experimenter will record subject's answer and response-time on a prepared form. At the termination of this constant time interval, another scale will be automatically exposed and the procedure will be repeated. Controlling the time interval from the end of one exposure to the beginning of the next will help to standardize and facilitate experimental procedures. Subjects will be informed of the controlled time interval and thus be prepared for each reading. Estimated total time for each subject is 50 minutes.

Planned Time Table of Events -- Phase A

1.	Workstatement by	Sept. 20, 1962
2.	Equipment Fabrication completed	Oct. 31, 1962
3.	Pre-experimental runs begin	Nov. 3, 1962
4.	Experimental runs begin	Nov. 10, 1962
5.	Experimental runs completed	Jan. 1, 1963
6.	Data reduction by	Jan. 21, 1963
7.	Data analysis completed	Feb. 1, 1962
8.	Write-up begins	Dec. 15, 1962
9.	Write-up completed	Feb. 28, 1963

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AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

Memorandum Report No. 62-10 28 September 1962

To: Capt. White (ASTFF), Capt. Harley (ASTFC) and Lt. J. Hall (ASRMCS-1)

From: C. A. Gainer

Subject: Summary of the Results of the Questionnaire Used During the Inflight Evaluation of the Pilot Orientation Instrument (Lifesaver).

Objective and Summary

The flight test was accomplished to determine if the Lifesaver instrument was effective in providing adequate information to assume a wings level - 180 degree heading. The test was performed in both jet and cargo aircraft and each test was conducted in as similar a manner as possible. There were maneuvers that were unique to each aircraft but the same questionnaire with minor adjustments was used in both situations. Thus, the following report includes the results from both aircraft types.

There were 28 pilots used -- fourteen for each aircraft type.

The results tended to imply a favorable outlook toward the instrument but that it would need some minor alterations. It seems that the more experience the pilots received with the instrument the more favorable their outlook. Certain limitations of the instrument became apparent as was demonstrated in the vertical roll maneuver, but, in general, recoveries from extreme attitudes could be made. It must be remembered that none of the above conclusions should be taken without reading in detail the results of the questionnaire.

Introduction

The questionnaire used to measure the pilot subjects' evaluations of the Lifesaver was organized into six parts. Part II was a seven step rating scale on a like-dislike continuum; subjects were asked to indicate their degree of liking or disliking the instrument during each of the maneuvers they were asked to perform. Part IV allowed the pilot more freedom of expression than Part II; it contained questions of a general nature designed to elicit specific comments about the display. Pre and post-flight "semantic differentials" were Parts I and VI respectively. A brief statement from Martin Memorandum Report 61-23 which describes in detail the development and use of the semantic differential will clarify its meaning.

"By definition the semantic differential is a combination of word association and scaling techniques designed to pull out inherent feelings. In this case an instrument is rated on a seven point scale bounded by polar adjectives, e.g., safe-risky, sensitive-sluggish, etc. The seven part scale is qualified by adverbs; the greater the intensity of feeling, the more extreme the displacement towards one or the other polar terms. This instrument was rated pre-flight and post-flight so that a semantic profile of the attitude can be established before flight and then compared to the attitude after flight. By computing Ds (the generalized distance function in n-dimensional space) the geometric relationship between concept or meaning may be formed."

Parts III and V were the split-ballot questionnaire which is a technique whose development and rationale are described in Martin Memorandum Report 61-21. The split-ballot questionnaire consists of a series of questions which pertain directly to various components of the display. Half of the questions are designed to elicit a "positive set" -- they are what is commonly known as "loaded" and are worded in such a way as to influence the pilot to comment positively about the display in question unless his opinion is strong enough to cause him to resist the influence of the question and answer in a contrary manner. The "positive set" is complemented by a "negative set" which tends to elicit negative comments about the instrument being evaluated unless the pilot has a strong positive feeling. A typical split-ballot couplet might consist of one question which asked if the instrument should be adopted and a second part which asked if it should be discarded. Identical responses to both questions, i.e. both "yesses" or both "nos" are interpreted as indicating contradictory or inconsistent feelings or a lack of strong feelings towards the instrument. The advantage of the technique is that it allows one to determine which opinions are strong. Much effort is being exerted to increase the validity of the inferences about the significance of identical responses to both questions in a split-ballot couplet by attempting to create new question pairs and redesign ones already used so that they are perfectly matched "positive" and "negative set" in that questions about the same aspect of the display will be worded so that they exert the same amount of influence over the subject to answer in a particular manner.

The evaluation of the Lifesaver which will soon be summarized was made by pilots whose current status are that of highly qualified Air Force pilots. Fourteen of the pilots had jet fighter background and fourteen had multi-engine cargo background. The primary duty of the subjects was either Fighter Test Operation or Cargo Test Operation. All subjects seemed to be cooperative and quite motivated.

Summaries of the results of the pilot evaluation of the Lifesaver will be described in terms of the parts enumerated above which will in turn have subsections on the questionnaire results of the Cargo, Fighter and Cargo and Fighter groups combined.

Method

Each subject was given a very general briefing about the experimental instrument and was then requested to rate this concept (Part I). He flew the instrument in the aircraft appropriate to his specialty. At the conclusion of his flight he filled out the questionnaire in the order of the numbered Parts II-VI.

Subjects

The pilots who participated in this study were highly qualified Air Force pilots on current status. They were from two pilot types. The first 14 had jet fighter background, and 14 had multi-engine cargo background. All pilots were assigned as primary duty to either the Fighter Test Operation or Cargo Test Operations. All subjects were observed to be cooperative and quite motivated.

Task

Two profiles were used one for cargo and one for fighter. These were as similar as possible, but it is obvious that they could not be the same. These profiles are specified below:

Test Profiles

The following maneuvers for cargo aircraft, were used in order and and the headings and banks listed were the conditions.

Heading 270 degrees straight and level
Heading 360 degrees nose low
Heading 180 degrees 45 degrees right bank
Heading 270 degrees nose up
Heading 160 degrees bank 45 degrees left
Heading 135 degrees nose high

Heading 225 degrees nose low
Heading 135 banked 45 degrees extremely nose high
Heading 335 degrees slightly nose low
Heading 45 degrees slightly nose high
Check level turns
Heading 180 degrees check "g"
Heading 180 degrees check accel and deccel

The profile used for the jet aircraft is as follows: The takeovers also occurred in the listed points.

Heading 270 degrees wings level
Heading 45 degrees inverted nose high
Heading 355 degrees inverted nose low
Heading 180 degrees 90 degree right bank nose high
Heading 160 degrees 90 degree left bank
Heading 360 degrees with nose low
Heading 225 degrees vertical call
Heading 335 degrees inverted nose low
Heading 90 degrees wings level
Spin

Semantic Differential

The semantic differential questionnaire consists of polar adjective pairs which have been selected because it is felt that they can measure generalized positive or negative feelings and that they represent aircraft system dimensions which are salient to the subjects' judging the Lifesaver. Fulfilling both conditions is difficult as often those adjective pairs which have the proper degree of vagueness to elicit general positive or negative feelings are so vague that they seem to the pilot population inapplicable to aircraft systems. The pre-flight profile's shape expresses the pilot's preconceptions of the Lifesaver and if the adjectives are well chosen in terms of the requirements just stated, the shape of the post-flight rating profile should be similar. It is felt when the shapes of these profiles diverge it is because the adjective pairs becomes too system specific to tap the overall feelings. The pairs instead elicit differential feelings about different aspects of the instrument and/or the meaning of the adjectives are not stable, in the minds of the subject because they seem to them to have no distinct relation to aircraft systems. (When the rating positions of a profile approach the limits of the scale a situation can arise in which adjective pairs may be well chosen but pre- and post-flight profiles still vary in shape. At the limits of the scale the profile shape is distorted and expected to "straighten out" because the subject does not have the opportunity of more intense ratings). In short, the primary consideration in interpreting semantic differential profiles is the comparative shapes and positions of different profiles -- varying positions can indicate a change of overall attitude towards an instrument, whereas degree of similarity between shapes permits evaluation of to what degree the adjective pairs are well chosen and changes in profile position can actually be validly interpreted as a change of attitude.

Various figures aid in the interpretation of the general attitudes of subjects towards the Lifesaver. Figures 1, 2, and 5 indicate pre- and post-flight semantic differential ratings for the Cargo subjects, the Fighter subjects and the Cargo and Fighter subjects combined respectively. Figure 3 shows the pre-flight semantic differential ratings of the Cargo and Fighter groups separately; Figure 4 offers the same information for post-flight. Each of these Figures will be discussed qualitatively and then quantitatively.

Figure 1, which describes the mean post- and pre-flight semantic differential ratings of the Cargo subjects, shows some constancy in the shapes of the two profiles and a trend towards a more favorable evaluation of the Lifesaver after some experience with it. The greater constancy of the profile shapes and the consistent shift of the post-flight ratings to a position which describes the Lifesaver more favorably than the pre-flight ratings shown in Figure 2 indicates that the adjective pairs are more general and/or more applicable to aircraft systems in the minds of Fighter subjects. Even more similar than the profiles in Figure 2 are those in Figure 3 which indicate that there is a certain homogenity in the preconceptions which Fighter and Cargo groups held about the "goodness" and "badness" of the Lifesaver. Figure 3 shows that in all cases but one, the Cargo group's profile's positions are more favorable to the Lifesaver instrument than the Fighter group's. One would expect that after identical experiences with the Lifesaver the degree of shift in profile rating postiions would be similar for both groups and that the changes positions of the post-flight profiles would bear the same relation to each other as the original pre-flight profiles' positions did. Figure 4 shows that this expectation is disappointed and that there is a greater discrepancy between the post-flight positions of the Cargo and Fighter profiles than the pre-flight positions of the Cargo and Fighter profiles than the preflight positions of the profiles of these groups. Figure 4 indicates that identical flight experience did not impress Fighter pilots as favorably as Cargo pilots. The particular adjectives which are downrated on the Fighter profile are interesting. It is possible that dissatisfaction with the vertical roll maneuver while using the Lifesaver influenced the fighter group. Probably the adjectives downgraded by the Fighter group did not have as specific a meaning to the Cargo as the Fighter Group since the standards of what constituted satisfactory

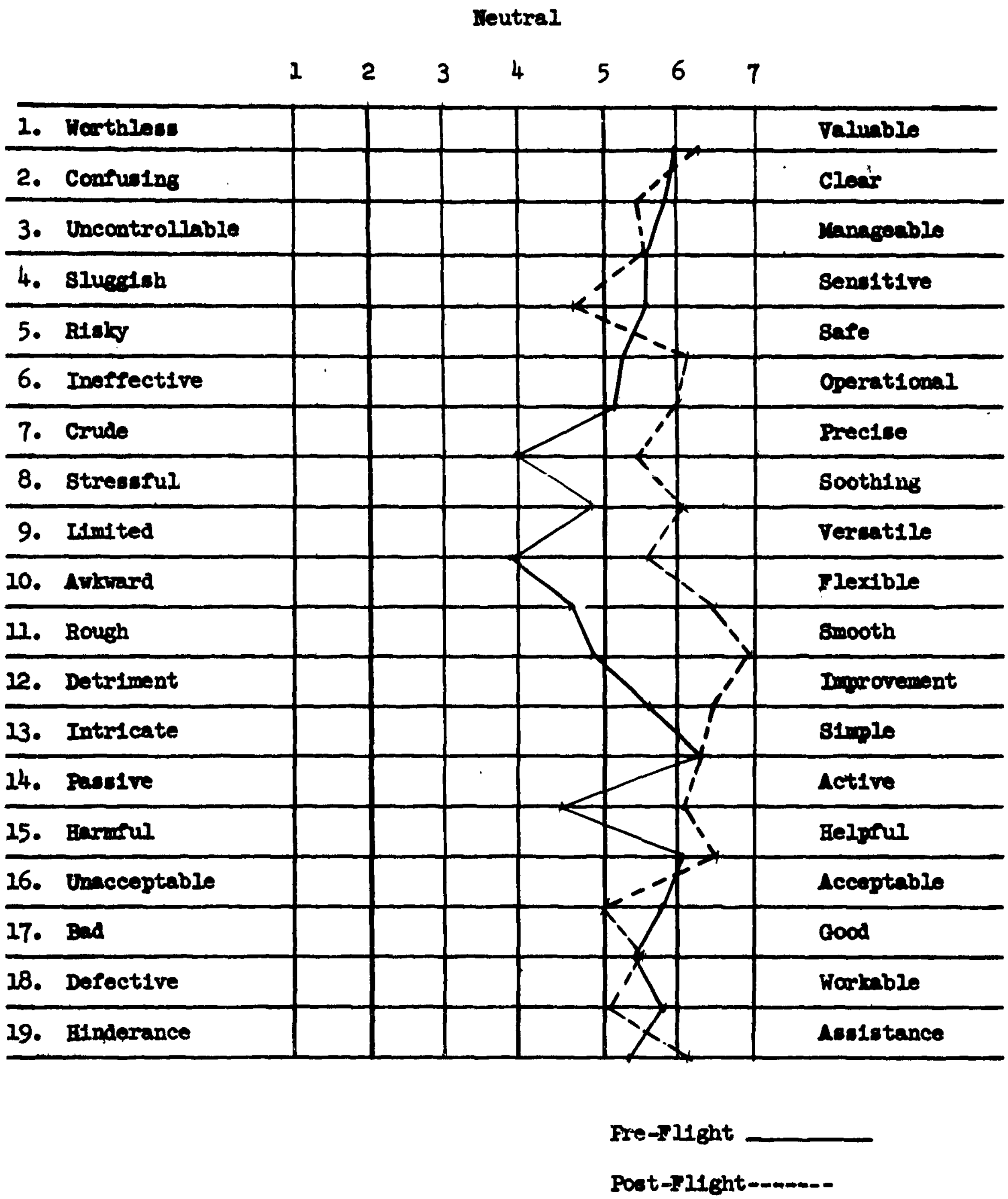

Figure 1. The Results of the Semantic Differential for Pre-Flight and Post-Flight Test of Cargo Pilots

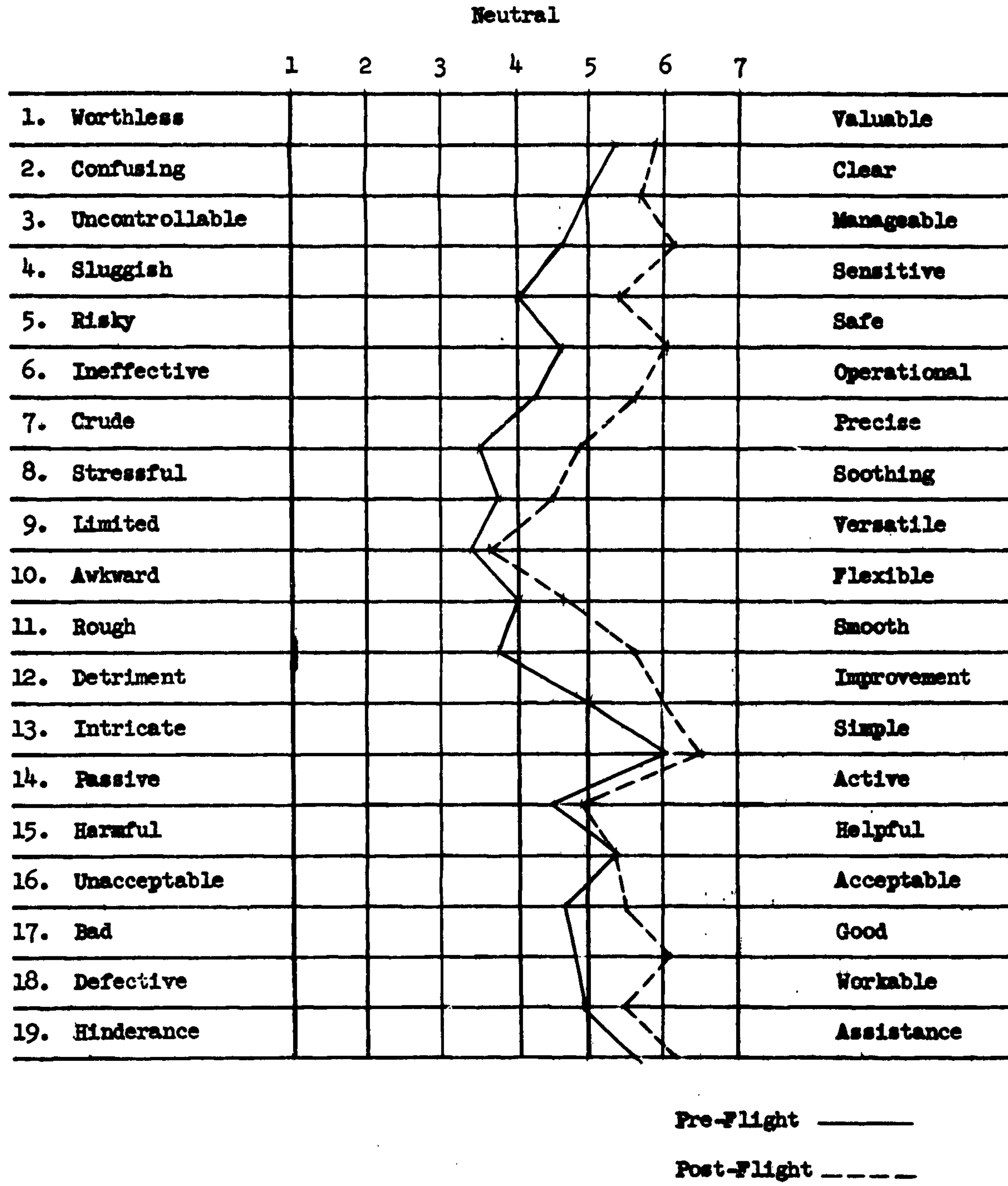

Figure 2. The Results of the Semantic Differential for the Pre-Flight and Post-Flight Tests of Fighter Pilots.

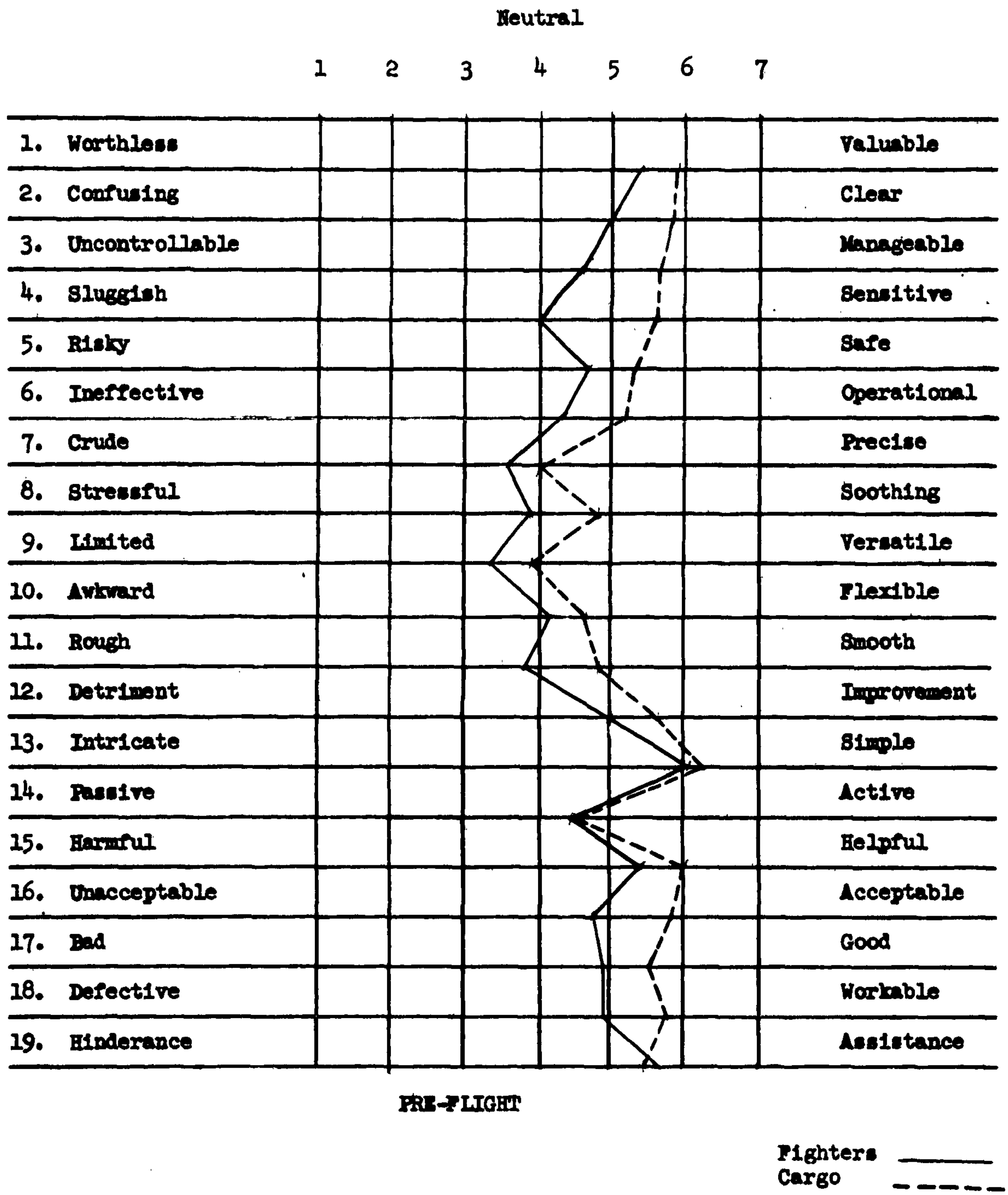

Figure 3. The Results of the Semantic Differential for Pre-Flight Test of Cargo and Fighter Pilots.

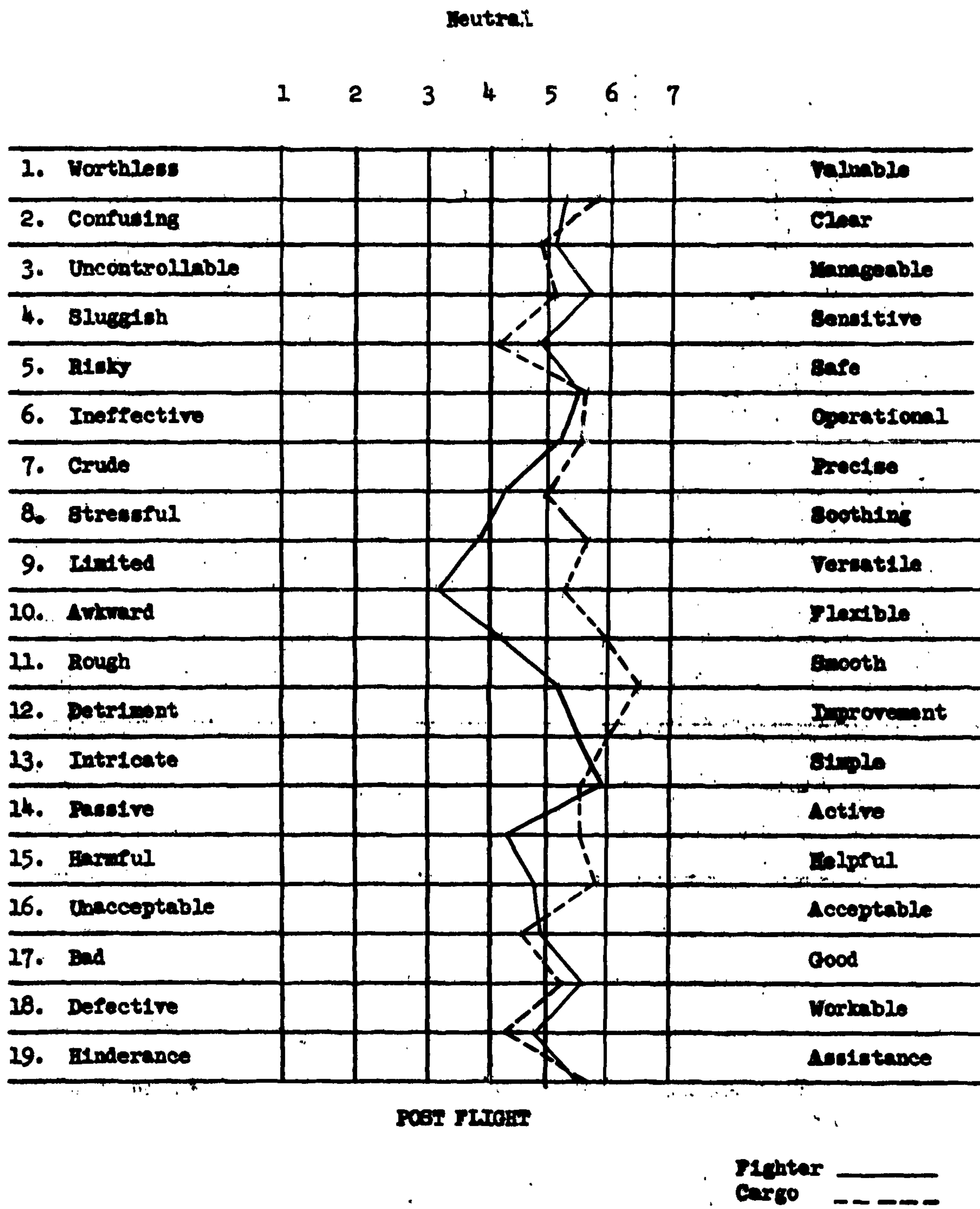

Figure 5. The Results of the Semantic Differential for the Post-Flight Test of Cargo and Fighter Pilots.

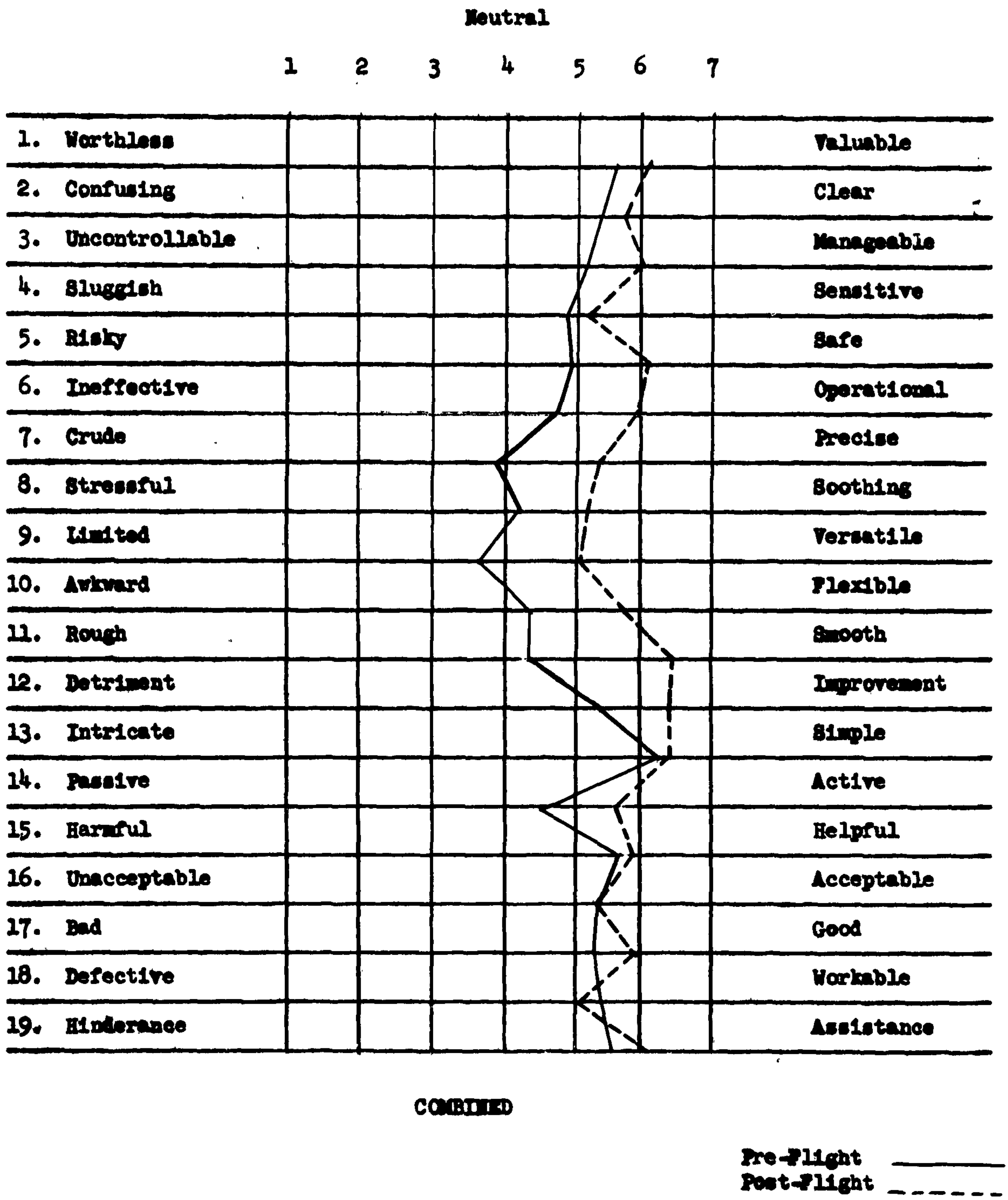

Figure 5. The Results of the Semantic Differential for the Combined Groups

achievement of a vertical roll varied for the two groups. In Figure 5 it is seen that when the ratings of Cargo and Fighter groups are combined the resultant pre- and post-flight profiles show considerable constancy of shape and a slight shift in position which indicates a slightly more favorable feeling towards the Lifesaver after some experience with it for subjects in both groups.

The pre- and post-flight positions of the various profiles differentiated by subject population are quantitatively comparable through the statistical technique. Osgood suggests a measure of relationship which takes into account both the mean discrepancies and the profile covariation. It ("D") is obtained by summing the squared differences one row at a time to each pair of variables and finding the square root of the resulting total. The greater the differences in position and discrepancy in shape the higher will be the value under the radical.

Variables	"D" Values
Pre- and post-flight Cargo profiles	23.46
Pre- and post-flight Fighter profiles	16.6
Pre- and post-flight Cargo and Fighter combined profiles	10.88
Post-flight Cargo and Fighter Separately	6.92
Pre-flight Cargo and Fighter separately	3.48

Rating Scale

Figures 6 and 7 summarize the ratings of the Cargo and Fighter respectively of the instrument against the maneuvers flown. The scale is arranged so that high numbers are associated with like dimension. It should be noted that the Fighter pilots had a higher rating even though one maneuver was badly downgraded. This low rating of the vertical roll maneuver by Fighter shows a deficiency for this particular maneuver. However, this one deficiency apparently did not influence to greatly their overall impression.

A chi-square was computed and as would be expected the rating of the instrument was a function of maneuvers. There was also a chi-square for goodness of fit of the frequency of selection of the categories based on an empirical curve that was derived in other instrument evaluations. The base curve is shown as follows:

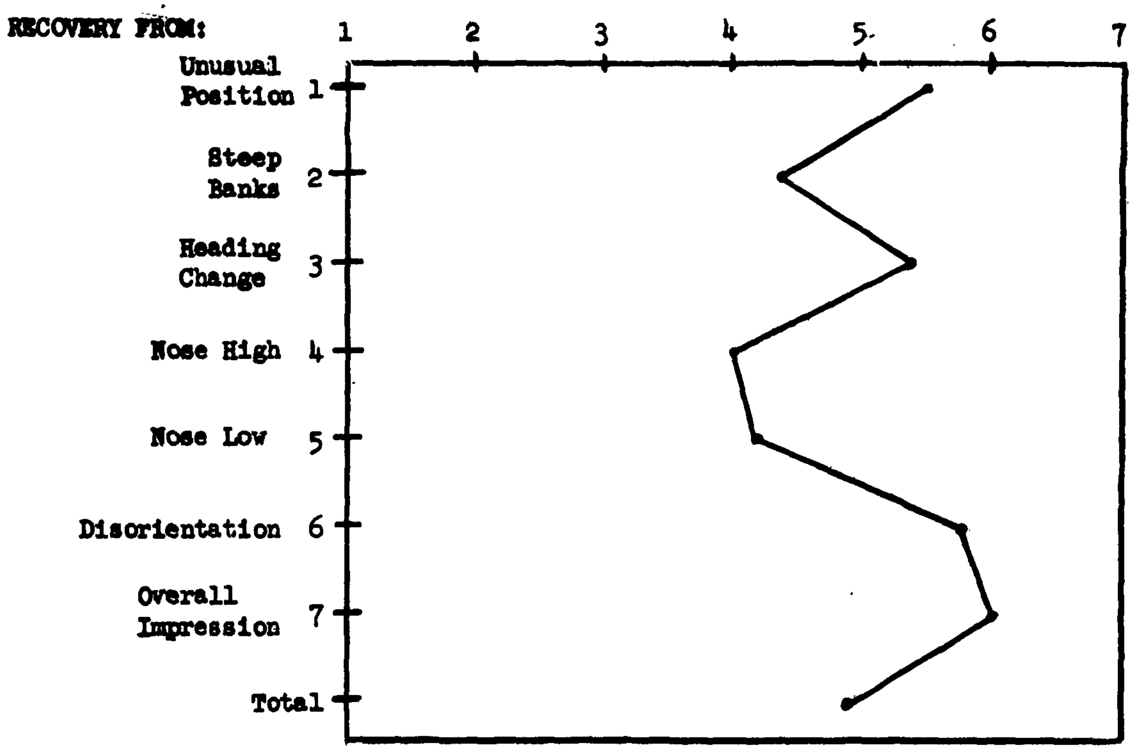

Figure 6. Rating Scale of the Lifesaver by Maneuver for the Cargo Pilot

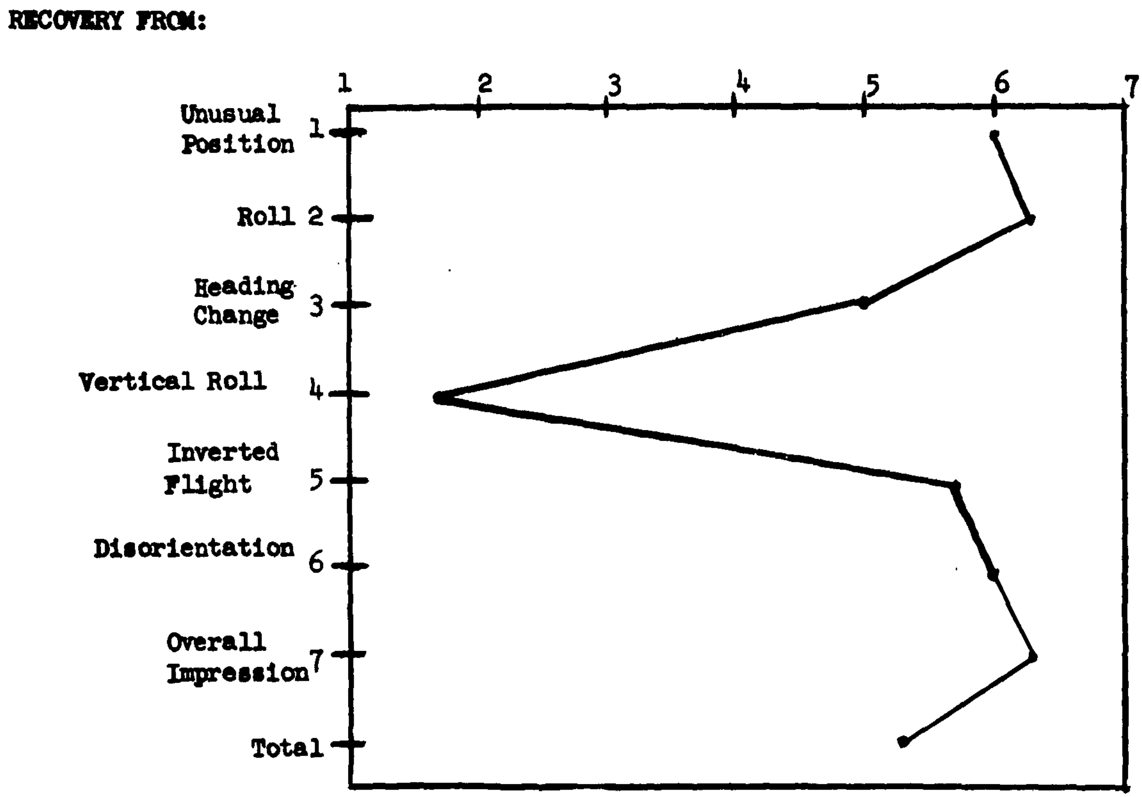

Figure 7. Rating Scale of the Lifesaver by Maneuver for the Fighter Pilots

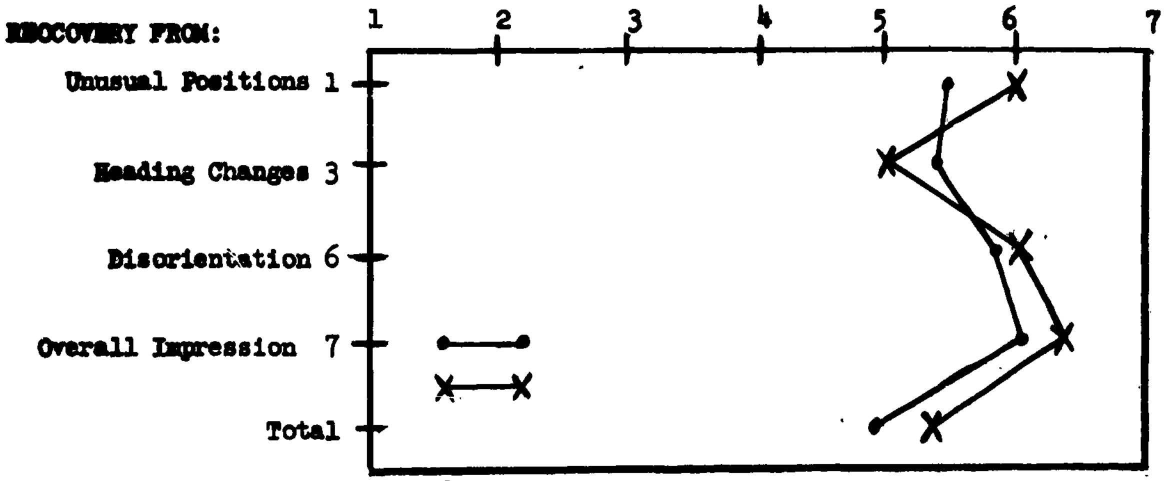

Figure 8. Rating of the Lifesaver by Maneuvers for both Cargo and Fighter for those maneuvers which were common to both groups

Table 1. Frequency and Associated % for the Selected Categories when all Maneuvers are Considered

		1	2	3	4	5	6	7	Total
Fighter	Frequency	7	6	5	8	8	31	33	98
	%	7.1	6.1	5.1	8.2	8.2	31.6	33.7	
Cargo	Frequency	5	7	5	19	12	41	9	98
	%	5.1	7.1	5.1	19.4	12.3	41.8	9.2	
Total	Frequency	12	13	10	27	20	72	42	
	%	61	66	5.1	13.8	10.2	36.8	21.4	

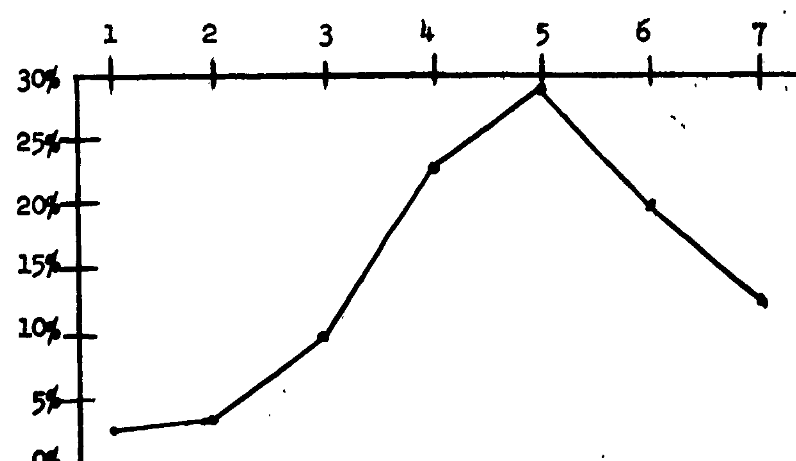

Figure 9. This is an empirical curve that was obtained when aircraft instruments were rated as a function of maneuver.

Table 1 shows the frequency of selected categories by subject group. Table 2 and 3 are the tables used to compute the chi-square.

Table 2 - Fighter Chi-Square

	1	2	3	4	5	6	7
Expected	2.4	2.9	9.3	22.0	28.1	19.5	12.0
Observed	7	6	5	8	8	31.0	33.0
Difference	4.6	3.1	4.3	14.0	20.1	11.5	21.0

$X^2 = 80.15$
df = 6
Sign .001

Table 3 - Cargo Chi-Square

	1	2	3	4	5	6	7
Expected	2.4	2.9	9.3	22.0	28.1	19.5	12.0
Observed	5	7	5	19	12	41	9
Difference	2.6	4.1	4.3	3.0	16.1	21.5	3.0

$X^2 = 43.90$
df = 6
Sign .001

As can be seen the chi-square values for both groups are a significant departure from the expected distribution.

Analysis of Split Ballot

To facilitate summarizing the results of the split ballot questionnaire a technique for describing the results of each question with a single number has been devised. There are four possible response patterns for a split ballot complete: negative (both questions are answered in a manner which indicates negative feeling towards the instrument in question), positive (both questions are answered in a manner which indicates positive feeling towards the instrument in question), neutral (one question is answered in such a way as to indicate positive feeling towards the instrument whereas its counterpart is answered in such a way that contradictory negative feeling is indicated) and fourthly the residual category of "no answer" or "not applicable" remains. The single number which shall be used to describe the response pattern for each couplet, which can be referred to as the F number, is the remaining difference when the total negative answers for a couplet are subtracted from the number of positive answers. The logic underlying the split-ballot technique necessitates that only the negative and positive answers are analyzed when seeking pilots' evaluations of an instrument; the neutral answers are considered indicative of weak, contradictory or inconsistent feeling towards the aspect of the instrument being evaluated. When attempting to characterize a group opinion the logic behind the computation of the F number assumes that the appearance of one totally negative answer negates a corresponding totally positive answer by another subject. A "high" F number then is obtained only if there are few neutral responses and if there is no balanced dichotomy between positive and negative answers -- in short, it is obtained only if the majority of subjects have strong opinions and their strong opinions are practically all in the same direction of positive or negative. To judge if an F number can be characterized as high one must recognize that there are 14 subjects in the Cargo cohort and 14 subjects in the Fighter cohort.

For organizational purposes it has been decided that an F number of 8 or more shall be considered high -- that is at least 8 positive or 8 negative answers to a split-ballot couplet must remain when negative answers are subtracted for the responses to be considered as characterizing a strong group opinion about a particular aspect of the instrument being evaluated. Let us assume that 18 persons respond positively and 10 persons negatively. The percent of positive responses is 64% while only 36% were against it. This can be assumed to be a significant percentage. For every case where there is less than the total 28 the ratio of percentage becomes greater. Thus, the "F" - number or 8 or greater does differentiate the attitude on each of the pairs. In certain instances in the summary below the F number of both Cargo and Fighter cohorts shall be presented together -- in such instances the largest possible sum of combined F numbers is 28 with each group contributing a single F number of 14. The below summary is arranged so that the first items (which will be stated in terms of what is considered to be the prevalent group opinion) are those which Cargo and/or Fighter groups exhibit strong positive opinions towards; following these are items which elicited weak, neutral responses or about which the members of either group had strongly divided contradictory feelings; finally appear items about aspects of the instrument which the Cargo and/or the Fighter group felt negatively towards. The actual data which the F number was derived from will accompany each item.

F--Fighter Response
C--Cargo Responses,

		F Number	Summed F Numbers	Cargo Positive Answers	Cargo Negative Answers	Cargo Neutral Answers	Cargo Non-applicable Ans.	Fighter Positive Answers	Fighter Negative Answers	Fighter Neutral Answers	Fighter Non-applicable Ans
HIGHLY POSITIVE RESPONSES											
It was possible to center the needle	C	12	26	13	1	0	0	14	0	0	0
	F	14									
Adequate Wings Level was maintained	C	12	25	12	0	2	0	13	0	1	0
	F	13									
The instrument was useful	C	12	24	12	0	1	1	12	0	0	2
	F	12									
The pilot adjusted rapidly to the instrument	C	10	23	10	0	3	1	13	0	1	0
	F	12									
On the following item only Cargo responded highly favorably towards the Lifesaver.											
It was possible to achieve normal recoveries	C	9	12	11	2	0	1	5	2	7	0
	F	3									
Only Cargo subjects were questioned about the following items. They elicited highly positive responses from the subjects.											
It was possible to make bank corrections		9	NA	10	1	3	0				
The pilot would consult the instrument when disoriented		9	NA	10	1	2	1				
There was adequate information about heading deviations	C	2	10	6	4	4	0	9	1	3	1
	F	8									
Slightly positive and neutral responses -- on the following items strong pilot opinion was not elicited. Only Fighter subjects were questioned about the following item											

F--Fighter Responses
C--Cargo Responses

SLIGHTLY POSITIVE RESPONSES

Item		F Number	Summed F Numbers	Cargo Positive Answers	Cargo Negative Answers	Cargo Neutral Answers	Cargo Non-applicable Ans.	Fighter Positive Answers	Fighter Negative Answers	Fighter Neutral Answers	Fighter Non-applicable Ans.
The Lifesaver presented correct representations of bank deviations		7	NA					9	2	3	0
On each of the following items Fighter F scores consitiute at least 7 points of combined F scores.											
There was adequate indication when needle deflection was a roll error	C	3	10	6	3	5	0	9	8	2	1
	F	7									
Control reversals were not made	C	0	7	7	7	0	0	1	2	3	0
	F	7									
On the following item the Cargo F score constitutes 4 points of the combined score.											
The use of this instrument enhanced performance on other flight instruments	C	4	4	5	1	7	1	3	3	8	0
	F	0									
Only Fighter subjects were questioned about the following items.											
The Lifesaver may have minimized vertigo		0						2	2	5	5
Responses indicating weak and moderate negative feelings towards aspects of the Lifesaver Cargo and Fighter groups contribute -7 to the combined F scores on the following item.											
The Lifesaver was not located in the position on the panel	C	7	14	3	10	1	0	2	9	3	0
	F	7									
Only Cargo subjects were questioned about the following item.											
The instrument is so reliable that it would be believed sooner than other instruments.		6		2	8	2	2				

From the above summary it can be concluded that the Cargo and/or the Fighter group feel that the Lifesaver instrument was useful, it can be used to advantage, it would be consulted when disorientation occurred and that a pilot could adjust to it rapidly; also the Cargo and/or Fighter group felt that it operated so that the following could be achieved: The needle could be centered, wings level could be maintained, 180 degree heading could be maintained, bank corrections could be made and normal recoveries could be achieved. The Cargo group saw the Lifesaver as a possible cockpit backup instrument. There was only a moderate amount of negative feeling in the Cargo and/or Fighter groups about the present location of the Lifesaver on the panel and as to the reliability of the instrument beyond that of previously used instruments.

Summary of General Questions

Cargo

Many of the pilots felt little confidence in their own ability to use the Lifesaver and constantly reiterated that they had not had enough experience with it to use it properly. In explaining situations in which sources of error stemmed from themselves they stressed that the operation of the Lifesaver was easily confused with the operation of the turn needle, that there was a tendency to overshoot and to make reversals. This last error was found to be especially true in maneuvers in which extremely steep banks were involved; one pilot suggested that a small placard to remind him to correct into the needle would have been helpful.

Even though the pilots viewed themselves as fallible they did not view the Lifesaver as infallible. A common complaint was that the needle stuck when flying steep banks and when the instrument was not level with panel. Another difficulty with the needle is that it disappeared when steep banks were being flown and that at any time it was not completely visible because the control volumn hid the instrument. Precise centering was difficult because the index and needle were too thick and because of needle variations accompanying changes in G's. A frequent complaint was that the Lifesaver was useful only in conjunction with other primary instruments and that sole dependence on it in an emergency would be disastrous.

Despite these complaints the feeling that with specific improvements the instrument could be quite useful was not absent. It was suggested that more appropriate panel locations for the Lifesaver would be the upper left corner of the panel, near the turn needle and in a less critical position than it now appears in. The majority of other suggestions approximated the following points: The needle should be centered better; the fudicial should be a tapered arrow or triangle; the grading should yield more precision; the face marking should be improved and the top index should be narrowed.

Fighter

Although many objections similar to those raised about the instrument were raised by both groups, the subjects in the Fighter group seemed to feel more favorably about the Lifesaver which demonstrated a change from the semantic scale which showed the Cargo the more favorable group. These objections will not be restated in this summary but an attempt to present objections which are unique to this group.

Various complaints centered about difficulties with the instrument in specific maneuvers. Great unanimity existed on the opinion that the instrument was inadequate for vertical roll maneuvers. There were complaints about difficulties with the instrument in coming out of a spin and in getting accurate pitch information when it was needed. The roll rate was too slow to correct quickly and one pilot complained that he got reversed roll indications. Maneuvers were difficult because you cannot tell whether you are turning with the instrument.

Both pilot groups objected to the inflexibility of the instrument in that it is adequate only when flying South. Also the recovery direction the Lifesaver indicated depended on the direction of roll into the roll and for this reason did not always indicate the shortest recovery route.

Both groups desired that the instrument be relocated on the panel; but the suggestions about replacement were quite contradictory. The former group seemed to wish it to be in a less noticeable more "out-of-the-way" position where as this group (with some exceptions) felt it ought to be nearer to primary instruments. This difference in conceptions of where the Lifesaver ought to be located probably reflected the difference between the two groups in their general acceptance of the instrument.

The specific comments appear in Appendix A.

Discussion

The results of the questionnaire have been presented in detail. In this section, these results and the other factors involved in this pilot orientation instrument will be covered. In addition to the standardized profile, the instrument was subjected to other testing, it was flown in areas of extreme magnetic disturbances, areas of large magnetic variation, instrument conditions and in Helicopters. In each of these cases the instrument proved to be useable and no failures were observed.

The instrument was flown at 24 degrees East variation and it had no apparent defects in its operation although the roll out heading of 180 degrees was effected. The areas of magnetic disturbance where this instrument was flown are listed with the pilot's comments.

1. Marquette - On a heading of 265 the instrument centered with 12 degree bank. On a heading of 90 degrees needle centered with 18 degree bank. Altitude flown was 5,500 feet the instrument appeared to be useable.

2. Marenisco - Same as above Marquette

3. Menahga - Same as the other two.

The instrument performed satisfactorily under all ambient environmental conditions to which it was subjected.

The instrument was also tested in a HU-1B Helicopter and although the comments and results are sketchy it was reported by the project pilot that certain characteristics of this instrument made it quite acceptable for Helicopter use. The comments made were as follows:

1. Less vibration than the turn needle
2. Possible to bracket East and West within $\pm$20 degrees
3. Possible to bracket North by using back course technique although it is difficult to fly.
4. Must have the capability of setting heading on the Lifesaver for use during power failures.

All of these comments are not unique to Helicopters but the project pilot felt that this device would be extremely useful for this type aircraft. The results of the opinion survey indicates that pilots have an outlook toward this instrument which is something other than passive and generally feel that this is a good instrument but does need a few modifications.

The results of the semantic differential and rating by maneuver demonstrate a generally positive attitude towards the Lifesaver by the subjects involved in the investigation -- the former indicates that experience with the Lifesaver intensified and in some cases held constant those positive preconceptions which the pilots possessed before flying with the Lifesaver. In practically every instance a pre-flight neutral response was converted to a positive post-flight response on the semantic differential. Only the Cargo group had some instances in which the Lifesaver was rated on certain adjective pairs more favorably pre-flight than post-flight.

The multiple choice split-ballot section and the open ended questions measured more specific aspects of pilot opinion. From the former it was concluded that the Lifesaver was generally considered an aid which could be used for the purpose for which it was designed and that it operated so that various significant maneuvers could be achieved. Dissatisfactions about the position of the Lifesaver on the panel was revealed by the split-ballot questionnaire. The open-ended questionnaire revealed various dissatisfactions. Some complaints failed to take into account the limited purposes that the Lifesaver was designed to fulfill and criticised it for its inability to perform tasks for which it was never intended, but many complaints had the legitimacy of indicating areas in which the Lifesaver was unable to adequately perform its major functions. These comments appear in the appendix.

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APPENDIX A

Table 4: Cargo Lifesaver - Split Ballot Summary

		+	-	0	N/A
1.	Enhance performance	5	1	7	1
2.	Would consult when disorientated	10	1	2	1
3.	Adequate information for heading deviation	6	4	4	
4.	Best location	3	10	1	0
5.	Achieve normal recovery	11	2	0	1
6.	Adoption is imminent could it be used to advantage	13	1	0	0
7.	Maintain wings level	12	0	2	0
8.	Incorporate instrument in cockpit as backup	12	0	2	0
9.	Able to maintain 180 degree heading	13	0	0	1
10.	Able to make appropriate bank corrections	10	1	3	0
11.	Capable of centering needle	13	1	0	0
12.	Achieve a primary objective of recovery from unusual attitude	4	0	8	2
13.	Reliable instrument would sooner believe than other instruments	2	8	2	2
14.	Adjust rapidly	10	0	3	1
15.	Adequate indication that needle deflection was a roll error	6	3	5	0
16.	Did you find it useful	12	0	1	1
17.	Make control reversals	7	7	0	0

Table 5: Fighter Lifesaver - Split Ballot Summary

		+	-	0	N/A
1.	Normal Recoveries	5	2	7	0
2.	Adaption	13	0	1	0
3.	Easily centering needle	14	0	0	0
4.	Maintain wings level	13	0	1	0
5.	180 degree heading	9	1	4	0
6.	Correct representation of bank deviation	9	2	3	0
7.	Find it useful	12	0	0	1
8.	Make Control reversals	9	2	3	0
9.	Incorporate as backup instrument	8	3	2	1
10.	Minimize vertigo	2	2	5	5
11.	Enhance performance on other instruments	3	3	8	0
12.	Placement advantageous on panel	2	9	0	3
13.	Used to advantage	7	1	2	4
14.	Adequate information as to roll deviation	9	2	2	1
15.	Adequate information as to a heading deviation	9	1	3	1

APPENDIX B

Summarized Categories of Comments on Lifesaver Questionnaire

Part II Maneuvers

1. Reversal problem
2. Instrument sticks

Part III

1. Did the use of this instrument enhance your performance on the other flight instruments?
    - A. Performance enhanced on instruments used within the experiment.

2. Since this instrument is so simple and is easily centered, would you consult it when disoriented?
    - A. Depends on what else is available.

3. Was there adequate information available in this instrument when a heading deviation existed?
    - A. Question unclear -- deviation from what heading?

4. Do you think that the present position of the instrument is the most advantageous placement?
    - A. Control column hides it
    - B. Prefer in upper left corner of panel
    - C. On the basis of present experience and information it appears to be correctly placed.

5. Where you able to achieve normal recoveries with this instrument?
    - A. Only if addition instruments were used.
    - B. Question does not specify what is meant by normal recovery (normal partial panel recovery was achieved).

6. Adoption of this instrument is imminent -- do you feel Lifesaver could be used to advantage?
    - A. Possibly, but not in the situations I have encountered in flying.

7. Could you handle the Lifesaver so that adequate wings level was maintained?
    - A. Don't understand how it is supposed to be used
    - B. Need more experience with it

9. Were you able to maintain a 180 degree heading with the Lifesaver?
   A. With the little practice given in the experiment it was difficult

10. Did this instrument direct you in making the appropriate bank corrections?
   A. Tendency to reversal great

11. Were you capable of easily centering the needle?
   A. Index is too wide

12. Did the Lifesaver instrument achieve one of its primary objectives -- that of directing the pilot to recover from an unusual attitude even though vertigo was experienced?
   A. Yes
   B. Vertigo not experienced

13. This is an extremely reliable instrument, would you believe its indication when in a vertigo state, sooner than your other instruments?
   A. I did not find it reliable; this must be because I have not had enough experience with it.
   B. No. The needle stuck

14. Did you make rapid adjustment to this display?
   A. Yes

16. Since this instrument is designed to be an aid -- did you find it useful?
   A. Only for 180 degree turns

17. Did you make control reversals while using this instrument?
   A. In extreme positions
   B. It is highly likely that this will occur

Part IV

1. What effect did the varying of "G" force have on the performance?
   A. None, negligible

2. Was there an evidence of erratic functioning with the indicating needle?
   A. No, and none that I noticed
   B. Stuck in extreme positions
   C. Stuck when instrument not level with instrument panel
   D. Yes

3. Was there any evidence of erroneous indications with this instrument?
   A. No
   B. Varying inaccuracies in centering, or when G varied
   C. Not inaccurate if used with needle and ball

D. Machine not inaccurate but it is designed so that it is easy for the pilot to be inaccurate in reading it -- specifically when on North heading easy to think one is oriented to the South.

4. What limitation, if any, did you experience while using this display?
   A. None
   B. The needle sticks
   C. General trouble with heading and specific trouble with southernly heading
   D. Needle not clear in steep banks
   E. Tendency to reversal
   F. Tendency to overshoot
   G. Inadequate except for 180 degree turns
   H. Worthless without additional instruments

5. How does the instrument compare with other standby indicators you have flown?
   A. Excellent
   B. Very good with some corrections
   C. Have nothing or little to compare this with
   D. Has advantages over standby magnetic compass when South is satisfactory heading

6. Additional Comments:
   A. None
   B. Valuable only in emergencies and in these emergencies only in certain types of planes
   C. Useless in emergency because it is inoperative without the aid of other instruments
   D. Face marking is bad
   E. Top index should be narrower
   F. It is easy to make reversals
   G. Irrelevant remarks
   H. Criticism of questionnaire -- it does not supply a frame of reference in terms of situations to evaluate the instrument in, and in terms of what functions (as an ancilliary or independent instrument) it is to be evaluated.

<u>Part V</u>

1. Can you visualize a more strategic placement of this instrument on the panel?
   A. upper left corner
   B. A less critical position
   C. Near the turn needle

2. Precise heading control is difficult with the Lifesaver instrument, but could you hold a heading of 180 degrees?
    A. Approximately 180.
    B. No because of the imperfection of the needle. i.e. it sticks, disappears in steep banks
    C. Only if other instruments or devices are used.
    D. It is difficult to distinguish between steady 180 and 360 degree heading.

3. Since a heading change is a resultant of a roll, we are concerned as to whether the instrument tended to be confusing as to the type of error which existed -- a roll or heading error?
    A. Not if other instruments are used.
    B. Eventual but not immediate perception of the distinction was possible.
    C. Irrelevant answer.

4. Were recoveries from unusual attitudes difficult when using this instrument?
    A. They were difficult but would have been more difficult without it.

5. Since there is some suspicion that the needle may be extremely difficult to center, did you have this experience?
    A. Any compass is difficult to center *(see original comment-- debateable interpretation)
    B. Bar on top too wide and needle too thin.
    C. Irrelevant comment.

6. Since this instrument provides both heading and roll information in the same needle we were wondering if you experienced any confusion as to what were the required corrections?
    A. Need other instruments to determine quickly and accurately.
    B. Tendency to correct as if it were a turn needle.

7. Since this is a new instrument and is quite dissimilar to any present instrument, many pilots have stated that they have experienced some adaptation difficulties, did you experience adaptation difficulties?
    A. Tendency for reversal.
    B. Additional instruments required.
    C. Needle should be centered.
    D. Needle should be more visible and not stick.
    E. Fudicial should be tapered arrow or triangle.
    F. Pilot needs small placard reminding him to correct into the needle.
    G. Numerical index marks or grading needed for more precision.
    H. He should change the thick black index to thin mark.
    I. Adaptation difficulty would not be experiences in small aircraft.
    J. Instrument is sensitive bank indicator.
    K. If several other instruments are available one can adapt.

8. Since uncertainty has been expressed as to whether the "Lifesaver" provides enough information for maintaining wings level, there is interest in whether you detected any difficulties while flying with the "Lifesaver" in maintaining control of wings level?
   A. Difficult if other instruments are not available
   B. Although wings level always uncertain it was more clear as South was approached.
   C. Unless on southerly heading *(look up original comment -- think that this is same as B category identified above.)

9. New instruments are difficult to accept even when the operation of the instrument and the display face are simple. Since you are very unfamiliar with this instrument do you think you would consult it when disoriented?
   A. If other instruments were operative
   B. If no other or none of the primary instruments were operative
   C. If I had more practice with it

13. Could the resultant effects of vertigo disorientation be minimized to a greater extent through the use of some display other than Lifesaver?
   A. Yes -- altitude, airspeed, and VV indicator are better
   B. Yes, only because I have more experience with others
   C. When there are gyros it is not best -- otherwise yes
   D. An optimistic philosophical note -- there must be a better way even though no man has discovered it yet.

14. This is a very new concept for application to a flight instrument. Since you have had very little experience with the Lifesaver would you believe the instrument, when experiencing vertigo before you would believe your other flight instruments?
   A. If I had more experience with it, then possibly I would
   B. No, one must have AS, Alt. etc. which are not indicated on Lifesaver.
   C. Only if I had nothing else
   D. Do not know

15. Would you like to see this instrument discarded?
   A. No, if it is used under specific conditions (a full partial panel)
   B. It would be acceptable with some changes
   C. It is better than a washer or a string

16. There is a great deal of negative feeling about this instrument. Should this instrument be accepted into the Air Force inventory as a standard display?
   A. Not in its present position on the panel (should be placed in the corner).
   B. Yes, if there are enough emergency situations in which it would be required to justify the cost.

Specific Comments from Cargo

Part II

Recovery from nose high -- reversal problems - 1

Maneuver 5. When given aircraft in left bank correction according to instructions received a complete reversal to a right bank. This would also be true given A/C in a right bank between 181 and 359 degrees. The larger correction being at the 270 degree and 90 degree points.

Instrument sticks -- 1

The instrument seems to work fine except for occasional sticking. I fail to see the application if it must always be oriented South.

Part III

1. Did the use of this instrument enhance your performance on the other flight instruments? - 2

   It did on those instruments which I used within the experiment.
   Answered yes on basis of that portion of flight conducted on this instrument plus pilot instruments.

2. Since this instrument is so simple and is easily centered, would you consult it when disoriented? - 4

   I would not necessarily pick this one.
   Depends on what's available
   Not in preference to other instruments if available
   Answered yes, assuming gyro instruments inoperative

3. Was there adequate information available in this instrument when a heading deviation existed? - 3

   Question is unclear -- should have specified 180 degrees as the heading and even from 180 degrees you still have no idea.
   I don't understand what is meant by heading deviations. From 180 degrees?
   Deviation from what heading? With turn needle, you can determine generally which direction you're going but without it, you have no idea. From 180 degrees, you still have no idea but it makes no difference really since your always correcting back.

4. Do you think that the present position of the instrument is the most advantageous placement? -7
   The control column which is too far forward especially in a tail heavy aircraft hides it.
   Not in C-131. Too hard to see behind the column, particularly if you're in a tail heavy aircraft with some flaps down, the column is too far forward. e.g. the 10 249 is 806.
   Prefer it in upper left panel corner.
   Would prefer upper left corner of panel
   Tentative agreement with present position of the instrument.
   Appears to be placed OK but would have to look further into question.

5. Were you able to achieve normal recoveries with this instrument? -5
   Only if additional instruments were used -- need altitude, heading and airspeed
   With use of altimeter & airspeed too.
   Recovery was safe however altitude and heading cannot be determined.
   Unclear about meaning of normal recovery -- could achieve a normal partial panel recovery.
   Yes, if by normal recovery is meant normal partial panel recovery.

6. Adoption of this instrument is imminent -- do you feel Lifesaver could be used to advantage? -3
   Possibly -- but not in the usual situations which I encounter in flying.
   It works but I'm lost as to specific application.
   Once in a great while.

7. Could you handle the "Lifesaver" so that adequate wings level was maintained? -4
   The way it is supposed to be used is unclear to me.
   Maybe I would if I understood how it would be used.
   I can achieve wings level with the instrument only if I have a long period of time to do so
   Yes, however, it would take some time to get perfectly level

9. Were you able to maintain a 180 degree heading with the Lifesaver? -2
   To do it adequately requires much practice -- i.e., I found this task very difficult to achieve with the instrument.
   Yes, however, more practice would help considerably.

10. Did this instrument direct you in making the appropriate bank corrections?
   It is quite likely that a pilot will read the bank directions backwards.
   Yes, but only because of specific briefing immediately prior to flight, otherwise, I think I'd have read it backwards. re my previous comment on reversing the indication.

11. Were you capable of easily centering the needle?
    Index should be nearrower
    Index needs to be narrow as previously suggested

12. Did the Lifesaver instrument achieve one of its primary objectives -- that of directing the pilot to recover from an unusual attitude even though vertigo was experienced?
    Yes
    No vertigo experienced
    Did not experience vertigo, maybe because of the instrument
    No vertigo experienced
    Vertigo was not experienced

13. This is an extremely reliable instrument would you believe its indication when in a vertigo state, sooner than your other instruments?
    Attribute lack of reliability to self -- i.e., I didn't find it reliable, this must be because I have not had much experience with it.
    Possibly more training
    I would have to work with instrument more
    Yes, further experience would be very helpful. Corrections were made.
    No, only because of unfamiliarity
    [illegible], the needle stuck a couple of times
    Partially because the needle stuck a couple of times

14. Did you make rapid adjustment to this display?
    Yes
    Fairly rapid
    Yes, consciously, rather than instinctively as is the case with a familiar instrument

16. Since this instrument is designed to be an aid -- did you find it useful?
    I can only think of one situation in which it is useful -- a 180 degree turn
    Very useful for a safe turn to 180 degrees. For other situations doubtful.

17. Did you make control reversals while using this instrument?
    In extreme positions
    In extreme positions when needle was nearly out of view
    Once, in first steep bank unusual position
    I did a few times and I did not but probably would have if not warned about this before I began to fly
    No only because of briefing as in (10) above
    A couple of times, however, easily corrected

1. What effect did the varying of "G" force have on the performance?

   None:
   No apparent motion noted
   None that was discernable to the eye
   None
   None
   None
   None
   None
   None I could see
   None - Variation in needle appeared no greater than variation in bank
   None that I noticed
   None
   Neglibile
   None
   Slight movement of a small magnitude

2. Was there any evidence of erratic functioning with the indicating needle?

   Six subjects answered "NO"
   Stuck only in extreme positions -- steep banks
   Yes, when in a steep bank it lagged & stayed there until a second or two after wings became close to level
   Yes stuck on stops in recovery from steep banks
   Stuck at extreme indication after control reversal caused extremely steep spiral
   Only when coming out of an extremely steep bank
   It only stuck when instrument was not level with instrument panel
   No, other than instrument was not level with instrument panel
   Yes, stuck a couple of times
   Yes

3. Was there any evidence of erroneous indications with this instrument?

   No -- Subjects: 3, 11, 2, 8, 13, 4, 5, 9, 12, 14, 10
   Yes -- Subject 6
   Varying inaccuracies: stuck a few times when G varied, slight inaccuracy when centered.
   Not exactly confusing as when centered and near South heading direction was too slight to be confusing
   No except see 2 (stuck a few times when G varied)
   Not with use of needle & ball
   Not with use of needle or ball though
   Machine not inaccurate but easy for pilot to make inaccurate estimates in reading it
   When on North heading believed to be oriented properly to the South

4. What limitation, if any, did you experience while using this display?

None that I noticed with my limited use of the machine
None, within limits of demonstration
None
Needle sticks
Needle stuck
Stuck at full scale detection and started operating
Difficulty with southerly heading--can't tell when turn stopped, and when you reached southerly heading
Difficult to determine when you have reached a southerly heading
Hard to tell when turn was stopped on southerly heading
General trouble with heading
Heading information
None except in determining heading
Needle not clear in steep banks
180 degree ambiguity
Adequate for banks of 30 degrees or less and moderate climbs and dives in absence of gyro instruments. This instrument and pilot instruments not adequate for extreme unusual positions
Needle disappears in steep bank
Bank angle, i.e., the needle is out of the free scale or the needle is fully deflected.
Tendency to reverse interpretation
Required specific though to keep from interpreting backwards
Tendency (for pilot) to overshoot mark
There is a tendency to over shoot the amount of bank required
It is adequate only for turns to 180 degrees
Could only accomplish one maneuver -- a safe turn to 180 degrees
No good without other instruments
Must have altimeter, vertical speed, airspeed, and either needle and ball or compass to increase ability and time to determine your position.

5. How does the instrument compare with other standby indicators you have flown?

Excellent, best, good but needs some corrections (6 out of 7 subjects say good without any reservations).
This is adequate instrument and seems to have good reliability but would be easier to use with the corrections pointed out.
Best
Favorably
Excellent
Good
Good
Very satisfactory

Have nothing to compare this to -- have flown nothing comparable
Have never had similar types in A/C
This is the only one I've flown
Have never flown any other type
No experience with anything comparable
Would not attempt comparison, since, to me, this is a new concept
Have only used standby compass
Have little to compare this with
Has advantages over standby mag. compass when south is a satisfactory heading
Will say: has definite advantage over standby mag. compass in that a bank indication is available as long as South is a satisfactory heading

6. Additional comments

None
None, other than shown elsewhere
Recognize its values in emergencies but feel it is not necessary in usual situations or feel that certain planes don't even need it in an emergency
A very valuable instrument under conditions of power loss. However, under normal unusual positions I would incorporate it with my other instruments.
If this is very cheap and can be mounted where it does not interfere with other necessary items it could be valuable. However, I do not feel it is necessary in modern cargo A/C.
Not useful in an emergency because it is not operative without the aid of other instruments
Having lost all other instruments, pilot would still need airspeed or altitude indication.
Face marking is bad--
I think some better face marking is necessary
Top index should be narrower--
Narrow top index
Made reversals--
I had a tendency on several occasions to fly the needle rather than turn toward it on initial corrections.
Irrelevant remarks --
Did not seem to worry about whether correction was heading or roll only to keep it centered.
This questionnaire could possibly give you a complete inaccurate picture of a pilot's comments. Why, because you ask evaluation of an instrument under several conditions. Partial - Partial Panel or Full partial panel with still no compass. You should state whether you consider the instrument a supporting instrument to the others or as a do it all alone type instrument which some questions lead you to believe. Test should be conducted using one configuration and stating the exact function the instrument is to perform.

Part V

1. Can you visualize a more strategic placement of this instrument on the panel?

    Upper left corner

    Since it would only be used as a last resort, I would locate it in a less critical or standby position

    Since our C-131's are all different, no specific spot. I would proximity to turn needle would be advantageous

2. Precise heading control is difficult with the Lifesaver instrument, but could you hold a heading of 180 degrees?

    With plus or minus 10 degrees

    In steep banks the needle is very hard to find. It goes below that black section of the instrument

    Steep Banks -- Needle almost disappears in steep banks -- difficult to spot it immediately. Could be eliminated with proper case or stops. Needle also tends to stick on the stops until close to wings level or angle of bank for centered needle.

    Using needle and ball or compass

    In recovering from all maneuvers using this instrument airspeed, altimeter, and vertical speed you cannot be sure for some time you are actually headed south. Unless you are extremely sharp and note change in required control pressures, and direction of same being applied. This may not be recognizable in varying degrees of turbulence. Another instrument must be brought in to determine when you actually are on South in a short period of time say 2-1/2 minutes or less. If using the standby compass a final direction of East or West would be better than North-South as a final direction of above an overcast depending on time of day wing tip on sun can aid in determining whether going N or S.

    It is difficult to distinquish between steady 180 degree heading and 360 degree heading.

3. Since a heading change is a resultant of a roll, we are concerned as to whether the instrument tended to be confusing as to the type of error which existed -- a roll or heading error?

    Difficult to realize when you first arrive at heading of 180 degrees

    Confusing only to the extent that it gives no indication at all as to which type of error exists. But who cares if you can keep it fairly well centered?

4. Were recoveries from unusual attitudes difficult when using this instrument?

    Yes, but would have been impossible without it

5. Since there is some suspicion that the needle may be extremely difficult to center, did you have this experience?

    Any compass

    Why the wide bar at the top and thin needle. Why not the usual needle or a white mark at the center of black bar to help with centering?

    By limiting bank to 180 degrees helps some in non-low nose high attitude.

6. Since this instrument provides both heading and roll information in the same, we were wondering if you experienced any confusion as to what were the required corrections?

    Still need a needle and ball or compass to determine quickly and accurately

    Once -- believe due to subconsciously correcting as if it were a turn needle

7. Since this is a new instrument and is quite dissimilar to any present instrument, many pilots have stated that they have experienced some adaptation difficulties, did you experience adaptation difficulties?

    Yes, but rapid adaption noted after first turn in wrong direction

    On one of my first unusual position recoveries from a steep bank I turned the wrong way, further steepening the bank (probably because I flew it like a turn needle) Familiarity with the instrument and better display would help in this respect.

    Again, only because of specific briefing and because the test of the instrument was the purpose of the flight. Otherwise, I have my doubts.

    For recovery from unusual positions the operation and interpretation of the instrument should correspond to the normal turn needle. The needle action should be reversed. I think in an emergency, the tendency would be to misintergret it the way it is now. Because of its similarity to standard turn needle. I definitely think reversing the action of the needle would be desirable

    Answers were checked with the idea in mind that these questions applied to that part of the mission that included unusual positions with only this instrument and the pilot instruments. For more than slight banks and shallow turns additional instruments are required.

    Impossible to tell when in a bank

    Should fly with needle centered for a definite period of time to be sure you are on South heading

    Works much better when used in conjunction with turn needle

Needle should have peg at maximum position so that it remains within sight, preferable should stay in white area. Peg should also prevent sticking as it does sometimes in the maximum position.
The fudicial should be a tapered arrow or triangle instead of bar.
Placard on instrument that reminds you to correct into the needle until pilot becomes very familiar with instrument.
Very good and practical type instrument. With a little training and experience, plus a larger display, some kind of numerical index marks or grading this could become quite a precise instrument. There are possibilities of integrating two of these instruments to affect a continuous and direct reading of both heading and bank.
I think it would be beneficial to change the thick black index to one thin mark.
Small aircraft would help this.
The instrument is a very sensitive bank indicator.
Using 1, 2, 3, and 4. Delete 4 and 5 and it would be questionable especially in heavy turbulance.

8. Since uncertainty has been expressed as whether the "Lifesaver" provides enough information for maintaining wings level, there is interest in whether you detected any difficulties while flying with the "Lifesaver" in maintaining control of wings level?
Unless on southerly heading
Must have more than altimeter, airspeed, & vertical speed. Answer no with additional instruments.
Was never quite sure if wings were level, however, I knew that they were nearly level as changes became very small as South was approached.

9. New instruments are difficult to accept even when the operation of the instrument and the display face are simple. Since you are very unfamiliar with this instrument do you think you would consult it when disoriented?
I would consult it, however, I would still check other instruments before completely relying on it.
Using 1, 2, 3, and either 4 or 5 it would be adequate under normal conditions.
If other instruments are operating.
In absence of primaries
Not unless all other instruments were out of commission.
Yes, with some instrument training practice using this instrument.
Training would help.

10. Did certain defects in the presentations of the instrument lead you to make control reversals?

    On the first maneuver only
    Assuming that you are in a right bank or level between 001 and 180 degrees and a left bank or level between 180 and 359 degrees. Otherwise no, it required a reversal of bank through wings level to return to a southerly heading.
    I think that shadows on that instrument face, seen through blue
    Immediately obvious of wrong direction of roll

11. About half the pilots who have flown this instrument indicated that bank deviations are incorrectly represented on this instrument. Do you think that the bank deviations are represented correctly?

    Actually it is difficult to say one way or the other. As I did not check it during the vertical thoroughly
    Not as accustomed but since same correction for bank or heading, I see no problem.

12. Did you find any features of this instrument which were in conflict with your performance on other flight instruments?

    Only with the tendency to fly the needle to the reference, instead of the reference to the needle.
    Initial reaction is that confusion is caused since operation is opposite to turn needle, a similar presentation. Conscious, rather than instinctive corrections will be required until instrument is familiar.
    Combines two instruments

13. Could the resultant effects of vertigo disorientation be minimized to a greater extent through the use of some display other than Lifesaver?

    Yes, but this may be based on past experience
    No, it aids but cannot replace instruments 1, 2, and 3 which are are basic and proven reliable.
    No, assuming no gyros
    Question has to be answered yes -- there is always a better way question is how?

14. This is a very new concept for application to a flight instrument. Since you have had very little experience with the Lifesaver would you believe the instrument, when experiencing vertigo before you would believe your other flight instruments?

Assuming that I had a chance to practice maneuvers with it a few times, there would be no difficulty in accepting it.
But this maybe based on past experience
Doubtful at this stage -- possibly, if others obviously untrustworthy
Naturally not, this question is rediculous. Lifesaver does not give airspeed, altitude, etc.
Hard to say.

15. Would you like to see this instrument discarded?

    Not using only instrument 1, 2, and 3. Full partial panel, yes.
    But it should be changed
    It's better than a washer or a string

16. There is a great deal of negative feeling about this instrument. Should this instrument be accepted into the Air Force inventory as a standard display?

    Backup way in the corner
    Conditioned on a study of cost vs. occurrence of situations in which it could save an aircraft and crew. In twenty years I have not experienced nor do I recall hearing of a situation in which all instruments were lost and this instrument would have done the job.

Part II -- Comments on Varying Maneuvers

1. Recovery from unusual position.

   The indication to the pilot that he is correcting in the optimum manner is delayed excessively (perhaps due to the narrow limit margin in roll of the instrument).

   Found it easy to follow needle commands. Roll rate was too slow to correct the needle as fast as it could allow. No problem recognizing which heading atmosphere I was turning through

   I believe the instrument's use allows a rapid recovery from unusual positions.

   For loading changes or pitch level banks a just wish to roll wings level not to a specific heading.

2. Recovery from roll.

   An oscillation of 1/4" of the needle was occassionally observed (this probably due to the magnetic influence of the fuel totalizer).

   Referred to the needle and rocked wings thinking the needle was unstable -- actually I caused the needle oscillation. I was slightly puzzled on this maneuver.

   It is possible to roll past inverted flight ans. still get a reverse roll indication from the instrument.

   Thought I was on South since needle was centered with no turn rate. Made check and determined that heading was actually North, then had no problem recognizing the quadrant. I believe that this would come with practice and this check would always be made if the needle is centered with no turn rate.

   The recovery direction indicated by the instrument depends on the direction of the roll or inverted position, i.e., a clockwise roll calls for a counter clockwise recovery regardless of whether the shortest recovery route would be to continue clockwise.

   The converse is also true.

3. Recovery from heading changes.

   Needle centered with no turn rate. The turn check showed me that I was near South

   Vertical or level vertical recoveries are directed on continuous rolls or reset in confused indications.

   The "Stop" limits were not symmetrical.

4. Recovery from Heading Changes.

I dislike the addition of another instrument giving same information. Don't need and some don't want.
Instrument itself is valueless to indicate vertical flight.
Very easy to determine direction to roll, then correct airspeed.
No confusion at all. Good roll-out rate. The turn and bank is obviously necessary for determining the direction and rate of turn and thus is the instrument which gives the clue to recognition of the proper heading quadrant.
Recovery from a vertical position is not possible to do safely if the indications of the needle are exclusively relied upon.
This is due primarily to the fact that in a vertical attitude a roll becomes a yaw and instrument gives random deflections.

5. Recovery from inverted flight.

Again, easy to interpret the needle and follow its commands.
Good roll out.
The instrument would appear in a different light if the turn needle were also failer. In that case, Lifesaver would be a considerable aid.

6. Recovery from disorientation.

Easy to determine general heading with needle centered and then needle in slight turn.
Same comment as above except that my roll rate was slightly high and noted one over-shoot of needle centering. Easy to recognize and quadrant of heading.

7. Overall Impression.

Noted needle oscillation as soon as I took over.
Maximum confusion in vertical position - roll left and right.
Originally thought that I was inverted nose low and the Lifesaver instrument was my first clue that I was inverted.

8. Additional comments.

In general, the sensitivity is good - very stable, no jumping on oscillation.
Noticed the fuel counter caused the needle to fluctuate. However, this is no major problem.
I like steady indication the instrument presents.
Needle is very stable and easy to center and hold centered. Could use a pip in dead center.
Instrument needs some device incorporated in it to prevent needle oscillations from the fuel counter. Was annoying but did not make the instrument unuseable.

Think that the instrument presentation should be reversed, i.e., fly the needle to the index, like the needle of a turn and slip indicator.

Recommend that the instrument be made rotatable so that a vertical presentation represents "On Course".

The Lifesaver, like many possible instrument ideas, has its merits but, like many other instruments, is not the complete answer to the problem. Primary advantage is that it is self-contained.

Major disadvantage is that you never know if you are turning or not. If you argue that the standby compass will give you this information, then why not use the needle with the compass.

If complete D. C. elec. failure compounds the loss of your primary instruments which are powered by inverters then you really aren't going anywhere with the aircraft fastened to you anyhow. The instrument functions very well in the capacity for which it was designed. I did not misread its indications and felt that it was damped sufficient enough to prevent overcontrol and overshoot.

If additional markings are incorporated on the instrument face to allow flight in some direction other than South.

It is pretty worthless for recovery from vertical flight. If the needle sticks, "you've had it". Need some means of maintaining a desired heading other than South.

I question the over-all value as an aid for electrical failure because it doesn't aid the most dangerous axis - that of pitch. In conjunction with an instantaneous vertical speed it would be great. It does give a positive side up indication, and this is good!

Rolled out slightly fast and noted one overshoot due to fast rate. Pegged instrument moves off peg so fast it is easy to overshoot when making correction.

Inverted nose high, 300 degrees with the needle and ball instrument covered. Again, no problem of recognizing which way to turn but was naturally unable to determine heading of quadrant since no compass or turn needle was available.

By this time, I found the approximate roll rate which was proper and was quite pleased with the roll out. No trouble centering the needle and keeping it there.

Part III

1. Were you able to achieve normal recoveries with this instrument?
   Not satisfactory for vertical recoveries.
   Except vertical
   Once I fought the situation inadverently by rocking wings.
   Depended upon unusual position
   All recoveries were good except #4, inverted which other pilot had to take over
   Recovery in a nose low attitude it can induce a further nose low condition. It is very good for level, slightly nose low, and nose high (not vertical recoveries).

3. Were you capable of easily centering the needle?
   Width of center mark is too wide
   Marking should be more precise
   Needle should move in opposite direction
   No comment. Would like needle to move opposite to present method
   The centered position is too crude as to width of the center mark is too wide for the fineness of the needle. It is not necessary to mark it like a needle-ball instrument. Also, it is possible to fly the indication to a much more precise marking.

4. Could you handle the Lifesaver so that adequate wings level was maintained?
   Going south -- not particularly in other directions
   Going South

5. Were you able to maintain a 180 degree heading with the Lifesaver?
   Approximately
   Maintain heading ±10

6. Were bank deviations correctly represented on the instrument?
   I answered yes because bank angles up to 90 degrees seemed to give proportional linear needle displacement. Beyond 90 degree bank, needle was pegged.
   This is a combination bank and heading sensing indicator so that a correction could be for bank or heading or a combination of the two.

8. Did you make control reversals while using this instrument?
   I believe this was due to the opposite presentation of this instrument from the needle of the turn & slip indicator.

For over-shoots in initial recovery
The term "control reversal" suggested overcontrolling which would give overshoot in bank control. No problem of this nature was experienced.
By saying control reversal I mean that I turned opposite to the best recovery direction -- see inverted flight comment.

9. Do you favor incorporating this instrument into the cockpit as a back up instrument?
If the cost if reasonable
In its present state no. If the question about geographic influences is answered and certain other refinements made new force it could be used.
The present presentation, i.e., rolling toward the needle, would certainly give much mental confusion if the attitude gyro had failed without a warning flag such as the MM-2 indicator and the KAB control pitch or roll channel failures which are not uncommon in fighter aircraft. The tendency would be strong to follow the attitude indicator.

10. Did the Lifesaver instrument fulfill one of its objectives -- that of minimizing vertigo?
Vertigo was not experienced during flight
Vertigo prevertion was excellent, (test aircraft compass and attitude information instruments were covered with tape). No sign of vertigo in any maneuver.
Vertigo is not a visually stimulated disorientation - so this instrument could hardly cure it.

11. Did the use of this instrument enhance your performance on the other flight instruments?
In recovery from unusual positions it did.

12. Do you think that the present position of the instrument is the most advantageous placement?
Would like to see it in other position to be sure
Should be closer to primary flight instruments
Place it where it is not magnetically disturbed and where it is near the altimeter and airspeed indicator.
As a standby instrument it was satisfactory; however, it would be in a better position if it were directly in front of the pilot.
Should be located near attitude indicator for crosscheck.

13. Adoption of this instrument is imminent, do you feel it could be used to advantage?

    For some people
    Not in its present configuration

14. Did the instrument provide adequate information as to whether a needle deviation was a roll error?

    But the air was smooth
    Yes, if roll error was greater than approximately 30 degree bank

15. Was there adequate information available in this instrument when a heading deviation existed?

    Going South
    Except on a heading of 360 degrees

Part IV

1. What effect did the varying of "G" force have on the performance?

    None Noted
    Slight
    None
    None
    None Noticed
    No noticeable effect
    I could not note any effect
    No effects noted
    None that I noticed
    None
    The application of both positive "G" and negative "G" had no effect on performance.
    It appeared to cause an increased roll error indication, but I was not certain of this
    High "G" maneuvers were not evaluated as specific portion of the test
    On heading of 180 degrees, 3 g would give a left needle deflection which required 15 mean degrees of right bank to center.

2. Was there any evidence of erratic functions with the indicating needle?

    Needle was not erratic, even in turbulence; however, it did stick in the extreme right hand position on several maneuvers.
    The needle sticks especially on a counter clockwise roll into inverted on the roll out the needle stays pegged until a near level attitude is reached. This induces an over shoot in the recovery.

Yes, stuck numerous times in full right position
Yes, the needle stuck to the right on one occassion.
The fuel flow indicator action caused a slight fluctuation in the needle
Slight oscillation, approx. 1/2 the width of black center strip, no.
In the centered position as heading approached 180 degrees needle would make a large scalar movement, then give indication of inadequate bank. Noticed in right turns to 180 degrees.
Yes, when the fuel counter was operating
On one occassion the needle hung-up when right correction was required.

3. Was there any evidence of erroneous indications with the instrument?
   9 Nos
   Yes, a roll past inverted sometimes resulted in a direction to reverse roll.
   Random indications when vertical overshoot as mentioned above

4. What limitation, if any, did you experience while using this display?
   Limited in vertical maneuvers.
   No good for vertical recoveries. Have no way of knowing the short to roll upright
   When the aircraft was climbing vertically the instrument did not tell me how to recover
   Information during vertical rolls was non-existant.
   Vertical flight
   Recovery from vertical flight
   No help in vertical recovery
   Not satisfactory for a vertical recovery nor straight down.
   The maximum deflection is reached at about 40 degrees and the instrument pegs on the opposite direction about 30 degrees past 180 degrees of roll, i.e., 210 degrees.
   It is incapable of handling vertical recoveries
   Lack of pitch information necessitates cross checking with airspeed and altimeter.
   Does not have the ability to indicate dangerous pitch attitudes
   Poor pitch interrputation during recovery from unusual positions which were extremely nose high or nose low. Recovery from inverted, nose low positions would be extremely hazardous.
   It did not tell me what the airplane attitude was until recovered.
   Excessively delayed response to large roll corrections.
   I found no real limitations, and I was confident after the first two maneuvers that the instrument would command me into a safe condition of bank.

5. How does the instrument compare with other standby indicators you have flown?

Very well

Best because it is not limited to level flight on attitude of the aircraft except vertical

Favorably

I would definitely prefer to have this instrument as a back-up instead of a standby attitude instrument which may always be reading differently than a primary one. I experienced this case in RAF fighters which have two altitude indicators and the confusion factor can be distressing. The pilot actually doesn't know which indicator to believe.

Not as good as standby pit indicator

It isn't as good as a standby attitude indicator, but it isn't as complicated either.

I prefer an attitude gyro

Only one other that standby gyro (horizon) I have flown. The artifical horizon weather stand-by or the full-blown instrument is better.

A self contained attitude gyro would be better. This instrument incorporates heading and bank information where as I would rather have them presented separately as with a mag. compass and an attitude gyro. The only time you have your wings level.

Favorably, in concept only

3 no answers and don't knows.

No comparison

6. Additional comments

Gives confidence in a quick successful recovery as soon as needle is centered, even before pitch is corrected. Reduces cross checking task and thus simplifies recovery.

I like it

Very impressive

It seems unnatural to roll toward the needle. I would prefer, if possible, an instrument which would require the same corrective measures learned for recovering from unusual positions using the turn needle.

(not turning) is South. I am interested in being able to hold other headings

I think the instrument could be very useful. I believe it should be tested in a century series A/C so that large airspeed changes could not be detected.

I think the instrument, in addition to not allowing recovery from vertical flight, would not permit recovery from a spin.

Part V

1. Would you like to see this instrument discarded?

   If it isn't reliable

2. Do you feel that vertigo could be eliminated to a greater extent than achieved by the Lifesaver instrument?

   Do not feel it would have any effect on vertigo one way or the other.

   This instrument was not adequate to recover from vertical climbs or descents. In these extreme positions, centering the needle did not correct the situation.

   Vertigo is not eliminated by any instrument

   I do not feel a visual instrument will eliminate vertigo.

   I think vertigo could be reduced by presenting pitch information on the same instrument

   I feel that an operative attitude indicator has a greater potential of eliminating vertigo than the lifesaver; however, I still do not like the idea of having two uncovered attitude instruments in plain view at all times. The question of standby electrical power for the additional attitude gyro has never been fully solved. I feel that the present state of the art dictates that the Lifesaver instrument be installed in lieu of the additional attitude gyro with its attendant power requirements.

3. Was the Lifesaver inadequate for maintenance of a 180 degree heading?

   ±10 degrees

   The needle was not covered so an indication of bank was available. Without the needle there would definitely be confusion as to which was required. This is not too important though as they both cancel as 180 degrees is approached.

4. Were you able to detect any weaknesses in this instrument in directing normal recoveries?

   The oscillations of the instrument during vertical flight could easily be mistaken for turbulence effects and this could delay a timely recovery. I do not think this is a serious shortcoming however, since the altimeter, airspeed and vertical speed should quickly indicate the nature of the attitude even if the Lifesaver is misunderstood.

   See previous comments on roll or vertical recoveries

   Recovery from vertical flight

   In vertical recovery

   Inability to accomplish vertical recovery

5. Did you find any features of this instrument which were in conflict with your performance on other flight instruments?

Works in reverse to mechanics of turn needle

Its reverse presentation to that of the turn and slip indicator

Roll corrections are toward the needle rather than the desired method of moving needle to center of instrument.

Works opposite turn needle

Distracted me from pitch control.

6. Can you visualize a more strategic placement for this instrument on the panel?

Near the attitude gyro and beside the vertical speed instrument

Recommend to right of these 2 instruments. Undesirable to have near the turn and bank indicator.

Closer to basic instrument group

Near the altimeter and airspeed indicators so that the crosscheck doesn't require so much eye movement.

I found that the vertical speed and the Lifesaver became primary when the other instruments were covered and for this reason I would like to see the fastest possible reaction to unusual situations

Closer to turn needle

Maybe

7. Since this is a new instrument, and many pilots stated that they had some adaptation difficulties, there is interest in determining if you had any trouble with this instrument?

Reversal problem

Not after a brief orientation flight

Poor question

8. Since a heading change is a resultant of a roll change, we are concerned as to whether the instrument tended to confuse you when an error existed as to whether it was a roll or heading error?

It could be confusing if no other bank reference were available but it doesn't matter. If the needle is centered the result will be as built into the instrument - wings lever southerly direction.

Didn't really care since required corrections were small.

9. Since this instrument provides both heading and roll information in the same needle, we were wondering if you experienced any confusion as to what were the required corrections?

Not as long as I had the turn needle.

10. There is a feeling that bank deviations are incorrectly represented on this instrument. Do you comply with this feeling?

    I can see no tendency to get into an unusual pitch or bank attitude by rising the instrument as is.

    A combination bank and heading is presented.

    You need another instrument to know which way you're banking.

11. There is a great deal of negative feeling about this instrument, do you feel it should be accepted?

    It is nice but something would have to go. What? Would prefer presentation to be reversed, i.e. left needle deflection required Right roll.

    Very poor question! Should the feeling or instrument be accepted. The instrument requires further sophistication. The principle is good.

    Not in present configuration.

    What, the feeling or the instrument? The instrument would be useful only if the turn needle was inoperable.

    Needs further study

    Loaded questions, and may therefore obscure the correct answer. However, I think that my answers are valid.

12. Considering the various aspects of the instrument that might have been a hindrance to you, do you still feel this instrument proved to be useful?

    Qualifiedly.

    For some things.

    There were times that it was useful but I could have done just as well without it -- under the conditions that existed when I flew it.

13. Since uncertainty has been expressed as whether the Lifesaver provides enough information for maintaining wings level, there is interest in whether you detected any difficulties while flying with the Lifesaver in maintaining control of wings level?

    Other than 180 degrees.

    Yes, off 180 degrees.

    No trouble when headed south.

15. Did certain defects in the presentations of the instrument and/or other factors lead you to make control reversals?

    Only on initial roll recovery.

    Only slightly.

Additional comment.

I think the instrument has much in simplifying the pilot's task in recovery by eliminating the requirement for extensive instrument cross checking. Also it provides a rapid indication that the pilots' input is correct and recovery is in progress. He needs only then to keep the needle centered (easy enough to do) while he stabilized his airspeed and attitude.

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Group
AF 33(657)-8600

Memorandum Report No. 62-11 8 October 1962

Task Consulting

To: Mr. G. Yingling (ASRMCS) and E. Vinson (Link Division)

cc: Mr. J. H. Kearns, Capt. E. Waggoner, Mr. S. G. Hasler, Mr. R. R. Davis, and Members of Martin Human Engineering Group.

From: W. K. McCoy

Subject: Scoring System Requirements

The following report describes a semi-automatic, flexible and fairly comprehensive scoring system for use in investigating control-display configurations and associated hardware in simulated environments. The requirements for this system come from the measurement needs of human engineers in conducting such investigations.

The human engineer is usually interested in the interaction between the human operator and the various control and/or display elements of the machine. The complexity of such interactions pose difficult measurement problems to gather information concerning these interactions. The current techniques involve taking overall system performance measures, which includes the outputs of the man as well as the outputs of the machine, while systematically varying control and/or display elements to determine which elements produce the desired system performance.

It is desirable to measure the total system performance along parameters that will discriminate between the variables of interest. It is apparent, then, that the more parameters that are measured, the more descripers of the total variance of the system that will be available. Thus, the information available to differeniate between the variables of interest will be more adequate.

Currently, the scoring systems used in such studies are limited in the number of parameters that can be simultaneously measured. These scoring systems are usually designed according to system specific criteria, and they are, thus, not flexible enough for use in subsequent studies unless identical parameters are of interest. This is a severe limitation. For each new study a new scoring system must be designed and built at a great expense in time.

The scoring system proposed in this report will measure more parameters simultaneously and be flexible enough for use in studies where a variety of parameters are of interest without major modifications. This property will, in the long run, save much time.

The following table lists many of the possible parameters for measurement.

PARAMETER	MEASURES			
Deviation from Steady state for:				
Azimuth	RMS	AE	AAE	X-Y Plot
Airspeed				
Altitude				X-Y Plot
Vertical Speed				
Angle of Attack				
Flight Path Angle				
Yaw				
Deviation from a command rate of change for:				
Airspeed				
Vertical Speed				
Pitch Angle				
Bank Angle				
Yaw Angle				
Time history for:				
Elevator Travel	Oscillographic Records			
Rudder Travel				
Aileron Travel				
Pitch Angle				
Bank Angle				
Yaw Angle				

Terminal measures for approach and landing profiles:

- Distance Down Runway
- Displacement from Centerline
- G's
- Airspeed
- Rate of Descent
- Pitch Angle
- Bank Angle
- Rate of Change of Pitch Angle
- Rate of Change of Bank Angle

The parameters shown in the table are descriptors of different aspects of the total system performance. It is felt that measures of these parameters would allow the evaluation of a large number of control and/or display elements. The overall system performance as measured along these parameters reflects the capabilities of the system elements, whether control modes or displays of flight parameters, for performing given maneuvers.

Certainly an extremely precise evaluation of overall system performance could be made from measures of all the parameters shown in the table, but such a task would, for practical reasons, not be feasible. In practice, experience has shown us that simultaneous measures of six parameters will provide adequate information for the evaluation of system performance. The parameters measured would vary according to the maneuver, or task being scored.

An adequate measure of a parameter should include three error scores that will describe the magnitude of error and the variability of error about the given parameter. These three error scores are: average error, to indicate the average of the deviation from a reference index with regard to algebraic sign; absolute average error, to reveal the average of the deviation from a reference index irregardless of sign; and root mean square error, to serve as an index of variability about the given reference performance level (i.e., $\frac{1}{T}\int e\,dt$, $\frac{1}{T}\int |e|\,dt$, and $\frac{1}{T}\int e^2\,dt$)

The scoring system, therefore, should include a computer that will provide six scoring channels, with each channel having enough amplifiers and multipliers to obtain the three error scores for each selected parameter. Ideally a sequencer and printer should be used to enable the printing out of scores at selected points in a predetermined profile. This property would allow the analysis of the error scores by maneuvers, or tasks. Further, if the parameters being scored on the six scoring channels could be changed at will a "full mission" profile could be scored, in that the parameters considered important for performing a given maneuver could be measured when that given maneuver occurred in the profile. That is, during any simulated flight of a pre-determined profile, the selected parameters being measured in the six scoring channels could be changed so that during different phases of the profile, different parameters could be measured. Scores for one phase of the profile could be printed out, clearing the channels, and the scoring channels could then be used to score parameters appropriate for the next phase of the profile, etc.

The full mission scoring capability also requires that the reference index from which the error scores are computed, be variable. That is, we should be able to change the reference index as appropriate to changes in maneuvers being scored. For example, in a climb out maneuver, the reference index for vertical speed may be 3,000 feet per minute from which to compute error. After level off this reference should be zero.

Also to avoid distorting scores on one maneuver because of errors on the preceding maneuver, we should be able to interrupt the scoring sequence to make any necessary adjustments of the position of the simulator so that all subject pilots would begin the maneuvers from the same point regardless of where they completed the preceding maneuver.

Along with the six scoring channels to obtain the error scores described above, it would be desirable to obtain, also, time histories of control movements, as reflected in elevator, rudder and aileron travel and vehicle movements in the pitch, roll, and yaw axes as well as X-Y plots of performance vs. range (altitude and azimuth vs. range, for approach and landing profiles and takeoff and climbout profiles).

In summary, the proposed scoring system should include the following basic components; a computer to provide six scoring channels that will give three error scores on each selected parameter; a sequencer and printer with associated decision making networks to provide the flexible full mission scoring capability; an eight channel oscillograph to provide the desired time histories of control and vehicle movement; and two X-Y plotters to provide the time histories of performance vs. range.

W. K. McCoy, Jr.

W. K. McCoy, Jr.

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Support Group
AF 33(657)-8600

MEMORANDUM REPORT 63-1 31 January 1963

Task No. Consulting

To: E. Bobbet

cc: Capt. E. Waggoner, Mr. E. Warren, Mr. R. R. Davis and all members of the Martin Human Engineering Group.

From: F. Mullen

Subject: Working Paper: Application of and Research Requirements of the Photochromic Display Device. Mark IV Control-Display System.

Description

The unique feature of this particular piece of equipment is its capability to present several types of information on a six by eight inch viewing screen for preselected periods of time. This information includes sixteen alphanumeric characters (ten numbers and six symbols) and four cursors which can be presented on the viewer with respect to X-Y coordinates. In addition to these symbols, a small, moving, comet-like dot of light can be continuously displayed anywhere on the screen. Moreover, this instrument can project six different background grids along with the aforementioned symbols for three different time exposures. Thus, it has the capability of displaying one moving vehicle plus certain information concerning its behavior with respect to a specific course of flight. There is, however, one major limitation with respect to the use of this instrument in aircraft or space vehicles, and that is the slow rate at which alphanumeric or cursor symbols can be displayed on the viewing screen. An estimated 5-10 seconds is required to present a combination of alphanumeric characters or cursors which, for all practical purposes, precludes the use of this instrument for the display of continuously changing data such as airspeed, vertical velocity, etc. However, this does not mean that the photochromic display device cannot in some way be utilized during the Mark IV simulation study or other future projects.

Use

With specific reference to the Mark IV program, the photochromic display device can be utilized to present two types of information. First, in order to enhance fidelity of simulation it is suggested that a prelanding checklist be presented to the pilot. This could easily be done by placing a slide of the checklist in the instrument to be projected just prior to entering the simulated flight profile. Duration of presentation can be controlled by the pilot by means of a background grid selection switch.

Secondly, it should be recalled that no horizontal situation indicator or distance measurement equipment is included among the Mark IV displays. Eventhough it is impossible to present a three dimensional display of the vehicle's flight path, desirable navigation information can be presented the pilot through use of the photochromic display device. A background grid containing an outline of the desired gross flight path profile would be projected on the viewer during the initial four minutes and twenty seconds of simulated flight (Figure 1). A background grid showing a magnified view of the remaining three minutes and twenty seconds of flight would then replace the gross flight profile on the viewer (Figure 2). A small, moving, comet-like dot of light would represent the flight of the vehicle along the desired course. This information would allow the pilot to gain valuable position information at a glance.

The photochromic capability of this instrument could be utilized by periodically presenting the pilot with data concerning the amount of time that remains before landing and the command altitude at specific points along the flight path profile (Figures 1 and 2). Data concerning the amount of flight time remaining would allow the pilot to continually prepare himself for landing during the entire mission, and the command altitude information would enable him to readily determine his deviation from the required altitude at several specific positions during the flight. This would be especially important during the Mark IV flight profile where a descent of some six miles is required during a period of less than eight minutes.

There are, however, several minor problems associated with the presentation of the aforementioned information. Since the photochromic display device has the capability of reproducing only twenty different symbols, the flight time remaining and command altitude data cannot be labeled directly as such; the use of symbols will be required. For example, command altitude data could be labeled with a plus sign, i.e., +25 000, and the flight time remaining data could be designated by the runway cursor, i.e. ||3 40 (Figures 1 and 2).

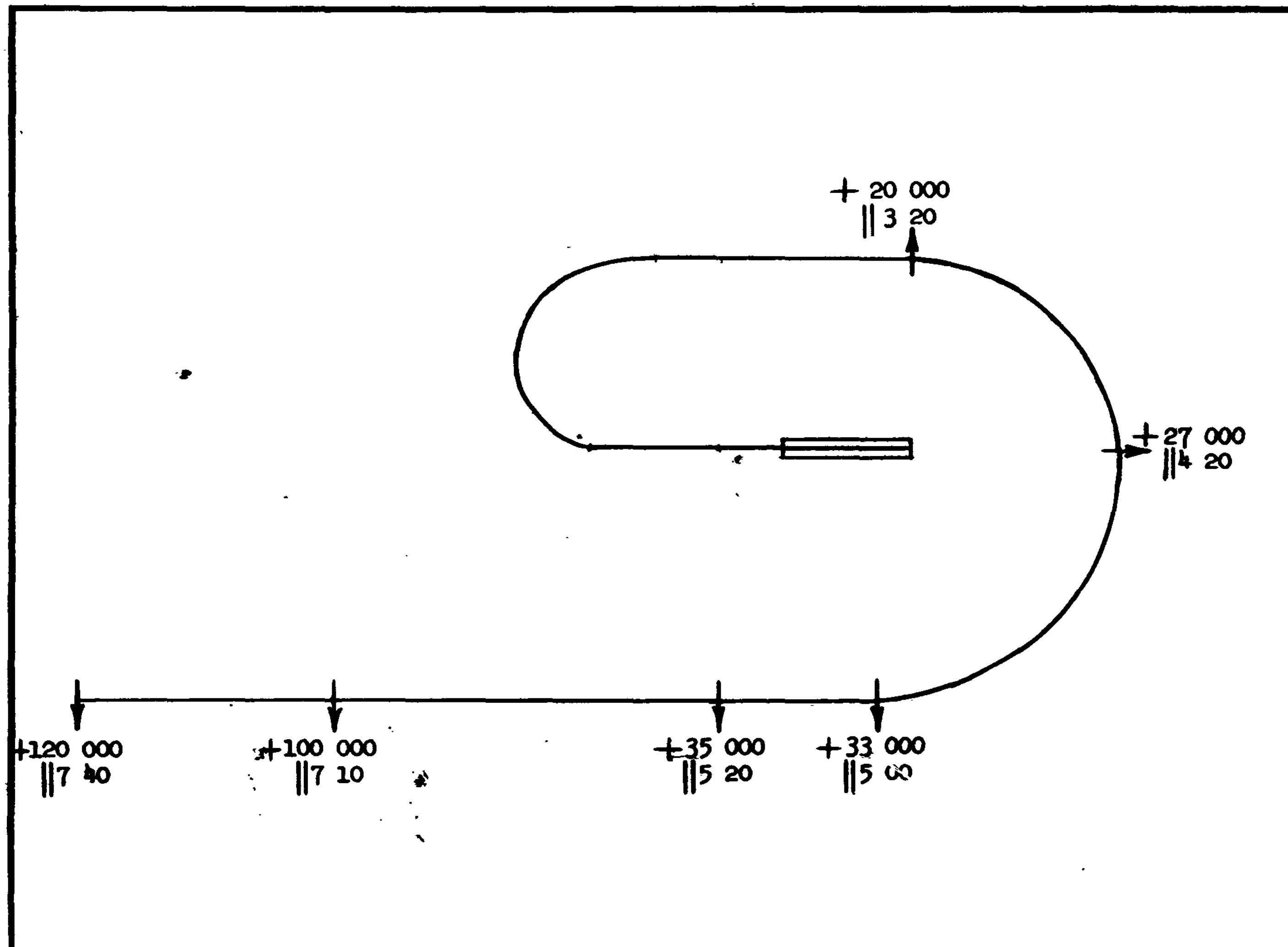

Figure 1. Gross Flight Profile

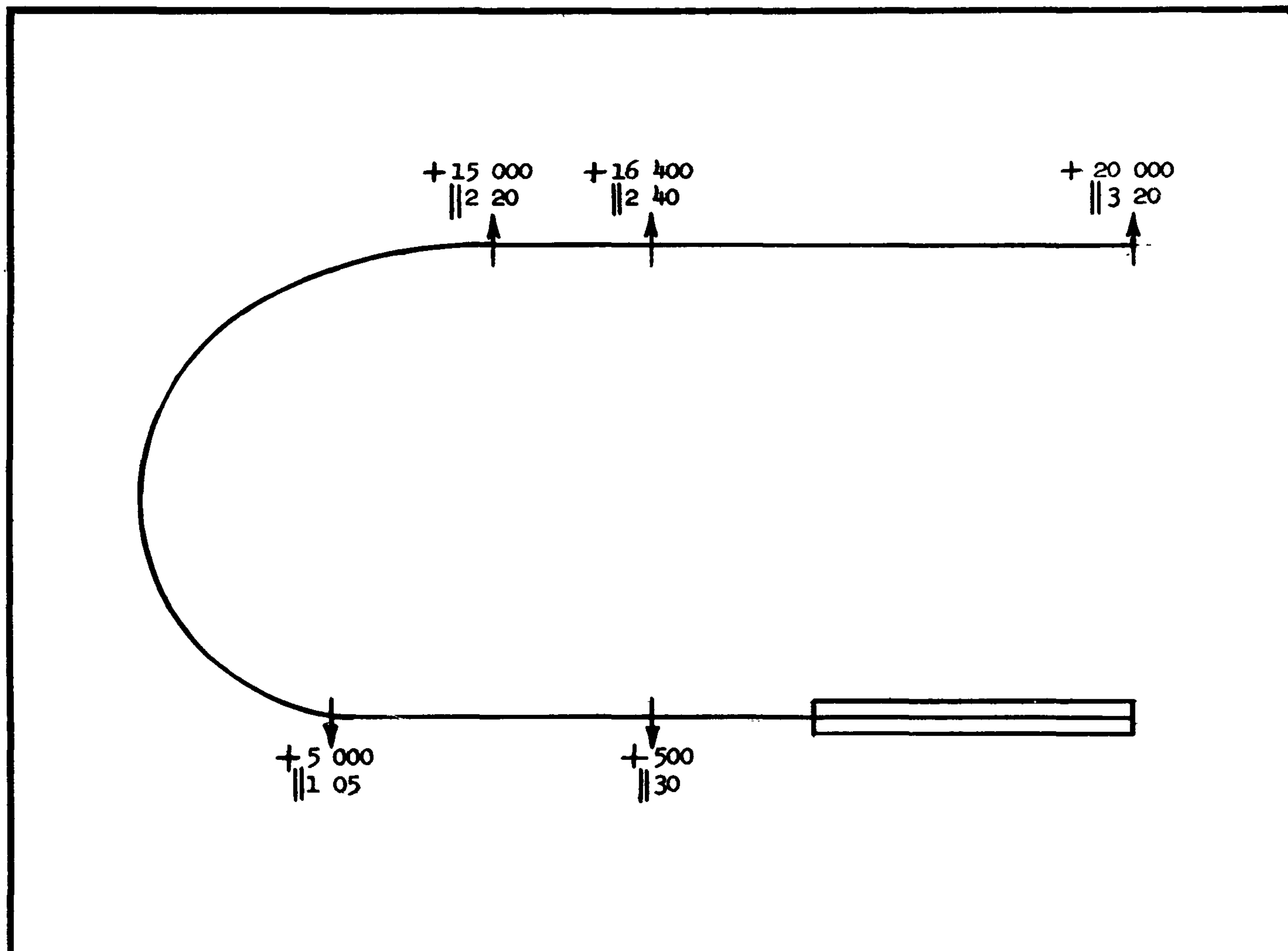

Figure 2. Magnified Flight Profile

A technical problem which must be resolved is the determination of the length of time required for the photochromic display device to present the command altitude and remaining flight time data on the viewing screen. This variable would determine how many times these data are to be presented during the entire mission.

There is possibly another technical problem which should not be overlooked, and that is the accuracy of the information presented on the viewer. When the background grid is changed from the gross view to the magnified view of the final portion of the flight path, care should be taken to make certain that the second background grid is in the same alignment as was the first. Misalignment would give the pilot an incorrect view of his vehicle in relation to the flight path.

Research

Even though the information conveyed to the pilot from this display may appear to be valuable and useful, it is strongly suggested that a research study be undertaken to determine whether or not these additional data actually enhance pilot performance during simulator flight. Such a study could be conducted in conjunction with the regular Mark IV research program. It would require that each subject be given one trial using the photochromic display device for each condition used during the Mark IV research study. For example, if during the Mark IV study, the pilot flies the simulator flight profile with only the pitch axis operating, and roll and yaw held constant, he would be required to fly one profile using the photochromic display and then repeat the same flight profile without the display. This would also be the case for all other conditions of the experiment. Trials, of course, would be counter-balanced for each condition of the experiment with respect to the use of the photochromic display. The same measurements would be taken for all experimental trials. The Mark IV data gathered without the use of the photochromic display would then be compared with the data obtained while the display was in use to determine whether or not any differences in performance are present. This effort would require approximately fifteen to thirty minutes additional time per subject per condition; no additional manpower would be needed.

Future Use

In the future, when the photochromic display device has the capability of receiving inputs directly from a computer, the use of the instrument can be expanded to include interception or rendezvous missions. It would be possible to represent the pilot's vehicle with the small, moving, dot of light as in the Mark IV program; an alphanumeric symbol would designate

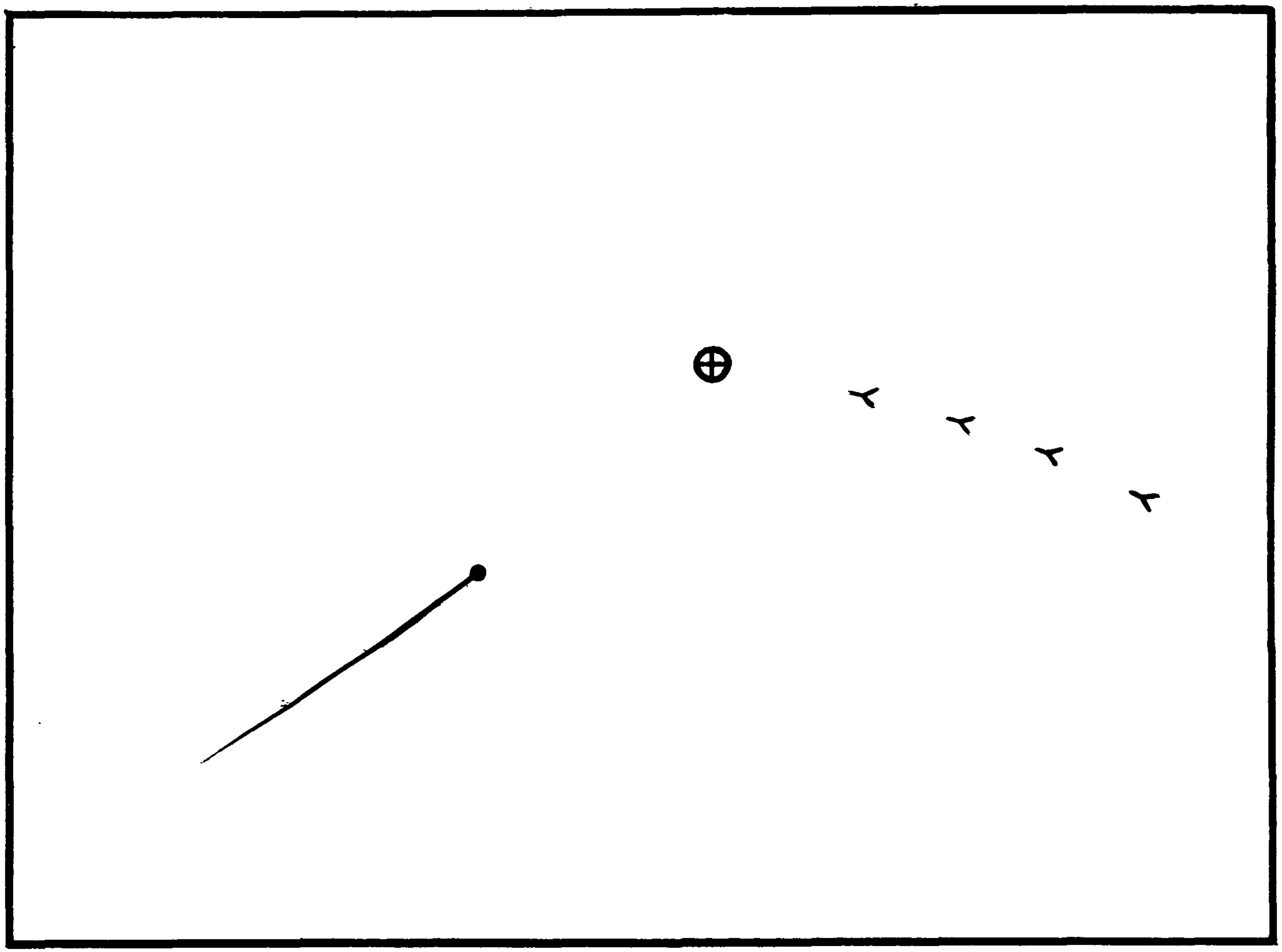

Figure 3. Interception

the position where the approaching aircraft will be intercepted (or point in space where rendezvous is to occur), and the flight direction of the approaching aircraft could be continually presented by means of a cursor symbol (Figure 3).

Presentation of the approaching vehicle presents a technical problem due to the estimated 1-3 seconds required to reproduce the cursor symbol on the viewer. However, this difficulty could be overcome by ascertaining the distance that the approaching vehicle would travel during this time lag and have the computer calculate the location of this vehicle at the time the cursor would appear on the viewer. The symbol of the approaching vehicle would not move continuously, but rather it would progress across the screen in small, distinct increments toward the point of interception. The pilot would thus be able to observe the progress of his vehicle and the progress of the target toward a predetermined point of contact.

Frank G. Mullen

Frank G. Mullen

AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM
Martin Human Engineering Group
AF 33(657)-8600

MEMORANDUM REPORT NO. 63-2 — 7 February 1963

Task No.: 16

To: Eldon M. Bobbett

cc: Mr. J. H. Kearns, Capt. C. E. Waggoner, Mr. E. L. Warren, Mr. R. R. Davis, Mr. R. W. Schwartz, Mr. E. D. Vinson, Mr. J. K. Charlton, Mr. R. H. Gehl, Mr. J. D. Vertrees, Mr. S. G. Hasler and all members of the Martin Human Engineering Group.

From: William L. Welde

Subject: Work Statement for the Mark IV-B Profile Measurement Task

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Introduction

This is the initial study of a program designed to investigate the feasibility of the proposed descent and land flight profile for the Mark IV manned space vehicle re-entering the earth's atmosphere after a 30 days sustained orbital mission. Although the Mark IV is a hypothetical space vehicle, it parallels closely with the Dynasoar vehicle and mission. Composed of two pilots and two technicians, the Mark IV's mission is to serve as a launching platform for five missiles, each of which can be programmed, fired, and maneuvered, to a limited extent, within the atmosphere to strike a pre-selected target (Ref. 1).

Because the Mark IV is constructed with aerodynamic characteristics that provide the pilots with the capability of flying the vehicle within the atmosphere, re-entry is initiated at a point which permits the vehicle to land at a desired base. As the vehicle re-enters the atmosphere, it will be controlled along a flight path which does not exceed certain maneuvering limits while at the same time allowing it to dissipate energy at the required rate to arrive at a terminal area with sufficient speed and altitude to effect a safe approach and landing.

Statement of the Problem

The basic question to be answered by this study is - Can the profile be flown? This query can be subdivided into numerous problems requiring investigation, of which the following are foremost:

1. Can the descent profile be flown as it presently exists to permit the space vehicle to reliably effect a safe approach and landing?

2. If the existing profile does not result in consistent performance of the flight task, what alterations should be instituted to achieve the optimum descent profile?

3. What additional cockpit instrumentation and controls are essential to simplify the pilot's task of information integration and, thus, enhance the probability of a safe approach and landing?

4. In flying the profile, what are the quantitative values of the more important flight parameters during each phase?

Pre-Experimental

The pre-experimental phase of the profile measurement study will be devoted to conducting three subject pilots through an extensive series of experimental sessions. To provide a representative sample of the pilot population to be employed in the study, one pre-experimental subject will be selected from each of the three participating organizations. By utilizing this sampling procedure, results obtained in pre-experimental work can be safely theorized to exist for the entire subject population. A more detailed discussion of the experimental subject pilots is presented later in this document.

The primary objective of the pre-experimental efforts will be directed toward resolving a salient issue regarding task learning, and the determination of conditions which produce increased learning efficiency.

As set forth in Underwood (Ref. 2), there are essentially three methods of performance measurement in multiple response learning from which learning curves can be constructed.

1. mastery level after a given number of trials or for a given length of time
2. number of trials or amount of time required to reach a given criterion of mastery set by the experimenter
3. error reduction

There are arguments for the use of all three methods, but rather than proceeding with a somewhat lengthy and involved discussion of the merits and difficulties of each, it's the intent only to point out the training technique to be instituted will evolve from the pre-experimental work.

Basically, the aim of the research on the proposed descent pattern is not to project differences in performance among the subjects after they have flown a pre-determined number of practice trials, but instead to permit each subject to attain a high degree of proficiency in the flight task, regardless of the number of trials required, before commencing with data collection runs. Thus, the problem is posed of judging when each subject has approached asymtote of performance and upon what set of criteria this decision will be founded.

The initial endeavor to select the point at which task learning attained by the subject results in an acceptable level of skill and reliability will be made by scoring and analyzing data measured from the parameters listed below: (refer to Scoring Equipment section for types of recordings)

1. altitude vs. range
2. altitude vs. time
3. Mach vs. time
4. Mach vs. altitude
5. vehicle track deviation from the desired pattern

Data from these parameters will be sampled at checkpoints 2 to 12 inclusive located throughout the entire profile (see pictorial layout of the descent pattern), which will provide 55 data points for each trial. The values obtained will be examined at each of the eleven significant checkpoints to ascertain if they fall within the desired tolerance for that parameter. During the pre-experimental phase, these tolerance bands will be specified by plotting the values scored from all runs flown by the three subject pilots. In this manner, a trend analysis of task learning can be performed resulting in realistic limits of acceptable skill levels on each parameter.

This trials-to-criteria technique, as outlined by Underwood in Method #2, transforms the raw scores into a plot of the number of trials it has taken each subject to reach arbitrarily established successive performance levels, thus, generally yielding a negatively accelerated learning curve.

In addition to using the five measured parameters as the fundamental criteria for evaluating the proficiency of the subjects on the flight task, a frequency count will be transacted during the practice trials to disclose the number of vehicle control losses and the time and condition existing when these failures occurred. Due to the unstable characteristics of the space simulator at the higher altitudes in the profile, it is anticipated that a spin-out will not be uncommon in the course of early practice runs. Recording these losses of vehicle control will provide another method of assessing the subject's progress with respect to flight task familiarization.

This tally corresponds to Underwood's third method since discrete parts of the performance can be measured separately. If a learning curve is constructed for each subject from these data, a study can be made of the sources of difficulty in learning the task.

In substance, the stage at which the subject pilot is considered to have achieved an acceptable degree of proficiency on the assigned task will be dependent upon a comparison of his measured values, scored on successfully completed runs, against an empirically determined set of standards.

However, if the pre-experimental phase reveals the criteria mentioned above for judging the subject's qualifying performance level necessitates extensive data reduction, a technique of giving an equal number of practice trials to all pilots will be employed. (Method #1) In using this approach to flight task learning, sufficient trials will be administered for the pilots to attain a realistic level of proficiency. Again, data derived from the pre-experimental subjects will be used for designating the quantity of practice trials essential for achievement of adeqpate flight task performance. Training will be accomplished in such a manner as to have approximately an equivalent amount of error for each individual prior to departure on the actual experimental runs.

Confidently, an intensive and critical examination of the data generated from the three pre-experimental subjects will provide an insight as to which of the two techniques, training to a criterion using an unequal number of practice trials or giving a specified number of trials to all pilots, will be best suited for this study.

A memorandum will be published at the conclusion of the pre-experimental work reporting the knowledge obtained and subsequent decisions.

<u>Experimental Procedure</u>

The study will be conducted in two parts. The initial sessions will be considered a practice period with the actual scoring of the runs for data analysis taking place during the final session.

Practice Sessions(s)

The object of the practice period is to provide an opportunity for each subject pilot to become completely familiar with the descent and land profile before being asked to perform for purposes of data measurement. Therefore, the subject pilot will be encouraged to practice until he is confident of the simulator's handling characteristics and in his ability to fly the assigned task.

Upon reporting for Session I, the subject will be briefed thoroughly on all facets of the descent and land profile. This instruction will be in the form of a "chalk talk" by the experimenter and will include values of airspeeds, altitudes, flight path angles, and headings to be flown, navigational aids available, location of check points in the profile, timing, and finally, a discussion of the simulator's flight dynamics. The manner in which the study is to be conducted and the time involved will be explained to the subject. Special emphasis will be placed upon the conception of establishing a relaxed informal atmosphere which will result in the maximum flow of information. Any questions presented by the subject dealing with the task or the experimental procedure will be readily answered.

At the conclusion of the flight task briefing, the subject will be familiarized with the cockpit controls and instrumentation. A pictorial layout of the descent pattern will be displayed in the cockpit above the instrument panel for use as a quick reference by the pilot while performing the task.

For trials 1 and 2, the experimenter will be seated in the cockpit and perform the duties of an instructor pilot by coaching the subject during the performance of the flight task and critiquing him at the termination of the run. Commencing with trial 3, the run will only be monitored from the experimenter's scoring station outside the simulator cockpit for the correction of misunderstandings regarding the assigned task and gross errors in the execution of it.

It is hoped that approximately 7 practice trials will be sufficient for the subject to attain at least an acceptable degree of skill and reliability on the descent profile and, optimistically, his asymototic performance level will have been reached. A stipulation will be imposed that a maximum of 7 trials can be flown in the first practice session, and a minimum of 6 be given, even though early achievement of desired task performance may have been acquired. Also, if it becomes readily apparent to the experimenter during Session I that the subject pilot is having difficulty in adjusting to the flight task, that individual will be requested to return for an additional training session.

The ultimate evaluation concerning task learning will not be made until the termination of the first training period for each subject, whereupon an analysis of the recorded data will be conducted. The decision will be based upon sample scoring of the practice runs and a comparison of the flight parameters, previously outlined in this document, with the predetermined performance criteria. This assessment will be facilitated by taking recorded measurements of trials 3, 4, 5, and 7 in order to construct a learning curve to depict the rate of the experimental subject's progress. And finally, a relatively stable estimate of the current proficiency level is needed to judge whether the subject is prepared to embark on data collection runs. A mean and standard deviation, computed from trials 5, 6 and 7, will be utilized as the values on which this decision is founded. For example, if these computed scores fall within the tolerance limits, which were empirically determined in the pre-experimental work, at 10 of the 11 significant check points, the subject will be considered to have had adequate training and can proceed with the experimental runs in the following session.

If the plotted learning curve indicates the pilot's proficiency on the flight task is still deficient, however, he will be scheduled for supplementary training. Should the subject fail to qualify to the acceptable level of performance after 15 practice trials, he will be excused from further participation in the study.

In summary, a scientific and objective evaluation on the feasibility of the descent and land profile under investigation demands that the data emanating from the study be authentic and consistent. These properties of valid measurements for all flight parameters being recorded and analyzed are predicated upon eliminating any significant effects of task learning prior to commencing with the data collection runs. Thus, it can be deduced that determination of whether each subject has attained the acceptable level of flight task proficiency, as set forth by the pre-experimental standards, is of extreme importance in producing accurate experimental results.

Time Breakdown of Practice Session I

Each trial consists of 8 minutes in duration with an additional 2 minutes required for resetting the equipment to the starting values and provide time for the pilot to establish the initial launch attitude conditions. Thus, a minimum of 10 minutes will be consumed for each complete descent run. The 2 minutes resetting time can be utilized by the subject as a short rest period and for asking questions.

Briefing on flight task	10 minutes
Discussion of experimental procedure	5 minutes
Cockpit checkout	5 minutes
7 practice trials	1:10
Total	1:30

Data Acquisition Session

The second and final part of the study will be devoted primarily to the actual collection of data on the degree of skill in which the subject pilots can reliably perform on the descent and land profile.

Each subject will be scheduled to return for the data acquisition session shortly after he has completed his flight task training. Ideally, the time interval between the final practice period and the actual experimental session would be 18 to 30 hours or overnight, but in any case, the time span will be no longer than 3 days, e.g., Monday - Thursday, Friday - Monday. By restricting the between-session-time-interval, the number of runs necessary for the individual to again achieve his peak proficiency level on the task will be kept to a minimum. Information derived from pre-experimental should indicate the number of practice trials needed in the final data acquisition session to relearn the flight task.

It is estimated that two practice trials will be adequate for the subject to become thoroughly competent again in flying the descent profile. Subsequently then, runs 3, 4, 5 and 6 will be scored for experimental data reduction and analysis.

It is essential to state at this time that the subject will be unaware that only selected trials will be scored for measurement purposes. During the course of the initial briefing prior to Session I, the experimenter will point out that decisions on the feasibility of the profile will be based on the data obtained from their performance of the task, therefore, it is of the utmost importance that each and every run be flown as precisely as possible.

At the conclusion of the four experimental runs, the subject will be administered a comprehensive questionnaire regarding his opinions on the descent and land profile and suggested methods for improving the reliability of successful touchdowns.

Time breakdown for Data Acquisition Session:

Re-briefing on flight task	10 minutes
2 practice trials	20 minutes
4 scored runs	40 minutes
Complete questionnaire	20 minutes
Total	1:30

Flight Task

The flight task to be performed by the subject pilots in the Hypersonic ME-1 simulator is a 360 degree flame-out pattern designed to permit a safe approach and landing for a space vehicle returning from an orbital mission. Beginning at a point where the pilot can make positive control inputs with respect to vehicle attitude (120,000 feet), and terminating on the runway at an altitude of 0 feet, the descent pattern is flown in a power-off or "dead stick" condition. (Refs. 3 and 4)

The vehicle is equipped with tip extensions, which will remain extended throughout the flight, speed brakes producing drag effect of varying amounts selected by the pilot, and finally, a "one-shot" landing skid system. Navigational information, presented by the HSI, will be composed of VOR stations with DME capability located at the high key and aiming points.

For a detailed description of the flight task, see the following figure of the descent pattern.

A delineation of Mach values for the entire altitude range is presented below:

Altitude	Mach	IAS	Significant Events
120 M	5.90		Starting values
110 M			deceleration phase
100 M	3.30	290 K	
90 M	2.65	290 K	
80 M	2.10	290 K	
70 M	1.70	290 K	
60 M	1.40	290 K	
50 M	1.14	290 K	
45 M	1.03	290 K	
40 M	.94	290 K	
35 M	.85	290 K	Begin decelerating to 180 K
30 M	.49	180 K	
25 M	.44	180 K	
20 M	.40	180 K	
15 M	.36	180 K	begin accelerating to 290 K
10 M			acceleration phase
5,000'	.48	290 K	
4,000'	.47	290 K	
3,000'	.465	290 K	
2,000'	.46	290 K	
1,000'	.45	290 K	Lower landing skids
500'	.38	250 K	Begin flare
touchdown	.265	175 K	V/V less than 600 FPM

Apparatus

The investigation of the descent profile will be conducted in a modified ME-1 flight simulator. The Link Division of General Precision Inc. transformed an ME-1 trainer into an evaluation device for first-generation space hypersonic flight instruments and systems typical of vehicles which will be operational by 1965. (Ref. 9).

This simulator, designated the Hypersonic ME-1, has flight equations similar to the proposed Air Force Dynasoar vehicle. The resulting dynamics are such that at altitudes above 80,000 feet the vehicle is highly unstable with an increase in stability, permitting greater precision flying, as the vehicle descends to lower altitudes.

Some of the simulator's capabilities that will be utilized in the present study are:

1. Mach .2 - 6.0
2. Altitude 0 - 120,000 feet
3. Vertical velocity rates 0 - 83,000 FPM
4. Speed brakes - variable degrees of extension
5. Tip extensions - Out
6. Skid system - replaces landing gear system

Cockpit controls have been provided for selecting any desired initial launch condition for Mach, altitude and heading. Also, a three-position switch permits the pilot to set up a descent attitude prior to starting on the run and if an out-of-control condition is encountered during the descent, the pilot can switch to a "panic" mode which returns the vehicle to straight-and-level flight. Other switches installed are a RELEASE button to launch the vehicle on the run and a RESET button to return the vehicle to the selected starting values.

Instrumentation in the Hypersonic ME-1 simulator will consist of:

1. Three-Axis-Attitude Indicator with the display of heading information on the rotating ball. Although they will not be utilized on the profile experiment, this Lear-built instrument also has the provision for depicting commanded information for pitch, bank and flight path angle.

2. Mach Indicator consisting of a moving tape with a scale extending from .00 to 6.0 Mach. Bendix is the manufacturer.

3. Altitude information from 0 to 120,000 feet is displayed on a Bendix moving tape instrument.

4. Vertical Velocity rates are provided by a moving tape and a moving pointer. The moving pointer describes vertical rates on a scale existing to 1500 FPM, and any rate exceeding the limits of this fixed scale are displayed in the appropriate window opposite the stalled pointer on the Kollsman instrument. (Ref. 10)

5. Angle of Attack and Acceleration is presented on a moving tape with a cross-hatched area representing "minimum safe speed" region. The acceleration tape scale is from 0 to 7 G's and a digital read-out can be seen below the tape on the Kollsman instrument. (Ref. 10)

6. Horizontal Situation Indicator (HSI) with DME capability.

7. Trim Indicators for elevators, ailerons and rudders gives the pilot the capability to set up the same pre-launch attitude for each run and to determine if his vehicle is trimmed up properly during the flight.

8. Skid Position Indicator

9. Hack Clock

Subjects

Because the flight profile to be performed in the Hypersonic simulator requires a high degree of skill, which possibly the average pilot cannot achieve without extensive training, selection of pilots will be rather discriminative.

Experimental subject pilots will be drawn from the following organizations:

1. Fighter Operations Division of Flight Test
2. Bomber Operations Division of Flight Test
3. Jet Instrument School of Patterson Training Division

Subjects procured from these units can be considered above the normal pilot population in ability, experience, and current flying proficiency due to the type of cockpit assignment in which they are engaged. In fact, several individuals from the Fighter and Bomber Test Divisions have been nominated for primary roles in the United States space effort.

Obviously then, there are no better qualified pilots available locally for performing in an investigation of the re-entry descent and land profile.

The number of pilots scheduled to fly in the study will vary between a minimum of four (4) and a maximum of twelve (12) with the exact quantity dependent on the availability of qualified pilots at the time. The criteria of availability includes scheduling for the data acquisition session within 1-3 days after completing flight task training.

Qualifications to be met by participating subjects are:

1. current instrument rating (mandatory)
2. qualified in jet aircraft (mandatory)
3. attained 1500 hours flying time (mandatory)
4. flown 100 hours in the last six months (mandatory)
5. simulator or in-flight experience with the Air Force integrated instrument panel (desired)
6. experience in space vehicle simulators (desired)

Since participation in the study by the subject pilots will be of a volunteer nature, an attempt will be made to credit one hour of simulator training for the subjects in the fulfillment of their annual ground training requirement.

The subjects selected and trained for this initial feasibility study of the descent profile will be considered as forming a nucleus of pilots to be called on to participate in future follow-on experiments. Due to the complexity of the task, training different pilots for each phase of the profile measurement program would prove to be unduly burdensome and time consuming. Thus, those pilots comprising this specific experimental subject pool will be familiar with the program objectives and, furthermore, will require merely a short refresher period in the simulator to again achieve an acceptable level of proficiency on the basic flight task.

<u>Scoring Equipment</u>

For the purpose of recording selected measurements from the simulator regarding the subject pilot's deviation from the prescribed flight task, two basic scoring instruments will be utilized. These scoring devices consist of two oscillographic recorders and four X-Y plotters measuring the following parameters: (Refs. 5 and 6)

Offner Oscillographic Recorder - scored from launch to touchdown

1. Altitude - three different scales were required to provide adequate resolution over the entire descent profile (120,000 to 40,000 feet, 40,000 to 5,000 feet, and 5,000 feet to touchdown).

Offner Oscillographic Recorder Cont.

2. Vertical velocity ($\dot{h}$)
3. Landing skids
4. G-load acceleration in the vertical axis (AZA)
5. Flight path angle (SIN)
6. Yaw or side-slip angle (β)
7. Time - one second intervals

Sandborne Oscillographic Recorder - scored from launch to touchdown

1. Indicated velocity (Vi)
2. G-load accelerations in the lateral axis (AYA)
3. Bank angle (SIN ϕ)
4. Speed brakes
5. Angle of attack (α)
6. Pitch attitude
7. G-load accelerations in the logitudinal axis (AXA)
8. Mach
9. Time - one second intervals

X-Y Plotter #1

This scoring device will be activated from launch to high key. The pen transcribes a line on graph paper as the vehicle progresses forward on the X axis (range) and descends on the Y axis (altitude).

X-Y Plotter #2

Scoring from launch to high key, the pen describes track deviation from North on the X axis as the vehicle descends on the Y axis.

X-Y Plotter #3

The flight path to be flown is pre-printed on the graph paper so the pen depicts the variance of the actual path flown against the desired flight path from high key to touchdown.

X-Y Plotter #4

A time history plot of heading from high key to touchdown is made on graph paper laid out in a circle.

Opinion Data

A comprehensive general opinion questionnaire will be administered to the subject pilots at the conclusion of the Data Acquisition Session. A brief sketch of the techniques to be employed on the questionnaire is presented.

1. Rating scale of descriptive adjectives - The scale is blocked out into columns and rows consisting of ten graphic terms, such as realistic, uncontrollable, sensitive, etc., listed across the top of the page and seven intervals of altitude from 120,000 feet to touchdown recorded down the side. The subject is asked to reflect his opinion of the response characteristics of the space vehicle at the various altitudes throughout the descent and land profile by placing an "x" in the appropriate column. He may mark as many descriptive terms for each altitude interval as he deems necessary. A compilation of this descriptive information will result in a general critique of the dynamics and stability system of the Hypersonic ME-1 simulator.

2. Unstructured rating scale - Printed on a page of the questionnaire will be a horizontal line of specific length representing strengths of difficulty on a continuum ranging from the least difficult value on the left to the most difficult on the extreme right. The subject's task is to strike a vertical line on the rating scale to depict the degree of difficulty he encountered in performing the assigned flight profile. Results derived from this technique will be portrayed by an estimated mean and median drawn on the scale. Caution must be exercised in the interpretation of the findings since the scale merely represents an attitude disposition of the subjects and not a precise and well-defined quantitative value.

3. Pictorial drawing of the pattern - Of extreme interest are any significant changes from the assigned task employed by the subject pilots that are considered to be of definite benefit in achieving the optimum descent profile. Points at which the speed brakes and landing skids were operated are also useful information. Therefore, a letdown plate of the descent pattern will be provided for the experimental subjects to indicate the location in the profile when these alterations or events occurred.

4. General questions - Approximately thirty questions will be presented to elicit specific written comments on a variety of topics including simulator stability and control, problem areas in the profile requiring further investigation, critique of the flight task instructions and the overall experimental procedure, etc.

It has been found in past simulator studies that subject pilots will not always express their opinions as easily or explicitly on a questionnaire as they will when talking informally with the experimenter. Therefore, to retain valuable information emitted by the subjects in candid on-the-spot comments made while they are actually flying the simulator on the profile, a microphone and tape recorder will be installed in the simulator. The experimenter will be able to record conversation within the cockpit or interphone communication between the cockpit and experimenter's station outside the cockpit. (Refs. 7 and 8) These taped conversations will be assimilated and combined with the written answers under a General Comments Section of the final task report.

Data Analysis

Because the profile measurement study is merely an abridged investigation regarding the inherent feasibility of the proposed descent pattern and not a typical experiment in which variables are manipulated, the statistical treatment of the data acquired from the oscillographic recorders and X-Y plotters will be limited to a certain extent. The data analysis performed will be principally for the purpose of describing the average flight path flown by the participating pilots and any consistently significant deviations from the programmed track.

The recorded measurements will be sampled at 10-second intervals, so there will be 46 data points (7 min. 40 secs.) for each of the 16 parameters being scored yielding a total of 736 values per experimental run. By adding the score derived at one of these specific points in time with the same respective point on all four of the data collection runs performed by a subject pilot, the mean and standard deviation (measure of dispersion or variability) of that selected point can be computed. Thus, a time-history plot of the computed mean and standard deviational values for all sixteen parameters will result in a representative observation of an individual's performance on the profile.

When the measured values for all experimental subjects has been reduced in this manner, a critical examination of the data can proceed in an effort to answer the four questions posed, and which the study was designed to resolve.

1. Does the existing profile permit consistent and effective performance?

   A statistical analysis of the plotted mean performance values of all subjects will determine if their flight paths seemed to be fairly similar or if a large variability in performance was prevalent. Sources of difficulty in the profile can be readily detected, and it will also be possible to estimate the percentage of safe approaches and landings accomplished.

2. What alterations are needed to improve the profile?

If the mean values from each individual are grouped together by parameter and then a mean and standard deviation are computed across all subjects at the 46 points, the resultant will be sixteen time-history plots of the entire profile describing the average track flown and the variation about it. When each of these mean profiles is compared point-by-point with the corresponding desired parameter value, significant deviations will be revealed, thus, indicating areas needing alterations and to what proportions the profile should be revised.

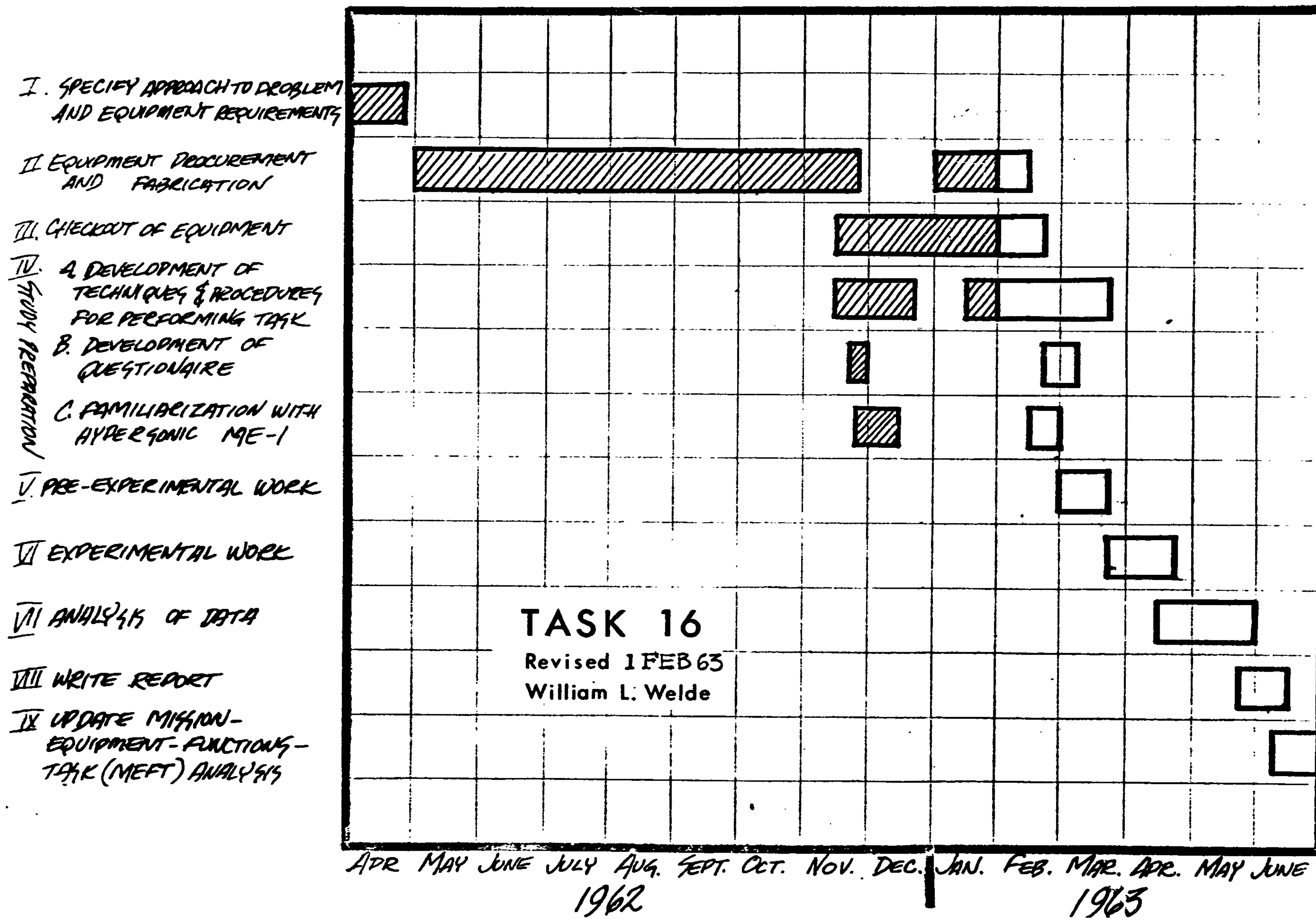
3. What additional cockpit instrumentation and controls should be installed to improve performance?

In a 360 degree overhead pattern of this type where engine thrust is not available, there is very little margin for error from the required values and still be able to safely reach the field. It is an especially tenuous condition if the pilot discovers he is falling short of the prescribed airspeeds and altitudes. Therefore, the problem of information integration and pre-planning is a very real one for the proposed descent and land profile. In order to simplify the pilot's flying task, an endeavor will be made to ferret out deficient areas of information display and vehicle control. A scrutiny of the regions in the profile that produced vast amounts of variability among the subjects, and also an inspection of excessive deviations between the sixteen mean parameter profiles, collapsed across subjects, and the established patterns, should provide a perception into what additional displays and cockpit controls would be appropriate. Furthermore, the opinion data, compiled from the questionnaire submitted to the subjects and the taped recordings of their verbal comments, will be useful in determining pilots' needs for supplemental cockpit equipment items.

4. What are the quantitative values for the MEFT parameters?

The mean values derived from the subjects on all experimental runs flown will be used to update the MEFT parameters that have been previously defined (Refs. 3 and 4) and to outline other important operator, vehicle, equipment and display functions. The MEFT analysis will describe the parameters at intervals of every 10 seconds, but a more precise breakdown of the information can be made if future requirements dictate.

There is a possibility that the data measured and recorded from the study may be so voluminous that a complete reduction and analysis of the information would be rather impractical from the standpoint of the excessive amount of time consumed and the number of personnel engaged in the activity.


I. SPECIFY APPROACH TO PROBLEM AND EQUIPMENT REQUIREMENTS
II EQUIPMENT PROCUREMENT AND FABRICATION
III. CHECKOUT OF EQUIPMENT
IV. STUDY PREPARATION
A. DEVELOPMENT OF TECHNIQUES & PROCEDURES FOR PERFORMING TASK
B. DEVELOPMENT OF QUESTIONAIRE
C. FAMILIARIZATION WITH HYPERSONIC ME-1
V. PRE-EXPERIMENTAL WORK
VI EXPERIMENTAL WORK
VII ANALYSIS OF DATA
VIII WRITE REPORT
IX UPDATE MISSION-EQUIPMENT-FUNCTIONS-TASK (MEFT) ANALYSIS
TASK 16
Revised 1 FEB 63
William L. Welde
APR MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
1962
JAN. FEB. MAR. APR. MAY JUNE
1963

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AIR FORCE CONTROL-DISPLAY INTEGRATION PROGRAM

Martin Human Engineering Support Group
AF 33(657)-8600

MEMORANDUM REPORT 63-3

Task No. 17

To: E. Bobbett

cc; J. H. Kearns, Capt. C. E. Waggoner, Mr. E. L. Warren, Mr. R. R. Davis, Mr. E. Vinson, Mr. J. K. Charlton, Mr. S. G. Hasler and all members of the Martin Human Engineering Group.

From: J. E. Brown

Subject: Some Research Variables for the Three-Axis Controller: Justification for Further Investigation of Location, Azimuthal Angle, Vertical Angle, and Handgrip Variables Associated with the Mark IV Three-Axis Force Controller.

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The purpose of this paper is to suggest some critical research areas for the Mark IV Three-Axis Force Controller and to present a discussion of each of these areas. In discussing the variables, the reasons for investigating each will be pointed out. It is hoped that the information contained herein will be of use in selecting the appropriate experimental design to be used to investigate the interrelationships of the proposed variables.

Introduction

The three-axis force controller which will be utilized in the Mark IV-B cockpit is a most unique type of control device. At present, very little empirical data is available concerning performace using this particular controller. To date, one study has been conducted to develop a techinque for setting the gains or control sensitivity for the controller. As a result of this study, several problem areas requiring additional analytical and empirical research efforts have been indicated.

Perhaps the more prominent of these research areas, and one to which this paper addresses itself, are the problems of location, vertical angle, and handgrip variables. Location refers to the placement of the three-axis controller in the Mark IV cockpit. The term vertical angle refers to the tilt of the control post from the perpendicular. Finally, handgrip variables refer to types of handgrips, such as palm-down and upright (pistol grip) handgrips. Before these variables are discussed, however, it would be useful to present some information about the three-axis controller.

Mark IV Three-Axis Force Controller

The three-axis controller referred to in this paper appeared initially as a concept in the Mark IV final Report (7). This concept was refined and developed until finally a usable proportional three-axis force control device was fabricated by Lear-Siegler, Inc., Grand Rapids, Michigan. In its present form, the Lear three-axis controller consists of the mechanism and handgrip shown in Figure 1. The handgrip is a shaped grip, and is used with the right hand placed in a palm-down position over the grip. The mechanism works upon the piezo-electric principle. Very simply, the principle is employed in the following manner: When pressure is applied to the handgrip it is transmitted through the control rod into the sensor unit. The control rod bends until it makes contact with an electrically charged ceramic crystal. Depending upon the amount of force applied, the control rod causes the ceramic crystal to be warped so that it resonates at a frequency proportional to the amount of pressure applied. Electrical pickoffs located on the crystal sense the changes in resonating frequency and send an electrical voltage proportional to the amount of force applied to the control system. There is some slight control displacement (.020 of an inch) due to the warping of the ceramic crystals and the bending of the control rod to which the handgrip is attached. The output curves for all three axes are reported by the manufacturer to be linear. The break-out force for each axis is approximately 3-inch pounds. Maximum force output for each axis is approximately 15-inch pounds. Mechanical stops prevent the maximum safe force limit from being exceeded. According to Mr. R. Lukso, Design Engineer of Lear-Siegler, Inc., the maximum safe force which could be applied to the three-axis controller is as follows:

(1) Pitch Axis................80 pounds of force
(2) Roll Axis.................80 pounds of force
(3) Yaw Axis..................22 pounds of twisting force

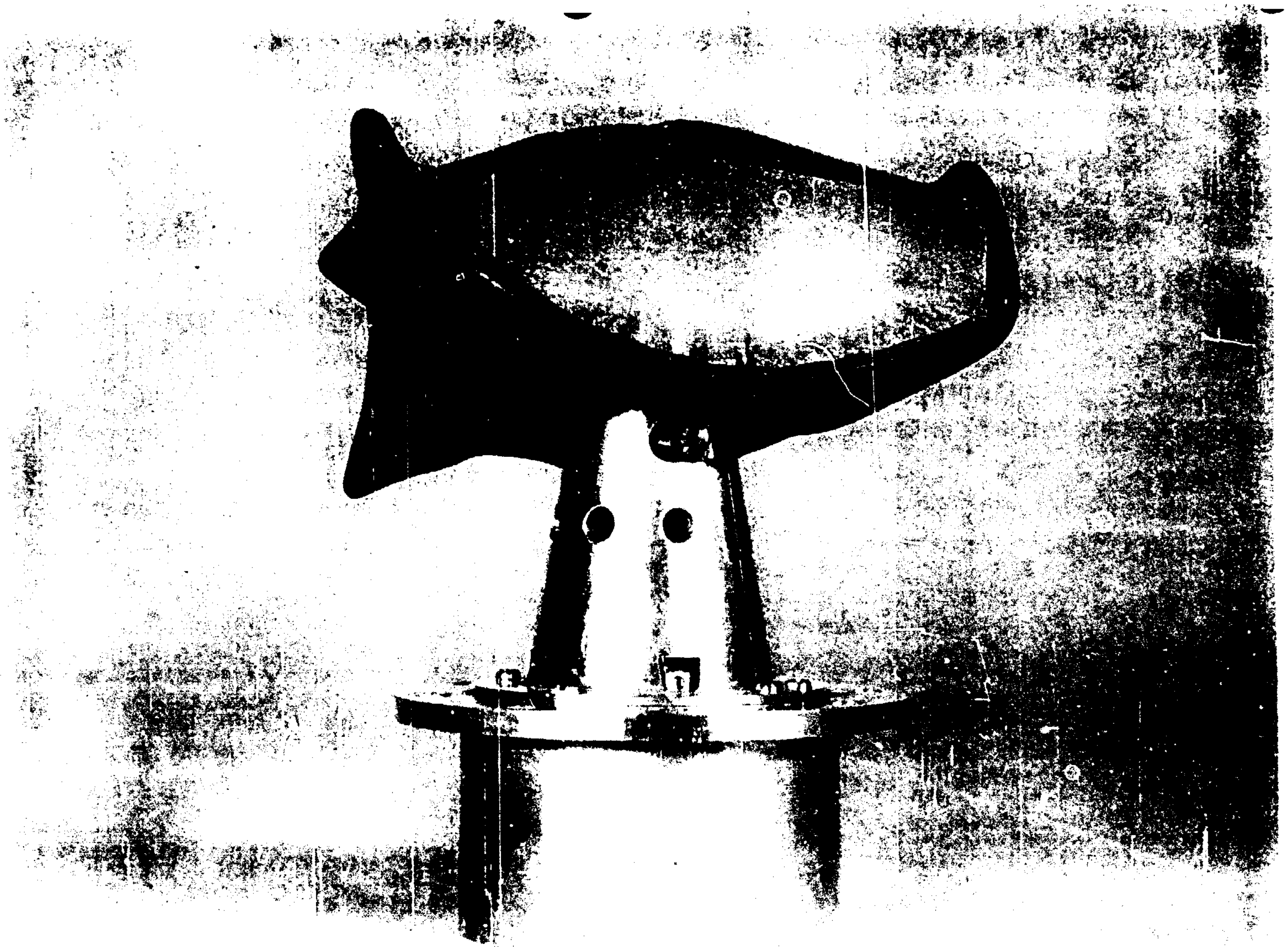


Figure [illegible]. Photograph showing the Mark IV Three-Axis Controller mechanism and handgrip.

The utility of the force controller is derived from the fact that the control inputs are made primarily through the use of the wrist and hand. Thus, purposeful control inputs by pilots under high "g" loadings would not require the movement of the arm, as in the case of a displacement type of control. The separation of the three axes is achieved normally by utilizing forces applied in the following manner: (a) With the controller mounted as shown in Figure 2, a pressure from the wrist in line with the longitudinal axis of the arm will result in an output in the pitch axis, (b) the roll axis is normally engaged by pressure applied in the direction of the lateral axis of the arm, (c) the yaw axis is normally engaged by a twisting pressure applied at the handgrip. Cross-coupled control is possible. The term "normally" is used here because the usual aircraft direction of motion relationships are presently employed (forward for pitch down, aft for pitch up, right for roll right, etc.) The force relationships and the breakout forces for each of the three axes are approximately the same. The output function of the controller axis is changeable by merely altering the output connections.

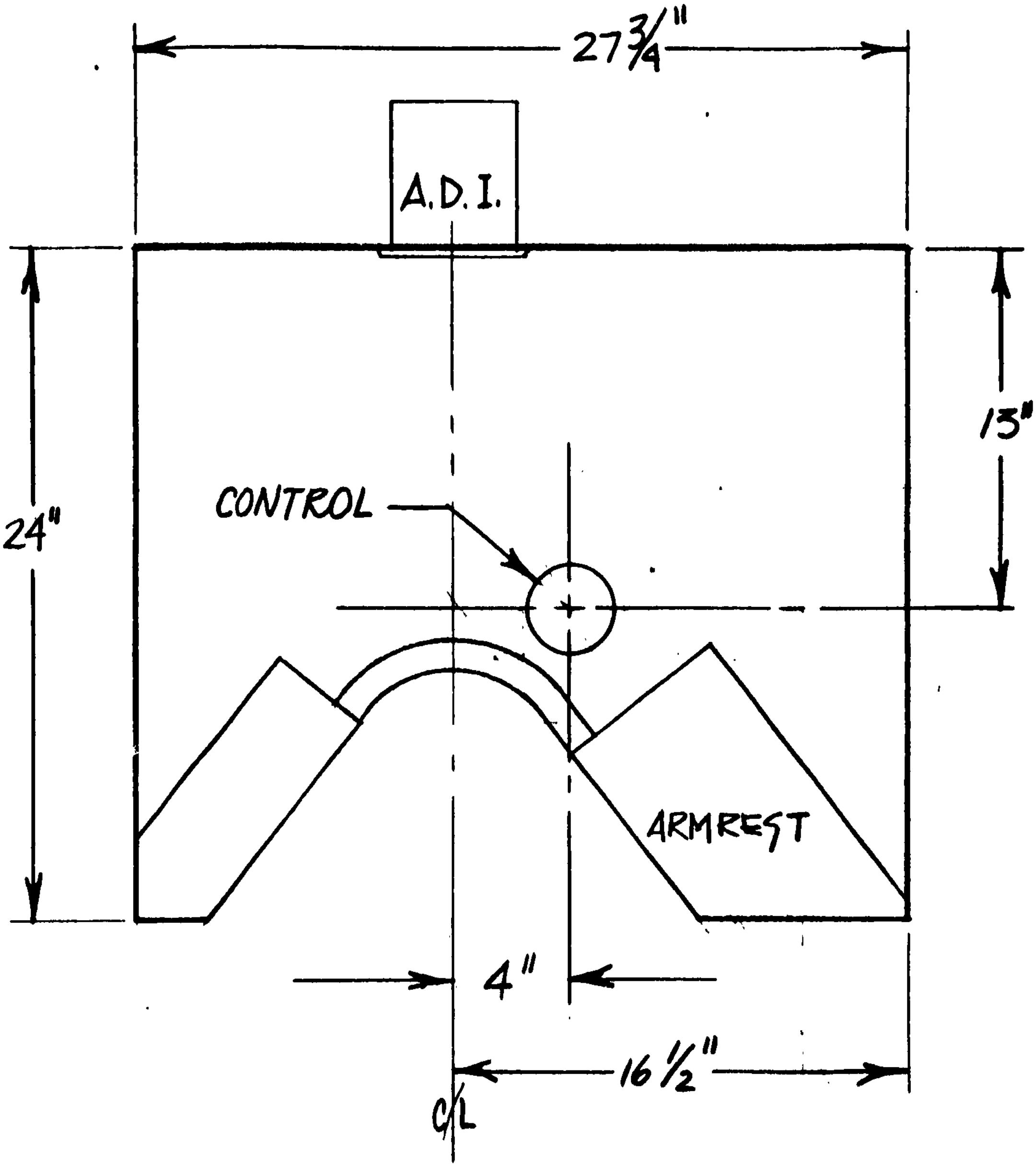
With the above information in mind, the reader's attention is now directed to the variables indicated in the initial portion of this paper.

Present Location, Vertical Angle, and Azimuthal Angle

Unfortunately, no exact specifications concerning the appropriate location or azimuthal angle of mounting were specified for this controller. The only specification that was made concerning the recommended mounting position was that the device be mounted so that the control rod was at a thirty degree angle to the right of the perpendicular. In the initial study using the controller (1), a location and azimuthal angle were approximated from a photograph shown in the Final Report of the Mark IV Program (7). This photograph is shown in Figure 2. The location and position used in the initial study are shown in Figure 3. As illustrated in Figure 2 and Figure 3, the location and azimuthal angle are such that the direction of control force in the pitch axis is in line with the longitudinal axis of the vehicle or the display panel. Roll and yaw inputs are made in the manner described earlier.

Although the reasons for mounting the controller in this fashion are not entirely evident, it might be speculated that one reason for mounting the controller as shown in Figure 2 was that the area in which the control is mounted is considered to be an optimum work area as defined by Ely, et.al. (2). In view with this supposition, it would be possible to assume that the thirty degree vertical angle and the azimuthal angle of the controller were specified for anthropometric and comfort reasons.

Figure 2. Photograph showing the location & Mounting of the three-axis controller in the Mark IV cockpit. The vertical angle was specified to be thirty (30°) degrees. Location was not specified. From Lear Report (7) .



PLAN VIEW

CONTROLLER LOCATION USED IN INITIAL STUDY

FIGURE 3

With the location of the controller as shown in Figure 2, it is almost physically impossible, without moving the body and the arm, to have the azimuthal angle such that the direction of force applied to the control for pitch and roll inputs would be in the same plane of reference as the display and/or the longitudinal axis of the vehicle. This impossibility is due to the limited mobility of the wrist when the palm-down handgrip is utilized. By arranging the controller so that its roll axis is perpendicular to the longitudinal axis of the forearm, the best utilization of the limited wrist movement can be achieved. Through this arrangement the operator has some cue as to the direction of movement for pure inputs to each axis. A wrist up-down movement is pitch, the rolling of the forearm is roll and twisitng the wrist left and right is yaw. In this instance the alignment of the controller with the axis of the forearm is especially important in order to salvage any cue information, where there exists a lack of congruency between the movement of the controller and the displays.

The thirty-degree vertical angle was probably specified because the arm and hand are in a more natural position at this angle in the location used.

In the initial study with the three-axis controller (1), it was unknown whether the location, and azimuthal angle were actually "good" approximations of the intended location and azimuthal angle was presented in the original Mark IV design. As the study progressed, it became more and more apparent that several factors were operating in the experimental situation which would require further examination.

Inadvertent stick outputs were occurring, i.e., outputs were occurring in axes where there should exist no control action. Since inadvertent outputs are actually errors, it would follow that performance was not optimum. An example of cross-coupling occurred in the yaw axis. Theoretically, there should have been no output in the yaw axis since the axis was never displayed. In addition, during the briefing pertaining to the proper use of the controller, the subjects were requested not to use the yaw axis. However, inspection of the oscillographic data containing yaw output indicated that inadvertent yaw outputs did occur quite frequently and in a number of instances were quite large. The same was true of roll outputs when only pitch output was displayed. Although the oscillographic data was not statistically analyzed, it is thought that the amount and frequency of inadvertent cross-coupling could not be discounted.

Examination of the possible causes of inadvertent outputs have yielded two possible categories of factors. One of these is a mechanical one while the other concerns the physical location, position, and mode of using the controller.

Due to the mechanics of the three-axis controller, it is thought that the bending of the control rod and the warping of the ceramic crystal could conceivably cause the user to inadvertently cross-couple into another axis. This type of cross-coupling, if it was occurring, could possibly be corrected by redesign of certain parts of the controller.

The view taken in this paper is that location, vertical angle, and handgrip variables interacted to produce these outputs. The explanation was suggested during the initial investigation of the 3-axis controller and supported by the verbal comments of the subjects who participated in that study. Further, this explanation is supported to some extent by the existing literature (5,8) and analytical examination of the present mounting of the controller.

In order to gather as much information as possible about the effects of physical mounting variables upon performance, three approaches to the problem were used. First, the present mounting of the controller was analytically examined for possible causes of performance detriment. Secondly, the literature concerning performance as a function location, azimuthal angle, vertical angle, and handgrip variables was reviewed. Lastly, the writer contacted the Anthropology Section, Human Engineering Branch, Behavioral Sciences Laboratory and requested their assistance. Their task was to suggest the optimum location and position for the three-axis controller in the Mark IV cockpit. The seating and cockpit dimensions were explained. No restrictions were made as to where the controller should be located or how it would be mounted. They were requested not to change the controller but merely to locate it in an optimem location. Here the use of the word "optimum" refers to the comfort and the usage. Finally, they were requested to reference or state the reasons for their recommendations. These recommendations will be discussed later in this paper.

Location and Azimuthal Angle

Defined earlier, location refers to the physical location of the force controller in the Mark IV cockpit. Azimuthal Angle refers to the horizontal positioning of the controller in a given location. Azimuthal

Angle is measured from a line paralleled to the display panel extending horizontally through the center of the location of the controller. Changing the azimuthal angle of moutning will change the direction of control forces required to achieve an output in the pitch and roll axes. For the purposes of this paper, it is thought that a further discussion of azimuthal angle will not be necessary due to the dependent relationship between azimuthal angle and location. Moreover, in further discussing the variable of location, this dependent relationship will be assumed.

In a previous section of this paper, it was stated that, with the three-axis controller, the direction of force presently required to make a control output in the pitch axis is not in line with either the display or the longitudinal axis of the vehicle. In the Mark IV, the longitudinal axis of the vehicle is represented by the longitudinal axis of the cockpit. Although the control motions, relative to each other, are the same as those used in present aircraft controls, forward for pitch down, right for roll right, etc., the orientation of these control motions is different. In the usual aircraft situation, pitch control is in line with the longitudinal axis of the vehicle and roll is in line with the lateral axis of the vehicle. However, in the Mark IV, pitch control is in line with the forearm which is aligned at an oblique angle to the longitudinal axis of the aircraft. Due to the thirty degree vertical angle and the location of the controller, roll axis control is aligned with the lateral plane of the hand but oblique to the lateral axis of the cockpit. How this arrangement of the pitch and roll axes affects the control-display relationships with which pilots are familiar, is not known. However, interpreted in terms of the existing literature, it would appear that the Mark IV control-display relationship may not be optimum in terms of performace. Examination of Lear Engineering Reports did not reveal any information concerning the affects of location and mounting variables upon performance with controls. Therefore, other sources of information concerning these variables were examined.

In a very excellent review of studies of control-display relationships, Narva (9) states, "The following statements may be advanced as being the ruler rather than the exception; (1) Subjects bring with them into the experimental situation certain response preferences, expectations, or 'stereotypes' which make them expect movement of the display element in a certain relationship to movement of the control, (2) These response tendencies are due to the prior perceptual-motor experience of the subjects, (3) The expectation that a certain display-control relationship will hold is more apt to manifest itself in differential performance when the control and the display element move in the same plane, (4) Performance generally is facilitated when there is congruency both in plane and in direction of the movement of the display element and the control, (5) Performance may not be influenced by the variation in display-control relationship if the task is not too difficult and the subject can readily adopt the 'set' required by the experimental situation, (6) As the difficulty of the task is increased, the subject is more apt to deteriorate in his performance level as a function of the use of a control-display relationship which is not in keeping with his natural response tendencies."

There is a great deal of support for these principles of control-display relationships in the literature. In a review of several studies, Ely et.al. (3) states, "The direction of movement of the control should be consistent with that of the controlled object of display." In another review of control-display relationships, Ely, et.al. (2) states, "Direct movement relationships should be used whenever possible, particularly when they result in vehicle movement. Thus, a movement of the control to the right should result in a movement to the right...., "right turn or right bank of the vehicle." Humphries (5), in reviewing other studies of control-display relationships, echoes much the same statement. He states, "The movement of the control should be in the same plane and in the same direction as the resulting display movement in order to obtain the highest performance level and the fastest learning."

One study which is directly relevant to the present variables is a study reported by Humphries (5) in 1958 and abstracted by Narva (9). The purpose of the study was to investigate the affect of control-display movement relationships, position of the operator relative to the control, and the plane of movement of the control on performance on the Toronto Complex Coordinator. This device consisted of a display panel which contained 81 light assemblies, each of which was a green light surrounded by a red light. The task of the subject was to match the location of a red light with a green light. An aircraft-type control stick was used by the subject to move the green light. The control was tested in both the vertical and horizontal plane of movement. The hypothesis was: "performance would be improved if the relationship of the control and display were congruent in both the vertical and horizontal axes of movement. In the horizontal axes of movement, congruency was possible between the display and the control movement in the horizontal direction. However, only partial consistency of control and display movement was possible in the vertical direction. It was concluded that performance was not significantly affected by the orientation of the control.

Four different control-display movement relationships were formed by changing the relationship in both the vertical and horizontal axes of movement. "In the condition where the operator directly faced the control and the display significant difference was observed when display-control movement relationships were reversed while maintaining the same axes of control movement. In the vertical plane of movement, performance was superior when the control moved up to move the display element up and moved right to move the display element right. In the horizontal plane of movement, this superior sensing condition becomes forwards-for-up and right-for-right. Additionally, there was an interaction between the orientation of the operator relative to the control and the control settings. However, for the superior or more 'natural' display-control movement relationship, performance was best when the operator faced the display."(8)

Actually, the results of the study by Humphries (5) do not tell us very much about what happens to performance when the direction of motion for a horizontally mounted control is oblique to the direction of motion of the display. However, the results do lend some support to the argument that "performance generally is facilitated when there is congruency both in plane and in direction of the movement of the display element and the control". (8)

There are exceptions to the principle of congruency of control and display movement. Among the most notable of these exceptions occurs in aircraft. The control of pitch, for example, requires a forward or rearward movement of the control rather than an up or down movement. However, this is more of a learned response because the use of a floor-mounted control stick negates the use of fully congruent control-display relationships. It should be noted that normal pitch control movements are perpendicular to, and in line with, the longitudinal axis of the aircraft. Normal roll control movements are made by moving the control left or right in a line perpendicular to the pitch axis and in line with the lateral plane of the vehicle. This separation of the pitch and roll axes is achieved in the Mark IV three-axis controller but the movement relationship of the control axis and the vehicle axis is not achieved because of the oblique position of the controller.

Handgrip

The palm-down shaped handgrip used on the Mark IV force controller is a very unique type of handgrip. The use of this type of handgrip, in comgination with the location presently employed in mounting the force controller in the Mark IV cockpit, requires that the vertical angle of the controller be tilted thirty degrees from the vertical so that a more natural position of the forearm is achieved. It is because of this relationship between the palm-down handgrip, the location and the vertical angle, that the control-display direction of motion relationships of the controller are questionable in terms of performance.

The inclusion of handgrip as a variable was done for several reasons. First, the effects upon performance of using a palm-down grip as opposed to using an upright or pistol-grip type of handgrip are not known. Most control stocks, including side-stick controls, for the aerodynamic control of aircraft, utilize the upright type of handgrip, either in the form of a 'pencil'grip or a 'pistol' grip. Control yokes, which require the use of two hands, utilize the same principle...the hands are in an upright position with the palms of the hands turned inward. This position is selected primarily because it is confortable, allows maximum use of the strength of the individual, and is the condition that pilots are most familiar with. In the case of side stick controllers, the palm-in position allows freedom of movement of the wrist and hand so that less total arm movement is required. Since the effects of the use of a palm-down handgrip are not known, it is thought that the collection of data concerning this type of handgrip in comparison to an upright or other type of handgrip would be of value.

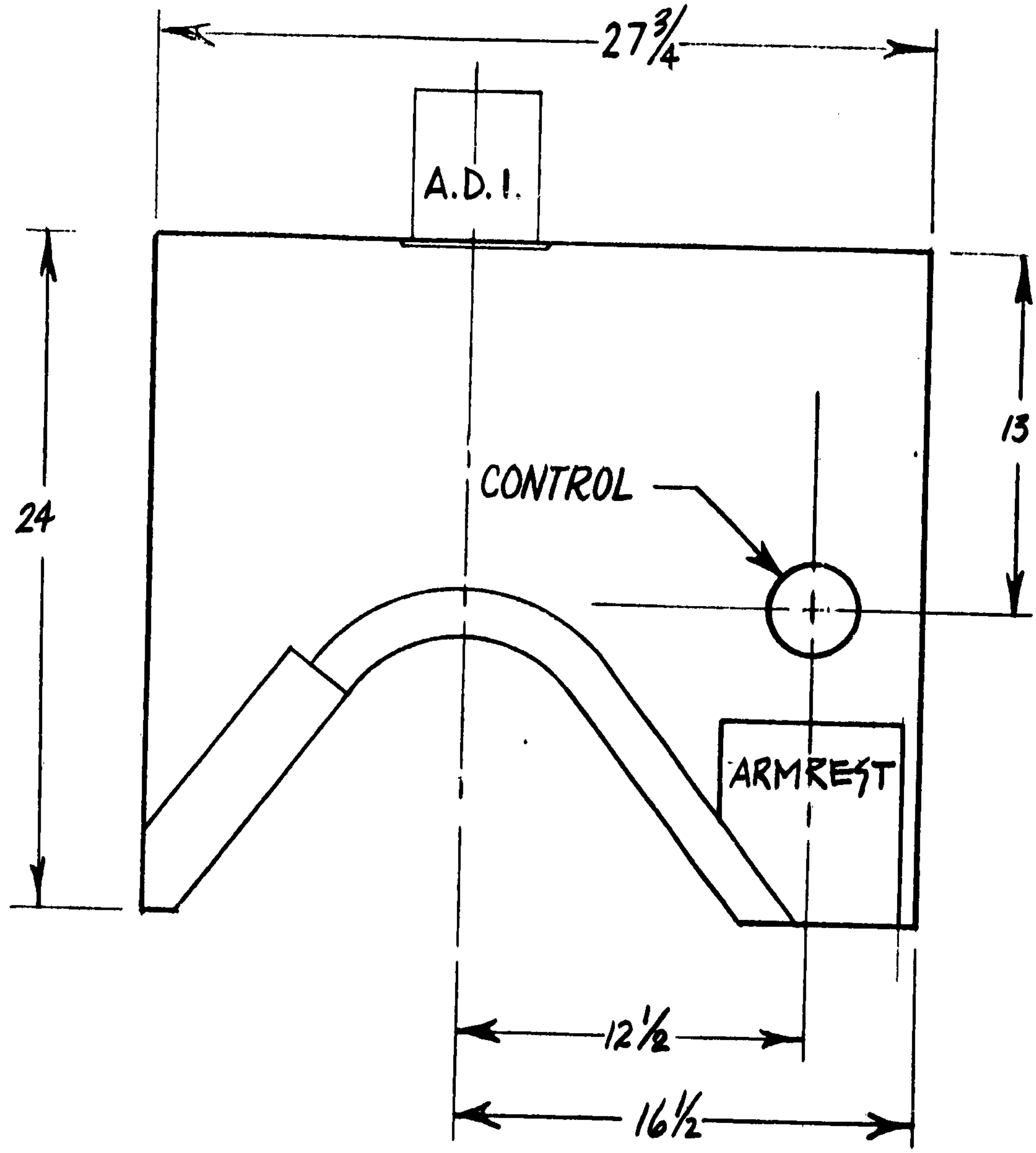
Secondly, it is suspected, on the basis of analytical examination of the controller location and mounting utilized in a previous study with the controller (1) that the palm-down handgrip may result in more cross-coupling inputs than would be present with an upright handgrip. In the first study, yaw outputs, which were inadvertent inputs, were achieved by a twisting motion of the handgrip about the center post of the controller. The application of a twisting force is a relatively simple motion with a palm-down type of grip because of the leverage that exists with this type of grip. For example, by applying a pushing pressure with the heel of the hand toward the display panel and a pulling pressure away from the display panel with the index fingers and thumb, a yaw output is achieved which requires very little strength. Yaw output might also be achieved by applying pressure to only one side of the palm-down handgrip thereby allowing the handgrip to pivot around the control post. The application of torque to the upright grip (pistol grip), however, depends more upon strength than upon leverage. In this case, the full hand must clasp the grip and the twisting force must be applied uniformly by the entire hand. In making an analytical comparison of the two types of handgrips (palm-down versus upright), it would appear that if outputs in the yaw axis are more difficult to achieve with the upright grip, then the probability of cross-coupled outputs occurring in the yaw axis is reduced.

Thirdly, the recommendations made by Mr. K. Kennedy, Anthropology Section, Human Engineering Branch, Behavioral Science Laboratory, concerning location and moutning of the force controller in the Mark IV cockpit, suggest that an upright type of handgrip be utilized. (6) For the readers information, a copy of Mr. Kennedy's recommendations is attached to this report. Very briefly, it was recommended that the three-axis controller be relocated to the right side of the operator so that the forearm and direction of force for pitch control are in line with the longitudinal axis of the cockpit. This location places the force controller in essentially the same location as conventional side-stick controllers. With respect to mounting the force controller in this location, Kennedy explains , "The orientation of the controller itself at the recommended location is such that manipulation coincides with the movement of the craft. Insofaras absolute comfort is concerned the grip should be grasped with the forearm rotated to a point where the hand-grip axis is parallel to the long axis of the upper arm (about thirty degrees to the left). Such orientation, however, would not coincide with the fore-aft vertical axis of the craft. I recommend, then, that comfort be compromised slightly and that the three-axis be oriented nearly parallel to the vertical (z) axis of the craft.

The y-axis "(Lateral axis)" of the controller, however, is depressed such that forward of the axis point it is depressed nine degrees, and to the rear of the axis point it is elevated nine degrees. This is recommended to accomodate to the normal grip axis of the hand, which is not perpendicular to the axis of the forearm, but depressed by this amount toward the under side of the forewarm.

In short - the orthogonal planes of the controller remain intact, except that the system is rotated nine degrees, top forward. This depresses the forward aspect of the x-y plane "(lateral-longitudinal)" elevating its rearward aspect. The x-z plane "(lateral vertical)" is rotated nine degrees forward along the x-axis. The y-z plane (Longitudinal-vertical) remains vertical, although rotated forward along the z-axis."

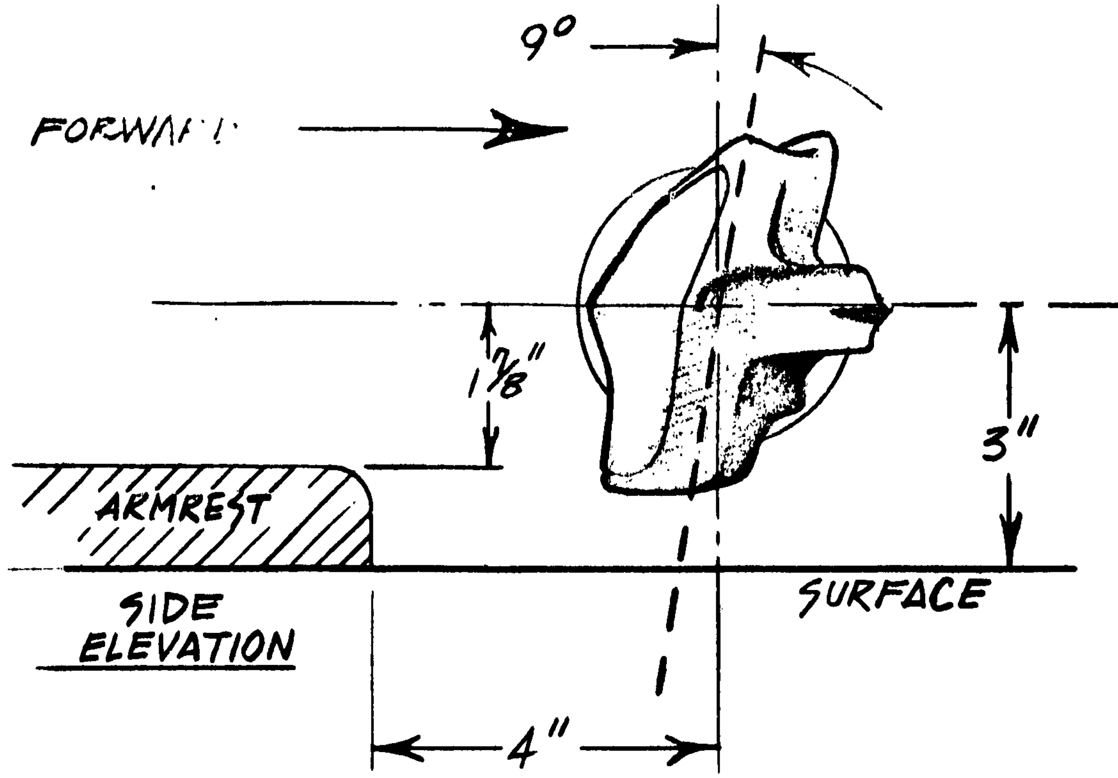
Figures 4 and 5 show the recommended mounting position of the controller. In translating the remarks of Kennedy into practical terms, he has recommended that an upright handgrip be utilized. In fact, by using an upright handgrip, the same end result may be accomplished without rotating the controller on its side as shown in Figure 5.



PLAN VIEW

RECOMMENDED 3-AXIS FORCE CONTROL LOCATION

FIGURE 4



RECOMMENDED MOUNTING OF FORCE CONTROLLER

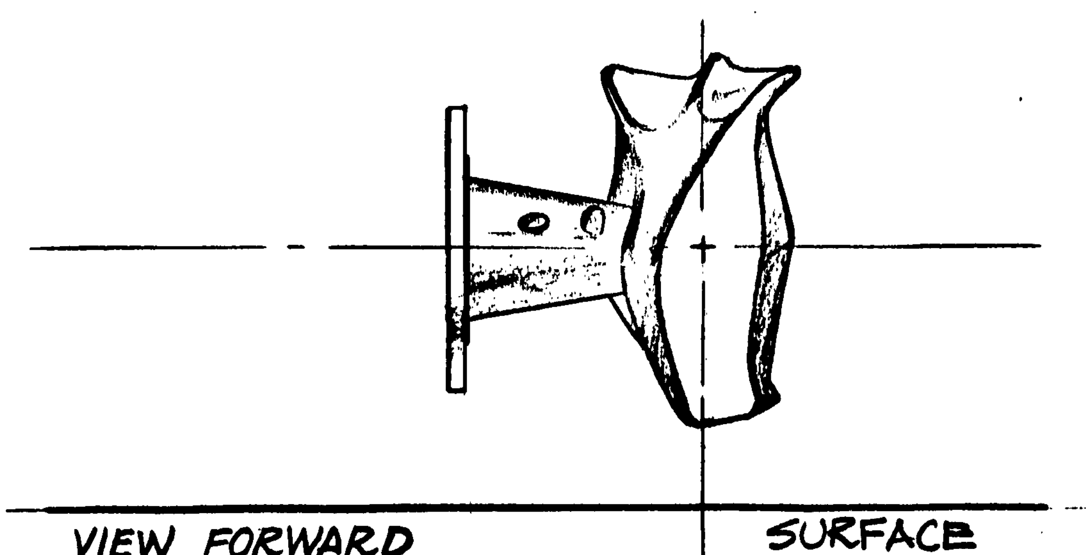


FIGURE 5

Finally, the variable of handgrips should be considered because it is mentioned as being an aspect of the three-axis force controller with which users of the controller are least satisfied. This statement was supported by comments made in the initial controller study (1) and per personal communication with the designer of the controller. Mr. R. Lukso, Lear-Siegler, Inc. (4) stated that the handgrip originally supplied was not receiving favorable reaction; in fact, they (Lear-Siegler, Inc.) were considering delivery of future controllers without the handgrip. However, Lear has designed a new handgrip which they would like to evaluate.

Summary

An examination of the variables of location, vertical angle, and handgrip indicate that there is excellent justification for an experimental investigation of the effects of each upon performance using the three-axis force controller. There is relatively little information at present concerning the effects upon performance of any of these variables.. let alone their possible interaction effects.

Recommendations

In view of the foregoing comments, and in an effort to obtain basic information about these variables, it is recommended that any experimental investigation should concern itself with different levels of all three variables in all possible combinations. It is thought that such a study would yield a maximum amount of basic information concerning general principles of location, vertical angle, and handgrip variables, and would also furnish specific evidence concerning where the present three-axis controller should be located and how it should be mounted. The levels of each of the variables recommended for experimental investigation are indicated below.

Location

It is recommended that three different locations be studied. One location should be one which closely approximates the location recommended in the Final Report of the Mark IV Program (7). The second location should be the one recommended by Kennedy (6). The third location should be one which is approximately half way between the other two locations. For all three locations, it is recommended that the azimuthal angle agree with each location so that the hand is always in line with the longitudinal axis of the forearm.

Vertical Angle

An examination of the vertical angle, location, and palm-down handgrip as these variables presently exist in the Mark IV cockpit, reveals that the vertical angle may be reduced by moving the location of the controller more toward the right side of the cockpit in line with the shoulder of the seated individual and the longitudinal axis of the cockpit. Thus, since three different locations were recommended for study, it will be necessary to utilize three different vertical angles, each of which will agree with one location. The three recommended vertical angles are thirty degrees, fifteen degrees, and zero degrees.

Handgrips

Up to now, the discussion of handgrip as a variable has centered about palm-down versus upright (pencil and pistol grip) types of handgrips. However, in utilizing both of these types of handgrips, congruency of display-control movement relationships is still not achieved. That is, rather than an up-for-up, right-for-right movement of the control, the control-display movement relationship. Thus, only partial congruency of display control direction of motion relationships is achieved.

It is thought that because so very much information is needed concerning control-display relationships with the force controller, it would be desirable to investigate the effects of location, vertical angle and handgrip variables under conditions of full congruency between control-display direction of motion relationships. One method of achieving fully congruent relationships would be to mount the controller horizontally beneath the armrest in the Mark IV cockpit, and use a flat planar type of handgrip upon which the hand would be rested. By placing the hand over the flat surface in a palm-down fashion and grasping the edge of the flat surface, the control may be moved up for pitch up, and down for pitch down. Roll maneuvers are performed by tilting the hand either to the left or to the right depending upon the desired aircraft roll direction. Yaw maneuvers are performed by side to side movement of the hand in the desired yaw direction. Thus, full consistency of control-display motion is achieved. The changes in the wiring connections that are required are that the normal roll axis of the controller be connected for yaw output and the normal yaw axis be connected for roll output. The pitch axis would not be changed. In recommending the investigation of fully congruent direction of motion relationships, it is thought that in addition to giving consistency of control-display direction of motion relationships, the flat planar surface handgrip, will furnish the subject with additional cues about the proper direction of control forces.

It is recommended that three different handgrips be investigated. These are as follows: (1) the present three-axis controller handgrip, (2) an upright type of handgrip---either pencil grip or pistol grip and, (3) the flat planar surface handgrip described above. The use of the three handgrips, in combination with all possible combinations of locations and vertical angles, should furnish information concerning:

1. Palm-down versus upright versus flat planar surface handgrips.
2. Partial congruency versus full congruency of control-display direction of motion relationships.
3. The effects of location and vertical angle upon performance with the three types of handgrips.
4. The optimum location and vertical angle for the three-axis controller using the present palm-down handgrip.

Finally, investigation of the three locations, three vertical angles, and three handgrips in all possible combinations should furnish information which will lead to the statement of principles concerning these variables.

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APPENDIX

Kennedy, K. Personal Communication (letter Recommendations for Location and Mounting of Mark IV Three-Axis Controller, Anthropometry Section, Human Engineering Branch, Aero Medical Laboratory, Wright-Patterson Air Force Base, Ohio, February 1963.

In accordance with recommended procedures in the layout of controls, the proposed location and orientation of the shaped, fixed side-arm controller under test is recommended to conform, when in use, to the orientation of the operator, the craft and to the display panel.

By placing this controller 12-1/2 inches to the right of the centerline, the axis of the operator's forearm, in most cases, may be maintained parallel to the longitudinal axis of the craft, parallel to the direction of travel and perpendicular to the base of the display panel. Locating it 11 inches forward of the rear edge of the forearm-rest will permit easy access by all operators and the use of the musculature of the forearm as a pivot for manipulation (much as in writing).

The orientation of the controller itself at the recommended location is such that manipulation coincides with the movement of the craft. Insofar as absolute comfort is concerned the grip should be grasped with the forearm rotated to a point where the handgrip axis is parallel to the long axis of the upper arm (about 30 degrees to the left). Such orientation, however, would not coincide with the fore-aft vertical axis of the craft. I recommend, then, that comfort be compromised slightly and that the z-axis of the controller be oriented nearly parallel to the vertical (z) axis of the craft.

The y axis of the controller, however, is depressed such that forward of the axis point it is depressed nine degrees, and to the rear of the axis point it is elevated nine degrees. This is recommended to accommodate to the normal grip axis of the hand, which is not perpendicular to the axis of the forearm, but depressed by this amount toward the ulnar side of the forearm.

In short--the orthogonal planes of the controller remain intact, except that the system is rotated nine degrees, top forward. This depresses the forward aspect of the x-y plane, elevating its rearward aspect. The x-z plane is rotated nine degrees forward along the x axis. The y-z plane remains vertical, although rotated forward along the x-axis.

Varying the shape of a handgrip need not require a change in position or orientation of the hand-arm system. Basic relationships between hand and arm must be maintained within ranges wherein comfort and performance are known to be high. The controller position described above permits orientation of the forearm with the long axis of the craft and, of course, the direction of travel. The wrist is maintained at the midpoint of total mobility. Since the x-z and x-y planes of the controller are varied from the vertical and horizontal to accomodate natural handgrip axis, this orientation of the grip will likely appear to the operator to be maintained. Biomechanical capabilities in terms of strength and control over fine adjustments should not be effected.

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