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ABSTRACT

A study investigated the relationship between avionics subsystem design characteristics and training time, training cost, and job performance. A list of design variables believed to affect training and job performance was established and supplemented with personnel variables, including aptitude test scores and the amount of training and experience. Thirty functional loops from ten avionics subsystems were selected as the units of equipment to be investigated. Ten students were observed performing each of the functional checkouts. Training time and training equipment cost data were collected for each loop. A factor analysis identified six factors which account for a major part of the variance in maintenance task performance: length of checkout procedure, equipment complexity, difficulty of checkout steps, nonautomatic checkout, diagnostic information, and clarity of information. The magnitude of the regression coeffients (.92 or better) establish this as a promising approach to deriving human resources data for systems under development. Additional research is needed to develop and quantify better hardware and personnel variables. (JK)

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RELATIONSHIPS BETWEEN DESIGN CHARACTERISTICS OF AVIONICS SUBSYSTEMS AND TRAINING COST, TRAINING DIFFICULTY, AND JOB PERFORMANCE

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AIR FORCE HUMAN RESOURCES LABORATORY
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This study was initiated by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio, under Project 1124, "Human Resources in Aerospace System Development and Operations," Melvin T. Snyder, Project Scientist, and Task 1124-02, "Relationship between Subsystem Design, Training, Personnel Skill Attributes and Maintenance Job Performance," Kenneth W. Potempa, Task Scientist. The research was performed at McDonnell Douglas Astronautics Company - East, St. Louis, Missouri, under Contract F33615-71-C-1620 with Dr. Larry M. Lintz, Engineering Psychology Department, as principal investigator. The research was conducted during the period from 1 July 1971 through 1 September 1972.

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This technical report has been reviewed and is approved.

Gordon A. Eckstrand, Ph.D.
Chief, Advanced Systems Division
Air Force Human Resources Laboratory

ABSTRACT

The relationships between subsystem design characteristics, training cost, training difficulty, and job performance were investigated for avionics subsystems. A list of relevant design characteristics was established, based on expert opinions of avionics engineers, Air Force (AF) training supervisors, and AF instructors. Functional loops were selected from 10 subsystems representing navigation, flight control, communications, and fire control subsystems. Performance tests for each of the 30 functional loops were identified or constructed. Ten AF students performed each of the tests. Time and errors were recorded for using equipment and reading technical orders (T.O.'s). Both stepwise regressions and factor analysis were used to derive equations to predict performance time, training time, T.O. time, errors, and training equipment cost from equipment design characteristics, personnel characteristics, and environmental variables. Multiple correlation coefficients were 0.88 or greater. Factors of Length of Checkout Procedure, Equipment Complexity, Difficulty of Checkout Steps, Nonautomatic Checkout, Diagnostic Information, and Clarity of Information were identified. Applications of these equations should, for the present, be made cautiously, particularly if any of the input data fall outside the ranges which entered into derivation of the equations.

SUMMARY AND CONCLUSIONS

1. PROBLEM

The human resources of the Air Force have a major impact on the operational capabilities and overall costs of systems. However, information on human resources requirements is generally introduced late or not at all into system design. Previous studies by the Air Force Human Resources Laboratory indicate such information does affect design if it is available in suitable quantitative form early in design and if the Statement of Work requires that it be used. This study investigated the relationship between avionics subsystem design characteristics and training time, training cost, and job performance.

2. APPROACH

A list of design variables believed to affect training and job performance was established, and supplemented with personnel variables. Twenty-nine measures of the equipment design were taken, ranging from the number of test points to the number of throw-away components. The personnel variables used were aptitude test scores, and amount of training and experience. Thirty functional loops, from ten avionics subsystems, were selected as the units of equipment to be investigated. A functional loop is defined as a network of circuits and equipment units within an avionics subsystem through which signals are processed to perform a specific function. Functional checkout procedures were identified or constructed for each functional loop. Ten Air Force (AF) students were observed performing each of the functional checkouts; performance time, Technical Order (T.O.) reading time, and errors were recorded. Training time and training equipment cost data were collected for each loop. Regression analyses and factor analysis were used to analyze the results and derive equations to predict training time, training equipment cost, and job performance time and errors from equipment characteristics.

3. RESULTS AND CONCLUSIONS

Four prediction equations were developed through the use of stepwise regressions. It was found that 94 percent of the variance in maintenance task performance time can be accounted for by the complexity of the subsystem, the number of steps in the maintenance task, the reliability of the test equipment used, and the ruggedness of the components being repaired. Ninety-four percent of the variance in task errors was found to be due to the number of steps in the maintenance task, the number of special conditions, such as cooling, that are required, extent to which the T.O. uses standard symbology, the amount of training, the number of dependent remotely located components, and the reliability of the test equipment. Eight-one percent of the variance in training time required for a task could be accounted for by the convenience of test point location, the length of the task, T.O. change data are clearly presented and the number of dependent remotely located components. The last equation showed that 77 percent of the variance in the cost of training equipment could be accounted for by the extent to which maintenance tasks are automated, the percent of identical circuits used and the T.O. time.

A factor analysis, using the orthogonal components methods, resulted in identifying 6 factors which account for a major part of the variance in the 20 independent variables which correlate significantly with performance. Names assigned to the 6 factors are: Length of Checkout Procedure; Equipment Complexity; Difficulty of Checkout Steps; Nonautomatic Checkout; Diagnostic Information; and Clarity of Information. Stepwise regressions of the performance variables on the factors resulted in prediction equations with multiple correlation coefficients of 0.92 or greater.

The magnitudes of the regression coefficients establish this as a very promising approach to deriving human resources data for systems under development. This has been shown to be true across a variety of avionics equipment, including communications sets, autopilots, air data computers, and fire control systems. The degree of predictive accuracy attained in this study cannot be expected to remain as high during replications of this study. However, the results of this study indicate that even with normal shrinkage, the predictive capability of the equations will remain highly significant.

4. DIRECTIONS FOR FUTURE RESEARCH AND APPLICATION

Additional research is needed to develop and quantify better hardware and personnel variables. When this has been accomplished, data need to be collected across a broader spectrum of avionics equipment design and maintenance tasks, in order to extend the generalizability of the prediction equations. Finally, predictions need to be based upon these equations, and these predictions tested against real-world observations. The prediction equations once validated should be used to generate quantitative forecasts of training and performance parameters for avionics systems during the design process. The predicted parameters should be compared with the results from current methods for predicting training and performance and the results should be documented to the AF to provide data for assessing the relative utilities and validities of the different methods.

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SECTION 1

INTRODUCTION

1. NATURE OF THE PROBLEM

The human resources of the Air Force account for a large part of systems costs and have a major impact on operational capabilities. However, human resources considerations are usually introduced late or not at all in system design. Consequently, the product which enters the AF inventory is often designed to provide the required operational capability at minimum initial cost. The design process and the data introduced into it often do not operate to minimize such important factors in life cycle cost as pay, allowances, and support for the necessary maintenance personnel, or the costs of training these people. If better methods are developed and implemented for predicting human resources costs during system design, then the design process can trade off system capability, equipment cost, and human resources costs to achieve an optimal product. That human resources considerations constitute an acute problem is clear from a recent Pentagon forecast (Aviation Week, 21 August 1972, p. 11) of a $112 billion defense budget in 1980, an increase of almost 35 percent over the current $83 billion budget. This forecast was accompanied by the caution that the 35 percent increase would represent no increase in purchasing power over the current budget because of inflation and because of rising manpower costs.

The currently available methods for predicting human resources costs from equipment design characteristics leave much to be desired. Frequently, only "best guess" data from someone familiar with AF personnel skills and operations can be provided. Objective methods of forecasting human resources requirements during the course of system design are needed. This study explored some possibilities for sharpening the precision of the data and for moving toward objectivity.

Smith and Westland (1971) reviewed the status of maintainability models. They concluded that the correlational approach to predicting maintainability appears to be "the only possible empirical approach for use in early design, short of simply providing subjective estimates." They stress the importance of a relevant and inclusive list of equipment characteristics, and the necessity for a valid data base. Topmiller (1964) pointed out the need for sampling across different classes of equipment, in order that the resulting predictive scheme can be generalized sufficiently to be of practical use.

The principle requirements for a correlational study of equipment characteristics influencing maintainability can be summarized:

(1) establish a comprehensive and valid listing of design characteristics for inclusion in the study;

(2) sample across classes of equipment so that the results of the study can be generalized to a range of practical equipment items; and

(3) collect as comprehensive a data base as possible using the best methods available.

2. GENERAL APPROACH

The general approach for this st[illegible] signed with the three criteria listed above in mind. To meet t[illegible]d cost limitations in this initial probe, restrictions had to be imposed but these were chosen to maximize the data base and the generalizability. The items of equipment which were investigated were 30 functional loops within 10 different avionics subsystems including navigation, flight control, communications, and fire control. A functional loop is defined as a network of circuits and equipment units within an avionics subsystem through which signals are processed to perform a specific function.

The data base consisted of on-site real-time observations of performance by experienced data collectors. There were no existing data bases applicable to the training situation. The possibility of drawing on expert opinion for ratings of task times and errors was considered, but as Smith and Westland (1971) concluded, "the basic problem associated with subjective techniques for acquiring performance data is simply that they have not been explored and evaluated to any significant degree." Meister, Finley, and Thompson (1971) included subjective measures in their study of maintenance performance, but were unable to obtain direct observation data on enough [illegible]ses to establish validity. Thus far, the most satisfactory method of collecting maintenance performance data is observation by observers who are familiar with the tasks they are scoring.

The major compromise which was utilized in this study to hold data collection to manageable proportions was in the selection of tasks to be observed. Ideally, all tasks or a broad sample of tasks on each functional loop should be investigated. This would include sampling all of the possible troubles and malfunctions that can occur. The compromise was to choose a task which could be specified for each functional loop, and which, if carried through without error, would indicate unambiguously that the functional loop was or was not operating and within specified tolerances. This task was the functional checkout procedure, and its attractiveness for this study's purposes lies in the facts that a complete functional checkout can be specified for each functional loop of avionics equipment, and that the functional checkout is the first stage of troubleshooting. The checkout verifies that the reported malfunction is indeed present, that it is in the loop under investigation, and within that loop identifies the area of malfunction.

The primary interest of this study was in training, and in job performance by students in the training environment. All observations of performance were carried out in the technical schools at Chanute, Keesler, and Lowry AFBs. The study was carried out in three broad phases: first, determine the design characteristics to be included, and select subsystems and functional loops to represent those characteristics; second, collect data; and third, analyze results.

SECTION II

PROCEDURE

1. ESTABLISH LIST OF DESIGN CHARACTERISTICS

The first task was to establish a list of design characteristics of avionics equipment which were believed to affect maintenance training. This was a two-stage process in which a number of sources were surveyed to generate an extensive list of characteristics, and this extensive list was ordered and reduced in conformity with expert ratings.

The design characteristics listed by Meister, Finley, and Thompson (1970) were taken as a starting point for the extensive list. The AF Design Handbooks, especially DH 1-8 and DH 1-9, were searched for additional likely characteristics. Further suggested characteristics which influence training were obtained from personnel of the Training Research Applications Branch (TTOE) and the Avionics Training Departments at Chanute, Keesler, and Lowry AFBs. Finally, the McDonnell Douglas Corporation (MDC) avionics engineering personnel sorted the list, eliminated obvious redundancies, and suggested additional design characteristics which might affect training. The end result of this effort was a list of 49 design characteristics. This listing was prepared in six different presentation orders, for use in the subsequent interviews.

2. ESTABLISH RELATIVE IMPORTANCE OF DESIGN CHARACTERISTICS

In order to establish the relative importance of the 49 design characteristics in determining the amount of training for maintenance personnel, individual interviews were conducted with 37 AF instructors and 11 AF students at Chanute, Keesler, and Lowry AFBs. The interview sample was as shown in Table I. Only avionics instructors and students with previous AF maintenance experience were interviewed. Lowry had, at the time of the interviews, no students with previous AF avionics experience. Consequently, only instructors were interviewed there.

TABLE I
MAKEUP OF INTERVIEW SAMPLE

	CHANUTE	KEESLER	LOWRY	TOTALS
INSTRUCTORS	13	8	16	37
STUDENTS	3	8	0	11
TOTALS	16	16	16	48

The data collected during these interviews were scaled using the method developed by Jones and Dubois (1955). Each interviewee was presented with 1 of the 6 orderings of the 49 design characteristics and asked to mark the 12 which had the most influence on amount of training with "+", and the 12 which had the least influence with "-." The remaining 25 unmarked characteristics represented a middle range, neither the strongest nor the weakest in their effects on training. Items marked "+" received a score of 2; items unmarked, 1; and items marked "-" received 0. Maximum possible score for an item was 96, if all 48 interviewees assigned it a "+". Minimum possible was 0, if all interviewees assigned it a "-". The complete listing of design characteristics and the results of this scaling operation are shown in Table II. It was decided that the 20 lowest-rated variables would be eliminated from further consideration in this study. Because the study dealt with organizational level maintenance, 2 of the first 31 variables were not applicable: T.O. specifies open loop measurements; and number of steps required in troubleshooting. The remaining 29 variables made up the listing used throughout the subsequent tasks.

3. SELECTION OF SUBSYSTEMS AND FUNCTIONAL LOOPS

The final task in this phase of the research was to match the selected characteristics with subsystems. The top 15 ranking design characteristics were used to identify subsystems which represented the widest practicable range of values across these design dimensions. The review for candidate subsystems combined the expert opinions of 10 Air Training Command instructors and 7 MDC Product Service Training instructors with broad experience in a number of subsystems. The experience background of these subjects is presented in Table III.

TABLE III
EXPERIENCE OF SUBJECTS USED IN SUBSYSTEM SELECTION

SUBJECTS	YEARS OF TECHNICAL EXPERIENCE IN ELECTRONICS	
	RANGE	MEAN
10 ATC INSTRUCTORS	1.1–21.5	12.3
7 IN-HOUSE PRODUCT SERVICE INSTRUCTORS	10.0–21.0	15.7

TABLE II
LIST OF DESIGN CHARACTERISTICS, AND THEIR RELATIVE IMPORTANCE TO TRAINING AS RATED BY AF INSTRUCTORS AND STUDENTS

DESIGN CHARACTERISTIC	RATING
T O CHECKOUT AND TROUBLESHOOTING INFORMATION IS COMPLETE	82
T O USES STANDARD SYMBOLOGY TO FULLEST EXTENT, AND EXPLAINS NON STANDARD SYMBOLOGY	72
CHECKOUT PROCEDURE REQUIRES FEW STEPS (VS MANY STEPS)	68
ONLY ONE PIECE OF TEST EQUIPMENT IS NEEDED (VS SEVERAL OR MANY)	66
T.O SPECIFIES TOLERANCES FOR ALL MEASUREMENTS	65
TEST POINTS ARE CONVENIENTLY LOCATED FOR EACH MODULE	65
T.O SECTIONS ARE IN LOGICAL SEQUENCE	65
CHECKOUT OF UNITS DOES NOT DEPEND ON OTHER SYSTEMS OR REMOTELY LOCATED COMPONENTS.	61
T.O PROVIDES QUANTITATIVE INFORMATION (VS GO – NO GO)	61
PLUG-IN CIRCUITS ARE USED (VS HARD-WIRED CIRCUITS)	60
TROUBLESHOOTING REQUIRES FEW STEPS (VS MANY STEPS)	60
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IDENTICAL CIRCUITS ARE USED REPEATEDLY	58
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SUBSYSTEM CHECKOUT DOES NOT REQUIRE SPECIAL CONDITIONS (COOLING, TEMPERATURE CONTROL, HYDRAULICS, SPECIAL VOLTAGES)	51
AGE OPERATION IS COMPLEX.	50
COMPONENTS CAN STAND REPEATED ADJUSTMENTS	49
BIT IS USED (VS CART AGE VS BENCH INSTRUMENTS)	49
T.O. SPECIFIES OPEN-LOOP MEASUREMENTS	48
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THE AGE GIVES QUANTITATIVE READINGS (VS GO – NO GO).	47
SYSTEM CONTROLS ARE CONVENIENTLY LOCATED RELATIVE TO AGE CONTROLS.	46
CHECKOUT PROCEDURE IS DOWN TO THE LOWEST LRU (VS DOWN TO MODULE LEVEL).	46
UNITS ARE EASILY REMOVED FROM THE SYSTEM.	45
ARRANGEMENT OF TEST POINTS OF FOLLOWS T O SEQUENCE	45
CONNECTORS ARE READILY ACCESSIBLE	44
IC'S AND LSI ARE USED (VS DISCRETE COMPONENTS).	43
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ALL CIRCUITS ARE ANALOG (VS DIGITAL OR HYBRID)	40
WORKING POSITION AND LIGHTING ARE CONVENIENT FOR EACH UNIT	40
EACH UNIT HAS FEW COMPONENTS (VS MANY COMPONENTS).	39
COMPONENTS ARE ARRANGED LOGICALLY WITHIN UNITS.	36
AGE IS OF CONVENIENT, MANAGEABLE SIZE.	34
THROW-AWAY COMPONENTS ARE USED (VS REPAIRABLE COMPONENTS).	33
MEMORY STORAGE IS IN FLIPFLOPS(VS MAGNETIC CORE, MAGNETIC TAPE, OR OTHER).	32
GOOD TYPES OF CONNECTORS ARE USED (SOLDER VS CRIMP, POTTED VS NON-POTTED, SCREW-ON VS QUICK CONNECT, ETC.)	32
SIZES OF UNITS ARE CONVENIENT AND MANAGEABLE	32
NUMBER OF CONNECTORS IS MINIMIZED.	31
CLEAN COMPONENTS ARE USED (VS POTTED, COATED, OR SEALED COMPONENTS).	31
DISPLAYS ARE ANALOG (VS DIGITAL).	29
DISPLAYS ARE ELECTROMECHANICAL (VS CRT OR OTHER).	28
STANDARD SIZE COMPONENTS ARE USED (VS MICRO-MINIATURE).	26
WEIGHTS OF UNITS ARE MANAGEABLE AND CONVENIENT.	25

The criteria for subsystem selection were:

(1) The subsystem should consist of airborne electronics equipment.

(2) The subsystem should be pairable with another subsystem on the basis of functional similarity.

(3) The paired subsystems should reflect different proportions of the design characteristics under study, to provide meaningful comparisons.

(4) The subsystem should not contain sensitive data in those areas where this study would impinge.

(5) The subsystem should be taught at Lowry, Keesler, or Chanute Technical Training Center.

On the basis of the above criteria, 16 subsystems were chosen and analyzed further by applying 2 other criteria:

(6) The functional loops selected should be those in which there was a reasonable amount of maintenance performance activities.

(7) The course of instruction for the selected functional loop should include hands-on practice as a learning objective.

Since the study was concerned with student interaction with hardware design features, criterion (7) served to establish the existence of a student population with some training in practical performance, while criterion (6) served to single out the best functional loops for meaningful coverage of a subsystem.

The final selection consisted of the 10 subsystems and 30 functional loops listed in Table IV. Information on the functions of these subsystems is also provided in Table IV. Four of the subsystems, the APQ-120, APQ-109, and ASG-19 Fire Control Systems and the ASN-91 Tactical Computer, used in the F4E, F4D, F105, and A7D fighter aircraft, respectively, were taught at Lowry AFB-Denver, Colorado. Threee others, the F111 Central Air Data Computer, the F111 Automatic Flight Control System, and the MB-5 Automatic Flight Control System used in the F101, were taught at Chanute AFB-Rantoul, Illinois. The remaining three, the ASN-48 Inertial Navigation System and the ARC-34 and ARC-51 UHF Communications Systems used in the F4C, C-130, and OV-10, respectively, were taught at Keesler AFB-Biloxi, Mississippi. Since three bases were involved, the location of the school was included as a variable in the study.

4. QUANTIFICATION OF HARDWARE DESIGN VARIABLES

Two methods were used in scaling the design characteristics. The most direct approach was to effect a physical count such as number of test points. This was possible on 14 of the design characteristics. For the

TABLE IV

AVIONICS SUBSYSTEMS AND FUNCTIONAL LOOPS INVESTIGATED IN THE STUDY

SUBSYSTEM AND FUNCTION DESCRIPTION	FUNCTIONAL LOOPS
APQ-120 FIRE CONTROL SYSTEM SEARCHES FOR, ACQUIRES, AND AUTOMATICALLY TRACKS AN AIRBORNE TARGET. THE CAPABILITY ALSO EXISTS OF DETERMINING RANGE TO A GROUND TARGET.	TRANSMITTER ELECTRICAL FREQUENCY CONTROL ASE (ALLOWABLE STEERING ERROR) AIM DOT CW ILLUMINATOR
APQ-109 FIRE CONTROL SYSTEM SEARCHES FOR AND ACQUIRES AN AIRBORNE TARGET, TRACKS THE TARGET AUTOMATICALLY AND SUPPLIES TARGET POSITION INFORMATION TO THE TARGET INTERCEPT COMPUTER AND INDICATORS.	TRANSMITTER ELECTRICAL FREQUENCY CONTROL ASE (ALLOWABLE STEERING ERROR) AIM DOT
ASG-19 RADAR PROVIDES AIR TO AIR SEARCH, TARGET ACQUISITION, TERRAIN AVOIDANCE AND AIR TO GROUND RANGING MODES OF OPERATION IT ALSO PROVIDES RANGE INFORMATION TO THE TOSS BOMB COMPUTER AND THE ATTACK AND DISPLAY SUBSYSTEM.	TRANSMITTER ELECTRICAL FREQUENCY CONTROL ON-TARGET STEERING
ASN-91 TACTICAL COMPUTER PROCESSES DATA FROM INTERFACED AIRPLANE SYSTEMS TO DERIVE COMPUTED AUTOMATIC NAVIGATION AND WEAPON DELIVERY CONTROL AND DISPLAY DATA.	ENTIRE SYSTEM
ASN-48 INERTIAL NAVIGATION SYSTEM COMPUTES INFORMATION REGARDING AIRCRAFT LATITUDE, LONGITUDE, HEADING, PITCH AND ROLL. THE COMPUTED OUTPUTS ARE SUPPLIED TO AIRCRAFT AVIONICS EQUIPMENT.	PLATFORM ALIGNMENT NAVIGATION
ARC-51 UHF COMMUNICATIONS PROVIDES 2 WAY AMPLITUDE-MODULATION, DOUBLE-SIDEBAND, FULL-CARRIER, RADIOTELEPHONE COMMUNICATION BETWEEN AIRCRAFT IN FLIGHT, AIRCRAFT AND SHORE, AND AIRCRAFT AND SHIP.	TRANSMITTER MAIN RECEIVER TUNING
ARC-34 UHF COMMUNICATIONS PROVIDES SHORT-RANGE VOICE TRANSMISSION AND RECEPTION FROM AIRCRAFT TO AIRCRAFT OR AIRCRAFT TO GROUND.	TRANSMITTER MAIN RECEIVER TUNING
F111 AUTOMATIC FLIGHT CONTROL SYSTEM PROVIDES AUTOMATIC CONTROL OF THE AIRCRAFT IN THE YAW, ROLL AND PITCH AXES. SEVERAL MODES OF OPERATION ARE PROVIDED WHICH THE PILOT MAY SELECT TO RELIEVE THE BURDEN OF FLYING THE AIRCRAFT OR TO ACCOMPLISH A WEAPONS DELIVERY MISSION.	PITCH ROLL YAW
F101 AUTOMATIC FLIGHT CONTROL SYSTEM PROVIDES AUTOMATIC CONTROL OF THE AIRCRAFT IN THE YAW, ROLL AND PITCH AXES. SEVERAL MODES OF OPERATION ARE PROVIDED WHICH THE PILOT MAY SELECT TO RELIEVE THE BURDEN OF FLYING THE AIRCRAFT OR TO ACCOMPLISH A WEAPONS DELIVERY MISSION.	PITCH ROLL YAW
F111 CENTRAL AIR DATA COMPUTER RECEIVES, COMPUTES, TRANSMITS AND DISPLAYS INFORMATION CONCERNING THE ENVIRONMENT IN WHICH THE AIRCRAFT IS FLYING. THE COMPUTED INFORMATION IS USED BY SYSTEMS REQUIRING AIR DATA FUNCTIONS ESSENTIAL TO THEIR PROPER OPERATION.	MACH ALTITUDE TRUE AIRSPEED

remaining design variables, a direct count was not possible and values were derived from a judgment survey. Examples of variables scaled in this way are "T.O. sections are in logical sequence" and "Components can stand repeated adjustment."

The judgment survey for scaling design variables was administered to 82 ATC instructors, supervisors, and course writers. From 5 to 14 raters were used for each subsystem, with ratings by any one rater limited to 3 functional loops which were presented in a counterbalanced order. Rating scales with scale divisions numbered 0 to 10 were constructed. For each design characteristic to be scaled, definitions were given to the 0 and the 10 on the scale. In scaling "T.O. sections are in logical sequence," for example, 0 was defined as "None of the T.O. sections for this functional loop are in logical sequence" and 10 was defined as "100 percent of the T.O. sections for this loop are in logical sequence."

Instructions emphasized that the ratings should apply exclusively to the functional loop identified on the rating form. By defining the scale values in terms of percentages, it was felt that the rater could effect a proportionality assessment to arrive at a value, such as "Of all the T.O. sections that are applicable to this loop, 85 percent are in logical sequence." The characteristics of the raters are described in Table V. The values for all design variables used in the study are summarized in Table VI and listed fully in Table XVI. The values given in Table XVI for variables scaled by the judgment survey represent means of the values assigned by all raters on a functional loop.

TABLE V
CHARACTERISTICS OF THE RATERS ON THE SCALING SURVEY

SUBSYSTEM	NUMBER OF RATERS	AVERAGE EXPERIENCE IN AVIONICS (YEARS)
F111 CADC	5	2.4
F101 AFCS	5	13.[illegible]
F111 AFCS	5	10.8
ASN-48 INS	5	9.1
ARC-34 UHF	14	9.0
ARC-51 UHF	12	8.1
APQ-120 FCS	12	14.6
APQ-109 FCS	14	10.5
ASG-19 RADAR	5	6.8
ASN-91 COMPUTER	5	8.0

TABLE VI
LISTING OF ALL VARIABLES, WITH RANGES, MEANS, AND STANDARD DEVIATIONS

VARIABLE NUMBER	DESCRIPTION OF VARIABLE	RANGE	MEAN	STANDARD DEVIATION
1	AQE ELECTRONICS SCORE	85.0– 93.5	88.50	2.74
2	PAST EXPERIENCE (MONTHS)	0 – 6.5	1.68	2.14
3	PAST TRAINING (MONTHS)	0 – 6.0	1.38	1.75
4	PERFORMANCE TIME (SECONDS)	249 –4385	1714	1365
5	T.O. TIME (SECONDS)	31.1–2419.7	585	571
6	NUMBER OF ERRORS	0.5– 16.8	6.56	5.20
7	TRAINING TIME (HOURS)	2.0– 122.0	41.05	32.45
8	CHANUTE (AT CHANUTE = 1, NOT CHANUTE = 0)	–	0.30	0.47
9	KEESLER (AT KEESLER = 1, NOT KEESLER = 0)	–	0.27	0.45
10	LOWRY (AT LOWRY = 1, NOT LOWRY = 0)	–	0.43	0.50
11	COMPLETENESS OF T.O. CHECKOUT INFORMATION (RATING ON 10-POINT SCALE)	7.0– 10.0	9.20	0.73
12	EXTENT TO WHICH T.O. USES STANDARD SYMBOLOGY (10-POINT RATING SCALE)	2.8– 9.7	8.66	1.68
13	NUMBER OF STEPS IN CHECKOUT PROCEDURE	41 – 787	285.97	219.21
14	NUMBER OF PIECES OF TEST EQUIPMENT NEEDED	0 – 3	1.27	1.08
15	PERCENTAGE OF MEASUREMENTS FOR WHICH T.O. SPECIFIES TOLERANCES	0 – 100	59.57	30.22
16	TEST POINTS ARE CONVENIENT (10-POINT RATING SCALE)	4.2– 10	8.28	1.71
17	T.O. SECTIONS ARE IN LOGICAL SEQUENCE (10-POINT RATING SCALE)	6.0– 10.0	8.74	1.01
18	NUMBER OF OTHER UNITS REQUIRED FOR CHECKOUT	1 – 9	2.37	1.63
19	PERCENTAGE OF MEASUREMENTS WHICH ARE SPECIFIED QUANTITATIVELY IN THE T.O. (VS GO-NO GO)	0 – 100	36.27	32.02
20	PERCENTAGE OF PLUG-IN CIRCUITS (VS HARDWIRED)	0 – 100	68.72	28.33
21	NUMBER OF STEPS IN TROUBLE SHOOTING	N A	N/A	N/A
22	CONTROLS ARE CLEARLY IDENTIFIED (10-POINT RATING SCALE)	4.4– 9.8	8.73	1.37
23	ACCESSIBILITY OF COMPONENTS (10-POINT RATING SCALE)	2.6– 9.9	7.56	1.95
24	NUMBER OF TEST POINTS	0 – 32	9.00	11.77
25	PERCENTAGE OF IDENTICAL CIRCUITS USED	0 – 64	13.27	23.27
26	PERCENTAGE OF CONNECTORS WHICH CAN BE INCORRECTLY CONNECTED (RATING SCALE)	0 – 92	36.81	24.96
27	NUMBER OF ADJUSTMENTS REQUIRED	0 – 11	2.57	3.64
28	T.O. CHANGE DATA ARE CLEARLY PRESENTED (10-POINT RATING SCALE)	5.0 - 10.0	8.32	1.44
29	RELIABILITY OF TEST EQUIPMENT (10-POINT RATING SCALE)	5.2– 10.0	8.04	1.39
30	NUMBER OF SPECIAL CONDITIONS REQUIRED FOR CHECKOUT (E.G. COOLING, HYDRAULICS)	0 – 2	1.10	0.96
31	COMPLEXITY OF TEST EQUIPMENT OPERATION (10-POINT RATING SCALE)	4.2– 9.9	7.25	1.59
32	COMPONENTS CAN STAND REPEATED ADJUSTMENT (10-POINT RATING SCALE)	5.2– 10.0	8.23	1.24
33	PERCENTAGE OF CHECKOUT WHICH IS BIT	0 – 100	42.97	45.53
34	PERCENTAGE OF CHECKOUT WHICH IS AUTOMATICALLY SEQUENCED	0 – 33	1.93	7.43
35	PERCENTAGE OF TEST EQUIPMENT READINGS WHICH ARE QUANTITATIVE	0 – 100	61.27	45.29
36	CONVENIENCE OF LOCATION OF SYSTEM AND TEST EQUIPMENT CONTROLS (10-POINT RATING SCALE)	3.0– 10.0	7.87	1.70
37	PERCENTAGE OF CHECKOUT WHICH IS TO LOWEST LRU	61 – 100	96.07	11.90
38	ACCESSIBILITY OF UNITS FOR TESTING AND REMOVAL (10-POINT RATING SCALE)	2.8– 9.8	7.67	2.12
39	TEST POINT ARRANGEMENT FOLLOWS T.O. SEQUENCE (10-POINT RATING SCALE)	3.0– 10.0	7.95	1.81
40	ALTERNATE FOR VARIABLE NO. 31; COUNT OF NUMBER OF CONTROLS AND DISPLAYS	0 – 115	35.00	37.89
41	ALTERNATE FOR VARIABLE NO. 16: PERCENTAGE OF TEST POINTS ACCESSIBLE WITHOUT REMOVING UNITS OR COVERS	0 – 100	93.33	177.98
42	PERFORMANCE OBSERVATION WEEK	4 – 34	16.53	8.01
43	TEST EQUIPMENT COST, DOLLARS	27 –1761	125.77	311.75

NOTE: THE NUMBERING OF VARIABLES THROUGHOUT THIS REPORT REFERS TO THIS LIST.

5. PERFORMANCE TESTS

The functional loops served as the baseline for identifying the performance tests to be used in the study. The Plans of Instruction, Criterion Checklists, Study Guides, and Sample Performance Tests, as well as other training materials were procured and analyzed for total training content, adequacy of existing performance testing, and additional requirements for testing. It was found that very few learning objectives were devoted to troubleshooting practice or adjustment/alignment activities. Where tests did exist, they were deficient in operator interaction and would have necessitated full-scale construction of examinations on our part as well as special arrangements with the bases to administer. Although some tests were specially devised and administered, the data sample was too small for these two maintenance categories. Consequently, they were excluded from the statistical analysis. The tests on which the major effort was expended were the functional checkout procedures. A complete functional checkout procedure was developed for each functional loop. This checkout consisted of preparatory tasks such as cable connections and test equipment setup; the actual tasks that determined the operational status of the equipment, such as switch positions for testing and display interpretation; and the final tasks of equipment shutdown.

The basic checkout procedures were extracted from the Technical Orders. Changes were required in many cases to reconfigure the examinations to reflect the use of the training hardware in the schools instead of the aircraft on the flight-line. Task clusters were broken down into behavioral steps and numbered in procedural sequence, for scoring purposes during test administration. The behavioral steps described the actions to be performed and the results, as, for example, "Press T-17 microphone button. Results: Power output 8 watts minimum." The specially constructed tests were the functional checkout procedures for the F101 Automatic Flight Control loops, the ARC-51 UHF loops, the ARC-34 UHF loops, and the F111 CADC loops, wherein task information from the T.O.'s and the training environment were integrated to provide suitable examinations for the study. The battery of tests for a complete functional checkout of a loop ranged from one to six tests per loop. Table XIX identifies the tests that were administered for each loop, the line replaceable units in the loop, and the test equipment used.

6. PERFORMANCE MEASURES

Since the study was designed to investigate the influence of design characteristics on student performance as one of the dependent variables, the examinations were analyzed into a sequential series of behavioral steps as previously discussed. A student's response action in a behavioral step represented his interaction with the equipment setup which incorporated the design characteristics in varying magnitudes. The performance measures used in the study were (1) performance time, (2) time spent consulting T.O., and (3) errors.

Performance time was recorded as subscores for task activities, and the subscores were added to obtain the total performance time on a test.

The task activities for the functional checkout were (1) preparatory tasks, (2) functional checkout tasks, and (3) shutdown tasks. The T.O. time was recorded under the same conditions. The errors were recorded for behavioral steps. An error was defined as any deviation from the prescribed standard of desired performance, the procedural sequence representing the standard. The type of error such as "omitted step," "selected wrong control," and "interpreted display incorrectly" was described on the data collection form.

7. PERFORMANCE DATA COLLECTION

The tests were performed by a total of 191 students - 104 at Lowry, 47 at Chanute, and 40 at Keesler. The AQE Electronics score, past experience in career field, and past training in career field were treated as personnel variables. A summary of these variables is included in Table VI.

All students were enrolled in an AF course leading to an Air Force Specialty Code (AFSC) skill level of 3. All students were graduating or qualified students. A graduating student was one who had successfully completed the block of instruction's theory and principle and was ready to perform hands-on testing. This occurred near the end of the block, and meant that during the observations by the data collectors, the student's performance was also being graded as "passed" or "failed" by the class instructor. The qualified students were those who had graduated out of the block within a period of 10 training days. It was necessary to include this population, since it was not possible to test all the students as they were being graduated.

Three MDC observers collected the performance data. Training for the data collectors included practice runs of the tests in-house for those subsystems that existed in the contractor's product line and at the bases prior to actual administration. Some of these dry runs were videotaped on the bases and brought back to the company for further study.

Two data recording devices were used. One was an MDC-designed battery-operated clipboard timer (Figure 1). Two digital readouts provided cumulative time and cumulative frequency readings. The clipboards were used by two data collectors who functioned as a team. The data collected on these digital readouts were the amount of time spent reading T.O. and a frequency count of T.O. usage. The performance times and errors for the tasks were recorded by the other observer of the two-man team who used either another clipboard of the same design or a stopwatch. To ensure that the clipboards were functioning accurately, the data collectors regularly performed a calibration check against a stopwatch, prior to actual use of the equipment.

The other data recording device was a Rustrak Event Recorder (Figure 2), operated from a hand-held switch box on which were installed four 2-position toggles, permitting the use of 4 channels. The first three channels recorded task time, T.O. time and frequency, and errors. The

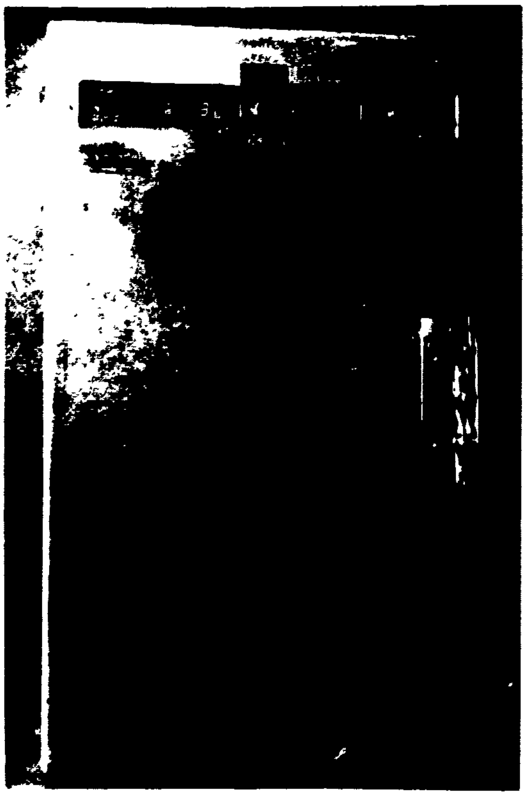

FIGURE 1 CLIPBOARD USED IN PERFORMANCE OBSERVATIONS

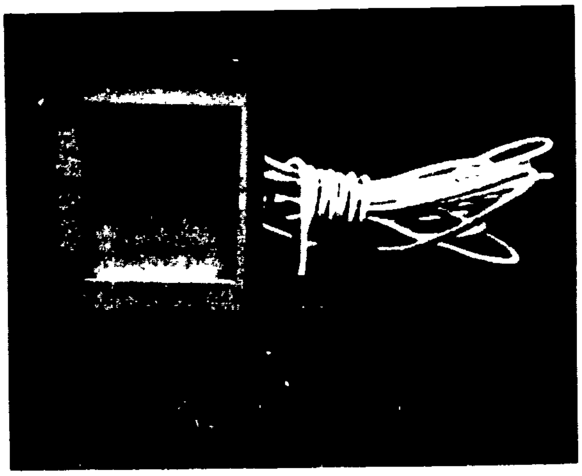

FIGURE 2 EVENT RECORDER AND OPERATOR'S CONTROL USED IN PERFORMANCE OBSERVATIONS

fourth channel was used to record downtime to be subtracted from the student's performance time. Downtime events included equipment malfunctions and other events not related to the test being observed. The event recorder was checked periodically against a stopwatch to ensure its accuracy.

Both data collection teams observed the performance of two students on the ASG-19 and two students on the ASN-91 for the purpose of establishing interrater reliability. There was exact agreement on number of errors (14 across the four performances), and interobserver correlations of 0.99 for performance times and 0.98 for T.O. times. The two resulting measures of total performance time differed by less than 1 percent.

Performance testing was carried out as early as the fourth week of a class, and as late as the thirty-fourth week, depending on when in a course a particular functional loop was taught. Since there was such a wide range in amount of cumulative training up to the test week, Performance Observation Week, defined as number of weeks into the course at the time of testing, was included as a variable in the study (Variable Y42, Table XVI). Where testing on a functional loop was performed in more than one block, the Performance Observation Weeks were averaged to provide the mean week into the course at test time. The weeks of AF technical training received by subjects prior to testing are listed in Table VII. The weeks of AF training include the Basic Electronics Course, and Performance Observation Weeks include only the advanced course times.

Student performance was observed between November 1971 and April 1972. Preliminary arrangements included a survey of the classroom environments where the tests were to be conducted, briefing of appropriate personnel as to the purpose of the data collection activity, and general instructions to students and classroom instructors.

The survey of the classroom environments checked on the adequacy of observation points for the data collectors. Where the class size or the equipment arrangement would have hampered data collection operations, special arrangements were made to procure the classroom solely for test purposes. The briefing helped to relieve apprehension on the part of both instructors and students of being evaluated on a personal basis. The general instructions defined test breaks and requested the student to verbalize his symptom interpretations, when asked by the data collector to do so, since there was often no other way of determining whether the student correctly diagnosed the functional state of the system.

Tests were performed by individual students except when Air Training Command policy dictated that a test was a two-man task. Where students were performing in pairs, arrangements were made with the instructor to have one student do the T.O. reading while the other actually performed. In such a test situation, the test constituted one set of data and the personnel variables were combined and averaged. Where multiple tests existed in a functional loop, the performance time, T.O. time, and errors represented the totals across all tests, and the method of averages was again applied to the personnel variables.

TABLE VII

NUMBER OF WEEKS OF AF TECHNICAL TRAINING RECEIVED BY STUDENT BEFORE PERFORMANCE OBSERVATION

FUNCTIONAL CHECKS	TECHNICAL TRAINING, WEEKS
ASN–91 COMPUTER LOOP	15
F101 AFCS PITCH LOOP	21
F101 AFCS ROLL LOOP	22
F101 AFCS YAW LOOP	22
APQ–120 TRANSMITTER	29
APQ–120 EFC	29
APQ–120 CW ILLUMINATOR	29
APQ–120 ASE	29
APQ–120 AIM DOT	29
APQ–109 TRANSMITTER	27
APQ–109 EFC	27
APQ–109 ASE	27
APQ–109 AIM DOT	27
ARC–51 UHF TRANSMITTER	29
ARC–51 UHF MAIN RECEIVER	29
ARC–51 UHF TUNING	29
ARC–34 UHF TRANSMITTER	20
ARC–34 UHF MAIN RECEIVER	20
ARC–34 UHF TUNING	20
ASN–48 NAVIGATION	34
ASN–48 PLATFORM	34
F111 CADC TAS	25
F111 CADC MACH	25
F111 CADC ALTITUDE	25
F111 AFCS PITCH	29
F111 AFCS ROLL	29
F111 AFCS YAW	29
ASG–19 TRANSMITTER	17
ASG–19 AEFC	17
ASG–19 ON-TARGET STEERING	23

The 10 observations required for each test were handled by one data collection team. The overriding factors in this approach were training for competence in technical content of the examination, in observation skills, and in the use of data collection tools. However, all data collectors were knowledgeable on all functional loops in terms of equipment function, equipment units, and related test equipment.

8. TRAINING TIME AND EQUIPMENT COST DATA COLLECTION

The training times for the subsystem loops were obtained by administering questionnaires to five course experts in each subsystem. The five course experts as a team evaluated their subsystems, and their answers represented the consensus of the group. They identified the portions of the Plan of Instruction applicable to each of the functional loops and estimated the training time given for each loop. The training time represented all training required for a given loop including theory and practice, but excluding basic electronics. The technical experience of the raters is described in Table VIII, and Table IX shows the training times for each of the functional loops.

The training equipment costs per student per functional loop are tabulated in Table X. The method of computation for these costs is presented in Table XI.

TABLE VIII
AVIONICS EXPERIENCE OF TRAINING TIME EVALUATORS

SUBSYSTEM	MEAN YEARS OF AVIONICS EXPERIENCE
APQ-120	7.9
APQ-109	9.3
ASG-19	3.7
ASN-91	4.0
F101 AFCS	6.8
F111 AFCS	5.5
F111 CADC	2.2
ASN-48	4.7
ARC-51	4.2
ARC-34	1.2

TABLE IX
HOURS OF TRAINING AS REPORTED BY EVALUATORS FOR EACH FUNCTIONAL LOOP

SUBSYSTEM	FUNCTIONAL LOOP	HOURS OF TRAINING
APQ-120	TRANSMITTER	27.5
	ELEC FREQ CONTROL	22.5
	CW ILLUMINATOR	17.5
	ASE CIRCLE	14.0
	AIM DOT	15.0
APQ-109	TRANSMITTER	27.0
	ELEC FREQ CONTROL	18.0
	ASE CIRCLE	2.0
	AIM DOT	4.0
ASG-19	TRANSMITTER	6.0
	AUTO ELEC FREQ CONTROL	20.0
	ON-TARGET STEERING	46.5
ASN-91	COMPUTER	60.5
ASN-48	NAVIGATION	10.0
	PLATFORM ALIGNMENT	28.0
ARC-51	TRANSMITTER	28.3
	MAIN RECEIVER	28.1
	TUNING	27.5
ARC-34	TRANSMITTER	65.3
	MAIN RECEIVER	64.6
	TUNING	64.2
F111 AFCS	PITCH	122.0
	ROLL	118.0
	YAW	77.0
G101 AFCS	PITCH	82.0
	ROLL	82.0
	YAW	76.0
F111 CADC	TRUE AIRSPEED	24.0
	MACH	25.0
	ALTITUDE	28.0

TABLE X
EQUIPMENT COST PER STUDENT PER FUNCTIONAL LOOP

SUBSYSTEM	EQUIPMENT COST (DOLLARS)/STUDENT
F111 AFCS	
PITCH	120
ROLL	120
YAW	115
F101 AFCS	
PITCH	16
ROLL	16
YAW	16
F111 CADC	
TRUE AIRSPEED	47
MACH	47
ALTITUDE	48
ASG-19 FIRE CONTROL	
TRANSMITTER	53
FREQUENCY CONTROL	53
STEERING	66
APQ-109 FIRE CONTROL	
TRANSMITTER	95
FREQUENCY CONTROL	154
ASE	12
AIM DOT	12
APQ-120 FIRE CONTROL	
TRANSMITTER	115
FREQUENCY CONTROL	115
CN ILLUMINATOR	94
ASE	75
AIM DOT	75
ASN-91	
COMPUTER	1,761
ASN-48	
NAVIGATION	106
ALIGNMENT	106
ARC-51	
TRANSMITTER	106
RECEIVER	106
TUNING	106
ARC-34	
TRANSMITTER	27
MAIN RECEIVER	27
TUNING	27

TABLE XI
STEPS IN COMPUTATION OF EQUIPMENT COST

1. IDENTIFY EACH ITEM OF EQUIPMENT USED IN TEACHING EACH BLOCK.
2. OBTAIN THE COST OF EACH ITEM.
3. MULTIPLY THE COST BY THE NUMBER OF UNITS OF EQUIPMENT EMPLOYED.
4. MULTIPLY THAT NUMBER BY THE PERCENTAGE OF THE TOTAL USE OF THAT EQUIPMENT REPRESENTED BY THAT BLOCK.
5. SUM THE EQUIPMENT COST ACROSS BLOCKS TO OBTAIN THE COST FOR THE FUNCTIONAL LOOPS.
6. DIVIDE THAT SUM BY THE TOTAL NUMBER OF STUDENTS PROCESSED THROUGH THE COURSE IN A TEN YEAR PERIOD TO OBTAIN EQUIPMENT COST/STUDENT.

SECTION III

RESULTS

1. SUMMARY

The means, ranges, and standard deviations for each of the variables included in this study are shown in Table VI. In all subsequent data tabulations, the numbering of variables is in accord with the numbering in this table. Variables 1 through 3 and 42 are personnel variables; 4 through 6 are performance measures; 8 through 10 are training locations; 11 through 41 are design variables; and 7 and 43 are training variables. For convenience in associating names with variables (Y_1 through Y_{43}), normalized variables (Z_1 through Z_{43}), and factors (U_1 through U_6), Table XXII is included as a foldout at the end of this report. A listing of values for all variables across all functional loops is given in Table XVI. Variables 8, 9, and 10 were dichotomous (for example, Variable 10 is "1" if taught at Lowry, "0" if not taught at Lowry), and are not included in Table XVI.

Stepwise regression analyses were used to derive prediction equations for performance time, errors, training time, and training equipment cost. The resulting equations are:

performance time = $641.97 - 1327.06\ Y_8 + 4.23\ Y_{13} - 330.40\ Y_{29} + 354.38\ Y_{32}$, multiple correlation coefficient (R) = 0.973, standard error of estimate (S.E.) = 337.30 seconds;

number of errors = $11.27 - 0.67\ Y_3 + 0.36\ Y_{12} + 0.23\ Y_{13} - 0.63\ Y_{18} - 1.48\ Y_{29} - 0.83\ Y_{30}$, R = 0.971, S.E. = 1.31 errors;

training time = $-75.66 - 0.01\ Y_4 + 9.93\ Y_{16} + 7.85\ Y_{18} + 4.97\ Y_{28}$, R = 0.902, S.E. = 15.08 hours; and

training equipment cost = $16.39 + 0.18\ Y_5 - 3.67\ Y_{25} + 28.67\ Y_{34}$, R = 0.879, S. E. $156.74.

The 20 independent variables which correlated significantly with performance were entered into a factor analysis using the method of orthogonal components. Six factors which accounted for a major part of the variance in the independent variables were identified: U_1, Length of Checkout Procedure; U_2, Equipment Complexity, U_3, Difficulty of Checkout Steps; U_4, Nonautomatic Checkout; U_5, Diagnostic Information; and U_6, Clarity of Information. Factor U_1 weights most heavily on (accounts for more than 20 percent of the variance of) variables 2, 10, 11, 13, 15, 18, 19, 24, 30, 33, and 35;

Factor U_2, on variables 1, 8, 10, 20, 22, 29, 32, and 36; U_3, on 2, 15, 18, 19, 22, and 33; U_4, on 1, 8, 18, 30, and 34; U_5, on 24, 35, and 41; and U_6, on 41. (Refer to foldout Table XXII for variable names.)

Subsequent to the factor analysis, stepwise regression analyses were used to derive equations for predicting performance time, T.O. time, and errors from the factors. The following equations were derived:

$$\text{Performance Time} = 1714.1 + 1018.9\ U_1 - 393.8\ U_2 + 204.1\ U_3 - 550.2\ U_4,$$

$$R = 0.924,\ S.E. = 563.6 \text{ seconds}$$

$$\text{T.O. Time} = 585.9 + 443.3\ U_1 + 83.4\ U_3 - 243.3\ U_4 + 109.6\ U_5,$$

$$R = 0.933,\ S.E. = 221.9 \text{ seconds}$$

$$\text{Number of Errors} = 6.57 + 4.03\ U_1 - 0.79\ U_2 + 1.00\ U_3 - 1.20\ U_4 + 0.92\ U_5$$

$$- 1.49\ U_6,\ R = 0.926,\ S.E. = 2.21 \text{ errors.}$$

2. PLOTS OF INDEPENDENT VARIABLES VERSUS DEPENDENT VARIABLES

Prior to beginning data analyses, each of the independent variables was plotted against performance time, against number of errors, against training time, and against equipment cost. All plots were inspected for evidence of nonlinear relationships between variables, and none of the plots presented a compelling picture of nonlinearity. Consequently, a conservative approach was adopted, i.e., only linear correlations and regressions were run. The magnitudes of the correlation and regression coefficients which are subsequently reported might have been increased by fitting curvilinear functions to the observed data points. However, in the absence of either previously formulated hypotheses or strong evidence from the data plots, the parsimonious approach was to assume linearity.

3. CORRELATIONS OF VARIABLES

Table XII shows the variables which correlate significantly with one or more of the performance variables. In each case, correlations are across 30 pairs of observations. With the resulting 28 degrees of freedom, a correlation of 0.306 is significant at the 0.05 level. A complete correlation matrix for all variables is given in Table XVIII. The correlations of principal interest are of the dependent variables (4, 5, 6, 7, and 43) with each of the independent variables. Of the 185 resulting correlation coefficients, 64 are significant at the 0.05 level or better.

4. STEPWISE REGRESSIONS OF THE INDEPENDENT VARIABLES ON DEPENDENT VARIABLES

Stepwise regressions were run to determine regression equations predicting performance time, errors, training time, and training equipment cost from the independent variables. In each regression analysis, an $\underline{F}$ level

TABLE XII
VARIABLES CORRELATING SIGNIFICANTLY WITH ONE OR MORE OF THE THREE PERFORMANCE VARIABLES

VARIABLE NUMBER (SEE TABLE XXII FOR NAMES)	PERFORMANCE TIME	T.O. TIME	ERRORS
1	−0.707	−0.489	−0.561
2	+0.660	+0.639	+0.626
8	−0.592	−0.318	−0.407
10	+0.597	+0.699	+0.657
11	+0.325	+0.388	+0.355
13	+0.786	+0.869	+0.876
15	−0.344	−0.445	−0.476
18	+0.385	+0.606	(+0.296)
19	(−0.185)	(−0.302)	(−0.281)
20	(+0.083)	+0.329	(+0.164)
22	(+0.120)	(+0.285)	+0.313
24	+0.438	+0.395	+0.598
29	−0.349	(+0.025)	(−0.210)
30	+0.414	+0.349	+0.416
32	(+0.088)	+0.309	(+0.098)
33	+0.336	+0.376	+0.401
34	+0.312	+0.486	(+0.189)
35	(−0.295)	−0.322	−0.313
36	−0.399	(−0.225)	−0.326
41	(+0.260)	(+0.135)	+0.317

NOTE:
NONSIGNIFICANT CORRELATIONS ARE IN PARENTHESES.

of 4.18 for inclusion and 3.00 for deletion was set, with a tolerance level of 0.50 (an explanation of tolerance level is included as Appendix II).

For performance time, the resulting equation is:

$$\text{Performance time (seconds)} = 641.97 - 1327.06\ Y_8 + 4.23\ Y_{23} - 330.40\ Y_{29} + 354.38\ Y_{32}$$

This results in a multiple correlation coefficient (R) of 0.973 and a standard error of estimate (S.E.) of 337.30 seconds.

For errors, the equation is:

$$\text{number of errors} = 11.27 - 0.67\ Y_3 + 0.36\ Y_{12} + 0.23\ Y_{13} - 0.63\ Y_{18} - 1.48\ Y_{29} - 0.83\ Y_{30},\ R = 0.974,\ S.E. = 1.31 \text{ errors.}$$

For training time, the equation is:

$$\text{training time} = -75.66 - 0.01\ Y_4 + 9.93\ Y_{16} + 7.85\ Y_{18} + 4.97\ Y_{28},$$

$$R = 0.902,\ S.E. = 15.08 \text{ hours.}$$

For training equipment cost, the equation is:

$$\text{training equipment cost} = 16.39 + 0.18\ Y_5 - 3.67\ Y_{25} + 28.67\ Y_{34},$$

$$R = 0.879,\ S.E. = \$156.74.$$

Analyses of variance were run to determine the significance of each of these regression equations. In the "worst case," training equipment cost, an _F_ ratio of 4.64 is required for the 0.01 level of significance and the actual _F_ ratio is 29.67. The _F_ ratios for the other equations range upward to 109.6 (for number of errors).

5. ORTHOGONAL COMPONENTS

As an alternative analysis to the stepwise regressions reported above, a factor analysis was run to determine orthogonal components. Where the stepwise regression brings in variables until no one of the remaining variables accounts for enough of the residual variance (with "enough" defined by the specified _F_ to enter and tolerance level), the orthogonal components analysis retains information about all the variables which are entered into the analysis. Subsequent to the orthogonal components analysis, regressions of the dependent variables on the factors were determined. The resulting principal components equations contain all the original predictor variables. The use of equations which contain all of the important parameters should cause the design engineer, T.O. writer, and training or personnel planner to take a more comprehensive view of the problem.

The aim of this analysis was to intercorrelate those variables which are significantly related to performance, and to determine the minimum number of orthogonal factors required to express the original performance variables. The correlations of each of the three performance variables (performance time, T.O. time, and number of errors) with the remaining variables were tabulated in descending order, with a cutoff point at a correlation of 0.301. Twenty variables correlated at 0.301 or higher with one or more of the performance variables (Table XII). These 20 variables were entered into the orthogonal components analysis.

From an orthogonal components analysis with 20 original variables, 20 orthogonal components are extracted. The question is, how many of these components must be retained to adequately account for the variance in the original 20 variables? One recommended procedure is to stop where the eigenvalues drop below 1.00 (Harman, 1960, p. 363). In this analysis, this occurs when six orthogonal components have been identified. As an alternative, the eigenvalue of 0.50 which is reached with nine factors was considered. Table XIII lists, for each of the 20 original variables, the proportion of variance accounted for by the first 9 factors. The additional information contributed by retaining nine factors as opposed to six does not seem sufficiently impressive to justify the additional complexity. Therefore, most of the subsequent analyses were run considering only the first six factors.

Table XIX presents the complete weights matrix from the orthogonal components analysis. Table XX presents the percents matrix, and Table XXI, the inverse matrix. Table XIV, derived from the percents matrix for the first 6 factors, indicates which of the 20 variables are accounted for by each of the 6 factors. A cell with no entry indicates that factor accounts for less than 10 percent of the variance of that variable; an open circle indicates more than 10 but less than 20 percent of that variable's variance is accounted for by that factor; and a filled circle indicates those variables which are more than 20 percent accounted for by a factor. The signs of five variables are reversed in order that all correlations with factor 1 (U_1) are positive.

A tentative grouping of variables is indicated along the right margin of Table XIV. Group I consists of those weighted positively by U_1 and strongly negatively by U_2. Group II consists of those weighted by U_1 and weighted either weakly or not at all by U_2. Group IV variables weight positively on U_2 but not on U_1; and Groups V and VI each consist of single variables.

Table XV lists the intercorrelations of these 20 variables. The correlations <u>within</u> any group are, with two minor exceptions in Group II, all positive. Group I correlations with Group II tend to be positive; I with III, positive or insignificant; I with IV, negative; and I with V, insignificant. For Group II, generally positive correlations with Group III are observed; II with IV, generally positive; II with V, mixed; II with VI, generally positive. Group III correlations with Group IV, V, and VI tend to be positive. Group IV tends to correlate negatively with V and VI. Group V has a very small correlation with Group VI.

TABLE XIII
PROPORTION OF VARIANCE OF EACH VARIABLE (ROWS) ACCOUNTED FOR BY EACH OF THE FIRST NINE FACTORS (COLUMNS)

FACTOR / VARIABLE	U1	U2	U3	U4	U5	U6	U7	U8	U9	VARIANCE
Z_1	0.1755	0.2124	0.1755	0.2710	0.0560	0.0018	0.0550	0.0059	0.0317	0.9852
Z_2	0.2567	0.0922	0.3974	0.0534	0.1082	0.0000	0.0053	0.0285	0.0231	0.9651
Z_8	0.0176	0.6240	0.0270	0.2583	0.0000	0.0043	0.0030	0.0030	0.0147	0.9521
Z_{10}	0.5285	0.3212	0.9067	0.0016	0.0001	0.0198	0.0805	0.0034	0.0004	0.9625
Z_{11}	0.5392	0.0168	0.0880	0.1027	0.0101	0.0055	0.0035	0.0233	0.1197	0.9092
Z_{13}	0.7747	0.0027	0.0423	0.0044	0.0777	0.0196	0.0347	0.0003	0.0030	0.9599
Z_{15}	0.3038	0.1366	0.2654	0.0013	0.1061	0.0893	0.0050	0.0052	0.0234	0.9366
Z_{18}	0.2928	0.1232	0.2154	0.2265	0.0001	0.0223	0.0190	0.0018	0.0307	0.9322
Z_{19}	0.3224	0.1648	0.2029	0.0052	0.0001	0.0018	0.0235	0.2048	0.0018	0.9277
Z_{20}	0.0565	0.6207	0.1014	0.0271	0.0367	0.0080	0.0388	0.0011	0.0560	0.9467
Z_{22}	0.0179	0.3728	0.2756	0.0667	0.0124	0.1545	0.0277	0.0076	0.0268	0.9624
Z_{24}	0.3998	0.0440	0.0009	0.0957	0.2471	0.0297	0.0799	0.0300	0.0220	0.9495
Z_{29}	0.0117	0.4115	0.1694	0.0595	0.0611	0.0339	0.1263	0.0013	0.0662	0.9412
Z_{30}	0.5546	0.0512	0.0046	0.2328	0.0169	0.0443	0.0175	0.0414	0.0030	0.9666
Z_{32}	0.0394	0.5691	0.0603	0.0213	0.0902	0.0414	0.0274	0.0660	0.0022	0.9177
Z_{33}	0.3913	0.0379	0.2683	0.0646	0.1429	0.0403	0.0156	0.0036	0.0082	0.9730
Z_{34}	0.0293	0.0461	0.1585	0.6416	0.0000	0.0028	0.0379	0.0074	0.0005	0.9245
Z_{35}	0.4021	0.1098	0.0480	0.0103	0.2029	0.0003	0.1018	0.0000	0.0440	0.9195
Z_{36}	0.1305	0.4794	0.0827	0.0020	0.0284	0.0654	0.0289	0.0994	0.0261	0.9431
Z_{41}	0.0794	0.0596	0.0041	0.0346	0.[illegible]482	0.4463	0.0739	0.0060	0.0003	0.9529
VARIANCE	5.3247	4.4969	2.5954	2.1816	1.4459	1.0320	0.8061	0.5410	0.5047	18.9287
PERCENT	26.62	22.48	12.97	10.91	7.23	5.16	4.03	2.70	2.52	94.62

TABLE XIV
RELATIVE AMOUNTS OF VARIANCE ACCOUNTED FOR BY EACH OF SIX FACTORS ($U_1 - U_6$) ACROSS TWENTY VARIABLES.

LEGEND: FILLED CIRCLE INDICATES <20% OF THE VARIANCE
OPEN CIRCLE INDICATES> 10% BUT <20%
NO ENTRY INDICATES <10%

*VARIABLE NO.	FACTORS						
	U1	U2	U3	U4	U5	U6	
1(–)	o	•–	o	•–			I**
36(–)	o	•–					I**
10	•	•–					I**
15(–)	•	o–	•–		o		II
13	•						II
30	•			•			II
11	•			o			II
24	•				•		II
33	•		•		o–		II
2	•		•		o		II
35(–)	•	o			•–		III
19(–)	•	o	•–				III
18	•	o	•–	•–			III
8		•		•			IV
32		•					IV
20		•	o				IV
29		•	o				IV
22		•	•			o–	IV
34			o–	•–			V
41					•–	•–	VI

*SIGNS REVERSED ON FIVE VARIABLES TO MAKE ALL CORRELATIONS WITH U_1 POSITIVE.

**ROMAN NUMERALS REFER TO VARIABLE GROUPINGS DISCUSSED IN SECTION IV

TABLE XV
INTERCORRELATION MATRIX FOR THE 20 VARIABLES USED IN THE ORTHOGONAL COMPONENTS ANALYSIS.

ROMAN NUMERALS REFER TO THE VARIABLE GROUPS FROM TABLE XIV
HEAVY LINES BLOCK OFF INTERCORRELATIONS AMONG VARIABLE GROUPS.

VARIABLE	(–) 1	(–) 36	10	(–) 15	13	30	11	24	33	2	(–) 35	(–) 19	18	8	32	20	29	22	34	41
1 (–)		I																		
36 (–)	0.30																			
10	0.55	0.63																		
15 (–)	–0.25	0.07	0.12																	
13	0.34	0.19	0.65	0.54																
30	0.20	0.35	0.69	0.19	0.60		II													
11	0.02	0.24	0.45	0.61	0.51	0.64														
24	0.10	0.52	0.47	0.41	0.64	0.51	0.40													
33	0.37	0	0.39	–0.05	0.50	0.64	0.41	0.30												
2	0.68	0.17	0.60	–0.04	0.65	0.37	0.08	0.42	0.35											
35 (–)	0.20	–0.05	0.16	0.40	0.35	0.36	0.55	0.17	0.51	–0.07		III								
19 (–)	–0.10	–0.02	0.09	0.65	0.41	0.38	0.48	0.26	0.22	–0.10	0.59									
18	0.05	0.08	0.22	0.58	0.44	0.13	0.38	0.07	0.07	0	0.59	0.59								
8	–0.71	–0.49	–0.57	0.28	–0.16	–0.07	0.26	–0.08	0.14	–0.52	0.12	0.35	0.03							
32	–0.05	–0.46	–0.16	0.16	0.21	–0.02	0.16	–0.26	0.51	–0.07	0.37	0.19	0.34	0.46		IV				
20	0	–0.48	–0.26	0.30	0.29	–0.12	0.16	0.07	0.38	0.20	0.26	0.32	0.29	0.51	0.69					
29	–0.46	–0.51	–0.31	–0.01	0.10	–0.02	–0.08	–0.11	0.24	0.05	–0.11	0	–0.03	0.53	0.49	0.51				
22	0.09	–0.55	–0.30	0.15	0.35	–0.25	–0.11	0.07	0.32	0.25	0.26	0.05	0.10	0.21	0.50	0.67	0.47		V	
34	–0.17	0	0.07	0.30	0.16	–0.31	0.05	–0.20	–0.25	–0.05	0.26	0.25	0.74	–0.17	–0.38	0.18	–0.15	–0.11		VI
41	0.18	0.02	0.34	0.08	0.22	0.28	0.21	0.11	0.25	0.06	0.18	0.04	–0.11	–0.18	–0.06	–0.30	–0.25	–0.02	0.14	

The variables represented in the six groups are

GROUP I	AQE Electronics Scores (-) Convenience of System Controls (-) Taught at Lowry AFB
GROUP II	T.O. Specifies Tolerances for Measurements (-) Number of Steps in Checkout Procedure Number of Special Conditions required for Checkout Completeness of T.O. Checkout and Troubleshooting Information Number of Test Points Percentage of Checkout Procedure using BIT Months of Past Experience
GROUP III	Percentage of Measurements which are Quantitative (versus Go-No Go) (-) Percentage of Test Indications for which T.O. gives Quantitative Information (-) Number of Other Systems or Components required During Checkout
GROUP IV	Components can stand Repeated Adjustment Proportion of Plug-in Circuits (versus Hard Wired) Reliability of AGE Controls are Clearly Identified Taught at Chanute AFB
GROUP V	Percentage of Checkout Steps which are Automatic
GROUP VI	Convenience of Location of Test Points

6. REGRESSIONS OF PERFORMANCE ON FACTORS

Stepwise regressions were run to determine the relationships of the first six factors to performance. The F for inclusion was 3.84, and the F for deletion was 3.00. Because the factors are orthogonal to each other, tolerance level is not meaningful and was set at 0.00 for these runs. The resulting regression equations, multiple correlation coefficients, and standard errors of estimate are:

$$\text{performance time} = 1714.1 + 1018.9\ U_1 - 393.8\ U_2 + 204.1\ U_3 - 550.2\ U_4$$

$$R = 0.924,\ S.E. = 563.6 \text{ seconds}$$

$$\text{T.O. time} = 585.9 + 443.3\ U_1 + 83.4\ U_3 - 243.3\ U_4 + 109.6\ U_5$$

$$R = 0.933,\ S.E. = 221.9 \text{ seconds}$$

$$\text{number of errors} = 6.57 + 4.03\ U_1 - 0.79\ U_2 + 1.00\ U_3 - 1.20\ U_4$$

$$+ 0.92\ U_5 - 1.49\ U_6,\ R = 0.926,\ S.E. = 2.21 \text{ errors.}$$

The smallest of the F ratios derived from analyses of variance testing the significance of the regressions was 22.97, significant at less than the 0.01 level.

SECTION IV

DISCUSSION

1. INTRODUCTION

The primary objective of this study was to determine if and how performance might be predicted from the design characteristics of avionics equipment and from personnel factors such as training and aptitude. The two statistical analyses undertaken to answer this question (regression on the design variables themselves, and on factors made up of the design variables) both result in high multiple correlation coefficients ranging from 0.879 for training equipment cost on design variables to 0.974 for errors on design variables.

Statistically, all of the multiple regressions reported are highly significant. In other words, the dependent variables in this study can be predicted surprisingly well from certain combinations and weightings of the independent variables. The high multiple regression coefficients are especially encouraging because none of the data was transformed to maximize correlations. A linear correlation model was used throughout this study.

Ezekiel and Fox (1959, p. 301) point out that "the smaller the number of observations, the larger the number of independent variables considered, and the more complex the curves employed, the greater will be the tendency for the observed standard error of estimate tc understate the true error of estimate in the universe, and for the observed correlation, simple or multiple, to overstate the true correlation in the universe." Complex curves were not fitted in this study, but the number of observations and the number of independent variables are such that some caution must be exercised in interpreting the results, and replication of the findings is most desirable.

2. REGRESSIONS ON THE DESIGN VARIABLES

The regression equations relating performance time and errors to the design variables are:

$$\text{performance time} = 641.97 - 1327.06\, Y_8 + 4.23\, Y_{13} - 330.40\, Y_{29} + 354.38\, Y_{32}$$

$$\text{errors} = 11.27 - 0.67\, Y_3 + 0.36\, Y_{12} + 0.23\, Y_{13} - 0.63\, Y_{18} - 1.48\, Y_{29} - 0.83\, Y_{30}$$

Both time and errors are dependent upon Y_{13} (number of steps in checkout) and Y_{29} (reliability of test equipment). The other variables entering the equation for performance time are Y_8 (taught at Lowry AFB) and Y_{32} (components can stand repeated adjustment). In the equation for errors, in addition to Y_{13} and Y_{29}, variables Y_3 (past experience), Y_{12} (T.O. uses standard symbology), Y_{18} (number of other units required during checkout), and Y_{30} (number of special conditions required during checkout) also enter.

The equations for predicting training time and training equipment cost from the design variables are:

$$\text{training time} = -75.66 - 0.01\ Y_4 + 9.93\ Y_{16} + 7.85\ Y_{18} + 4.97\ Y_{28} \text{ and}$$

$$\text{training equipment cost} = 16.39 + 0.18\ Y_5 - 3.67\ Y_{25} + 28.67\ Y_{34}.$$

Training time is a function of performance time, convenience of test points, number of other units required during checkout, and the clarity with which change data are presented in the T.O. Training equipment cost is a function of T.O. time, the extent to which identical circuits are used, and the use of automatic checkout.

3. REGRESSIONS ON THE FACTORS

In the equations resulting from stepwise regressions of the performance variables on the factors, performance time was found to be a function of factors U_1, U_2, U_3, and U_4; T.O. time, a function of U_1, U_3, U_4, and U_5; and errors a function of all six factors. As a starting point for interpreting these factors, the ways in which they relate to the performance measures can be considered. Factor U_1 enters positively into the equations for performance time, T.O. time, and errors. Factor U_3 also enters positively into all three equations, and U_4 enters negatively into all three. Factor U_2 enters only into performance time and errors, and enters negatively for both. Factor U_5 enters positively into T.O. time and errors, and U_6 enters negatively into the equation for errors. Tables XIV and XV along with the list of variables by group given in the text, provide clues toward naming the factors. It should be emphasized that Table XIV, as well as the discussion which follows here, implies that some variables do not enter into some factors. This is a relative matter, and variables with less than 10 percent of their variance accounted for by a given factor receive no entry in Table XIV and are spoken of below as not present or not significant. In actuality, each factor is a function of all of the 20 variables which were entered into the orthogonal components analysis, with coefficients as listed in the inverse matrix (Table XXI). Equations expressing each factor in terms of the design variables can be written using the Table XXI coefficients.

The first factor (U_1) extracted by the orthogonal components analysis accounts for variance in the Groups I, II, and III variables of Table XIV. It seems reasonable to hypothesize that the variables in Group I are associated primarily because Lowry (fire control systems) is the driving influence. Group II includes Y_{13}, number of checkout steps, as well as several other variables which are either obviously or less plainly related to the steps in the checkout procedure. Group III variables seem to cluster here because they relate to quantitative versus qualitative checkout information. Groups I, II, and III enter into U_1 because of some common quality. Of the 20 variables in this analysis, there is only 1, Y_{13}, which has variance accounted for by only 1 factor. The most appropriate name for this factor, U_1, appears to be "Length of the Checkout Procedure."

The second factor, U_2, is distinguished from U_1 in that Group I variables weight negatively on U_2, Group II variables do not weight on U_2, and Group IV variables do weight on U_2. Group IV is made up of Chanute and four other variables, and some commonality exists in terms of Chanute. In U_2, then, Chanute weights positively, and Lowry weights negatively. It seems reasonable to suggest that factor U_2 represents "Equipment Complexity." Because the factors in the orthogonal components analysis are each completely independent of all others, U_2 is independent of U_1. In extracting U_1, the variance associated with "Length of the Checkout Procedure" was removed from the correlation matrix. Factor U_2, then, would more properly be named "Equipment Complexity, adjusted for length of checkout procedure."

Factor U_3 is more difficult to name. Taking information from Table XIV, and changing signs of variables back to their original state because the usefulness of the changed signs is exhausted after the first two factors are identified, these results are obtained:

U_3 weights positively on, and accounts for more than 20 percent of the variance in:

Y_{15}, T.O. specifies tolerances for measurements:

Y_{19}, T.O. gives quantitative information;

Y_{22}, controls are clearly identified;

Y_{33}, BIT is used; and

Y_2, past experience.

U_3 weights negatively on, and accounts for more than 20 percent of the variance in,

Y_{18}, number of other units required during checkout.

According to the regression equation, as U_3 increases, performance time, T.O. time, and errors increase. Tentatively, U_3 represents "Difficulty of Checkout Steps, adjusted for number of steps and for equipment function." This hypothesis receives some support from the correlations of the variables entering into U_3 with variable Y_{42}, weeks of training, which fell just short of correlating highly enough with errors to be entered into the orthogonal components analysis.

Factor U_4 is related to performance time, T.O. time, and errors. Increases in U_4 lead to improved times and errors, i.e., to shorter times and fewer errors. U_4 is a function of AQE, number of special conditions required during checkout, T.O. provides complete information, Chanute, use of automatic checkout, and checkout depends on other units. It seems likely that U_4 can be named "Nonautomatic Checkout, adjusted for the effects of U_1, U_2, and U_3."

Factor U_5 contributes positively to T.O. time and errors. This factor weights on number of test points, past experience, quantitative measurements from the test equipment, convenience of test point location, T.O. specifies tolerances, and use of BIT. This factor can perhaps be named "Diagnostic Information," as adjusted for factors U_1 through U_4.

Factor U_6 appears only in the equation for errors, and not in the equations for performance and T.O. times. As U_6 increases, number of errors tends to decrease, and U_6 weights on convenience of test points and clearly identified controls. Factor U_6 appears to be a "Clarity of Information" factor.

4. SCALING OF VARIABLES AND DIRECTIONALITY OF EFFECTS

The regression equations given in the preceding sections express the dependent training and performance variables as functions of various independent variables, and of factors which are functions of the independent variables. In some cases, the direction (positively or negatively) in which an independent variable enters into an equation is difficult to interpret adequately. An example of an easily interpretable design variable is Y_{18}, number of other units required for checkout. As Y_{18} increases, the equations predict that task time, T.O. time, errors, and training time will increase. Less easily understandable are, for example, the predicted effects of Y_{17} (as the T.O. is in more logical sequence, training time will increase) or Y_{32} (as components are better able to stand repeated adjustment, T.O. time will increase). An examination of the results indicates a possible relationship between the method of scaling a variable and the ease with which that variable's effects on the criterion measures can be interpreted. Of the 29 design characteristics used in this study, 14 were scaled objectively and 15 were scaled using expert judgments. Only two of the objectively scaled characteristics, Y_{33} and Y_{34}, are difficult to interpret: as use of BIT increases, predicted task time, T.O. time, and errors increase; and as use of automatic checkout increases, T.O. time and errors increase. However, 8 of the 15 characteristics which were scaled subjectively have seemingly paradoxical effects on predicted times or errors. These eight are Y_{17} and Y_{32}, which were mentioned above, and variables Y_{11}, Y_{16}, Y_{22}, Y_{23}, Y_{28}, and Y_{38}.

Subjective scaling was used where no adequate method of objective scaling could be identified. Whether because of the nature of the subjectively scaled characteristics, or because of error or lack of reliability in the subjective scaling itself, these results emphasize the need for additional research directed toward developing methods for objectively quantifying additional design characteristics.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

1. PREDICTION EQUATIONS FOR PERFORMANCE

One of the primary goals of this study was to investigate the relationship between job performance and equipment design characteristics. Two statistical methods were used to relate the design characteristics data to the performance data: first, stepwise multiple regressions of the performance variables on the design characteristics; and second, a factor anlaysis of the design characteristics followed by stepwise regressions of the performance variables on the factors. The smallest of the resulting multiple correlation coefficients was 0.879 for the regression of training equipment cost on the design characteristics, and the largest was 0.974 for number of errors on the design characteristics. These large correlation coefficients signify that the equations are able to account for a very large part of the variance in the set of performance data collected for this study.

Applications of these equations should, for the present, be made cautiously, and particular care should be taken to temper the interpretation of results when any of the input data fall outside the ranges which entered into derivation of the equations. Validation and improvement of the equations is needed before they are implemented in the design of AF avionics equipment.

2. PREDICTION EQUATIONS FOR TRAINING

The second of the primary goals was to investigate the relationship between training and equipment design characteristics. The multiple regression equations for predicting training time and training equipment cost from design characteristics account for 83 percent of the observed variance in training time, and 77 percent of the observed variance in training equipment cost.

The equations for training time and for training equipment cost should be the subject of further controlled studies aimed at validating and improving the present equations. The training times collected in this study were distributed across a wide range. However, the training equipment costs tended to cluster in the low range. Therefore, the equations for costs should be interpreted with care, and are particularly in need of validation across a better distribution of training equipment costs.

3. INDEPENDENT VARIABLES: DESIGN CHARACTERISTICS

In the absence of an adequate taxonomy of avionics design characteristics which affect training, this study began by establishing an extensive listing of characteristics which previous studies and expert opinion suggested were potentially important. The initial listing of 49 design characteristics was reduced to 29 by interviewing instructors and students to determine which of the 49 were believed to be most important in the actual training situation. Of the 29, only 19 appear in one or more of the equations for predicting performance and training. The remaining 10 which did not enter into any of the equations either do not relate to performance and training for the functional checkout tasks, or overlap with the included 19 to such an extent that the 10 contribute no significant additional information. The design characteristics considered in future studies in this area should be tailored to include the 19 significant design variables, and to omit many or all of the 10 nonsignificant variables.

Further research is needed to establish a taxonomy of design characteristics which adequately spans present and future equipment, as well as the complete range of maintenance tasks. The listing established here is based on data collected in the training situation, not on the flight line or in the shop. To the extent that line and shop maintenance requires activities not included in the present study, the list of design characteristics should be expanded. For example, remove and replace activities are specifically excluded in almost all of the training courses; troubleshooting may be to a level not reached by the functional checkout; and adjustment activities are very frequently not practiced in the functional checkout.

4. INDEPENDENT VARIABLES: PERSONNEL CHARACTERISTICS

Four personnel variables were included in the present study: AQE electronics score; past experience; past training; and performance observation week. All four entered into one or more of the prediction equations, and were sufficient for accurately fitting the observed performance data. For the three-level formal school training situation, with the present makeup of student personnel, these personnel variables appear to be quite adequate. For more advanced five- or seven-level courses, for OJT, and for field or shop performance, it is probable that additional personnel variables would be needed to achieve accurate prediction.

5. INDEPENDENT VARIABLES: ENVIRONMENTAL VARIABLES

The three so-called environmental variables included in this study reflect the three training school locations, Chanute, Keesler, or Lowry AFB. The Chanute, Keesler, and Lowry variables may indicate equipment complexity and training differences between training centers rather than physical location. Fire control systems are taught at Lowry, communications systems at Keesler, and navigation and flight control at Chanute. Future research should investigate these possibilities and extend considerations of equipment complexity and its influence on performance beyond the formal training situation to the organizational and intermediate maintenance environments.

6. DEPENDENT VARIABLES: PERFORMANCE

Two time measures, performance time and T.O. time, were included in this study. The correlation of performance time with T.O. time is 0.848, indicating that T.O. time and performance time have 71 percent of variance in common. It would appear to be an unnecessary refinement, in further research in this area, to continue to collect both measures.

7. DESIGN FACTORS

Six factors were isolated by an orthogonal components analysis and assigned names. Each factor is made up of portions of the variances of the 20 design characteristics which correlated significantly with the performance measures. The factors, in order of identification, are:

- Length of Checkout Procedure
- Equipment Complexity
- Difficulty of Checkout Steps
- Nonautomatic Checkout
- Diagnostic Information
- Clarity of Information

Each factor in the list is derived from residual variance with the effects of the preceding factors removed. Also, each factor can be expressed in terms of the original 20 design variables by normalizing each variable to a mean of 0 and a standard deviation of 1, and then assigning coefficients as indicated in the inverse matrix (Table XXI).

Assigning names to factors is partly science, but the remainder is art, wishful thinking, or desperation. The rationale for naming these factors has been described in considerable detail, and the necessary weights and percents matrices are included so that the process can be reconstructed in full. The accuracy and the usefulness of the names should be validated during practical applications of the equations and in research to replicate and extend the present study.

8. RECOMMENDATIONS FOR APPLICATION OF RESULTS TO AIR FORCE SYSTEM DESIGN

The results of this study provide a quantitative means for predicting training time, training equipment cost, and performance time and errors, given certain information about equipment design. The statistical evaluations of the significance of the results certainly indicate sufficient confidence levels that these results offer promise for the future. However, further research and validation are needed before practical applications are warranted. A highly desirable method of validation is to utilize the prediction equations during the design of AF avionics systems. The best available quantitative information on the design should be fed into the prediction equations to derive predicted training times, costs, and performance figures. These predictions should be compared with predictions derived from the methods currently in use, and followed through into operational use of the system to obtain measures of validity. Training and performance are two human resources items that contribute heavily to the life-cycle costs of AF systems. The results of this study strongly suggest a means can be developed for introducing these items into the system design process quantitatively. When developed and implemented, this could lead to increased operational capability at decreased cost.

APPENDIX I

TABLES OF DATA AND RESULTS

TABLE XVI

ALL VARIABLES ACROSS ALL FUNCTIONAL LOOPS

Values or Means, as Appropriate, for all Variables Across all Functional Loops

FUNCTIONAL LOOPS	MEAN AQE SCORE	MEAN MONTHS OF EXPERIENCE	MEAN MONTHS OF PAST TRAINING	MEAN PERFORMANCE TIME, SEC	MEAN T.O. TIME, SEC	MEAN ERRORS	HOURS TRAINING TIME	T.O. CHECKOUT COMPLETE	T.O. USES STANDARD SYMBOLOGY	NO. OF CHECKOUT STEPS
	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y11	Y12	Y13
ASN-48 NAVIGATION	85.0	0	0	2697.0	562.0	8.4	10.0	9.00	9.60	179
ASN-48 PLATFORM	85.0	2.4	0	3135.9	469.6	8.4	28.0	8.90	9.60	152
ARC-51 TRANSMITTER	87.5	2.4	2	345.5	380.1	1.5	28.3	8.33	8.83	49
ARC-51 MAIN RECEIVER	87.5	2.4	2	565.6	34.8	1.4	28.1	8.50	8.83	67
ARC-51 TUNING	87.5	2.4	2	465.4	31.1	0.5	27.5	8.50	8.66	41
ARC-34 TRANSMITTER	90.5	0	0	685.4	47.8	1.6	65.3	7.00	8.58	58
ARC-34 MAIN RECEIVER	90.5	0	0	910.7	79.6	8.1	64.6	7.83	8.91	83
ARC-34 TUNING	90.5	0	0	629.4	45.9	1.3	64.2	8.20	9.20	52
F101 AFCS PITCH	93.5	0	2.7	708.1	338.8	6.7	82.0	9.88	9.70	375
F101 AFCS ROLL	93.5	0	3.6	711.6	356.0	6.0	82.0	9.88	9.70	377
F101 AFCS YAW	93.5	0	3.6	791.9	383.9	7.6	76.0	9.84	9.70	378
F111 AFCS PITCH	90.8	0	0	575.1	381.6	2.4	122.0	9.58	8.02	286
F111 AFCS ROLL	90.8	0	0	421.6	273.6	1.7	118.0	9.45	8.50	253
F111 AFCS YAW	90.8	0	0	302.6	208.5	1.1	77.0	9.76	8.02	225
F111 CADC MACH	90.8	0	0.4	380.9	318.5	2.5	25.0	9.02	8.02	71
F111 CADC ALTITUDE	90.0	0	0.4	353.3	321.7	1.7	28.0	9.00	8.60	64
F111 CADC TAS	90.0	0	0.4	249.5	232.7	1.4	24.0	9.00	8.60	56
APQ-109 TRANSMITTER	85.6	1.7	1.3	3097.0	875.1	12.5	27.0	9.91	9.75	430
APQ-109 EFC	85.6	1.7	1.3	3097.0	875.1	12.5	18.0	9.83	9.16	430
APQ-109 ASE	85.6	1.7	1.3	3097.0	875.1	12.5	2.0	10.00	8.83	430
APQ-109 AIM DOT	85.6	1.7	1.3	3097.0	875.1	12.5	4.0	9.66	9.00	430
APQ-120 TRANSMITTER	85.1	6.5	0.4	2631.5	1208.4	11.1	27.5	9.41	9.58	531
APQ-120 EFC	85.1	6.5	0.4	2631.5	1208.4	11.1	22.5	9.83	9.66	531
APQ-120 CW	86.0	4.7	0.2	4385.2	1515.3	15.7	17.5	9.83	9.66	682
APQ-120 ASE	86.3	4.9	0	4062.9	1492.0	16.8	14.0	8.91	2.83	787
APQ-120 AIM DOT	86.6	6.1	0.2	3328.6	1288.8	12.1	15.0	8.66	8.66	581
ASG-19 TR	90.5	0.6	5.1	1731.9	260.1	2.1	6.0	10.00	9.20	135
ASG-19 EFC	87.5	0.6	6.0	675.6	112.1	0.5	20.0	9.20	9.40	62
ASG-19 ON-T	90.5	1.0	5.0	1909.3	451.6	4.3	46.5	9.60	9.40	191
ASN-91	88.1	1.9	0.8	3748.9	2419.9	11.6	60.5	9.60	9.40	593

TABLE XVI

ALL VARIABLES ACROSS ALL FUNCTIONAL LOOPS (Continued)

Values or Means, as Appropriate, for all Variables Across all Functional Loops

FUNCTIONAL LOOPS	PIECES OF TEST EQUIPMENT	T.O. SPECIFIES TOLERANCES	TEST POINTS ARE CONVENIENT	T.O. SECTIONS ARE LOGICAL	CHECKOUT NOT DEPENDENT ON REMOTE COMPONENTS	QUANTITATIVE T.O. INFORMATION	PLUG-IN CIRCUITS	CONTROLS CLEARLY IDENTIFIED	COMPONENTS ACCESSIBLE
	Y14	Y15	Y16	Y17	Y18	Y19	Y20	Y22	Y23
ASN-48 NAVIGATION	1	59	6.00	9.20	4	14	8.00	8.90	8.00
ASN-48 PLATFORM	1	32	6.10	9.20	3	12	9.87	8.70	8.00
ARC-51 TRANSMITTER	0	100	8.66	8.66	1	50	4.83	9.00	7.16
ARC-51 MAIN RECEIVER	2	100	7.91	9.66	1	100	5.83	9.00	8.08
ARC-51 TUNING	1	100	8.00	9.08	1	100	4.80	9.50	7.66
ARC-34 TRANSMITTER	1	100	8.00	7.41	1	50	5.00	9.00	6.00
ARC-34 MAIN RECEIVER	2	57	7.83	8.16	1	57	3.50	8.50	7.16
ARC-34 TUNING	1	100	9.10	9.20	1	100	4.60	9.40	8.60
F101 AFCS PITCH	3	0	9.66	9.82	3	0	8.12	9.60	6.20
F101 AFCS ROLL	3	0	9.72	9.88	3	0	7.38	8.80	7.02
F101 AFCS YAW	2	0	9.80	9.86	2	0	7.82	9.54	7.96
F111 AFCS PITCH	0	59	9.92	9.16	5	0	7.98	9.22	9.96
F111 AFCS ROLL	0	61	9.93	9.18	4	0	9.95	9.20	9.95
F111 AGCS YAW	0	63	9.92	9.16	2	0	9.98	9.16	9.98
F111 CADC MACH	1	83	7.96	8.60	1	63	10.00	9.00	9.34
F111 CADC ALTITUDE	1	75	7.98	8.20	1	57	10.00	9.00	9.38
F111 CADC TAS	1	79	7.14	7.20	1	54	10.00	9.02	9.36
APQ-109 TRANSMITTER	0	55	9.91	8.08	2	29	3.58	9.13	6.38
APQ-109 EFC	0	55	9.91	8.25	2	29	6.50	9.50	7.66
APQ-109 ASE	0	55	6.00	9.00	3	29	6.16	8.16	4.50
APQ-109 AIM DOT	0	55	5.83	6.75	3	29	4.83	8.50	5.66
APQ-120 TRANSMITTER	2	67	9.50	8.66	2	37	9.25	9.16	8.16
APQ-EFC	0	67	8.66	6.00	2	36	9.16	9.83	6.16
APQ-120 CW	2	28	9.58	9.66	2	40	[illegible]	9.75	9.00
APQ-120 ASE	3	64	9.83	7.83	2	38	6.00	9.50	9.58
APQ-120 AIM DOT	3	68	8.25	7.75	3	36	10.00	9.50	9.66
ASG-19 TR	3	61	4.20	9.80	2	95	1.00	5.00	2.80
ASG-19 EFC	2	89	4.40	10.00	2	0	0	4.40	2.60
ASG-19 ON-T	2	55	8.80	9.09	2	33	3.60	5.20	6.00
ASN-91	1	0	10.00	9.87	9	0	9.5	[illegible]	8.50

TABLE XVI
ALL VARIABLES ACROSS ALL FUNCTIONAL LOOPS (Continued)
Values or Means, as Appropriate, for all Variables Across all Functional Loops

FUNCTIONAL LOOPS	NO. OF TEST POINTS	IDENTICAL CIRCUITS	CONNECTORS CANNOT BE INCORRECTLY CONNECTED	NUMBER OF ADJUSTMENTS REQUIRED	T.O. CHANGE DATA CLEAR AND CONCISE	AGE IS VERY RELIABLE	CHECKOUT REQUIRES SPECIAL CONDITIONS	TEST EQUIPMENT OPERATION IS COMPLEX
	Y24	Y25	Y26	Y27	Y28	Y29	Y30	Y31
ASN-48 NAVIGATION	0	63	0.0	0	8.50	5.50	0	9.90
ASN-48 PLATFORM	0	18	0.0	3	8.50	5.40	0	9.80
ARC-51 TRANSMITTER	0	0	3.16	0	7.50	8.16	0	7.16
ARC-51 MAIN RECEIVER	0	0	2.00	0	7.33	7.40	0	6.00
ARC-51 TUNNING	0	0	1.00	0	7.41	7.80	0	6.83
ARC-34 TRANSMITTER	2	0	4.66	0	7.33	8.91	0	8.16
ARC-34 MAIN RECEIVER	1	0	1.66	1	8.33	8.33	0	8.83
ARC-34 TUNING	1	0	2.00	0	8.20	9.10	0	6.40
F101 AFCS PITCH	32	23	4.60	11	9.88	8.62	1	5.04
F101 AFCS ROLL	21	15	4.24	6	9.68	8.05	1	6.20
F101 AFCS YAW	15	20	4.22	7	9.82	8.82	1	5.62
F111 AFCS PITCH	0	0	4.00	0	9.56	9.80	2	5.60
F111 AFCS ROLL	0	0	4.95	0	9.20	10.00	2	7.25
F111 AFCS YAW	0	86	4.00	0	9.56	10.00	2	7.40
F111 CADC MACH	0	0	1.00	0	7.22	8.98	0	8.76
F111 CADC ALTITUDE	0	0	1.04	0	7.20	9.00	0	8.80
F111 CADC TAS	0	0	1.00	0	7.20	9.02	0	8.76
APQ-109 TRANSMITTER	6	0	7.16	1	7.08	6.25	2	5.50
APQ-109 EFC	5	0	6.83	6	5.50	7.16	2	5.66
APQ-109 ASE	31	24	4.66	1	8.50	7.00	2	6.50
APQ-109 AIM POINT	32	46	2.83	10	8.66	5.16	2	8.00
APQ-120 TRANSMITTER	13	0	7.58	5	9.41	9.08	2	8.25
APQ-120 EFC	26	0	2.33	7	9.58	9.25	2	8.16
APQ-120 CW	16	0	4.00	0	9.75	9.58	2	6.83
APQ-120 ASE	19	60	1.61	0	5.25	8.25	2	8.16
APQ-120 AIM DOT	29	43	1.75	4	5.00	8.33	2	8.83
ASG-19 TR	0	0	9.20	0	10.00	7.00	2	4.20
ASG-19 EFC	1	0	7.60	4	9.80	6.00	2	6.80
ASG-19 ON-T	20	0	7.80	11	9.80	6.60	2	4.40
ASN-91	0	0	3.30	0	8.80	8.60	0	9.60

TABLE XVI

ALL VARIABLES ACROSS ALL FUNCTIONAL LOOPS (Continued)

Values or Means, as Appropriate, for all Variables Across all Functional Loops

FUNCTIONAL LOOPS	COMPONENTS CAN STAND REPEATED ADJUSTMENTS	BIT IS USED	AUTOMATIC CHECKOUT	TEST EQUIPMENT GIVES QUANTITATIVE READINGS	SYSTEM CONTROLS CONVENIENT TO TEST EQUIPMENT CONTROLS	CHECKOUT DOWN TO LOWEST LRU	UNITS EASILY REMOV-ABLE	TEST POINT ARRANGEMENT FOLLOWS T.O. SEQUENCE
	Y32	Y33	Y34	Y35	Y36	Y37	Y38	Y39
ASN–48 NAVIGATION	8.60	0	25	38	8.40	100	5.80	9.50
ASN–48 PLATFORM	8.40	0	0	28	8.40	100	5.80	9.40
ARC–51 TRANSMITTER	6.83	0	0	100	9.00	100	9.16	7.66
ARC–51 MAIN RECEIVER	7.00	0	0	100	8.66	100	9.00	8.25
ARC–51 TUNING	6.41	0	0	100	8.83	100	8.00	7.83
ARC–34 TRANSMITTER	7.83	0	0	100	8.16	100	8.00	6.50
ARC–34 MAIN RECEIVER	7.66	0	0	100	7.50	100	8.33	6.33
ARC–34 TUNING	8.20	0	0	100	8.40	100	9.40	8.20
F101 AFCS PITCH	6.64	0	0	50	7.60	62	6.64	6.78
F101 AFCS ROLL	7.78	0	0	50	8.62	62	7.02	8.76
F101 AFCS YAW	8.18	0	0	80	8.80	62	6.84	9.88
F111 AFCS PITCH	10.00	100	0	0	10.00	100	9.96	8.96
F111 AFCS ROLL	10.00	100	0	0	9.73	100	9.95	9.13
F111 AFCS YAW	10.00	100	0	0	9.98	100	9.96	8.96
F111 CADC MACH	10.00	43	0	100	9.20	100	9.36	9.58
F111 CADC ALTITUDE	9.34	67	0	100	9.18	100	9.54	9.56
F111 CADC TAS	10.00	64	0	100	8.98	100	9.56	9.54
APQ–109 TRANSMITTER	8.50	100	0	0	9.08	100	5.08	8.91
APQ–109 EFC	8.33	100	0	0	8.58	100	5.41	8.91
APQ–109 ASE	7.50	100	0	0	3.00	100	4.50	5.33
APQ–109 AIM DOT	8.16	100	0	0	4.00	100	5.50	5.66
APQ–120 TRANSMITTER	8.16	78	0	100	8.16	100	8.66	9.33
APQ–120 EFC	8.33	100	0	0	6.83	100	8.33	9.66
APQ–120 CW	8.83	78	0	92	7.16	100	9.16	9.58
APQ–120 ASE	8.58	68	0	100	8.08	100	9.83	6.00
APQ–120 AIM DOT	8.33	91	0	100	7.58	100	9.83	5.66
ASG–19 TR	8.00	0	0	100	5.20	100	3.00	3.00
ASG–19 EFC	5.20	0	0	100	4.60	100	2.80	6.00
ASG–19 ON-T	6.20	0	0	100	6.80	100	6.60	5.60
ASN–19	10.00	0	33	0	7.50	100	9.00	10.00

TABLE XVI

ALL VARIABLES ACROSS ALL FUNCTIONAL LOOPS (Concluded)

Values or Means, as Appropriate, for all Variables Across all Functional Loops

FUNCTIONAL LOOPS	ALTERNATE FOR Y31	ALTERNATE FOR Y16	PERFORMANCE OBSERVATION WEEK	EQUIP-MENT COST, $
	Y40	Y41	Y42	Y43
ASN–48 NAVIGATION	58	0	34	106.00
ASN–48 PLATFORM	58	0	34	106.00
ARC–51 TRANSMITTER	0	0	29	106.00
ARC–51 MAIN RECEIVER	28	0	29	106.00
ARC–51 TUNING	23	0	29	106.00
ARC–34 TRANSMITTER	3	100	20	27.00
ARC–34 MAIN RECEIVER	28	100	20	27.00
ARC–34 TUNING	23	100	20	27.00
F101 AFCS PITCH	123	100	8	16.00
F101 AFCS ROLL	123	100	9	16.00
F101 AFCS YAW	115	100	9	16.00
F111 AFCS PITCH	0	0	16	120.00
F111 AFCS ROLL	0	0	16	120.00
F111 AFCS YAW	0	0	16	115.00
F111 CADC MACH	24	0	14	47.00
F111 CADC ALTITUDE	24	0	14	48.00
F111 CADC TAS	24	0	14	47.00
APQ–109 TRANSMITTER	0	100	17	95.00
APQ–109 EFC	0	100	17	154.00
APQ–109 ASE	0	100	17	12.00
APQ–109 AIM DOT	0	100	17	12.00
APQ–120 TRANSMITTER	44	100	17	115.00
APQ–120 EFC	0	100	17	115.00
APQ–120 CW	7	100	15	94.00
APQ–120 ASE	88	100	13	75.00
APQ–120 AIM DOT	88	100	13	75.00
ASG–19 TR	92	100	4	53.00
ASG–19 EFC	66	100	4	53.00
ASG–19 ON-T	66	100	10	66.00
ASN–91	35	0	4	1761.00

TABLE XVII
LIST OF PERFORMANCE EXAMINATIONS, LINE REPLACEABLE UNITS, AND TEST EQUIPMENT FOR THE FUNCTIONAL LOOPS

SUBSYSTEM LOOPS	PERFORMANCE EXAMINATIONS	LINE REPLACEABLE UNITS	TEST EQUIPMENT
		APQ-120	
TRANSMITTER	BIT	RADAR TRANSMITTER POWER SUPPLY CONTROL MONITOR RADAR SET CONTROL ANTENNA ELECTRICAL SYNCHRONIZER CONTROL OSCILLATOR WAVEGUIDE ASSEMBLY	RADAR TEST SET AN/APM-283A OSCILLOSCOPE AN/USM-140C
ELECTRICAL FREQUENCY CONTROL	BIT	RADAR TRANSMITTER CONTROL MONITOR RADAR SET CONTROL CONTROL OSCILLATOR RADIO FREQUENCY OSCILLATOR WAVEGUIDE ASSEMBLY	NONE
ASE	BIT ASE (RTS) ASE (CTS)	TARGET INTERCEPT COMPUTER INTRA TARGET DATA INDICATOR (FWD) INTRA TARGET DATA INDICATOR (AFT) CONTROL INDICATOR	RADAR TEST SET AN/APM-283A COMPUTER TEST SET AN/APM-282 ELECTRONIC VOLTMETER AN/ASM-340 AN/ASM-340
AIM DOT	BIT AIM DOT	TARGET INTERCEPT COMPUTER ANTENNA ANTENNA CONTROL CONTROL INDICATOR RADAR SET CONTROL INTRA TARGET DATA INDICATOR (FWD) INTRA TARGET DATA INDICATOR (AFT)	RADAR TEST SET AN/APM-283A ELECTRONIC VOLTMETER AN/ASM-340 OSCILLOSCOPE AN/USM-140C
CW ILLUMINATOR	CW MODULATION AND NOISE PSEUDO SIGNAL GENERATION PSEUDO SIGNAL DISTRIBUTION BIT	TARGET INTERCEPT COMPUTER RADIO FREQUENCY AMPLIFIER MODULATOR – OSCILLATOR RADAR TRANSMITTER CONTROL MONITOR RADAR SET CONTROL CONTROL OSCILLATOR WAVEGUIDE ASSEMBLY	RADAR MODULATION TEST SET AN/APM-84B RF POWER TEST SET TS-2059/AWM-18
		APQ-109	
TRANSMITTER	BIT MAGNETRON CURRENT	CONTROL POWER SUPPLY RADAR SET CONTROL AUXILIARY RADAR SET CONTROL RADAR RECEIVER TRANSMITTER MODULATOR VOLTAGE MONITOR ELECTRICAL SYNCHRONIZER ANTENNA	NONE
ELECTRICAL FREQUENCY CONTROL	BIT	RADAR SET CONTROL RADAR RECEIVER TRANSMITTER VOLTAGE MONITOR ELECTRICAL FREQUENCY CONTROL	NONE
ASE	BIT	INDICATOR CONTROL UNIT AZ-EL-RANGE INDICATOR (FWD) AZ-EL-RANGE INDICATOR (AFT) RADAR SET CONTROL TARGET INTERCEPT COMPUTER ELECTRICAL SYNCHRONIZER	NONE
AIM DOT	BIT	AZ-EL-RANGE INDICATOR (FWD) ANTENNA ELECTRICAL SYNCHRONIZER RADAR SET CONTROL CONTROL POWER SUPPLY RADAR MODULATOR (CW) TARGET INTERCEPT COMPUTER INDICATOR CONTROL AZ-EL-RANGE INDICATOR (AFT)	NONE

TABLE XVII

LIST OF PERFORMANCE EXAMINATIONS, LINE REPLACEABLE UNITS, AND TEST EQUIPMENT FOR THE FUNCTIONAL LOOPS (Continued)

SUBSYSTEM LOOPS	PERFORMANCE EXAMINATIONS	LINE REPLACEABLE UNITS	TEST EQUIPMENT
		F111 CADC	
TRUE AIRSPEED	FUNCTIONAL CHECK	TOTAL TEMPERATURE PROBE TRUE AIRSPEED INDICATOR AIR DATA COMPUTER	PNEUMATIC TEST SET TTU-205
MACH	FUNCTIONAL CHECK	MAXIMUM SAFE MACH ASSEMBLY AIRSPEED MACH INDICATOR AMI AMPLIFIER AIR DATA COMPUTER	PNEUMATIC TEST SET TTU-205
ALTITUDE	FUNCTIONAL CHECK	AIR DATA COMPUTER ALTITUDE VERTICAL VELOCITY INDICATOR AVVI AMPLIFIER	PNEUMATIC TEST SET TTU-205
		F111 AFCS	
PITCH	FUNCTIONAL CHECK	PITCH FLIGHT CONTROL COMPUTER YAW FLIGHT CONTROL COMPUTER FEEL AND TRIM ASSEMBLY AUTOPILOT DAMPER PANEL CONTROL STICKS AUXILIARY FLIGHT CONTROL PANEL GROUND CHECK PANEL	NONE
ROLL	FUNCTIONAL CHECK	ROLL FLIGHT CONTROL COMPUTER YAW FLIGHT CONTROL COMPUTER FEEL AND TRIM ASSEMBLY AUTOPILOT DAMPER PANEL CONTROL STICKS GROUND CHECK PANEL	NONE
YAW STABILITY AUGMENTATION	FUNCTIONAL CHECK	YAW FLIGHT CONTROL COMPUTER FEEL AND TRIM ASSEMBLY LATERAL ACCELEROMETER ASSEMBLY YAW RATE GYRO ASSEMBLY ROLL RATE GYRO ASSEMBLY ANGLE OF SIDESLIP TRANSMITTER ANGLE OF ATTACK TRANSMITTER AUTOPILOT DAMPER PANEL CENTER AUXILIARY FLIGHT CONTROL PANEL AUXILIARY FLIGHT CONTROL TEST PANEL	NONE
		F101 AFCS	
PITCH ATTITUDE HOLD	FUNCTIONAL CHECK	AFCS CALIBRATOR VERTICAL GYRO CONTROL STICK FORCE TRANSDUCER FUNCTIONAL SELECTOR PANEL MACH AND QC TRANSDUCER STABILATOR SERVOS STABILATOR POSITION TRANSMITTER	TEST SET UG637A7 POSITION POTENTIOMETER TESTER UG360A-2 AN/PSM-6 METER
ROLL ATTITUDE HOLD	FUNCTIONAL CHECK	AFCS CALIBRATOR VERTICAL GYRO CONTROL STICK FUNCTION SELECTOR PANEL MACH AND QC TRANSDUCER AILERON INTEGRATED POWER CYLINDER AILERON POSITION TRANSMITTER	TEST SET UG637A7 POSITION POTENTIOMETER TESTER UG360A-2 AN/PSM-6 METER
YAW STABILITY AUGMENTATION	FUNCTIONAL CHECK	AFCS CALIBRATOR YAW RATE GYRO ROLL RATE GYRO LATERAL ACCELEROMETER MACH AND QC TRANSDUCER RUDDER INTEGRATED POWER CYLINDER	TEST SET UG537A7 AN/PSM-6 METER

TABLE XVII
LIST OF PERFORMANCE EXAMINATIONS, LINE REPLACEABLE UNITS, AND TEST EQUIPMENT FOR THE FUNCTIONAL LOOPS (Continued)

SUBSYSTEM LOOPS	PERFORMANCE EXAMINATIONS	LINE REPLACEABLE UNITS	TEST EQUIPMENT
		ASG-19	
TRANSMITTER	MINIMUM PERFORMANCE CHECK TRANSMITTER SYSTEM CHECK	RADAR ANTENNA RADAR TRANSMITTER RADAR CALIBRATION CONTROL WAVEGUIDE COUPLING AUTOMATIC ELECTRICAL FREQUENCY CONTROL	RADAR ANALYZER OSCILLOSCOPE AN/USM-140C RADAR TEST SET UPM-108
AUTOMATIC ELECTRICAL FREQUENCY CONTROL	AEFC FUNCTIONAL CHECK	RADAR ANTENNA AUTOMATIC ELECTRICAL FREQUENCY CONTROL POST I-F AMPLIFIER RADAR TRANSMITTER WAVEGUIDE COUPLING	RADAR ANALYZER OSCILLOSCOPE AN/USM-140C
ON-TARGET STEERING	MINIMUM PERFORMANCE CHECK STEERING DOT ZERO STEERING DOT SCALE FACTOR	DIRECT RADAR FLIGHT INDICATOR RADAR ANTENNA ELECTRICAL SYNCHRONIZER	RADAR ANALYZER OSCILLOSCOPE AN/USM-140C
		ASN-91	
ENTIRE SYSTEM	TACTICAL COMPUTER MEMORY LOADING AND VERIFICATION TEST SELF-TEST INSTALLATION AND COMPUTER LOADING OF OPERATIONAL TEST PROGRAM TAPE OPERATIONAL TEST PROGRAM TESTS INSTALLATION AND COMPUTER LOADING OF OPERATIONAL FLIGHT PROGRAM OPERATIONAL CHECK	TACTICAL COMPUTER TACTICAL COMPUTER CONTROL PANEL	COMPUTER MEMORY LOADER VERIFIER AN/ASM-395
		ASN-48	
NAVIGATION	SYSTEM TEST PREPARATION PROCEDURE PROGRAMMED TEST PROCEDURE SCHULER (VELOCITY) TEST PROCEDURE	COMPUTER OUTPUT SIGNAL DISTRIBUTION UNIT NAVIGATION SET CONTROL INERTIAL PLATFORM	INS TEST SET AN/ASM-188
PLATFORM ALIGNMENT	SYSTEM TEST PREPARATION PROCEDURE REPEATABILITY TEST PROCEDURE ATTITUDE ALIGNMENT TEST PROCEDURE	COMPUTER OUTPUT SIGNAL DISTRIBUTION UNIT NAVIGATION SET CONTROL INERTIAL PLATFORM	INS TEST SET AN/ASM-188
		ARC-34	
TRANSMITTER	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL ANTENNA UHF ANTENNA RELAY	WATTMETER AN/URM-11
MAIN RECEIVER	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL ANTENNA UHF ANTENNA RELAY	SIGNAL GENERATOR AN/USM-44 OUTPUT METER TS-585
TUNING	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL	SIGNAL GENERATOR AN/USM-44
		ARC-51	
TRANSMITTER	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL ANTENNA	NONE
MAIN RECEIVER	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL ANTENNA	SIGNAL GENERATOR AN/USM-44 OUTPUT METER TS-585
TUNING	FUNCTIONAL CHECK	RECEIVER-TRANSMITTER CONTROL PANEL	SIGNAL GENERATOR AN/USM-44

TABLE XVIII

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	1.000	−0.677	0.322	−0.707	−0.489	−0.561	0.719	0.713	−0.112	−0.559	−0.023	0.121	−0.346	0.303	−0.258	0.256	0.367	−0.054	−0.097	0.005	0.0	−0.034	0.070	−0.104	−0.115	0.109
2		1.000	−0.232	0.660	0.639	0.626	−0.472	−0.523	−0.128	0.597	0.088	−0.348	0.654	0.152	0.045	0.142	−0.330	0.001	0.099	0.199	0.0	0.252	0.100	0.419	0.047	−0.021
3			1.000	−0.206	−0.255	−0.243	−0.064	−0.018	−0.221	0.213	0.334	0.295	−0.170	0.433	−0.186	−0.309	0.459	−0.082	−0.051	−0.610	0.0	−0.732	−0.712	0.169	−0.199	0.595
4				1.000	0.848	0.911	−0.510	−0.592	−0.240	0.762	0.325	−0.211	0.786	0.060	−0.344	0.010	−0.186	0.385	−0.185	0.083	0.0	0.120	−0.043	0.438	0.235	0.077
5					1.000	0.815	−0.264	−0.318	−0.454	0.699	0.388	−0.242	0.869	0.054	−0.445	0.281	−0.151	0.606	−0.302	0.329	0.0	0.285	0.164	0.395	0.144	0.046
6						1.000	−0.385	−0.407	−0.315	0.657	0.355	−0.221	0.876	0.100	−0.476	0.195	−0.260	0.296	−0.281	0.164	0.0	0.313	0.031	0.598	[illegible]	0.026
7							1.000	0.603	−0.029	−0.532	−0.015	0.134	−0.120	−0.067	−0.287	0.562	0.319	0.295	−0.405	0.214	0.0	0.208	0.338	−0.183	−0.102	0.077
8								1.000	−0.395	−0.572	−0.261	0.042	−0.165	−0.027	−0.284	0.325	0.174	0.032	−0.352	0.506	0.0	0.213	0.419	−0.082	0.078	−0.122
9									1.000	−0.527	−0.773	0.135	−0.562	−0.080	0.435	−0.210	0.048	−0.279	0.462	−0.231	0.0	0.120	0.006	−0.443	−0.083	−0.460
10										1.000	0.449	−0.159	0.654	0.097	−0.125	−0.113	−0.204	0.220	−0.086	−0.262	0.0	−0.304	−0.393	0.471	0.002	0.523
11											1.000	0.249	0.509	−0.048	−0.614	0.127	0.231	0.382	−0.480	0.158	0.0	−0.114	−0.144	0.404	0.136	0.447
12												1.000	−0.333	−0.288	−0.222	−0.114	0.294	0.028	−0.075	−0.156	0.0	−0.170	−0.390	−0.201	−0.442	0.270
13													1.000	0.168	−0.539	0.426	−0.141	0.438	−0.411	0.292	0.0	0.349	0.157	0.638	0.295	0.162
14														1.000	−0.279	−0.072	0.347	−0.097	0.112	−0.158	0.0	−0.266	−0.145	0.260	0.055	0.114
15															1.000	−0.303	−0.358	−0.576	0.652	−0.300	0.0	−0.147	−0.012	−0.409	−0.166	−0.142
16																1.000	0.027	0.167	−0.258	0.433	0.0	0.643	0.632	0.080	−0.031	0.032
17																	1.000	0.281	−0.165	−0.126	0.0	−0.270	−0.085	−0.253	−0.067	0.261
18																		1.000	−0.592	0.288	0.0	0.106	0.112	0.076	0.136	0.043
19																			1.000	−0.323	0.0	−0.054	−0.066	−0.266	−0.346	−0.186
20																				1.000	0.0	0.672	0.751	0.074	0.219	−0.483
21																					0.0	0.0	0.0	0.0	0.0	0.0
22																						1.000	0.711	0.079	0.150	−0.547
23																							1.000	−0.231	0.198	−0.544
24																								1.000	0.299	0.123
25																									1.000	−0.259
26																										1.000

TABLE XVIII

CORRELATION MATRIX (Continued)

VARIABLE NUMBER	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
1	0.100	0.354	0.460	−0.199	−0.375	0.059	−0.368	−0.171	0.205	0.304	−0.619	0.184	−0.030	0.515	−0.181	−0.444	−0.087
2	0.106	−0.219	0.045	0.366	0.211	−0.074	0.353	−0.059	0.071	−0.171	0.266	0.182	0.017	−0.231	0.062	0.107	0.057
3	0.477	0.412	−0.380	0.215	−0.658	−0.684	−0.466	−0.142	0.230	−0.413	−0.430	−0.644	−0.463	0.636	0.076	−0.475	−0.097
4	0.141	−0.189	−0.349	0.414	0.199	0.083	0.336	0.312	−0.295	−0.399	0.243	−0.211	−0.076	−0.169	0.260	−0.025	0.296
5	0.095	−0.120	0.025	0.349	0.285	0.309	0.376	0.486	−0.322	−0.225	0.134	0.095	0.149	−0.165	0.135	−0.291	0.614
6	0.267	−0.202	−0.210	0.416	0.181	0.098	0.401	0.189	−0.313	−0.326	−0.013	−0.124	0.001	−0.116	0.317	−0.084	0.181
7	0.012	0.389	0.559	−0.043	−0.214	0.253	−0.083	−0.019	−0.232	0.509	−0.407	0.384	0.275	0.159	−0.136	−0.180	0.114
8	0.018	0.229	0.528	−0.069	−0.084	0.467	0.142	−0.173	−0.117	0.490	−0.509	0.343	0.393	0.225	−0.183	−0.303	−0.139
9	−0.349	−0.184	−0.204	−0.703	0.247	−0.305	−0.579	0.098	0.298	0.199	0.201	0.078	0.003	−0.070	−0.192	0.792	−0.097
10	0.294	−0.048	−0.306	0.692	−0.143	−0.160	0.385	0.072	−0.158	−0.631	0.291	−0.386	−0.366	−0.146	0.341	−0.426	0.216
11	0.403	0.446	−0.081	0.646	−0.411	0.165	0.415	0.051	−0.552	−0.236	−0.308	−0.346	0.107	0.168	0.211	−0.482	0.120
12	0.198	0.653	−0.175	−0.193	−0.245	−0.173	−0.292	0.133	−0.228	−0.090	−0.210	−0.412	0.307	0.206	0.104	0.075	0.100
13	0.274	−0.064	0.103	0.600	0.027	0.209	0.500	0.158	−0.351	−0.195	−0.140	0.075	0.052	−0.065	0.218	−0.336	0.269
14	0.215	0.048	−0.018	0.007	−0.153	−0.350	−0.469	−0.066	0.621	−0.137	−0.439	−0.078	−0.377	0.736	−0.098	−0.383	−0.106
15	−0.441	−0.417	0.014	−0.192	0.110	−0.161	0.046	−0.304	0.404	0.071	0.668	0.184	−0.191	−0.532	−0.076	0.419	−0.341
16	0.059	−0.089	0.631	0.108	−0.144	0.340	0.254	−0.001	−0.195	0.636	−0.287	0.618	0.510	−0.138	0.152	−0.115	0.225
17	−0.110	0.453	−0.023	−0.085	−0.384	−0.196	−0.498	0.223	0.092	0.061	−0.373	−0.205	0.034	0.522	−0.187	−0.161	0.211
18	0.034	0.245	−0.030	0.130	0.177	0.344	0.067	0.740	−0.594	−0.081	−0.062	−0.010	0.174	0.071	−0.110	−0.256	0.773
19	−0.365	−0.349	0.008	−0.376	−0.082	−0.187	−0.229	−0.254	0.592	−0.020	0.384	0.123	−0.255	−0.196	−0.038	0.296	−0.218
20	−0.069	−0.082	0.506	−0.122	0.504	0.699	0.382	0.188	−0.266	0.482	−0.108	0.617	0.684	−0.097	−0.3[illegible]	0.104	0.198
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	−0.178	−0.357	0.474	−0.247	0.358	0.499	0.324	0.111	−0.261	0.546	−0.144	0.633	0.624	−0.315	0.016	0.350	0.143
23	−0.351	−0.354	0.572	−0.210	0.395	0.697	0.317	0.099	−0.037	0.773	0.087	0.855	0.640	−0.322	−0.192	0.243	0.130
24	0.697	0.083	−0.114	0.510	−0.177	−0.257	0.296	−0.206	−0.170	−0.525	−0.394	−0.164	−0.329	0.208	0.119	−0.298	−0.202
25	0.070	−0.102	−0.150	0.213	0.250	0.164	0.211	0.161	−0.251	−0.040	−0.088	0.030	−0.122	0.007	−0.117	0.107	−0.118
26	0.313	0.373	−0.093	0.645	−0.687	−0.300	0.090	−0.194	−0.087	−0.310	−0.091	−0.507	−0.368	0.197	0.368	−0.550	−0.018
27	1.000	0.297	−0.283	0.369	−0.314	−0.421	−0.011	−0.190	−0.152	−0.337	−0.507	−0.357	−0.180	0.452	0.059	−0.305	−0.165
28		1.000	0.072	0.204	−0.317	−0.119	−0.210	0.066	−0.196	−0.232	−0.348	−0.267	0.040	0.405	−0.140	−0.285	0.057
29			1.000	−0.022	0.028	0.488	0.240	−0.149	0.110	0.511	−0.111	0.778	0.375	−0.163	−0.254	−0.243	0.084
30				1.000	−0.435	−0.025	0.641	−0.308	−0.363	−0.359	0.035	−0.261	−0.308	−0.112	0.287	−0.456	−0.194
31					1.000	0.407	0.061	0.421	0.002	0.127	0.348	0.361	0.351	−0.262	−0.282	0.345	0.279
32						1.000	0.508	0.252	−0.373	0.464	0.191	0.529	0.539	−0.367	−0.056	−0.061	0.293
33							1.000	−0.254	−0.513	−0.000	0.320	0.212	0.154	−0.627	0.245	−0.096	−0.139
34								1.000	−0.267	0.003	0.088	−0.006	0.273	0.068	−0.141	0.013	0.796
35									1.000	0.045	0.009	0.169	−0.266	0.302	−0.190	−0.018	−0.296
36										1.000	−0.094	0.650	0.665	−0.098	−0.016	0.295	0.020
37											1.000	0.133	−0.098	−0.761	−0.013	0.333	0.119
38												1.000	0.455	−0.366	−0.315	0.151	0.140
39													1.000	−0.160	−0.029	0.251	0.273
40														1.000	−0.092	−0.357	−0.065
41															1.000	−0.118	−0.102
42																1.000	−0.235
43																	1.000

TABLE XIX

ORTHOGONAL COMPONENTS ANALYSIS WEIGHTS MATRIX

Columns are Factors, Rows are Variables

	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17	U18	U19	U20
Z_1	-0.4189	0.4608	-0.4190	0.5205	0.2367	-0.0434	0.2347	0.0769	-0.1780	-0.0179	-0.0066	0.0578	0.0638	-0.0631	-0.0221	-0.0150	-0.0156	0.0257	0.0271	0.0251
Z_2	0.5067	-0.3037	0.6304	-0.2312	0.3289	0.0015	0.0728	-0.1689	0.1520	-0.0719	0.0280	-0.0626	0.1126	0.0196	0.0737	-0.0447	-0.0581	0.0257	0.0189	0.0064
Z_8	-0.1327	0.7899	-0.1645	0.5082	0.0034	0.0656	-0.0553	0.0551	0.1212	0.0916	0.1292	0.0369	-0.0238	0.1226	0.0057	-0.0534	-0.0163	0.0475	-0.0055	-0.0165
Z_{10}	0.7270	-0.5667	0.0820	-0.0406	-0.0124	0.1407	0.2837	0.0588	0.0213	0.0715	0.0165	-0.0219	-0.0122	-0.0331	-0.1616	-0.0567	0.0050	0.0091	0.0276	-0.0093
Z_{11}	0.7343	0.1298	-0.2967	0.3205	-0.1009	0.0741	0.0597	0.1527	0.3460	-0.2637	0.1205	-0.0229	-0.0554	0.0198	0.0198	-0.0097	0.0141	-0.0411	0.0108	0.0107
Z_{13}	0.8802	0.0526	0.2057	-0.0670	0.2788	-0.1400	0.1865	-0.0183	-0.0552	0.0206	-0.0943	0.1024	-0.1059	0.0470	0.0108	-0.0429	0.0385	0.0184	-0.0533	0.0127
Z_{15}	-0.5512	-0.3696	0.5152	-0.0371	-0.3257	0.2989	-0.0714	-0.0724	-0.1532	0.0384	0.2172	0.0826	0.0062	0.0126	0.0270	-0.0669	0.0449	-0.0092	0.0073	0.0112
Z_{18}	0.5411	0.3510	-0.4641	-0.4760	0.0120	0.1494	0.1378	-0.0432	-0.1753	-0.0346	0.0304	0.0690	0.1991	0.1406	-0.0142	0.0239	0.0118	-0.0209	0.0029	-0.0012
Z_{19}	-0.5678	-0.4060	0.4504	-0.0721	0.0105	0.0427	0.1535	0.4526	0.0434	-0.2300	-0.0081	0.0999	0.0841	0.0023	-0.0082	0.0312	0.0005	0.0257	-0.0207	-0.0067
Z_{20}	0.2378	0.7878	0.3184	-0.1648	0.1917	0.0895	-0.1971	0.0344	0.2366	0.1301	0.0689	-0.0672	0.1140	-0.0782	-0.0420	0.0451	0.0584	0.0242	-0.0066	0.0066
Z_{22}	0.1338	0.6106	0.5250	-0.2584	0.1114	-0.3930	-0.1665	0.0876	-0.1639	-0.1308	-0.0039	0.0240	-0.1064	0.0649	-0.0205	0.0137	0.0201	0.0036	0.0565	-0.0011
Z_{24}	0.6323	-0.2099	0.0309	0.3093	0.4971	-0.1725	-0.2826	0.1732	-0.1484	0.1029	0.1227	0.1127	0.0592	-0.0766	0.0205	-0.0177	-0.0157	-0.0397	-0.0057	-0.0098
Z_{29}	-0.1084	0.6415	0.4116	0.2439	0.2472	0.1841	0.3554	-0.0371	-0.2574	-0.1054	0.0822	-0.1955	-0.0277	-0.0224	0.0090	0.0101	0.0037	-0.0245	-0.0210	-0.0094
Z_{30}	0.7447	-0.2264	0.0678	0.4825	-0.1301	0.2106	0.1323	-0.2035	-0.0556	-0.0568	-0.0304	0.1140	-0.0041	-0.0536	0.0722	0.0719	0.0331	0.0305	0.0258	-0.0118
Z_{32}	0.1986	0.7541	0.2455	-0.1461	-0.3004	0.2036	0.1657	0.2570	0.0470	0.1813	-0.1900	0.0356	0.0171	-0.0442	0.0767	-0.0520	-0.0049	-0.0264	0.0191	-0.0033
Z_{33}	0.6256	0.1947	0.5182	0.2542	-0.3780	0.2008	-0.1250	0.0600	-0.0907	0.0919	0.0289	0.0298	-0.0377	0.0429	-0.0576	0.0741	-0.0650	-0.0039	-0.0146	0.0133
Z_{34}	0.1712	0.2147	-0.3982	-0.8010	0.0042	0.0535	0.1949	0.0863	-0.0227	0.0510	0.2092	0.0481	-0.1270	-0.0825	0.0402	0.0282	-0.0289	0.0233	-0.0001	-0.0006
Z_{35}	-0.6341	-0.3313	0.2192	0.1014	0.4504	0.0181	0.3190	-0.0089	0.2099	0.2450	0.0280	0.0627	-0.0538	0.0870	0.0061	0.0624	0.0064	-0.0298	0.0183	0.0024
Z_{36}	-0.3613	0.6924	0.2876	-0.0453	-0.1686	-0.2557	0.1700	-0.3153	0.1617	-0.1087	0.0240	0.1837	0.0353	-0.0689	-0.0570	-0.0129	-0.0209	-0.0253	-0.0140	-0.0060
Z_{41}	0.2818	-0.2442	0.0644	0.1861	-0.4982	-0.6681	0.2719	0.0778	-0.0156	0.1424	0.1055	-0.0853	0.0823	0.0083	0.0341	0.0123	0.0130	0.0051	-0.0044	0.0007

TABLE XX

PERCENTS MATRIX. ENTRIES REPRESENT THE PROPORTION OF VARIANCE OF EACH VARIABLE (ROWS) ACCOUNTED FOR BY EACH FACTOR (COLUMNS).

VARIABLES \ FACTORS	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17	U18	U19	U20
Z_1	0.1755	0.2124	0.1755	0.2710	0.0560	0.0018	0.0550	0.0059	0.0317	0.0003	0.0000	0.0033	0.0040	0.0039	0.0004	0.0002	0.0002	0.0006	0.0007	0.0006
Z_2	0.2567	0.0922	0.3974	0.0534	0.1082	0.0000	0.0053	0.0285	0.0231	0.0051	0.0007	0.0039	0.0126	0.0003	0.0054	0.0020	0.0033	0.0006	0.0003	0.0000
Z_8	0.0176	0.6240	0.0270	0.2583	0.0000	0.0043	0.0030	0.0030	0.0147	0.0084	0.0167	0.0013	0.0005	0.0150	0.0000	0.0028	0.0002	0.0022	0.0000	0.0002
Z_{10}	0.5285	0.3212	0.0067	0.0016	0.0001	0.0198	0.0805	0.0034	0.0004	0.0051	0.0002	0.0004	0.0001	0.0011	0.0261	0.0032	0.0000	0.0000	0.0007	0.0000
Z_{11}	0.5392	0.0168	0.0880	0.1027	0.0101	0.0655	0.0035	0.0233	0.1197	0.0695	0.0145	0.0005	0.0030	0.0003	0.0003	0.0000	0.0002	0.0016	0.0001	0.0001
Z_{13}	0.7747	0.0027	0.0423	0.0044	0.0777	0.0196	0.0347	0.0003	0.0030	0.0004	0.0089	0.0104	0.0112	0.0022	0.0001	0.0018	0.0014	0.0003	0.0028	0.0001
Z_{15}	0.3038	0.1366	0.2654	0.0013	0.1061	0.0893	0.0050	0.0052	0.0234	0.0014	0.0473	0.0068	0.0000	0.0001	0.0007	0.0044	0.0020	0.0000	0.0000	0.0001
Z_{18}	0.2928	0.1232	0.2154	0.2265	0.0001	0.0223	0.0190	0.0018	0.0307	0.0011	0.0009	0.0047	0.0396	0.0197	0.0002	0.0005	0.0001	0.0004	0.0000	0.0000
Z_{19}	0.3224	0.1648	0.2029	0.0052	0.0001	0.0018	0.0235	0.2048	0.0018	0.0529	0.0000	0.0099	0.0070	0.0000	0.0000	0.0009	0.0000	0.0006	0.0004	0.0000
Z_{20}	0.0565	0.6207	0.1014	0.0271	0.0367	0.0080	0.0388	0.0011	0.0560	0.0169	0.0047	0.0045	0.0130	0.0061	0.0017	0.0020	0.0034	0.0005	0.0000	0.0000
Z_{22}	0.0179	0.3728	0.2756	0.0667	0.0124	0.1545	0.0277	0.0076	0.0268	0.0171	0.0000	0.0005	0.0113	0.0012	0.0004	0.0001	0.0004	0.0000	0.0032	0.0000
Z_{24}	0.3998	0.0440	0.0009	0.0957	0.2471	0.0297	0.0799	0.0300	0.0220	0.0105	0.0150	0.0127	0.0035	0.0058	0.0004	0.0003	0.0002	0.0015	0.0000	0.0000
Z_{29}	0.0117	0.4115	0.1694	0.0595	0.0611	0.0339	0.1263	0.0013	0.0662	0.0111	0.0067	0.0382	0.0007	0.0005	0.0000	0.0001	0.0000	0.0006	0.0004	0.0000
Z_{30}	0.5546	0.0512	0.0046	0.2328	0.0169	0.0443	0.0175	0.0414	0.0030	0.0032	0.0009	0.0130	0.0000	0.0028	0.0052	0.0051	0.0011	0.0009	0.0006	0.0001
Z_{32}	0.0394	0.5691	0.0603	0.0213	0.0902	0.0414	0.0274	0.0660	0.0022	0.0329	0.0361	0.0012	0.0002	0.0019	0.0058	0.0077	0.0000	0.0006	0.0003	0.0000
Z_{33}	0.3913	0.0379	0.2683	0.0646	0.1429	0.0403	0.0156	0.0036	0.0082	0.0084	0.0098	0.0008	0.0014	0.0018	0.0033	0.0055	0.0042	0.0000	0.0002	0.0001
Z_{34}	0.0293	0.0461	0.1585	0.6416	0.0000	0.0028	0.0379	0.0074	0.0005	0.0026	0.0437	0.0023	0.0161	0.0068	0.0016	0.0007	0.0008	0.0005	0.0000	0.0000
Z_{35}	0.4021	0.1098	0.0480	0.0103	0.2029	0.0003	0.1018	0.0000	0.0440	0.0600	0.0007	0.0039	0.0028	0.0075	0.0000	0.0038	0.0000	0.0008	0.0003	0.0000
Z_{36}	0.1305	0.4794	0.0827	0.0020	0.0284	0.0654	0.0289	0.0994	0.0261	0.0118	0.0005	0.0337	0.0012	0.0047	0.0032	0.0001	0.0004	0.0006	0.0001	0.0000
Z_{41}	0.0794	0.0596	0.0041	0.0346	0.2482	0.4463	0.0739	0.0060	0.0003	0.0203	0.0111	0.0072	0.0067	0.0000	0.0011	0.0001	0.0001	0.0000	0.0000	0.0000

TABLE XXI
OROTHOGONAL COMPONENTS ANALYSIS, INVERSE MATRIX

	Z_1	Z_2	Z_8	Z_{10}	Z_{11}	Z_{13}	Z_{15}	Z_{18}	Z_{19}	Z_{20}	Z_{22}	Z_{24}	Z_{29}	Z_{30}	Z_{32}	Z_{33}	Z_{34}	Z_{35}	Z_{36}	Z_{41}
U_1	−0.0786	0.0951	−0.0249	0.1365	0.1379	0.1653	−0.1035	0.1016	−0.1066	0.0446	0.0251	0.1187	−0.0203	0.1398	0.0373	0.1174	0.0321	−0.1190	−0.0678	0.0529
U_2	0.1024	−0.0675	0.1756	−0.1260	0.0288	0.0117	−0.0822	0.0780	−0.0902	0.1751	0.1357	−0.0466	0.1426	−0.0503	0.1677	0.0433	0.0477	−0.0736	0.1539	−0.0543
U_3	−0.1614	0.2429	−0.0633	0.0316	−0.1143	0.0792	0.1985	−0.1788	0.1735	0.1227	0.2022	0.0119	0.1585	0.0261	0.0946	0.1995	−0.1534	0.0844	0.1108	0.0248
U_4	0.2386	−0.1060	0.2329	−0.0186	0.1469	−0.0337	−0.0170	−0.2181	−0.0330	−0.0755	−0.1184	0.1418	0.1118	0.22[illegible]1	−0.0670	0.1165	−0.3671	0.0465	−0.0207	0.0853
U_5	0.1637	0.2275	0.0023	−0.0085	−0.0697	0.1928	−0.2252	0.0083	0.0072	0.1325	0.0770	0.3438	0.1709	−0.0899	−0.2078	−0.2614	0.0029	0.3115	−0.1166	−0.3445
U_6	−0.0420	0.0015	0.0636	0.1364	0.0718	−0.1356	0.2896	0.1447	0.0414	0.0867	−0.3808	−0.1672	0.1784	0.2041	0.1973	0.1946	0.0519	0.0176	−0.2478	−0.6473
U_7	0.2911	0.0903	−0.0686	0.3520	0.0740	0.2313	−0.0885	0.1710	0.1904	−0.2445	−0.2065	−0.3506	0.4409	0.1641	0.2055	−0.1551	0.2417	0.3958	0.2108	0.3373
U_8	0.1422	−0.3122	0.1018	0.1088	0.2823	−0.0339	−0.1338	−0.0798	0.8366	0.0636	0.1620	0.3201	−0.0686	−0.3761	0.4752	0.1109	0.1595	−0.0164	−0.5828	0.1438
U_9	−0.3528	0.3011	0.2402	0.0422	0.6855	−0.1094	−0.3036	−0.3474	0.0860	0.4688	−0.3248	−0.2940	−0.5099	−0.1101	0.0931	−0.1798	−0.0451	0.4158	0.3203	−0.0389
U_{10}	−0.0529	−0.2117	0.2698	0.2104	−0.7762	0.0608	0.1137	−0.1018	−0.6770	0.3830	−0.3851	0.3028	−0.3102	−0.1673	0.5337	0.2706	0.1502	0.7210	−0.3199	0.4193
U_{11}	−0.0314	0.1334	0.6144	0.0788	0.5729	−0.4487	1.0341	0.1449	−0.0388	0.3280	−0.0187	0.5837	0.3909	−0.1446	−0.9034	0.1377	0.9947	0.1333	0.1142	0.5017
U_{12}	0.3610	−0.3908	0.2308	−0.1367	−0.1432	0.6392	0.5157	0.4307	0.6238	−0.4194	0.1503	0.7037	−1.2203	0.7118	0.2224	0.1863	0.3002	0.3914	1.1469	−0.5324
U_{13}	0.4696	0.8281	−0.1756	−0.0900	−0.4076	−0.7791	0.0461	1.4643	0.6186	0.8388	−0.7828	0.4355	−0.2043	−0.0302	0.1263	−0.2775	−0.9343	−0.3956	0.2599	0.6054
U_{14}	−0.7367	0.2993	1.4315	−0.3869	0.2315	0.5492	0.1473	1.6416	0.0268	−0.9131	0.7578	−0.8943	−0.2617	−0.6254	−0.5157	0.5010	−0.9634	1.0160	−0.8040	0.0978
U_{15}	−0.3909	1.2982	0.1019	−2.8465	0.3487	0.1913	0.4762	−0.2517	−0.1448	−0.7400	−0.3611	0.3621	0.1598	1.2720	1.3509	−1.0146	0.7095	0.1081	−1.0041	0.6007
U_{16}	−0.4037	−1.1987	−1.4318	−1.5210	−0.2617	−1.1497	−1.7938	0.6414	0.8364	1.2087	0.3683	−0.4763	0.2708	1.9294	−1.3942	1.9875	0.7576	1.6728	−0.3466	0.3115
U_{17}	−0.8354	−3.1108	−0.8769	0.2704	0.7571	2.0606	2.4032	0.6348	0.0317	3.1279	1.0758	−0.8432	0.2015	1.7749	−0.2641	−3.4782	−1.5493	0.3444	−1.1183	0.6953
U_{18}	1.9190	1.9176	3.5355	0.6809	−3.0642	1.3718	−0.6861	−1.5616	1.9193	1.8022	0.2718	−2.9586	−1.8272	2.2748	−1.9667	−0.2968	1.7387	−2.2231	−1.8845	0.3805
U_{19}	2.4989	1.7394	−0.5135	2.5428	0.9972	−4.9048	0.6787	0.2672	−1.9069	−0.6083	5.2017	−0.5316	−1.9339	2.3790	1.7592	−1.3505	−0.0142	1.6884	−1.2938	−0.4100
U_{20}	11.9925	3.0754	−7.9202	−4.4681	5.1334	6.0862	5.3820	−0.5946	−3.2219	3.1783	−0.5643	−4.7019	−4.5043	−5.6656	−1.5807	6.3754	−0.3149	1.1840	−2.8957	0.3662

EQUATIONS EXPRESSING EACH FACTOR AS A FUNCTION OF THE NORMALIZED VARIABLES CAN BE WRITTEN WITH CELL ENTRIES AS COEFFICIENTS
FOR EXAMPLE. $U_1 = -0.0786Z_1 + 0.0951Z_2 - 0.0249Z_8 + \ldots + 0.0529Z_{41}$.

APPENDIX II

EXPLANATION OF TOLERANCE LEVEL

Before any variable is entered during the stepwise regression procedure a test is made on its resulting F-value, and its "tolerance." The test on the F-value is to insure that the entering variable can account for at least some threshold proportion of the variance of the dependent variable.

The "tolerance," on the other hand, measures the colinearity between the entering variable and those independent variables already in the equation. It is the rule for determining the impact that the entering variable will have on the coefficients of the independent variables already in the equation. It also serves the function of guarding against inverting a singular or near singular cross products matrix. The tolerance is a measure of the proportion of the variance of the entering variable that is not accounted for by the independent variables already in the equation (i.e., a tolerance of 1.0 indicates that the entering variable is orthogonal to the independent variables already in the equation, a tolerance of 0.0 means it is an exact linear function, and in between means there is some correlation).

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TABLE XXII

VARIABLE NUMBER	OESCRIPTION OF VARIABLE
1	AQE ELECTRONICS SCORE
2	PAST EXPERIENCE (MONTHS)
3	PAST TRAINING (MONTHS)
4	PERFORMANCE TIME (SECONOS)
5	T.O. TIME (SECONDS)
6	NUMBER OF ERRORS
7	TRAINING TIME (HOURS)
8	CHANUTE (AT CHANUTE = 1, NOT CHANUTE = 0)
9	KEESLER (AT KEESLER = 1, NOT KEESLER = 0)
10	LOWRY (AT LOWRY = 1; NOT LOWRY = 0)
11	COMPLETENESS OF T.O. CHECKOUT INFORMATION (RATING ON 10-POINT SCALE)
12	EXTENT TO WHICH T.O. USES STANOARD SYMBOLOGY (10-POINT RATING SCALE)
13	NUMBER OF STEPS IN CHECKOUT PROCEOURE
14	NUMBER OF PIECES OF TEST EQUIPMENT NEEDEO
15	PERCENTAGE OF MEASUREMENTS FOR WHICH T.O. SPECIFIES TOLERANCES
16	TEST POINTS ARE CONVENIENT (10-POINT RATING SCALE)
17	T.O. SECTIONS ARE IN LOGICAL SEQUENCE (10-POINT RATING SCALE)
18	NUMBER OF OTHER UNITS REQUIREO FOR CHECKOUT
19	PERCENTAGE OF MEASUREMENTS WHICH ARE SPECIFIEO QUANTITATIVELY IN THE T.O. (VS GO-NO GO)
20	PERCENTAGE OF PLUG-IN CIRCUITS (VS HARDWIREO)
21	NUMBER OF STEPS IN TROUBLE SHOOTING
22	CONTROLS ARE CLEARLY IOENTIFIEO (10-POINT RATING SCALE)
23	ACCESSIBILITY OF COMPONENTS (10-POINT RATING SCALE)
24	NUMBER OF TEST POINTS
25	PERCENTAGE OF IOENTICAL CIRCUITS USEO
26	PERCENTAGE OF CONNECTORS WHICH CAN BE INCORRECTLY CONNECTEO (RATING SCALE)
27	NUMBER OF AOJUSTMENTS REQUIREO
28	T.O. CHANGE OATA ARE CLEARLY PRESENTEO (10-POINT RATING SCALE)
29	RELIABILITY OF TEST EQUIPMENT (10-POINT RATING SCALE)
30	NUMBER OF SPECIAL CONOITIONS REQUIREO FOR CHECKOUT (E.G. COOLING, HYORAULICS)
31	COMPLEXITY OF TEST EQUIPMENT OPERATION (10-POINT RATING SCALE)
32	COMPONENTS CAN STAND REPEATEO AOJUSTMENT (10-POINT RATING SCALE)
33	PERCENTAGE OF CHECKOUT WHICH IS BIT
34	PERCENTAGE OF CHECKOUT WHICH IS AUTOMATICALLY SEQUENCEO
35	PERCENTAGE OF TEST EQUIPMENT READINGS WHICH ARE QUANTITATIVE
36	CONVENIENCE OF LOCATION OF SYSTEM ANO TEST EQUIPMENT CONTROLS (10-POINT RATING SCALE)
37	PERCENTAGE OF CHECKOUT WHICH IS TO LOWEST LRU
38	ACCESSIBILITY OF UNITS FOR TESTING ANO REMOVAL (10-POINT RATING SCALE)
39	TEST POINT ARRANGEMENT FOLLOWS T.O. SEQUENCE (10-POINT RATING SCALE)
40	ALTERNATE FOR VARIABLE NO. 31: COUNT OF NUMBER OF CONTROLS ANO OISPLAYS
41	ALTERNATE FOR VARIABLE NO. 16: PERCENTAGE OF TEST POINTS ACCESSIBLE WITHOUT REMOVING UNITS OR COVERS
42	PERFORMANCE OBSERVATION WEEK
43	TEST EQUIPMENT COST, DOLLARS

FACTOR	NAME
U_1	LENGTH OF CHECKOUT PROCEOURE
U_2	EQUIPMENT COMPLEXITY
U_3	OIFFICULTY OF CHECKOUT STEPS
U_4	NONAUTOMATIC CHECKOUT
U_5	OIAGNOSTIC INFORMATION
U_6	CLARITY OF INFORMATION

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13. ABSTRACT

The relationships between subsystem design characteristics, training cost, training difficulty, and job performance were investigated for avionics subsystems. A list of relevant design characteristics was established, based on expert opinions of avionics engineers, Air Force (AF) training supervisors, and AF instructors. Functional loops were selected from 10 subsystems representing navigation, flight control, communications, and fire control subsystems. Performance tests for each of the 30 functional loops were identified or constructed. Ten AF students performed each of the tests. Time and errors were recorded for using equipment and reading technical orders (T.O.'s). Both stepwise regressions and factor analysis were used to derive equations to predict performance time, training time, T.O. time, errors, and training equipment cost from equipment design characteristics, personnel characteristics, and environmental variables. Multiple correlation coefficients were 0.88 or greater. Factors of Length of Checkout Procedure, Equipment Complexity, Difficulty of Checkout Steps, Nonautomatic Checkout, Diagnostic Information, and Clarity of Information were identified. Applications of these equations should, for the present, be made cautiously, particularly if any of the input data fall outside the ranges which entered into derivation of the equations.

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