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ABSTRACT

This study focused on two objectives. The first objective was to identify and classify the characteristics of conceptual design trade studies that have high potential impact on human resource requirements of Air Force weapon systems. The approach used was a case history review and analysis of 129 F-15 aircraft design trade studies. The analysis indicated that the avionics system demonstrated the greatest potential impact on human resources. It was also found that trade studies dealing with design alternatives that encompass widely different technologies have substantial impact on human resources. The types of human resources data (HRD) most influenced by alternative design options were maintenance task times and personnel costs. The second study objective was to determine the accuracy of using subjective estimates as a technique for deriving the HRD impact of trade study options. Using only engineering information for six avionics subsystems, from the conceptual design phase, Air Force maintenance technicians made subjective estimates of the impact of the designs on selected HRD items. It was found that technicians can make accurate estimates of the amount of time, the Air Force occupational specialty, the level of technical skill, and the number of personnel needed to perform field maintenance tasks. (Author/JB)

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IMPACT OF DESIGN TRADE STUDIES ON SYSTEM HUMAN RESOURCES

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This study was undertaken to accomplish two objectives. The first objective was to identify and classify the characteristics of conceptual design trade studies that have high potential impact on human resource requirements of Air Force weapon systems. The approach used was a case history review and analysis of 129 F-15 aircraft design trade studies. The analysis indicated that the avionics system demonstrated the greatest potential impact on human resources. It was also found that trade studies dealing with design alternatives that encompass widely different technologies have substantial impact on human resources. The types of human resources data (HRD) most influenced by alternative design options were

SUMMARY

Problem

Human resources (HR) refer to the man-related variables of a system. Such considerations as manpower quantities, skills, occupational categories, and training requirements are included in the term. Although HR account for a major portion of system costs and effectiveness, they are not included early in major system design decisions. This study sought to define the categories and characteristics of trade studies that have potential impact on human resources. If HR information is to be used in early design decisions, accurate data must be made available to the design engineer. One source of such data is the subjective estimates of experienced maintenance technicians. The accuracy of subjective estimates of the impact of design alternatives on human resources was investigated using conceptual phase design packages as stimulus materials.

Approach and Results

A case history approach for identifying trade studies with HR implications was employed. One hundred twenty-nine F-15 aircraft design trade studies were analyzed and fitted into five system categories. The HR influence of trade studies assigned to each category was evaluated. The "Avionics System" was found to have the greatest effect on HR; the "Basic Aircraft System" was found to have the least influence. Further analysis revealed that maintenance task times and personnel costs were the components of HR judged to be most influenced by conceptual design decision options. HR items of maintenance location (flight line or shop), methods of instructing technicians and career fields were least effected. A cluster analysis of trade studies showed that a wide technological disparity between design alternatives was associated with high impact on HR.

The accuracy of subjective estimates of HR was evaluated using four groups of experienced Air Force technicians and conceptual design engineering packages of avionics autopilot and fire control systems. Checking their subjective HR estimates with criteria data obtained from field supervisors resulted in accurate predictions of crew size, skill level, career field and task completion times for flight line maintenance actions.

Conclusions

Trade studies with potential HR impact can be identified. Avionics, as an aircraft subsystem, was found to offer the most fruitful area for introducing the HR considerations. Maintenance task time and personnel cost differences emerged as HR items most sensitive to impact by design alternatives.

Experienced Air Force technicians were found to be able to respond to limited descriptions of avionics systems with accurate estimates of maintenance task completion times, skill levels, career fields and crew sizes. The results serve as a preliminary indication that technicians can and will make reasonably accurate estimates of important HR items using conceptual design phase information.

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PREFACE

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, Major Duncan L. Dieterly, Project Scientist, and Task 112401, Personnel, Training and Manning Factors in the Conception and Development of Aerospace Systems, William B. Askren, Task Scientist.

Appreciation is extended to Mr. Howard K. Geritzen of the Deputy for Development Planning, Aeronautical Systems Division, for his support in the use of engineering data for the Advanced Tactical Fighter Aircraft. Appreciation is also extended to McDonnell Douglas Corporation personnel who supported the research effort, especially Herb A. Chase for assistance regarding manpower estimation, William J. Edens, Jr. for statistical consultation, and Edward R. Jones for advice and direction in conducting the study. The authors also gratefully acknowledge the cooperation and considerable assistance provided by operational Air Force installations. Tactical Air Command personnel from the 27th Tactical Fighter Wing, Cannon Air Force Base, New Mexico, and the 4th Tactical Fighter Wing, Seymour-Johnson Air Force Base, North Carolina, provided information on flight line maintenance requirements. Air Training Command personnel from Chanute Air Force Base, Illinois, and Lowry Air Force Base, Colorado, provided the subjective estimations of flight line requirements for avionics systems. Authorized manpower summaries were supplied by Headquarters Tactical Air Command, Langley Air Force Base, Virginia.

The conceptual design engineering packages were prepared under the direction of Donald R. Kozlowski by McDonnell Aircraft Company, St. Louis, Missouri. The conceptual phase data for the F-111D aircraft was supplied by General Dynamics Corporation, Fort Worth, Texas. This study was conducted during the period May 1973 through July 1974.

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INTRODUCTION

Human resources are a major determinant of an Air Force weapon system's operational effectiveness and life-cycle costs. Askren (1969) has estimated that 50 percent of system performance and cost may be accounted for by human resource considerations. In spite of the importance of man-related factors, data on human resources usually are not introduced into the system development process until after firm design decisions have been reached. The design engineer tends to gain equipment simplicity, compatibility, and availability at the expense of increased manpower, the need for new specialty areas, variation in skill levels and diminished feelings of job satisfaction. When human resources are examined, their implications are often identified too late to have major impacts on system design.

Recent research has demonstrated that human resource data (HRD) can beneficially influence design if personnel manning, skill constraints, and the supporting task information are given to the design engineer at the beginning of his assignment (Meister, Sullivan, and Askren, 1968; Meister, Sullivan, Finley, and Askren, 1969a). Design engineers consistently translate personnel skill constraints into certain system characteristics such as test points, troubleshooting procedures, and types of test equipment (Meister, Sullivan, Finley and Askren, 1969b). Askren and Korkan (1971) found that system design choices can be predetermined and described in decision-tree schematic form, providing a means for relating HRD to specific design options. Lintz, Askren, and Lott (1971) demonstrated that design engineers can and will include HRD in engineering design trade studies, and that the trade off process is very much dependent on the personal style and judgments of the engineer. All of the research results point to one conclusion: HRD can be introduced into the system design process, and can be expected to enhance the design product.

Equipment selections and designs are made continuously throughout the development of every major system. However, the most significant decisions in terms of hardware and software are typically arrived at during the initial and early phases of development, often referred to as conceptual and definition phases. Once a system progresses toward full scale production, major design changes must be held to a minimum because such changes would jeopardize programmed completion schedules as well as add to the procurement costs of the system.

Consequently, two questions were addressed by this study.

(1) Are there categories or types of trade studies performed during the early phases of design which have particularly significant impact on subsequent personnel requirements and should, therefore, include human resources data as a design parameter? If these trade studies can be categorized, then attention may be directed at obtaining the necessary quantitative data that engineers need to make trade off decisions.

(2) What is the accuracy of subjective estimates of the impact of design alternatives on human resource requirements? Since human resource effects data are not generally available during the conceptual design phase, an accurate source for predicting human resource implications must be developed. A potential source for human resource forecasts is the opinion of experienced technicians. The accuracy of using technicians as predictors of the impact of conceptual designs on man-related factors was examined.

This report is divided into two sections. The first section deals with question 1, and involves a detailed analysis of early trade studies for a recently developed Air Force fighter aircraft, the F-15 system. The second section addresses question 2, and concerns the accuracy of using experienced maintenance technicians to forecast human resource requirements for the electronic subsystems of two fighter aircraft.

CHARACTERISTICS OF DESIGN TRADE STUDIES WHICH IMPACT SYSTEM HUMAN RESOURCE REQUIREMENTS

Approach

The F-15 fighter aircraft was chosen to serve as a test bed system for a review of trade studies, because records of the conceptual and early definition phase design decisions were found to be complete and accessible for the study. In addition, many of the personnel who took part in the aircraft's development were available to provide technical clarification and background information.

The F-15 has been in full scale production since March 1973. The preliminary design formulation commenced approximately six years earlier. Major aircraft design formulation and definition was most active during the 1967 to 1969 time frame. It was during this segment of system development that numerous major design trade studies were performed and consequently available for review and analysis.

Each formal design trade study for the F-15 was documented by a System Engineering Task Statement (Appendix A) which contained detailed information in the following format:

- Title
- Purpose
- Baseline/Alternative Solutions
- Functions/Systems/Data
- Factors Influencing Evaluation
- Expected Results
- Task Definition

The task statement was found to be the best source for descriptions of the overall trade study requirements and the alternative designs considered for meeting system requirements. The task statements for the F-15 design trade studies served as the basis for the case history analyses.

Procedures and Results

The case history approach lends itself to a narrative reporting style. For this reason it was considered appropriate to combine procedures and results into one section. The detailed procedures and results are reported below.

Categories of design trade studies. One hundred twenty-nine trade studies were initiated during the early conceptual/definition phases of the F-15 (Appendix B). The task statement for each was reviewed by the senior author and an F-15 personnel subsystem specialist, and its relevance to one or more of the aircraft's systems was determined. In this way, a distribution of trade studies was assembled under the following headings: basic aircraft; avionics; propulsion; utilities, and, all aircraft systems.

Table 1 contains the distribution of the trade studies across system areas. The classification of "all systems" contains four trade studies that were of such a broad scope that they influenced the design characteristics of the entire aircraft.

TABLE 1

DESIGN TRADE STUDIES INVOLVING THE BASIC AIRCRAFT, AVIONICS, PROPULSION, UTILITIES AND ALL SYSTEMS

TRADE STUDIES	BASIC AIRCRAFT	AVIONICS	PROPULSION	UTILITIES	ALL SYSTEMS	TOTAL
Total	43	34	25	23	4	129
Percentage	33.3	26.4	19.4	17.8	3.1	100

The majority of trade studies, 43, dealt with design issues involving the basic aircraft, with the design questions primarily focused on airframe and flight control surface configurations. A considerable number of trade studies, 34, were directed at the avionics systems; i.e., the electronic devices used for navigation and control of the aircraft and associated weapons. An additional finding was that only 2 of the 129 trade studies contained human factor evaluation parameters except for flight crew considerations.

Trade studies which influence human resources. Next, the trade studies were evaluated for the level of influence the engineer's choice of a design alternative would have on the human resources that would eventually be needed to maintain the system (the system in this study refers to F-15 aircraft hardware and software components). Human resources may be viewed as an entity comprising the personnel requirements associated with a system. Human resources in this case were specified as personnel attributes and maintenance characteristics. Ten such items were identified as follows:

(a) number of technicians needed to maintain a system

(b) occupational specialty of the technicians

(c) skill level within an occupational specialty

(d) time that would be required to perform typical maintenance tasks

(e) probability of errors in task performance

(f) location of maintenance activities (flight-line or shop)

(g) training time needed to teach technicians to perform required maintenance

(h) training content

(i) methods of instruction

(j) overall personnel cost.

The task statement for each design trade study was submitted for review to five McDonnell Douglas Corporation (MDC) engineering psychologists familiar with human resource requirements. The psychologists (Table 2) were independently asked to make a judgment as to the potential influence the selection of trade study alternatives contained in each of the 129 task statements would have on the above 10 human resource items. If the design alternatives appeared to be choices that would influence significantly the characteristics and/or procedures of the personnel that would be needed for system maintenance, the trade study was categorized as having "Human Resource Data (HRD) Influence." On the other hand, if the design alternatives of a trade study offered little or no potential impact on field personnel characteristics, it was placed in the "No HRD Influence" group. The dichotomization was based solely upon an individual reviewer's subjective appraisal of the trade study's apparent effect on field maintenance personnel requirements.

TABLE 2

CHARACTERISTICS OF TRADE STUDY REVIEWERS (n = 5)

AGE, YEARS		HUMAN FACTORS EXPERIENCE, YEARS		GRADE LEVEL*	
RANGE	MEAN	RANGE	MEAN	RANGE	MEAN
31-62	41.8	6-17	10.2	4-13	9.3

*MDC Psychologist Grade Levels: 4 = Associate Psychologist, 7 = Psychologist, 10 = Senior Psychologist, 11 = Group Psychologist, 13 = Senior Group Psychologist

When four of the five reviewers were found to have independently concurred with the amount of HRD influence for a given trade study, it was assigned to the agreed upon category; i.e., "HRD Influence" or "No HRD Influence." ~~If~~ 80% agreement was not reached with regard to the trade study's potential effect on HRD, it was classified into the "Influence on HRD Not Clear" category. Figure 1 summarizes the results of the evaluation of the impact of the 129 trade studies on human resource factors in general, and shows that 39 trade studies were judged to influence HRD and 36 trade studies would not effect HRD. For 54 trade studies, it was unclear whether or not there would be any effect.

Relationship between system areas and trade study influence on HRD. The relationship between the assigned HRD category and the five aircraft system areas (basic aircraft; propulsion; utilities; avionics; and, all systems) was examined. Table 3 summarizes the frequency distributions of trade studies by HRD category and aircraft system.

TABLE 3

FREQUENCY DISTRIBUTIONS OF HRD CATEGORIES
ACROSS TRADE STUDY SYSTEM AREAS

SYSTEM INVOLVED WITH TRADE STUDY	HRD CATEGORY			TOTAL
	INFLUENCE	NO INFLUENCE	NOT CLEAR	
Basic Aircraft	6	19	18	43
Avionics	16	6	12	34
Propulsion	8	4	13	25
Utilities	6	6	11	23
All Aircraft Systems	3	1	0	4
TOTAL	39	36	54	129

A chi square analysis was performed on this frequency distribution. For purposes of the chi square analysis, the fifth system category of all aircraft systems was omitted because of the low cell frequencies. Table 4 presents the observed (O) and expected (E) values. The chi square statistic ($\chi^2 = 15.08$) was significant beyond the .05 level.

The greatest differences between observed and expected frequency values occurred in the basic aircraft and avionics rows. Fewer trade studies were judged to have HRD influence in the basic aircraft area than would be expected. In the avionics area, a greater number of trade studies were found to have HRD

FIGURE 1 FREQUENCY GROUPING OF F-15 CONCEPTUAL PHASE TRADE STUDIES BY POTENTIAL INFLUENCE OF HUMAN RESOURCES REQUIREMENTS

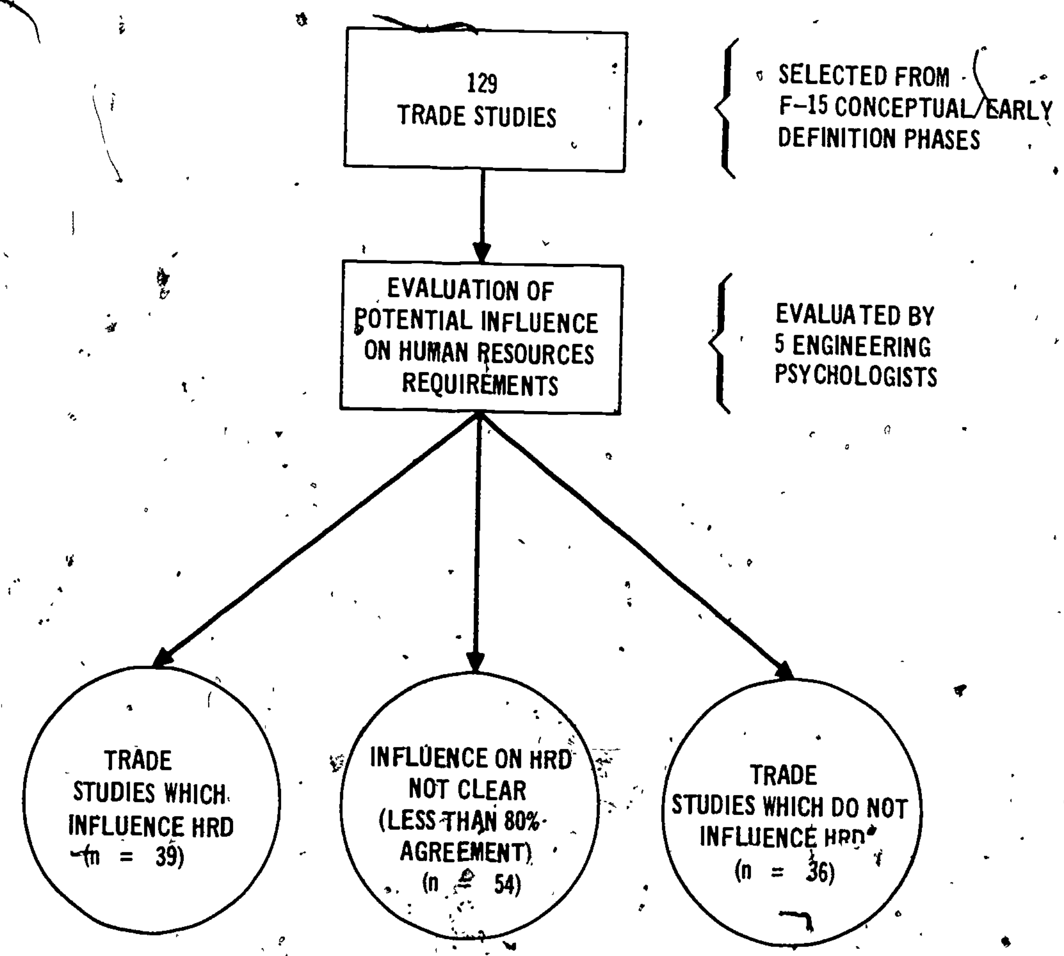

TABLE 4

OBSERVED AND EXPECTED VALUES OF THE CHI SQUARE* SUMMARY MATRIX

SYSTEM AREA	HRD CATEGORY					
	INFLUENCE		NO INFLUENCE		NOT CLEAR	
	O	E	O	E	O	E
BASIC AIRCRAFT	6	12.4	19	12.0	18	18.6
AVIONICS	16	9.8	6	9.5	12	14.7
PROPULSION	8	7.2	4	7.0	13	10.8
UTILITIES	6	6.6	6	6.4	11	9.9

*$X^2 = 15.08$; df = 6; $\alpha < .05$

O = OBSERVED FREQUENCY; E = EXPECTED FREQUENCY

influence than would be expected. These results indicate that for the F-15 system, trade studies in the avionics area have the greatest potential effect on human resource requirements.

Impact of trade studies on individual human resource data items. The research was also aimed at identifying the individual items of human resource data which are effected by trade study decisions. Toward this end, particular attention was directed at the 39 trade studies that were identified as having an influence on HRD. The task statements for these 39 trade studies were evaluated for impact on individual human resource items by using a six point rating scale (Table 5).

Ratings of impact were obtained from six MDC engineering psychologists. Table 6 contains biographical information on the evaluating psychologists. Four of the six psychologists had also participated in the initial trade study review described in the previous section. An average and a measure of variance was computed for each of the ten HRD items across the 39 trade studies. These results are presented in Table 7.

Based upon the average ratings, "Time to Complete Maintenance" and "Overall Personnel Costs" were the items most heavily influenced by the design trade studies. The items "Maintenance Location," "Methods of Instruction," and "Air Force Specialty" were the least influenced. Based upon the standard deviation values, there is best agreement on ratings for "Maintenance Location," and poorest agreement on "Number of Technicians."

TABLE 5

SIX POINT RATING SCALE USED TO EVALUATE THE POTENCY OF TRADE OFF STUDIES ACROSS HRD ITEMS

Indicate your appraisal of the nature of the trade study's impact on operational unit maintenance personnel requirements.

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
The trade study involves alternatives that would vary the number of maintenance technicians assigned to the operational unit.	( )	( )	( )	( )	( )	( )
Personnel occupational specialties or career fields vary with the design alternatives.	( )	( )	( )	( )	( )	( )
The trade study decision involves alternatives that would require different skill levels or degrees of technical competency.	( )	( )	( )	( )	( )	( )
The amount of time needed to perform typical maintenance tasks (such as inspections, checkout, or troubleshooting) would be different for each alternative design.	( )	( )	( )	( )	( )	( )
The probability or likelihood of a technician committing maintenance errors appears as a factor in the alternative design choices.	( )	( )	( )	( )	( )	( )
The maintenance location (i.e., field, shop, or depot) differs with alternative designs.	( )	( )	( )	( )	( )	( )
The design alternatives differ from each other with regard to technical training time for maintenance personnel, i.e., the duration of courses, OJT, or field training would be affected by the final design selection.	( )	( )	( )	( )	( )	( )
The training content or course subject matter would be quite different for each alternative.	( )	( )	( )	( )	( )	( )
The methods of instructing technicians to perform maintenance tasks appear to differ across the alternative design options.	( )	( )	( )	( )	( )	( )
The design decision involves options that influence overall personnel costs due to training considerations, technical proficiency, number of technicians and/or the ease of performing maintenance.	( )	( )	( )	( )	( )	( )

TABLE 6

CHARACTERISTICS OF HRD IMPACT EVALUATORS (n = 6)

AGE, YEARS		HUMAN FACTORS EXPERIENCE, YEARS		GRADE LEVEL*	
RANGE	MEAN	RANGE	MEAN	RANGE	MEAN
31-62	43.8	7-32	14.8	4-13	10.0

*MDC Psychologist Grade Levels: 4 = Associate Psychologist, 7 = Psychologist, 10 = Senior Psychologist. 11 = Group Psychologist, 13 = Senior Group Psychologist

TABLE 7

IMPACT OF TRADE STUDIES ON HRD ITEMS*

HRD ITEM	MEAN RATING**	STANDARD DEVIATION
Time to Complete Maintenance	4.59	.86
Overall Personnel Costs	4.46	.77
Content of Training Courses	3.98	.78
Number of Technicians	3.98	.95
Training Time Requirements	3.94	.74
Maintenance Errors	3.94	.80
Skill Level	3.47	.82
AF Specialty	3.12	.88
Method of Instruction	3.06	.75
Maintenance Location	2.75	.67

*Based on 39 trade studies judged as having an effect on human resource data.

**Rating form used a six point scale:
6 = Strongly Agree that HRD item influenced by trade study.
1 = Strongly Disagree that HRD item influenced by trade study.

Cluster analysis of trade studies. A cluster analysis was performed on the 39 trade studies with potential HRD influence. The intent of this analysis was to identify those trade studies that received similar ratings across the ten HRD items. The assumption was made that trade studies with identical or very similar profiles might have some common traits or characteristics.

The average rating given each of the ten HRD elements for each trade study was compared with the overall mean obtained for the respective HRD item across all 39 trade studies. If the HRD item mean for a trade study was greater than the overall mean for the HRD item, it was assigned a value of 1. If the HRD item mean has less than the overall mean for that item, it was assigned a value of 0. In this way, the impact of each trade study on the ten HRD items was reduced to a series of ten binary notations. A ten item profile was computed for all 39 trade studies (Table 8).

The binary profiles were then examined for similarity. When trade study profiles were found to share a common profile on 8 or more of the 10 HRD items, the studies were established as a cluster or group. Trade studies with 8 or more values of "1" were considered to be "high impact" HRD profiles; 8 or more values of "0" were considered to be "low impact" HRD profiles. Table 9 presents the results of the profile examination. Twelve trade studies made up the high impact cluster; eight trade studies made up the low impact cluster. The titles of the trade studies in these two clusters are given in Table 10.

Analysis and evaluation of trade studies in high and low clusters. The 12 trade studies in the high cluster and the 8 trade studies in the low impact cluster were reviewed by the senior author and one other engineering psychologist familiar with personnel requirements and aircraft hardware. From a content analysis of the trade study task statements it was hypothesized that the high HRD impact trade studies were dealing with alternative design choices that involved wide departures from one another in technical characteristics. For example, a trade study dealing with the flight control system design received a very high HRD profile rating (10 values of 1). The design evaluation considered alternatives ranging from a baseline manual flight control system to a fly-by-wire system in which the pilot would actuate flight control systems via electrical impulses. By contrast, the design alternatives in the low HRD rating cluster dealt with alternatives not nearly as diverse. For example, the low profile group includes a study of the evaluation of navigation equipment. The study involves a baseline tactical air navigation (TACAN) system with range and bearing as opposed to a TACAN with bearing only. The degree of technological disparity between the TACAN alternatives appears to be minimal. Based upon the content review of the high and low HRD impact groups, the following hypothesis was generated: The greater the technological disparity between trade study design alternatives, the greater will be the potential impact of the design decision on human resources requirements.

TABLE 8
BINARY PROFILES* OF HRD ITEMS FOR TRADE OFF STUDIES FOUND TO HAVE IMPACT ON PERSONNEL REQUIREMENTS

TRADE STUDY NO.	HRD ITEM									
	NUMBER OF TECHNICIANS	AFSC	MAINTENANCE TIME	SKILL LEVEL	MAINTENANCE ERRORS	TRAINING CONTENT	OVERALL COSTS	METHOD OF INSTRUCTION	TRAINING TIME	MAINTENANCE LOCATION
1	1	0	1	1	1	1	1	1	1	1
2	0	0	0	0	0	1	1	1	1	1
3	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1
5	1	0	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1
7	1	1	1	0	1	0	1	0	0	1
8	1	1	1	1	1	1	1	1	1	1
9	0	0	1	0	1	0	1	0	0	0
10	1	0	1	0	1	0	1	0	0	0
11	0	1	0	1	1	0	0	0	0	0
12	1	0	1	0	1	0	1	1	0	0
13	0	1	1	1	1	1	1	1	1	0
14	0	1	0	1	1	1	0	1	1	1
15	1	0	1	1	1	0	1	0	1	0
16	1	1	1	0	1	0	0	1	1	0
17	1	1	0	1	1	0	1	1	0	1
18	0	1	0	0	0	1	0	1	0	0
19	1	1	1	1	0	0	0	0	0	0
20	1	1	1	1	1	1	1	1	1	1
21	1	1	1	1	1	1	0	1	1	0
22	1	1	1	0	0	1	1	0	0	0
23	1	0	1	1	1	1	1	0	1	0
24	1	1	1	1	1	1	1	1	1	1
25	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0
27	1	1	0	1	0	1	1	0	1	1
28	0	1	0	0	0	0	0	0	0	0
29	1	1	1	1	1	1	1	1	1	1
30	1	0	1	0	0	0	1	0	1	0
31	1	1	1	1	1	0	1	0	1	1
32	0	0	1	0	1	1	0	0	1	1
33	1	0	0	0	0	0	0	0	0	0
34	1	1	1	1	1	1	1	1	1	1
35	0	0	1	1	1	1	1	0	0	0
36	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0
39	1	0	1	0	1	0	1	0	0	0

*ITEM MEANS WERE CONVERTED TO BINARY EXPRESSIONS.

1 = HRD ITEM MEAN FOR TRADE STUDY EXCEEDS OVERALL HRD ITEM MEAN.

0 = HRD ITEM MEAN FOR TRADE STUDY IS LESS THAN THE OVERALL HRD ITEM MEAN.

TABLE 9
BINARY PROFILES AND THE FREQUENCY OF THEIR OCCURRENCE FOR TRADE STUDIES WITH IMPACT ON HUMAN RESOURCES

HRD PROFILE											NUMBER OF TRADE STUDIES WITH PROFILE
HIGH IMPACT CLUSTER*	1	1	1	1	1	1	1	1	1	1	7
	1	0	1	1	1	1	1	1	1	1	2
	1	1	1	1	1	1	0	1	1	0	1
	1	1	1	1	1	0	1	0	1	1	1
	0	1	1	1	1	1	1	1	1	0	1
	0	0	0	0	0	1	1	1	1	1	1
	0	0	1	0	1	0	1	0	0	0	1
	0	0	1	0	1	1	0	0	1	1	1
	0	0	1	1	1	1	1	0	0	0	1
	0	1	0	0	0	1	0	1	0	0	1
	0	1	0	1	1	0	0	0	0	0	1
	0	1	0	1	1	1	0	1	1	1	1
	1	0	1	0	1	0	1	0	1	0	1
	1	0	1	0	1	0	1	0	0	0	2
	1	0	1	0	1	0	1	1	0	0	1
	1	0	1	1	1	0	1	0	1	0	1
	1	0	1	1	1	1	1	0	1	0	1
	1	1	0	1	0	1	1	0	1	1	1
	1	1	0	1	1	0	1	1	0	1	1
	1	1	1	0	0	1	1	0	0	0	1
	1	1	1	0	1	0	0	1	1	0	1
	1	1	1	0	1	0	1	0	0	1	1
	1	1	1	1	0	0	0	0	0	0	1
LOW IMPACT CLUSTER**	1	0	0	0	0	0	0	0	0	0	1
	0	1	0	0	0	0	0	0	0	0	1
	0	0	0	0	0	0	0	0	0	0	6

*HIGH CLUSTER CONTAINS 8 OR MORE VALUES OF 1
**LOW CLUSTER CONTAINS 8 OR MORE VALUES OF 0

TABLE 10

TITLES OF DESIGN TRADE STUDIES IN HIGH AND LOW HUMAN RESOURCES IMPACT CLUSTERS

HIGH IMPACT CLUSTER (n = 12)
Evaluation of Auxiliary Power Units
Evaluation of Flight Control System Design Concept
Evaluation of Quantitative and Qualitative AGE Determination
Evaluation of Escape System Ejection Seats vs. Escape Capsule
Evaluation of Built-in-Test Equipment
Evaluation of Fire Control System
Evaluation of Flight Control Actuator Configuration
Evaluation of Field Shop Automation Control
Evaluation of Oxygen System
Evaluation of Integrated CNI Control and Displays
Evaluation of Identification System
Evaluation of Stability and Control Requirements
LOW IMPACT CLUSTER (n = 8)
Evaluation of Crash Data Recorder
Evaluation of Avionic Interface and Computational Analysis
Evaluation of Trainer and Training Equipment (Aircrew)
Evaluation of Navigation Subsystem
Evaluation of Electro-optical Identification Tracking
Evaluation of Inflight Engine Restarting Methods
Evaluation of Electrical Generating System
Evaluation of Aircraft Mounted Auxiliary Drive

In order to check the hypothesis, the trade studies contained in the two clusters were randomly submitted to systems engineers for a technical evaluation of the degree of disparity among design alternatives. Five experienced systems engineers (Table 11) reviewed each trade study. For a given trade study, they were first asked to identify the two design choices that contained the greatest differences in technological content. Then the degree of disparity was quantified by setting one of the two design choices at "0" and having the engineer express the extent to which alternative design varied in technology on a 100 point scale. If the disparity was large, it was expressed by a high number; a small difference in technology was reflected by a low number.

TABLE 11

CHARACTERISTICS OF TECHNOLOGY EVALUATORS (n = 5)

AGE, YEARS		ENGINEERING EXPERIENCE, YEARS		EDUCATION, YEARS		GRADE LEVEL*	
Range	Mean	Range	Mean	Range	Mean	Range	Mean
41-55	47.0	21-27	23.4	16-20	18.0	13-16	14.4

*Engineering Grade Levels: 13 = Senior Group Engineer; 15 = Project Engineer; 16 = Section Manager

The five estimates of technological difference assigned to the alternatives of each trade study were averaged. The average estimate of technological differences for the twelve trade studies in the high HRD impact cluster was 38.7. The average estimate of the technological difference for the 8 trade studies in low HRD impact cluster was 17.7. A t-test was performed to test a null hypothesis regarding the significance of the difference between evaluations given the high and low cluster trade studies. The difference between clusters was significant at the $\alpha < .10$ level. Table 12 summarizes the statistical results.

TABLE 12

SUMMARY OF t-TEST STATISTICS FOR COMPARING TECHNOLOGICAL DIFFERENCE BETWEEN DESIGN ALTERNATIVES FOR TRADE STUDIES WITH HIGH IMPACT AND LOW IMPACT

High Impact on HRD		Low Impact on HRD
$n = 12$		$n = 8$
$\overline{X} = 38.7$		$\overline{X} = 17.7$
$sd = 27.1$		$sd = 31.1$
	$t = 1.5$ $df = 18$ $\alpha < .10$	

<u>A comparison of human resources for two operational systems</u>. A comparison of two fighter aircraft systems from different time periods was performed to determine which subsystems showed the most change in manpower requirements. The two systems chosen were the older F-4 and the more recently developed F-111. The approach used was to compare changes in the manning assigned to the common career fields used to support both aircraft. Table 13 contains the distribution of authorized manpower allocations for an F-4 and an F-111 tactical fighter wing, as reported by the Air Force Manpower and Organizational Directorate, Tactical Air Command (as of June 1973).[1] The manpower allocations differ quite noticeably in the avionics systems career field.

These findings confirm the earlier results that avionics systems have the greatest impact on human resource considerations. It is speculated that this change is accounted for by a substantial disparity in avionics equipment designs between the two aircraft. It is further speculated that the technological differences between the other subsystems were not as great.

Table 14 illustrates the skill level distributions of personnel assigned to the F-4 and F-111 avionics career fields. It is interesting to note that although the number of technicians assigned to F-111 avionics was greater than that assigned to the F-4, the average skill level of F-111 avionics technicians was less. This factor has implications for other human resources data such as training time, availability of personnel by aptitude level, and consequent costs associated with manning needs.

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[1] Reference: 22 June 1973 letter to Air Force Human Resources Laboratory, Advanced Systems Division, Wright-Patterson Air Force Base, Ohio 45433, from Headquarters Tactical Air Command, Langley Air Force Base, Virginia.

TABLE 13
QUANTITIES OF MAINTENANCE MANPOWER

CAREER FIELD	F-4	F-111	CHANGE
AVIONICS SYSTEMS	202	329	127
AIRCRAFT MAINTENANCE	482	580	98
MUNITIONS AND WEAPONS	390	331	59
MISSILE ELECTRONIC	26	2	24
INTELLIGENCE	11	28	17
METALWORKING	56	71	15
ADMINISTRATION	78	91	13
AIRCRAFT ACCESSORY	185	197	12
SUPPLY	13	20	7
MAINTENANCE ANALYSIS	6	9	3
INTRICATE EQUIPMENT	2	0	2
EDUCATION AND TRAINING	11	11	0
MEDICAL	22	22	0
FABRIC AND RUBBER PROTECTION	12	12	0
COMMAND CONTROL	16	16	0
FIRST SERGEANT	4	4	0
TOTAL	1,516	1,723	207

*SUMMARY IS BASED UPON AUTHORIZED MANNING FOR TACTICAL WINGS OF 72 AIRCRAFT IN A COMBAT CONFIGURATION. COMPLETE STAFF AND BASE SUPPORT FUNCTIONS ARE NOT INCLUDED.

TABLE 14

DIFFERENCES IN SKILL LEVEL* ALLOCATIONS OF AVIONICS TECHNICIANS ASSIGNED TO F-111 AND F-4 AIRCRAFT

SKILL LEVEL	F-111	F-4
3	73	43
5	184	109
7	65	45
9	7	5
TOTAL	329	202
Mean skill value	4.4	5.1

*AF Skill Levels: 3 = Apprentice

5 = Specialist

7 = Technician

9 = Superintendent

Summary and Discussion

This part of the study used a case history approach to first identify and then analyze trade studies that have significant impact on human resource requirements of an aircraft system. The approach was primarily descriptive in nature, and was intended to point out likely areas for including human resources data as a parameter in arriving at final design decisions.

The 129 trade studies from the F-15 system were fitted into 5 categories. Approximately 60% of the studies were categorized as "basic aircraft" and "avionics" tradeoffs. The remaining 40% of the studies were "propulsion," "utilities" and "all systems" investigations. Thirty nine (30%) of these 129 trade studies were judged as definitely having the potential to significantly influence human resource requirements. Thirty six (28%) were rated as definitely having no influence on human resources. For the remaining fifty four (42%) it was uncertain as to their influence. The group of 39 trade studies showing the greatest effect on human resources was primarily concerned with studies of avionics systems. The group of 36 with least influence was primarily concerned with basic aircraft studies. Further analysis of the 39 trade studies with the greatest influence showed that human resources data items of maintenance task time and personnel cost were the most severely impacted. Human resource items of maintenance location, method of instruction, and career field were the least effected. There was medium impact on training course content, quantity of maintenance technicians, training time, skill level, and task performance errors.

The cluster analysis of the 39 trade studies with greatest potential influence on human resources resulted in two dominant clusters: one which isolated 12 studies with the most powerful effect on the individual human resources data item and the second which isolated 8 trade studies that had the lesser effect on the individual human resource items. It was found that the two clusters of trade studies differed significantly in terms of the amount of technological difference that existed between design alternatives for the trade studies. The cluster with greatest impact on the individual human resources data items had the greatest technological difference between design options, viz, the avionics systems. The analysis of manpower changes from an older to a newer fighter aircraft system showed the greatest quantity change occurred for avionics systems.

These results strongly suggest that subsystems with rapidly changing technologies, or subsystems with design alternatives involving distinctly different technologies should be examined closely for HRD implications. The avionics area appears to be an area of rapid change and a high degree of influence on the human resource requirements of new systems. The ten human resource data items were variously effected by trade studies. Maintenance task time and personnel costs should receive priority attention as data to be provided to engineers for use in design trade studies.

31

ACCURACY OF SUBJECTIVE ESTIMATES OF THE IMPACT OF DESIGN ALTERNATIVES ON SELECTED HUMAN RESOURCE DATA ITEMS

Approach

If HRD is to be used as a parameter in the trade study process, it must be supplied to the engineer. Engineers have neither the time nor the background to develop HRD. One potential source for HRD is subjective estimates by experienced maintenance technicians. As a specialist in the daily maintenance and utilization of systems equipment, he appears to be in the position to offer predictions on the impact that alternative conceptual designs might have on personnel, training, and maintenance factors. Since maintenance task time emerged in the first part of the study as a top rated human resource factor for design trade studies, it was decided to test the accuracy of the subjective estimate method for predicting that class of data. In addition, since data on Air Force specialty careers (AFSC), crew sizes, and skill levels are used to calculate personnel costs (the second most important HRD item in Table 8) an effort was made to determine the accuracy of subjective estimates of these kinds of data. Whereas avionics emerged as the system technology area with the greatest impact on HRD, it was chosen as a test bed system for this phase of the study.

MDC avionics engineers compiled engineering data packages describing the avionics systems for two aircraft at a conceptual phase of development. Using the historical records for the F-4E aircraft at McDonnell Aircraft Company and the F-111D at General Dynamics Corporation, the engineering packages were assembled. To insure that only information that normally exists during the conceptual design phase was included, avionics systems for a third aircraft, the advanced tactical fighter (ATF), were used as conceptual models. At the time of this study the advanced tactical fighter was in the conceptual design phase and served as an operational definition for what was, and what was not, conceptual phase engineering data (Appendix C).

The completed engineering packages were then reviewed for consistency and standardization by technicians from the MDC Product Support Department. The conceptual data packages were then ready to serve as stimulus material for HRD predictions.

Air Force technicians, with training and field experience in avionics maintenance, independently reviewed the conceptual packages and made subjective estimates of the maintenance task times, career fields, crew sizes and skill levels of personnel that would be required to support such a system at an operational base. Their predictions were averaged and checked for accuracy with the actual human resource requirements reported by shop supervisors who controlled the daily maintenance for operational F-4E and F-111D avionics systems.

Procedures

Engineering data packages used as stimulus material for subjective estimates. Using the ATF system as the model, six packages were assembled describing the design data available during the conceptual phase of the following avionics subsystems: (1) F-4E autopilot; (2) F-111D autopilot; (3) ATF autopilot; (4) F-4E fire control; (5) F-111D fire control; and (6) ATF fire control. The ATF data package is contained in Appendix C.

Description of personnel making human resource data predictions. Six groups of experienced Air Force technicians from the avionics maintenance career field served as sources for the human resource predictions (Tables 15 and 16). Each group made estimates for one of the six avionics conceptual designs. Special care was taken to insure that no technician had actual field experience with the subsystem for which he was to make task time predictions as would be the case during a conceptual design effort.

Type of human resource data predicted. Utilizing only the information contained in the design data packages, the technicians made predictions on the amount of elapsed time that would be required to perform the following flight line maintenance tasks: prepare; troubleshoot; remove and replace; adjust; align; functional test; and, close-up. These estimates were recorded on the form shown in Figure 2. Estimates were made for each component of the subsystem. For example, for the F-4E autopilot, predictions were made for the following components: control amplifier; transducer; g-limit accelerometer; lateral accelerometer; pitch rate gyro; roll rate gyro; yaw rate gyro; and, controller. Estimates were also made of the career field, skill level and quantity of the personnel required to perform the maintenance tasks for each component.

Following their predictions, each technician was individually interviewed and asked to critique the information contained in the engineering design package. He was asked to suggest changes to the data package which would increase his confidence in his human resource data estimates.

Criteria for evaluating the accuracy of the human resource data predictions. Visits were made to operational Air Force Tactical Air Command bases[2] to collect criterion task completion times, crew sizes, career fields, and skill levels required to perform flight line maintenance actions for both the F-4E and F-111D autopilot and fire control avionics systems. The criterion data was first sought from base-level Air Force Manual 66-1 time records, however, these data were expressed as manhours rather than total elapsed times for maintenance actions. Direct observation and timing of maintenance actions would have entailed resources and time expenditures beyond the scope of the study. For these reasons, the information was

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[2] Seymour Johnson AFB, NC
Cannon AFB, NM

TABLE 15

CHARACTERISTICS OF TECHNICIANS WHO ESTIMATED THE IMPACT OF CONCEPTUAL AUTOPILOT DESIGNS ON HUMAN RESOURCES DATA

Personnel Making F-4E Predictions						
n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	27.6	23–33	5.4	5–6	7.0	3.1–12.8

Personnel Making F-111D Predictions						
n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	30.8	25–38	5.5	5–6	8.3	6.0–12.0

Personnel Making ATF Predictions						
n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	29	24–36	5.2	5–6	9.8	4.5–18.0

*AIR FORCE GRADE TITLES:

1 = AIRMAN BASIC
2 = AIRMAN
3 = AIRMAN 1ST CLASS
4 = SERGEANT
5 = STAFF SERGEANT
6 = TECHNICAL SERGEANT
7 = MASTER SERGEANT
8 = SENIOR MASTER SERGEANT
9 = CHIEF MASTER SERGEANT

TABLE 16
CHARACTERISTICS OF TECHNICIANS WHO ESTIMATED THE IMPACT OF CONCEPTUAL FIRE CONTROL DESIGNS ON HUMAN RESOURCES DATA

Personnel Making F-4E Predictions

n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	31.2	28–37	6.6	5–7	11.7	10.3–13.7

Personnel Making F-111D Predictions

n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	33	25–39	5.6	5–7	13.3	5.5–21.2

Personnel Making ATF Predictions

n	AGE (YRS)		GRADE TITLE*		AVIONICS EXPERIENCE (YRS)	
	AVERAGE	RANGE	AVERAGE	RANGE	AVERAGE	RANGE
5	30.6	23–40	5.2	4–7	9.0	1.7–20.0

*AIR FORCE GRADE TITLES:

1 = AIRMAN BASIC
2 = AIRMAN
3 = AIRMAN 1ST CLASS
4 = SERGEANT
5 = STAFF SERGEANT
6 = TECHNICAL SERGEANT
7 = MASTER SERGEANT
8 = SENIOR MASTER SERGEANT
9 = CHIEF MASTER SERGEANT

FIGURE 2 FORM USED BY TECHNICIANS TO RECORD PREDICTIONS OF HUMAN RESOURCES DATA

SYSTEM/SYSTEM MODEL: FLIGHT CONTROL (AUTOPILOT)

AIRCRAFT: F-4E

COMPONENTS	TASK TIMES (ELAPSED TIME IN MINUTES)																				
	ORGANIZATIONAL MAINTENANCE																				
	(A)			(B)			(C)			(D)			(E)			(F)			(G)		
	PREPARE			TROUBLE SHOOT			REMOVE AND REPLACE			ADJUST			ALIGN			FUNCTIONAL TESTS			CLOSE-UP		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE	MINUTES	AFSC/SKILL	JOB CREW SIZE
ESTIMATES WERE MADE FOR EACH COMPONENT CONTAINED IN THE PROPOSED DESIGN. FOR EXAMPLE, FOR THE F-4E THE COMPONENTS WERE: CONTROL AMPLIFIER TRANSDUCER ACCELEROMETER (g-limit) ACCELEROMETER (lateral) PITCH RATE GYRO ROLL RATE GYRO YAW RATE GYRO CONTROLLER																					

(A) PREPARE – TIME REQUIRED TO SET UP AGE, CIRCUIT BREAKER SETTINGS, CABLE CONNECTIONS AND GAINING ACCESS TO COMPONENT.
(B) TROUBLESHOOT – TIME TO PERFORM FAULT ISOLATION PROCEDURE.
(C) REMOVE AND REPLACE – LRU REPLACEMENT TIME.
(D) ADJUST – TIME TO SET CORRECT OPERATING VALUES.
(E) ALIGN – TIME TO PLACE LRU WITHIN CORRECT OPERATING VALUES.
(F) FUNCTIONAL TESTS – TIME TO VERIFY THE OPERATION REPLACED LRU.
(G) CLOSE-UP – TIME TO DISCONNECT AGE, RESET CIRCUIT BREAKERS AND REPLACED PANELS, ETC.

obtained from the shop supervisors responsible for scheduling, directing and administering the activities of their maintenance work center. Their judgments were considered to be highly accurate as the supervisors were senior enlisted personnel who had frequently monitored and performed the maintenance tasks of interest. Each supervisor's HRD judgment was further reviewed by the senior technician assigned to each F-4E and F-111D Chief of Maintenance Office.

Results

Accuracy of predicted maintenance task times. A comparison of the predicted times from design engineering data with actual times reported by supervisors for the completion of flight line maintenance tasks is provided in Figures 3 and 4. Figure 3 compares predicted with actual times for the autopilot subsystems. Figure 4 compares predicted with actual times for the fire control subsystems. The accuracy of the average time predictions was within 8.3% to 66.8% of the actual times required to perform the tasks (Table 17). Three of the estimates were less than the actual values. The worst estimate occurred for the F-111D autopilot system. With regard to all four avionics systems, the technicians made an overall underestimation of actual task times by 29.4%.

One application of these results could be to apply an adjustment to the estimated task time values for a conceptual phase design. Such an adjustment in estimated values would serve to compensate for the tendency of technicians to underestimate actual times. The correction equation would take the following form:

$$\text{Corrected Task Time} = \frac{\text{Subjective Estimated Time}}{\text{1-Percent of Underestimation}}$$

$$\text{CTT} = \frac{\text{SET}}{1-.294}$$

$$\text{CTT} = \frac{\text{SET}}{.706}$$

For the ATF the corrected task time for the autopilot system design would be 1878 minutes and for the fire control system the corrected task time would be 1356 minutes.

FIGURE 3. COMPARISON OF PREDICTED AND ACTUAL TIMES TO PERFORM FLIGHT-LINE MAINTENANCE TASKS ON AUTOPILOT SUBSYSTEMS

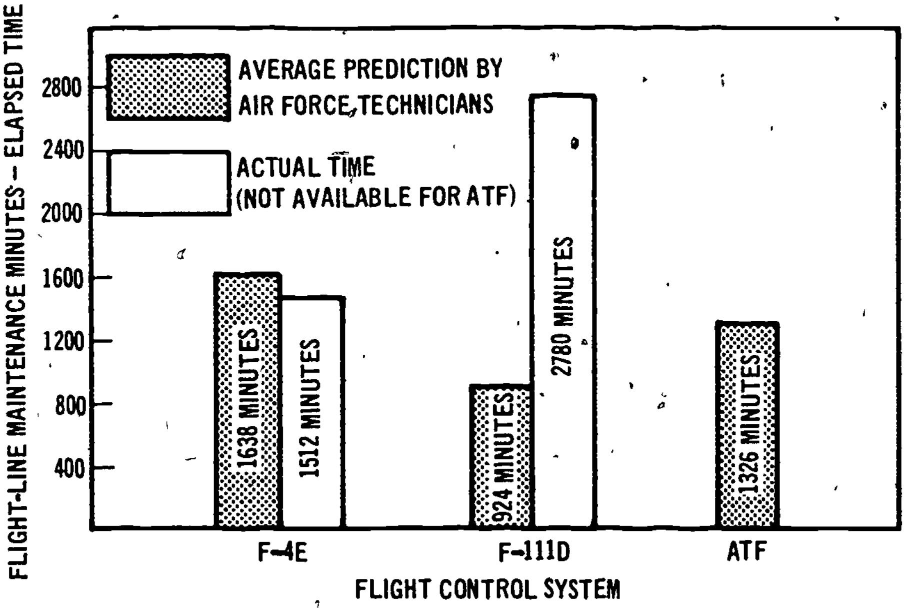


FIGURE 4. COMPARISON OF PREDICTED AND ACTUAL TIMES TO PERFORM FLIGHT-LINE MAINTENANCE TASKS ON FIRE CONTROL SUBSYSTEMS

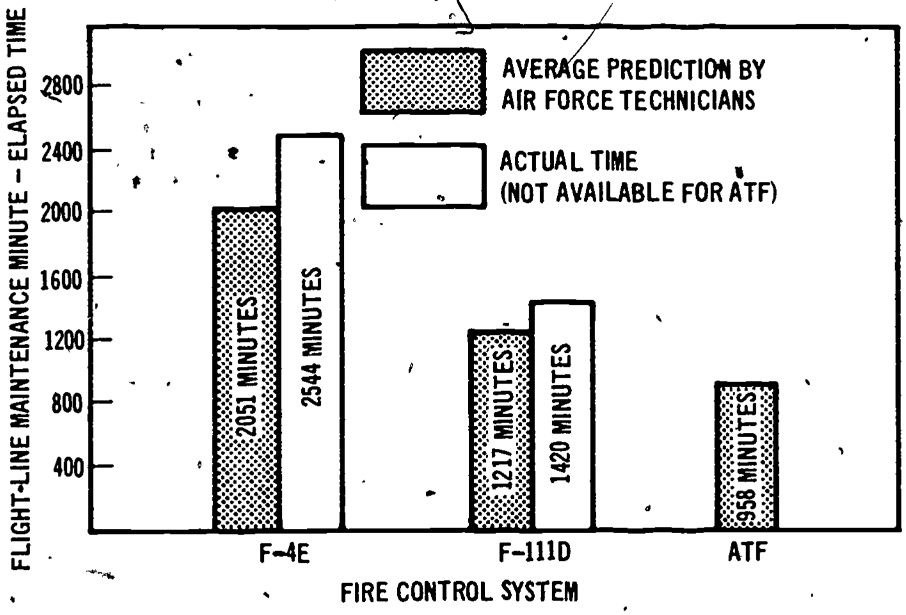


TABLE 17

PERCENT DEVIATION OF MEAN PREDICTED TIMES FROM ACTUAL TIMES TO PERFORM FLIGHT LINE MAINTENANCE

System	Deviation of Mean Predicted from Actuals
F-4E Autopilot	8.3% Greater
F-111D Autopilot	66.8% Less
F-4E Fire Control	19.4% Less
F-111D Fire Control	14.3% Less
Mean Deviation	29.4% Less

<u>Accuracy of predicted career field, skill level, and crew size</u>. Little variation within rating groups occurred with regard to prediction of Air Force Specialty Code (career field), skill level or crew size. In all cases the avionics career field was listed. Skill levels were set at a mix of 3 and 5 levels. Crew sizes for most flight line maintenance tasks were set at 2 men. These data matched almost perfectly the actual flight line manning as reported by the maintenance supervisors (Table 18) at the operational units. The Air Force's maintenance philosophy and safety program tends to set minimum crew

TABLE 18

COMPARISON OF PREDICTED AND ACTUAL FLIGHT LINE CREW SIZES AND SKILL LEVELS FOR SELECTED F-4E AND F-111D MAINTENANCE TASKS

HRD ITEM	AUTOPILOT SYSTEM				FIRE CONTROL SYSTEM			
	F-4E		F-111D		F-4E		F-111D	
	Estimated	Actual	Estimated	Actual	Estimated	Actual	Estimated	Actual
Average Skill Level	4.2	4.5	4.0	3.8	4.0	4.6	4.5	4.2
Average Number	2.1	2.4	2.2	2.6	1.9	2.0	2.0	2.1

sizes for specific tasks at 2 men. The accuracy of the predictions in this area of human resource requirements may be interpreted as an awareness on the part of the technicians of the way in which the Air Force provides manpower for maintenance on avionics systems. This knowledge of the Air Force policy regarding assignment of career field, skill level and crew size resulted in highly accurate predictions of personnel requirements for field maintenance activities.

Critiques of engineering data packages. The stimulus data packages for the autopilot and fire control subsystems for the F-4E, F-111D and ATF aircraft contained data set to the conceptual phase of hardware design. Air Force technicians, who made human resource predictions were asked to critique the completeness of the data package in a follow-on interview. They were asked to make suggestions as to how the data package could be improved so as to improve their confidence in the human resources estimates they made. Tables 19 and 20 summarize the number of times a given category of information was mentioned as needing more detail or needing to be more fully explained. Approximately half the technicians mentioned that there was some information that was of little or no interest to them when making their predictions. Data on aircraft flight parameters, general fuselage and propulsion descriptions, and performance envelopes were considered "nice to know" but not particularly relevant to the prediction task.

With regard to data packages on the autopilot systems, the lack of detailed information on component locations and access requirements was most frequently mentioned as hampering the accuracy of task completion time forecasts. This could be corrected by using a drawing of the fuselage and illustrating the proposed location of system components.

Descriptions of type and need for aerospace ground equipment (AGE) such as electrical and hydraulic power units, air conditioning units, and special stands was listed as too general or not described. The remaining deficiencies were related to lack of information on: shop level maintenance equipment; built-in-test equipment modes, operation and test time lengths; component adjustment requirements; access panel location, number and design; fuller descriptions of components; flight-line test equipment; and a more complete explanation of system redundancy.

For the fire control system data packages the lack of detailed description of the built-in-test equipment was mentioned most frequently as lowering the confidence of human resources data predictions. The technicians also reported that additional information on component adjustment, alignment and pressurization requirements, shop level maintenance equipment, access panel location, number and design, AGE requirements, radome opening, descriptions of components, functional checkout and block diagrams would have improved their prediction of human resources requirements for the system.

TABLE 19

SUMMARY OF CRITIQUES OF ENGINEERING DATA PACKAGES FOR AUTOPILOT SYSTEMS

Information not Detailed Enough with Regard to:	F-111D Flight Control System	F-4E Flight Control System	ATF Flight Control System	Total
Component Locations and Access	5	2	6	13
Aerospace Ground Equipment Requirements	3	4	2	9
Shop Level Maintenance Equipment	2	4	2	8
Built-in Test Equipment Modes of Operation and Test Lengths	3	0	4	7
Access Panel Location, Number and Design	3	3	0	6
Component Adjustment Requirements	0	5	1	6
Flight Line Test Equipment	0	5	0	5
Descriptions of Components	2	0	3	5
Explanation of System Redundancy	2	0	2	4

TABLE 20

SUMMARY OF ENGINEERING DATA PACKAGE CRITIQUES FOR FIRE CONTROL SYSTEMS

Information not Detailed Enough with Regard to:	F-111D Fire Control System	F-4E Fire Control System	ATF Fire Control System	Total
Built-in-Test Equipment Modes of Operation and Test Lengths	5	4	4	13
Component Adjustments, Alignments and Pressurization Requirements	4	0	6	10
Shop Level Maintenance Equipment	2	5	3	10
Access Panel Location, Number and Design	3	3	3	9
Aerospace Ground Equipment Requirements	1	1	5	7
Radome Operating	3	1	2	6
Descriptions of Components	2	2	2	6
Scope and Duration of Functional Checkout Procedure	2	1	2	5
Component Locations and Access	2	1	2	5
A Functional Block Diagram	1	1	1	3

Development of future data packages for use as stimulus materials. The critiques obtained from the technicians can be used to form a picture of what a good data package should include. The items presented in Tables 19 and 20 point out specific subjects that should be addressed in detail by the data package. The type of illustration contained in Figure 5 would be a suitable format for presenting information on component location.

The feasibility of applying the guidelines for conceptual design data packages remains to be demonstrated. It is possible that the level of detail requested for test equipment operation, the exact location of a component, and the relative locations of other system hardware (such as hydraulic lines) would not be available at the conceptual phase.

Qualifications of personnel making human resource data predictions. Most of the technicians who participated in making the time estimates felt that the approach was valid and should be expanded. During the course of the interviews several suggestions were made on how the accuracy of predictions might be improved. The generation of a more complete package of equipment characteristics was one such area and was discussed above. The careful selection of experienced technicians was another. Based upon the experience gained in this study, the following qualifications should be applied to technicians who make human resource predictions from design engineering data packages: (1) recent field experience in performing maintenance on subsystem equipment with design characteristics similar to the conceptual system being studied, and (2) high aptitude technicians should be utilized. The forecast procedure involves formulating subjective assumptions that appear easier for high aptitude technicians to make. In addition, technicians should be motivated to participate in the predictive process and be assured that their opinions will be given serious consideration.

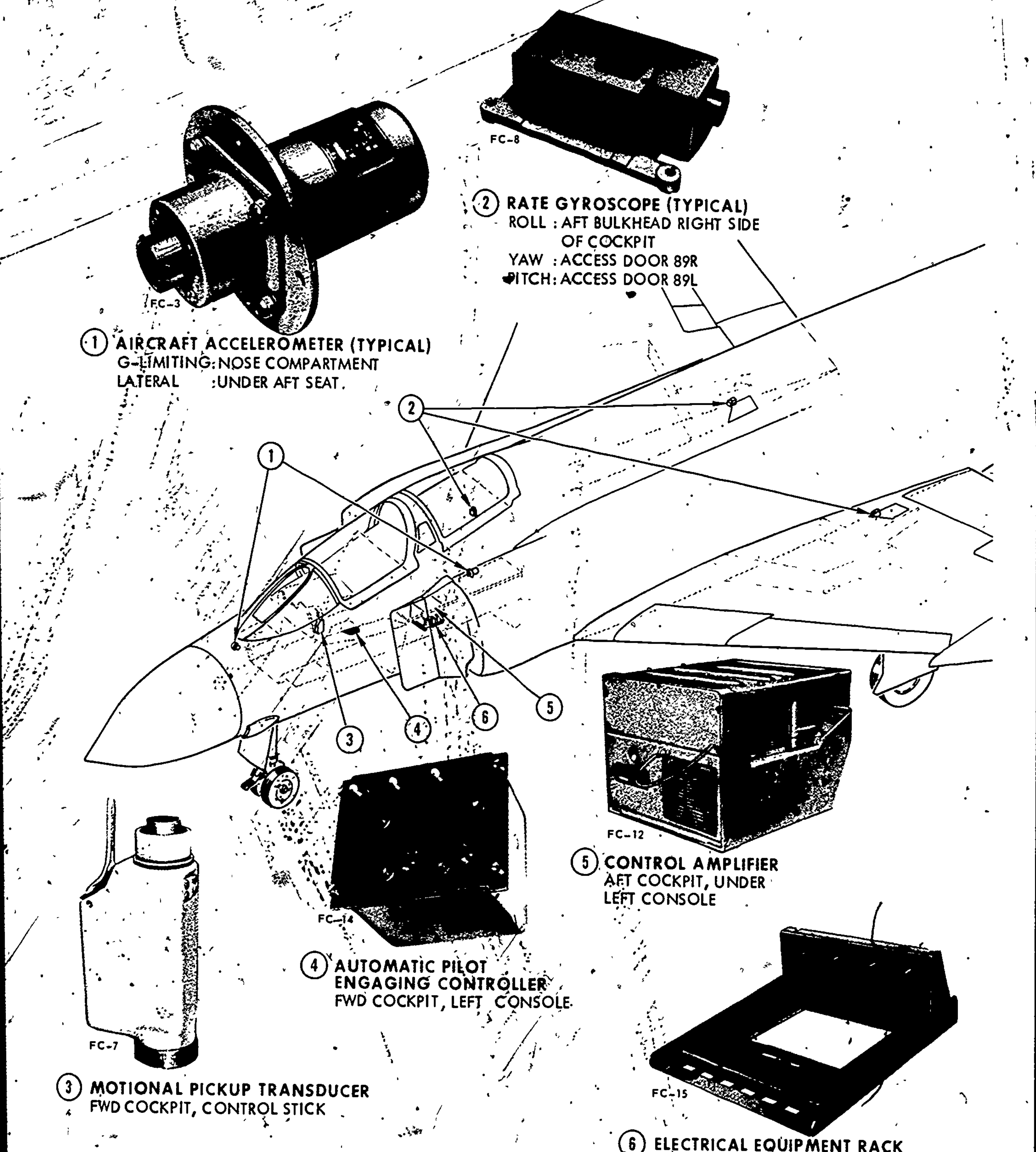
Summary and Discussion

This part of the study was concerned with checking the accuracy of subjective predictions of human resource requirements for avionics equipment still in the conceptual phase of design. The intention was to determine the validity of using experienced technicians as a source for human resource data that could then be used by a design engineer to form design trade-off decisions.

The approach used was to develop conceptual phase engineering packages to serve as stimulus materials for subjective estimates of human resource data items. Experienced Air Force avionics technicians made the estimates, and were then interviewed for their opinions of the approach as well as the completeness of the stimulus materials.

The subjective estimates were checked for accuracy by comparing them with data reported by avionics shop supervisors. Overall the technicians underestimated flight line maintenance task times by 29.4%. In addition, the predictions of crew size, specialty code and skill levels were found to be highly accurate.

FIGURE 5 COMPONENT LOCATION



① AIRCRAFT ACCELEROMETER (TYPICAL)
G-LIMITING: NOSE COMPARTMENT
LATERAL : UNDER AFT SEAT.

② RATE GYROSCOPE (TYPICAL)
ROLL : AFT BULKHEAD RIGHT SIDE OF COCKPIT
YAW : ACCESS DOOR 89R
PITCH: ACCESS DOOR 89L

③ MOTIONAL PICKUP TRANSDUCER
FWD COCKPIT, CONTROL STICK

④ AUTOMATIC PILOT ENGAGING CONTROLLER
FWD COCKPIT, LEFT CONSOLE

⑤ CONTROL AMPLIFIER
AFT COCKPIT, UNDER LEFT CONSOLE

⑥ ELECTRICAL EQUIPMENT RACK
AFT COCKPIT UNDER LEFT CONSOLE

It is most probable that the predictive accuracy of the human resources data could be improved still further by altering the procedure used to collect the data. Some suggested procedural changes are: more thorough briefing of technicians on the subsystem; discussions between design engineers and the technicians who do the rating in the subsystem of interest (especially with regard to airframe design and characteristics of access point locations); and, cross-talk and time for detailed discussions among technicians. A major consideration that accounts for disparities between predicted task times and actual times are the numerous and sometimes major alterations between conceptual designs and full scale production models. This aspect probably cannot be accounted for when using the subjective estimation technique.

The results should be interpreted as a preliminary indication that experienced technicians can and will make reasonably accurate estimates of several human resource data items based upon conceptual phase design information.

SUMMARY AND CONCLUSIONS

Two questions were addressed by the study: (1) Can design trade studies with potential impact on human resource requirements be identified and categorized? and, (2) What is the accuracy of subjective estimates of the impact of design alternatives on human resource requirements?

In an attempt to identify and categorize trade studies that have bearing on the human resources of a weapon system, a descriptive case history approach was utilized. F-15 aircraft design trade studies were reviewed and analyzed for potential influence on personnel variables. Those judged to have influence were further analyzed to determine where commonality existed. The degree of technological disparity between design study alternatives emerged as an important factor in setting human resources impact. An independent evaluation of technological differences between trade study alternatives lent confirmation to the hypothesis that distinctive technologies should be closely examined for human resource implications. Prime human resource considerations were found to be maintenance task completion times and personnel costs.

At the present time in aerospace hardware development, the avionics system emerged as the system area with the greatest concentration of design decisions with impact on maintenance task times and personnel costs. This system represents a rapidly moving technology, and should, more so than the other system areas examined, take into consideration the man-related implications of equipment configuration and design.

The second question dealt with accurate forecasts of human resource needs based upon conceptual designs and engineering descriptions. Experienced technicians made estimates of maintenance task completion times, numbers of personnel, skill levels, and career fields that would be required to support several avionics systems.

A comparison of the human resource predictions with the criterion data showed that experienced technicians could respond to conceptual descriptions of avionics systems with sufficiently accurate estimates of maintenance task times, crew sizes, specialty codes and skill levels to justify use of these data in engineering design studies. The predictive accuracy of subjective estimates might be further enhanced by developing more detailed conceptual engineering packages, altering the procedures followed when making predictions, and better controlling the characteristics of the technicians (such as experience and ability) asked to make the forecasts.

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Askren, W. B. and Korkan, K. D., Design Option Decision Trees. A Method for Relating Human Resources Data to Design Alternatives. AFHRL-TR-71-52, December 1971. AD-741 768.

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APPENDIX A

SYSTEM ENGINEERING TASK STATEMENT

COG. ENGR ____________________

SYS ENGR ____________________

APPROVED ____________________

APPROVED ____________________

REPORT ____________________

MODEL ____________________

DATE ____________________

SYSTEM ENGINEERING TASK STATEMENT
TRADE-OFF STUDY PROCEDURE

TITLE

PURPOSE

A brief statement defining the objective (the "what") of the study, i.e., feasibility study of--, evaluate methods of--, define requirements for--, etc.; the reason (the "why") for conducting the study, i.e., satisfy requirements for--, practical applications--, determine the effect (or effectiveness) of--, provide improvements--, etc.; and the affect of the study on W/S performance, i.e., mission definition/effectiveness, air vehicle performance, crew effectiveness, subsystem interfaces/interrelationships, equipment selection etc.

BREVITY and CONCISENESS throughout this form are required to demonstrate your understanding of the proposed study and provide management with justification for allocating budget.

BASELINE/ALTERNATIVE SOLUTIONS

State the baseline configuration and the alternative solutions selected for study. Tabulate these for ease of identification and evaluation. Proposed solutions must be briefly stated yet definitive. Two or more solutions must be identified to qualify as a trade study, i.e., baseline plus one or more alternatives, or two or more alternative solutions (baseline TBD).

FUNCTIONS/SYSTEMS/DATA INVOLVED IN THIS STUDY

Functions: a. Tabulate all applicable functions from System Engineering's functional block diagrams.

b. In the absence of inputs from functional block diagrams, define the function(s) of the subject of the study. (Use the verb - adjective (if required) - noun form for functional definition, example: drop torpedo, provide altitude data.)

Systems; Tabulate the systems/subsystems which interface with this study or will be affected by the results of this study.

Data: Tabulate in outline heading form, (1) the data inputs required from supporting organizations, customer, and/or suppliers to complete this study. These data include analyses, parametric plots, layouts, inputs, for weight, maintainability, safety, reliability, cost, etc., supplier proposals/data and so on, and (2) applicable existing documents, i.e., MIL Specs, drawings, reports etc.

Enter the date that the decision resulting from this study is required by the

REQUIRED STUDY COMPLETION DATE cognizant (requesting) engineer to meet his scheduled commitments.

STUDY SUPPORT REQUIRED FROM:

☐ STRENGTH
☐ LOADS
☐ WEIGHTS
☐ STRUCTURAL DYNAMICS
☐ GUIDANCE & CONTROL MECH
☐ AERODYNAMICS
☐ HUMAN FACTORS
☐ ENGG LABORATORIES
☐ THERMODYNAMICS
☐ OPERATIONS ANALYSIS
☐ MAINTAINABILITY ENGG
☐ LOGISTICS ENGG
☐ AGE ENGG
☐ ENGG RELIABILITY
☐ FLIGHT TEST
☐ ELECTRICAL ENGG
☐ ELECTRONIC SYSTEMS ENGG
☐ STRUCTURAL ENGG
☐ MECHANICAL ENGG
☐ PROPULSION
☐ FLUID SYSTEMS ENGG
☐ AUTOMATION CO.
☐ SAFETY ENGG
☐

FACTORS INFLUENCING EVALUATION

Tabulate the factors which will become pertinent in evaluating the merits of the alternatives under study. Typical factors include mission effectiveness, performance factors, cost, safety, weight, installed volume, schedule fabrication/procurement problems, testing, logistics, crew interface problems, reliability, maintainability, support requirements, etc.

EXPECTED RESULTS

Summarize briefly the expected results or gain from the study for the VS(X) program. "Results" include as applicable, (1) the probable superiority of the baseline or of alternative solution "n", (2) the influence the decision may have on interfacing subsystems, (3) the nature of the impact on performance, M & R, revisions to customer data requirements, cost, etc., (4) the possible need for associated trade studies, and (5) procurement/design specification requirements. "Gain" includes the negation of the estimated consequences of making the wrong selection.

TASK DEFINITION

Task definition consists of two parts as follows:

1. Statement of Ground Rules: List all of the constraints, factors held constant, common denominators, etc., which form the premise for conducting this study.
2. Statement of Work: Briefly state in outline form the tasks of the supporting organizations. Enter them as separate line items to facilitate project evaluation and scheduling.

TOTAL MANHOURS REQUIRED:________________ STUDY START DATE ____________

Enter manhours required for your discipline to support the study.

APPENDIX B

TITLES OF F-15 TRADE STUDIES

TITLES OF F-15 TRADE STUDIES
(1968)

Evaluation of Arresting Hook Configuration
Evaluation of Trailing Edge Flap Actuation
Evaluation of Wing Fuel Tank Drainage Provisions
Evaluation of Leading Edge Flap Actuation Methods
Evaluation of Brake Heat Sink Material
Evaluation of Wing-to-Fuselage Splice
Evaluation of Nuclear Survivability/Vulnerability
Evaluation of Structural Strength Level
Evaluation of Maneuver Load Factor
Evaluation of Field Shop Automation Control
Evaluation of Trainer and Training Equipment - Maintenance Training Equipment
Evaluation of Trainer and Training Equipment - Aircrew Training Equipment
Evaluation of Additional Hard Points - Armament Suspension
Evaluation of Auxiliary Power Units (APU)
Evaluation of Cockpit Noise Reduction
Evaluation of Lubrication and Cooling System for the Airframe Mounted Accessory Drive System (AMADS)
Evaluation of Oxygen System
Evaluation of Canopy Transparent Enclosure
Evaluation of Canopy Actuator Concepts
Evaluation of Canopy Motion Concepts
Evaluation of Windshield Transparent Enclosure
Evaluation of Gun Placement
Evaluation of Flight Control System Design Concept
Evaluation of Optimal Allocation of Subsystem MTBFs
Evaluation of Quantitative and Qualitative AGE Determination
Evaluation of Hydraulic Reservoir Design
Evaluation of Hydraulic Filters
Evaluation of Hydraulic System Cooling Methods
Evaluation of Hydraulic Tubing and Fittings
Evaluation of Hydraulic System Configuration
Evaluation of Leading Edge Flap Mechanization
Evaluation of Rudder Pedal Adjust System
Evaluation of Low Stage Bleed Air vs. Low and High Stage Bleed Air
Evaluation of Flight Vehicle Power Extraction Method
Evaluation of Engine Combat Damage Protection Methods
Evaluation of Flight Control System Precision Flying
Evaluation of Tactical Nuclear Weapon Delivery Capability
Evaluation of Voice Warning Hazard Alerting System
Evaluation of Integrated CNI Control and Displays
Evaluation of Cockpit Lighting
Evaluation of Red Line Display
Evaluation of Fire Resistant Hydraulic Fluid
Evaluation of Emergency Systems
Evaluation of Engine Configuration and Envelope
Evaluation of Foreign Object Damage Protection
Evaluation of Fuel System Configuration

Evaluation of Aircraft Oil Cooling System Hydraulic and Lubrication
Evaluation of In-Flight Refueling Receptacle Location
Evaluation of Use of Bleed Air from APU for Ground Cooling Chart
Evaluation of Design, Construction and Materials
Evaluation of In-Flight Monitoring (IFM) of Non-Avionic Systems
Evaluation of Environmental Control Systems - Use of Hot Air vs. Electrical Conductive Coating for Defogging the Windshield
Evaluation of Environmental Control System - Use of Compressor Discharge Air vs. Interstage Bleed and Compressor Discharge Air for the Environmental Control System
Evaluation of Environmental Control System - Simple Air Cycle vs. Bootstrap Air Cycle
Evaluation of Environmental Control System - Area Modulation and Thrust Recovery Outlets vs. Fixed Simple Outlet in the Ram Circuit of the Air Cycle System
Evaluation of Environmental Control System - Use of Bleed Air for APU, for Ground Cooling vs. Use of Ground Cooling Cart vs. Use of Internal Blowers
Selection of Test Bed Airplane for F-15 Avionics Development
Evaluation of Escape System - Ejection Seats vs. Escape Capsule
Evaluation of Fuel Booster Pumps
Evaluation of Fuel Quantity Gaging Methods
Evaluation of Fuel Tank Inerting System
Evaluation of Smoke Detection Methods
Evaluation of Thrust Reverser/Controller vs. Speed Brake
Evaluation of Optimum Aerodynamic Systems Concept
Evaluation of Stability and Control Requirements
Evaluation of Back-Up Starting Methods
Evaluation of Modular Gun System Concept
Tactical Electronic Warfare System Analysis
Integrated CNI Antenna Analysis
Evaluation of Integrated CNI Controls and Displays
Evaluation of Build-In Test Equipment (BITE)
Evaluation of Navigation Subsystem
Evaluation of Electro-Optical Identification Tracking (EOIAT)
Evaluation of IFF (APX 81 Type)
Evaluation of Helmet Mounted Sight
Evaluation of Crash Data Recorder
Evaluation of Fire Control System
Evaluation of Engine Oil Tank Location
Evaluation of Communication Systems
Evaluation of Identification System
Evaluation of Avionics Interfaces
Additional Longitudinal and Lateral Control Trade-Off
Evaluation of Radar Dish Diameter
Avionics Interface and Computational Analysis
Supersonic Tank Trade Study
Configuration Trade-Off
Evaluation of Gun Sight Camera/Video Recorder
Evaluation of Flight Control Servo Actuator Configuration
Pitot Boom Location

Supplemental Heat Sink-Water vs. Regenerative Air vs. Fuel
Boresight Technique Selection
Evaluation of Inflight Engine Restarting Methods
Electric Generating System
IR Suppression Trade-Off
Exhaust Nozzle Configuration Trade-Off
Air Induction Configuration Trade Study
Engine Evaluation Studies
Base Drag Reduction Studies
Inlet Aspect Ratio Trade Study
Nozzle Jet Impingement/Expansion Ratio Study
Cascade vs. Alternate Type Thrust Reversers
Bypass, Spill, Bleed Trade-Off
Bypass vs. No Bypass System
Inlet/Engine Anti-Icing Study
Inlet Ramp Scheduling Trade Study
Engine Scaling Effects
Engine Flexibility
Manufacturing Test Equipment Trade
Evaluation of AMAD Configuration
Evaluation of Wing Splices
Evaluation of Engine Installation/Removal/Transportation AGE
Methods of Providing Avionics Ground Cooling
Aircraft Weight Penalties vs. Avionics Cooling Capacity
Windshield Washer Requirements for Removal of Insects and Salt
Engine Build-Up/Q.E.C. Kits
Evaluation of Torque Box Joint Design and Skin Fabrication Methods - Inbdend
Evaluation of Aileron Actuation
Evaluation of F-15 Canopy Jettison System
Evaluation of APU Inlet and AMAD Ventilation
Evaluation of Windshield Support Structure
Canopy Normal Actuation System Trade Study
Forward Fuselage to Center Fuselage Splice
Inlet First Ramp Actuation Study
Center and Aft Fuselage Splice
Stabilator Hinge Line Location Trade Study
Escape System Initiation Trade Study
Emergency Stabilator Power
Efficiency, Cost, and Time Reduction of Engine Installation Provisions
Alternate Emergency Hydraulic Power Schemes

APPENDIX C

ENGINEERING DATA PACKAGE WHICH DESCRIBES THE CONCEPTUAL DESIGN OF THE FIRE CONTROL SYSTEM FOR THE ADVANCED TACTICAL FIGHTER

DIRECTIONS

McDonnell Douglas Corporation is under contract with Air Force Systems Command to identify and evaluate approaches that may be used to better estimate manpower requirements associated with avionics subsystem hardware designs. One approach under consideration is to have experienced avionics technicians review an avionics subsystem and then comment on the probable number and types of personnel that will be needed to maintain it.

The information contained in this booklet describes an avionics subsystem. Based upon the equipment design, functions and physical characteristics, you will be asked to estimate the probable time that will be required to perform common maintenance tasks. We would also appreciate having your opinion of the AFSC, skill level and training that would be needed to match maintenance personnel with equipment characteristics.

Please read the technical description. When you feel that you have a fair understanding of the equipment, indicate to the Study Investigator that you are ready to comment on the subsystem. For purposes of this study, we would prefer to have you form your opinions independently, without the benefit of discussion with other technicians.

Finally, we want to thank you for your cooperation. If you have any questions on the procedure to be followed or the intention of the study, please direct them to the Study Investigator at this time.

NOTE

This information is based on conceptual design phase data and it not intended to reflect the actual system performance in the field.

1.0 GENERAL DESCRIPTION

The aircraft is a single place, twin engine, supersonic, all-weather, tactical, fighter-bomber. Prime mission weapons are: two 2000 lb guided weapons; two short range missiles; and one 25mm internal gun with 700 rounds of ammunition. The propulsion system consists of two mixed-flow turbofan engines with afterburners. The approximate overall dimensions of the aircraft are:

Span:	37 feet, 7 inches
Length:	72 feet
Height:	17 feet, 2 inches.

The approximate weights of the aircraft are:

empty operating weight - 28,810 pounds
operating weight - 56, 540 pounds.

The aircraft performs offensive tactical missions in a challenging defense environment. The aircraft's stability characteristics rely upon the flight control system to provide artificial dynamic stability and positive control of the airplane. As a control configured vehicle (CCV), the aircraft relies heavily upon the avionic computer for the systematic analysis and synthesis techniques demanded by the multi-variable system. The computer performs optimal and suboptimal gain calculations and provides the control outputs to the flight control system. A CCV results in relaxed static stability requirements for the aircraft and offers the following benefits:

- reduced control surface size
- reduced trim requirements and
- improved maneuverability.

INTRODUCTION

The ATF radar is a compact, highly reliable coherent air-to-ground radar with additional capability for air-to-air search and target track. Physically, the radar incorporates proven, advanced high density packaging techniques resulting in a basic radar configuration in the 350 ground category. Excellent reliability is achieved through maximum utilization of digital circuitry in the form of full wafer LSI, conventional hybrids and integrated circuit designs. The system incorporates a Built-In-Test (BIT) system which provides a continuous measure of system performance as well as fault isolation capability.

The system provides the following air-to-ground capabilities:

(1) Real Beam Ground Map

(2) Air-to-Ground Ranging

(3) Navigation System Update

(4) Synthetic Aperture Map

(5) Ground Moving Target Indication/Track

(6) Terrain Clearance

(7) Terrain Avoidance.

Ground Map - A real beam, 80, 40, 20 or 10 mile ground map is included in the baseline design. Improved range resolution is provided in the system through pulse compression means.

Air-to-Ground Ranging - In this mode, the radar is slaved to the target designator symbol which appears on the VHUD. The position of the symbol can be controlled by the force controller throughout the VHUD field of view. The radar measures the range along the boresight to the target utilizing the elevation monopulse difference signal as a range discriminant. The range measurement is entered into the weapon delivery computer by depressing the action switch.

Navigation System Update - Angle and range information utilized by the navigation computer can be updated by using cursor displacement signals and the ground map. The cursor is positioned initially by the navigation computer to a reference point on the display: the error as measured by the radar can be reduced by manually positioning the cursor to the radar detected reference point. The new range and azimuth coordinates are entered into the navigation system by depressing the radar action switch.

Synthetic Aperture Map - Synthetic aperture radar (SAR) utilizes coherent doppler gradient processing across the antenna beamwidth to achieve azimuth resolution significantly improved over that which could be achieved from conventional brute force processing across the real beam. Two different synthetic aperture modes are provided; a doppler beam sharpened (DBS) mode and a squinted spotlight mode.

The DBS mode provides 10:1 improvement in the azimuth resolution over the forward sector 10° to 45° off the velocity vector either side in a forward sector scanning mode. This is illustrated in Figure 1. The DBS mode processed video would be displayed on a sector-scanned PPI type display format.

The squinted spotlight SAR mode provides constant azimuth resolution independent of range and fixed range resolution resulting from pulse compression. This mode can be used for passing scene mapping where the antenna is held at constant squint angle or map a fixed ground sector by scanning the antenna. This SAR mode could be used over squint angles from 30° to 90°. The number of looks refers to the number of map images which are non-coherently summed to alleviate target scintillation and homogenous terrain intensity variation.

Ground Moving Target Indication/Track - Ground moving target detection and tracking is provided by this mode.

Terrain Clearance - A method of sensing a terrain profile in a vertical corridor, the computation and display of maneuver templates that can be superimposed upon the radar data as a visual warning and the generation of vertical steering commands to the pilot is provided.

Terrain Avoidance - A manually selected mode including radar sensing and display to aid the pilot in manually controlling the aircraft so as to avoid terrain features projecting above the clearance plane.

The following air-to-air modes are provided:

Air-to-Air Search - The radar is mechanized to search a wide volume (± 90° x ± 60°) with 1, 2 or 4 bar scan. The operator may select the scan width and number of bars and position the search pattern anywhere within the antenna gimbal limits. During search, unambiguous range and angle are presented to the pilot on a clean (clutter free) display by processing programmed multiple PRFs during the time-on-target throughout the entire search volume.

Acquisition and Track - Target acquisition (or radar lock-on) is initiated through use of a range and azimuth cursor and a computer controlled auto-acquisition scan. After the cursor is manually positioned to the approximate range and azimuth of the target, a depression of the acquisition switch causes the radar to acquire automatically the designated target. Angle, range, and

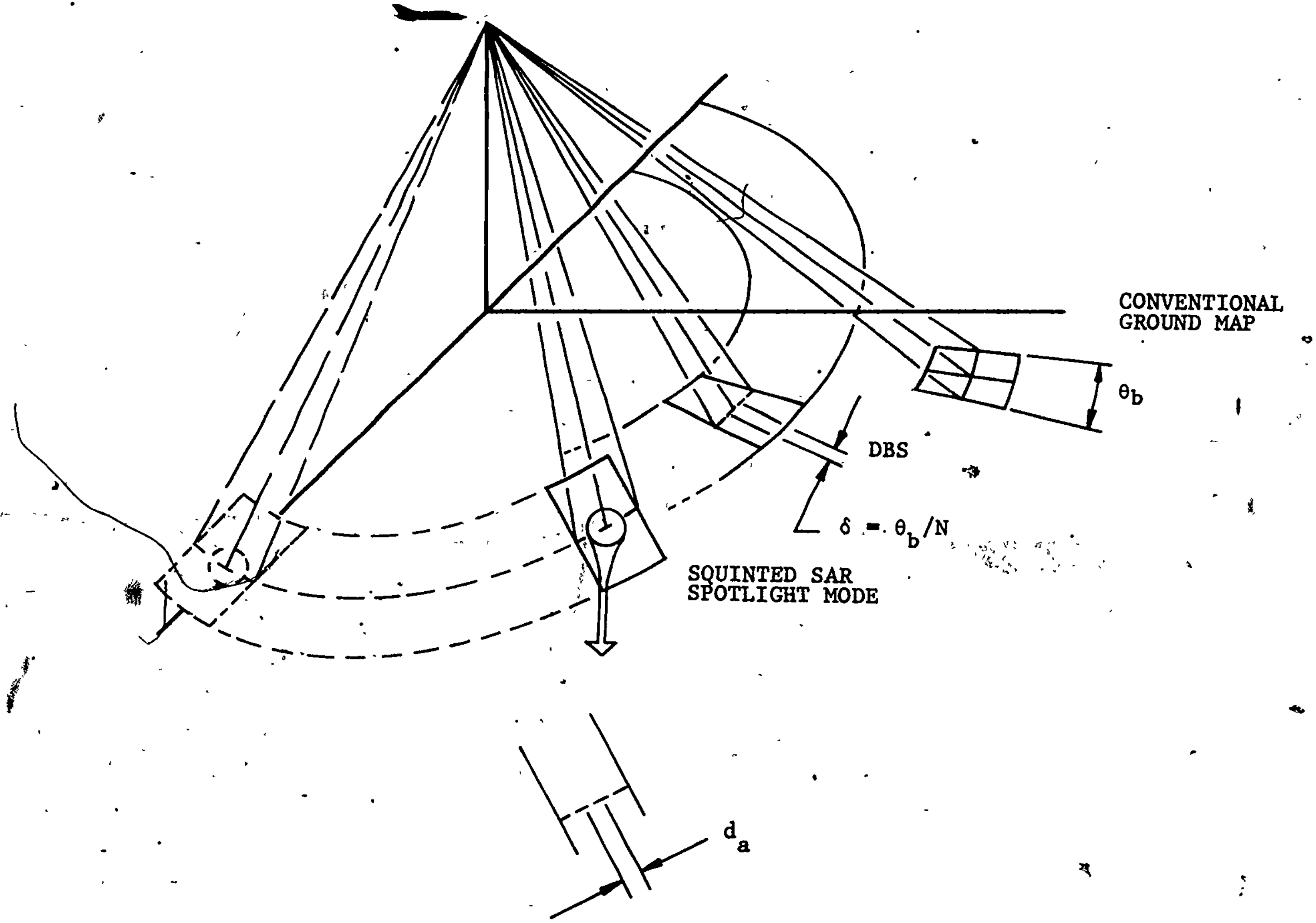


FIGURE 1

GROUND MAPPING MODES

velocity tracks are achieved within two seconds. Target illumination, prelaunch timing signals, and tracking data needed for employment of the Sparrow missile is incorporated into the system.

Dogfight - The dogfight mode is designed to provide a head-up acquisition and attack capability. Depressing the dogfight switch causes the antenna to automatically scan a 20° x 20° volume centered along armament boresight. A symbol is presented on the HUD at the target look angle, permitting the pilot to verify visually that the radar is locked on to the desired target.

INSTALLATION

The system consists of six Line Replaceable Units (LRUs) as given in Table I. The radar antenna installation is shown in Figure 2. The transmitter and receiver/exciter are installed directly behind the antenna and the remaining LRUs are installed in the avionics compartment below the cockpit. Radar parameters are contained on Table II.

TABLE I

LRU	WEIGHT
Antenna	55 Lbs
Transmitter	165 Lbs
Radar Signal Processor	40 Lbs
Radar Data Processor	23 Lbs
Receiver/Exciter	41 Lbs
Low Voltage Power Supply	26 Lbs
	350 Lbs

Prime power is estimated to be 8600 watts. Liquid cooling will be required for the transmitter. Forced air cooling will be required for all other units except for the antenna which will be free connection cooled.

ANTENNA

The antenna is a 24 inch diameter circular X-band planar array incorporating a sum and difference network to provide a monopulse capability and six dipole elements to provide an IFF capability.

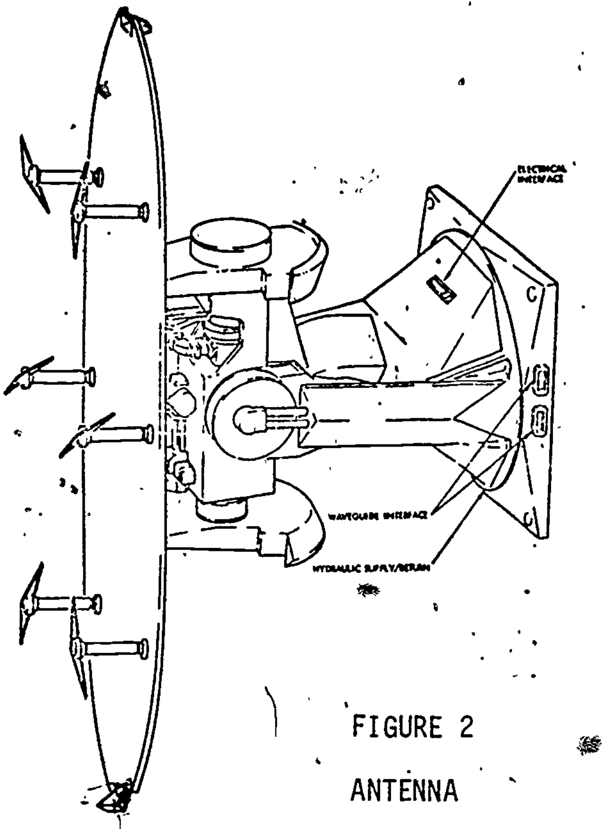


FIGURE 2

ANTENNA

TABLE II

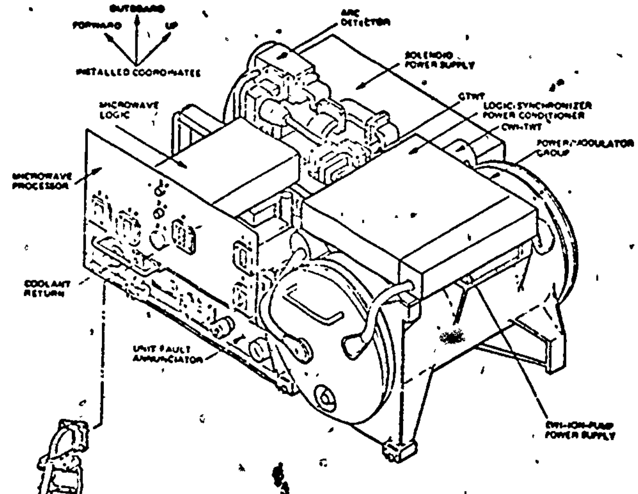
RADAR PARAMETERS

RF Frequency	X-Band
Antenna	
Type	Planar Array
Diameter	24 Inch
Gain	33.8 db
Beamwidth	3.8°
Scan Limits	± 90° (AZ) x ± 60° (EL)
Average Transmitter Power	800 Watts
PRF	
Low	0.8 - 4 KHz
Medium	8 - 17 KHz
Noise Figure	2.5 db

The function of the planar array is to receive a high-power X-band RF signal from the radar transmitter and to radiate a narrow beam for target illumination. Radar echoes are received and routed through the microwave processing circuitry of the antenna. Three signals (a sum, an elevation difference, and an azimuth difference) are obtainable from the planar array sum-and-difference network on receive, so that two-plane monopulse capability is provided. These signals are combined within the microwave processing circuitry to provide a signal from which angular tracking information is available.

TRANSMITTER

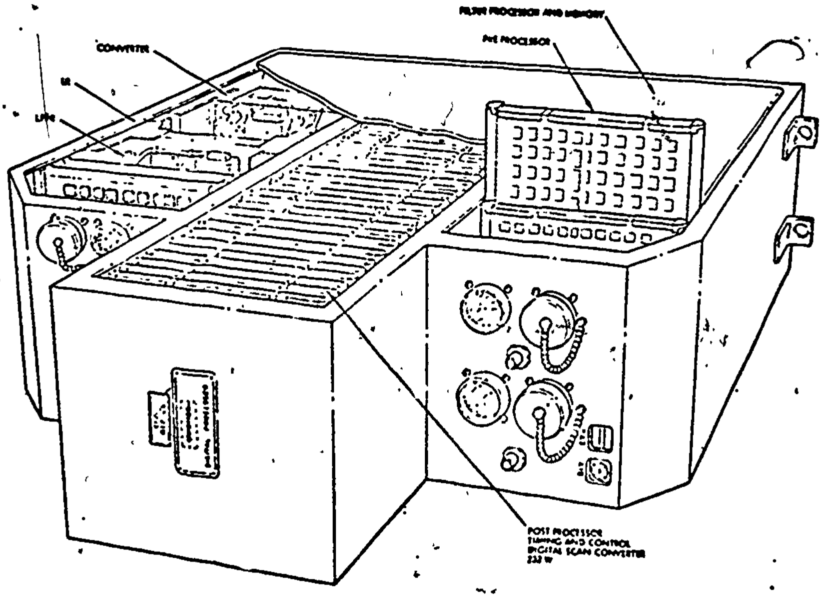
The primary function of the transmitter is to amplify and modulate the X-band signals suitable for transmission through the antenna for the principal radar functions. A gridded traveling wave tube (GTWT) is utilized as the final amplifier for the pulsed radar signals. A CW traveling wave tube provides continuous wave RF signals for AIM-7E and F Sparrow Missile illumination. TWT power supplies and protection circuitry, modulators, transmitter control circuitry and various related microwave components are located in this unit. Both the GTWT final amplifier and the CW TWT are liquid cooled. The high power portions of the waveguide, up to the multipactor, are pressurized.



TRANSMITTER

RADAR SIGNAL PROCESSOR

The radar signal processor provides range gating, doppler filtering, post-detection processing, and timing and control functions. The synthetic aperture processing of the digital signals for the high resolution ground map mode and the GMTI processing are performed within this LRU. The range gated doppler filtering required for the medium PRF air-to-air modes is included in this unit. In addition, the digital processor provides low PRF outputs for air-to-air pulse operation, air-to-ground mapping, and air-to-ground ranging operation. During tracking and air-to-ground ranging, the monopulse signals are processed and gated to the RDP where angle, range, and doppler errors are derived. The digital processor includes a timing and control function that provides the basic radar clock for range gating, processor timing, and medium PRF generation; in addition, it provides synchronization for changes in RF frequencies.



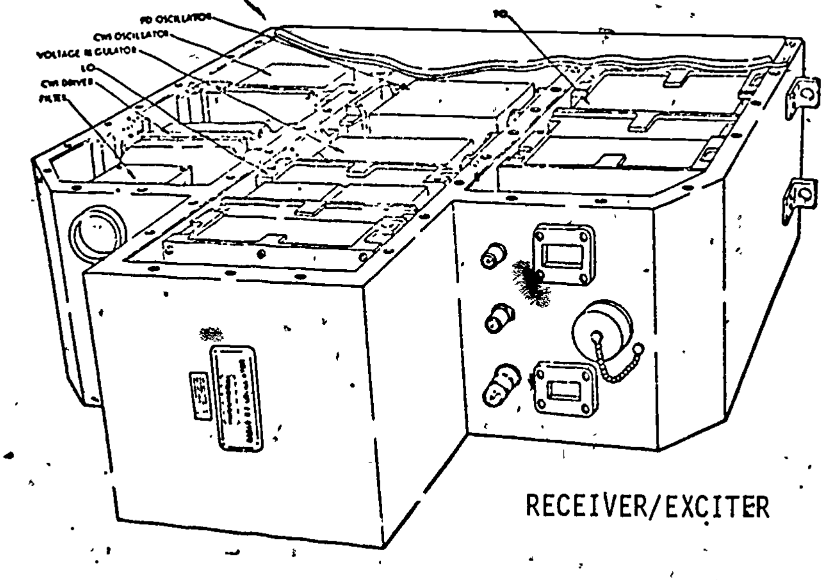
RADAR SIGNAL PROCESSOR

RECEIVER/EXCITER

The Receiver/Exciter LRU performs the low noise amplification and conditioning of the received signals and provides the coherent local oscillator signals and RF drive signals for the transmitter.

The radar receiver portion performs low noise amplification and signal conditioning on low level X-band energy reflected from the target and received by the antenna group. The receiver configuration is primarily governed by the requirement for a parametric amplifier and two-channel monopulse capability. By various combinations of microwave and IF switching, the receiver provides three distinct operational capabilities: (1) low noise parametric amplifier and two-channel monopulse receiver. The low noise parametric amplifier operation is provided in the sum (Σ) channel only. To ensure wideband monopulse performance, identical components are used, where possible, in the two channels.

The exciter provides phase coherent, low noise, RF drive for the gridded traveling wave tube (GTWT) and CW RF drive for the CW TWT in the transmitter unit. This unit also generates and provides a local oscillator (LO) signal to the receiver unit. The RF oscillator is capable of tuning the transmitter drive and LO signal to any one of six radar channels in the RF band while maintaining a highly accurate frequency offset between the two signals. Six CW channel frequencies are also provided. The RF oscillator unit also provides (1) the frequency modulation ranging (FMR) for the GTWT drive, (2) coding oscillators for the AIM-7E and F missile frequencies, (3) binary phase shifter for coding the GTWT RF drive during pulse compression modes and (4) RF blanking of the GTWT drive output when commanded by the transmitter unit to prevent GTWT drive leakage during receiver listening time. Basically, this consists of six



RECEIVER/EXCITER

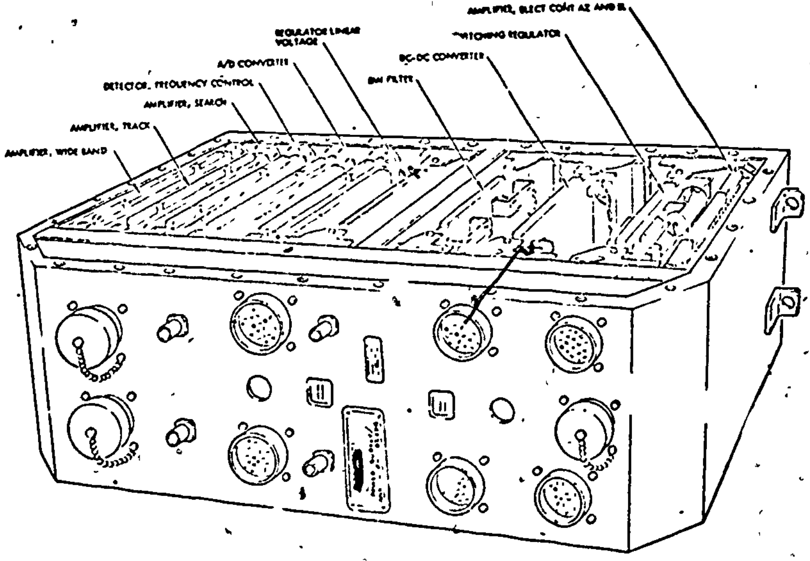
plug-in modules and a filter assembly. The modules are: (1) PD RF generator control, (2) radar RF generator, (3) LO reference generator, (4) voltage regulator and channel control, (5) CWI RF generator control and (6) CWI RF generator. All input and output signals, except those supplied through coax connectors, are filtered by individual filters located within the filter assembly.

LOW VOLTAGE POWER SUPPLY

The low voltage power supply and antenna servo electronics are combined within this LRU.

The function of the low voltage power subsystem is to convert and condition aircraft prime power to the voltage forms required by the applicable units of the radar set. This subsystem consists of three modules in the low voltage power supply unit, the power conditioner in the digital processor and thirty linear regulators located throughout the radar. The power supply processes the aircraft 115 Vac three-phase, 400 Hz power and provides eight semiregulated, two regulated, and one special dc voltage output. Linear regulators are located in the LRUs. The linear regulators provide the final regulation and ripple reduction required, as well as current limiting.

The antenna servo system is composed of a number of rotating components, mounted on the antenna gimbals, and the servo electronics, which are located in the low voltage power supply. The gimbal servos (elevation and azimuth) can be operated in either a space-stabilized or an aircraft-referenced mode. The space-stabilized mode is mechanized through the use of rate integrating gyros. The aircraft-referenced mode is provided through the use of tachometers. Azimuth and elevation positions are controlled by dc analog rate commands from the radar data processor.



LOW VOLTAGE POWER SUPPLY

BUILT IN TEST

BIT tests are designed to exercise and analyze the radar set as it normally would be used. BIT uses system functions and BIT monitors in an interwoven test design consisting of continuous monitoring by on-line devices, continuous (at the end of antenna bar and/or frame) monitoring of the selected mode and initiated testing at operator discretion. Tests are mechanized which provide the maximum test capability without weight or volume penalty or operational performance degradation.

The BIT provisions accomplish testing in all modes of operation whether in flight or on the ground. The tests are organized into software sequences which continuously test the mode of operation selected at the radar set control. Additional tests which are either on line continuously or can be intermittently initiated provide fault detection of critical element failures which would not otherwise be obvious. Operator initiated BIT tests are provided for those functional tests which would disrupt normal system operation were they automatically commanded.

The in-flight tests are designed to detect failures within the radar set, communicate the failure indication to the operator, store the test result in the RDP memory and set a latching annunciator if the failure can be isolated to a specific line replaceable unit (LRU). Failures detected in flight which cannot readily be isolated to a single LRU are fault isolated after completion of the mission. This fault isolation test makes use of additional software routines after the weight on wheels indication is received. The added tests are required only for failures which occur in difficult interfaces such as the target acquisition checks, RDP input/output interfaces or Radar Set/external avionics interfaces. Most common failures (> 80 percent of total failures) will be isolated to an LRU automatically; therefore, ground fault isolation will not be required in most cases of radar set organizational level maintenance. Fault isolation consists of special software data reduction routines which search the test result matrix for logical fault assignments by deductive reasoning.

RELIABILITY

The radar is designed to have a system reliability in excess of 63.4 hours. Experience in modern radar design and production plus advances in microcircuit technology, improved thermal design and packaging techniques, provide the basic guidelines to be employed in achieving high reliability: Standardization of parts selection is being achieved through close coordination between component specialists and responsible design activities; particular emphasis is being placed on documenting component application and derating criteria for refinement of standard parts lists. Specific MTBFs for the LRUs and system are given in Table III.

TABLE III

RELIABILITY AND MAINTAINABILITY DATA

	MTBF (Hrs)	λ	Organizational		Intermediate	
			TTR	λ x TTR	TTR	λ x TTR
Antenna	296	338	0.682	230.52	0.683	230.85
Transmitter	345	290	0.682	197.78	0.956	277.24
Radar Signal Processor	347	288	0.516	148.61	0.352	101.38
Radar Data Processor	380	263	0.516	135.71	0.441	115.98
Receiver/Exciter	485	206	0.682	140.49	0.956	196.94
Low-Voltage Power Supply	525	191	0.516	98.56	0.405	77.36
	63.4	1576		951.67		1000.36
				MTTR = 0.60 Hrs		MTTR = 0.63 Hrs

*Failure rate - percent per 1000 hrs.
TTR - Total time to repair
MTTR - Mean time to repair

MAINTAINABILITY

Maintainability design features incorporated in the radar simplify maintenance procedures as evidenced by the minimum skill level requirement of personnel and the low system mean time to repair (MTTR) at the Organizational and Intermediate levels of maintenance. The prediction for MTTR at-aircraft is less than 40 minutes where usually only one apprentice mechanic performs the maintenance tasks of replacing the faulty LRU and verify system repair. LRU maintenance in the shop is performed by mechanic level personnel who accomplish fault isolation to the shop replaceable assembly (SRA), replace the faulty item and verify repair in a mean time of less than 40 minutes. Bit and piece repair of faulty SRAs is accomplished at the Depot level of maintenance. Organizational and Intermediate level MTTRs are given in Table III.

The most significant contributor to the ease of maintenance and low MTTR at-aircraft is the built-in-test (BIT) design of the radar. The BIT mechanization enables both airborne and ground evaluation of the functional characteristics of the radar and indicates the go-no-go, status to the pilot or maintenance personnel. BIT detects 95% of radar catastrophic failures and measured out of tolerances conditions, and provides fault isolation to the WRA. BIT thus eliminates the usual lengthy fault isolation procedures associated with at-aircraft maintenance and the need for any at-aircraft test equipment. The proposed mechanization is a proven design similar to that now incorporated in current production radars.

ORGANIZATIONAL LEVEL TEST EQUIPMENT

Built-In Test (BIT) is used almost exclusively for Organizational (flight line) level support. With an absolute minimum of additional equipment, BIT is fully capable of detecting and isolating faults to the aircraft replaceable LRU and verifying repairs. No external equipment, except aircraft services, is required to operate BIT. It features both airborne and ground continuous monitoring and initiated test sequences. All failure information is preserved in computer memory for use by maintenance personnel. Only a few items, in addition to BIT, are needed to support the ARS at the Organizational level. These include handling equipment, means of measuring aircraft cabling integrity and a waveguide pressure leak detector. Failed LRUs are returned to the Intermediate level shop for repair. No harmonization or other adjustments are required when replacing an LRU at the aircraft. In many cases, the stored BIT data (BIT matrix) provides enough information to isolate below the LRU level - information that could be vital for emergency repairs or to assist shop personnel in reducing shop maintenance time.