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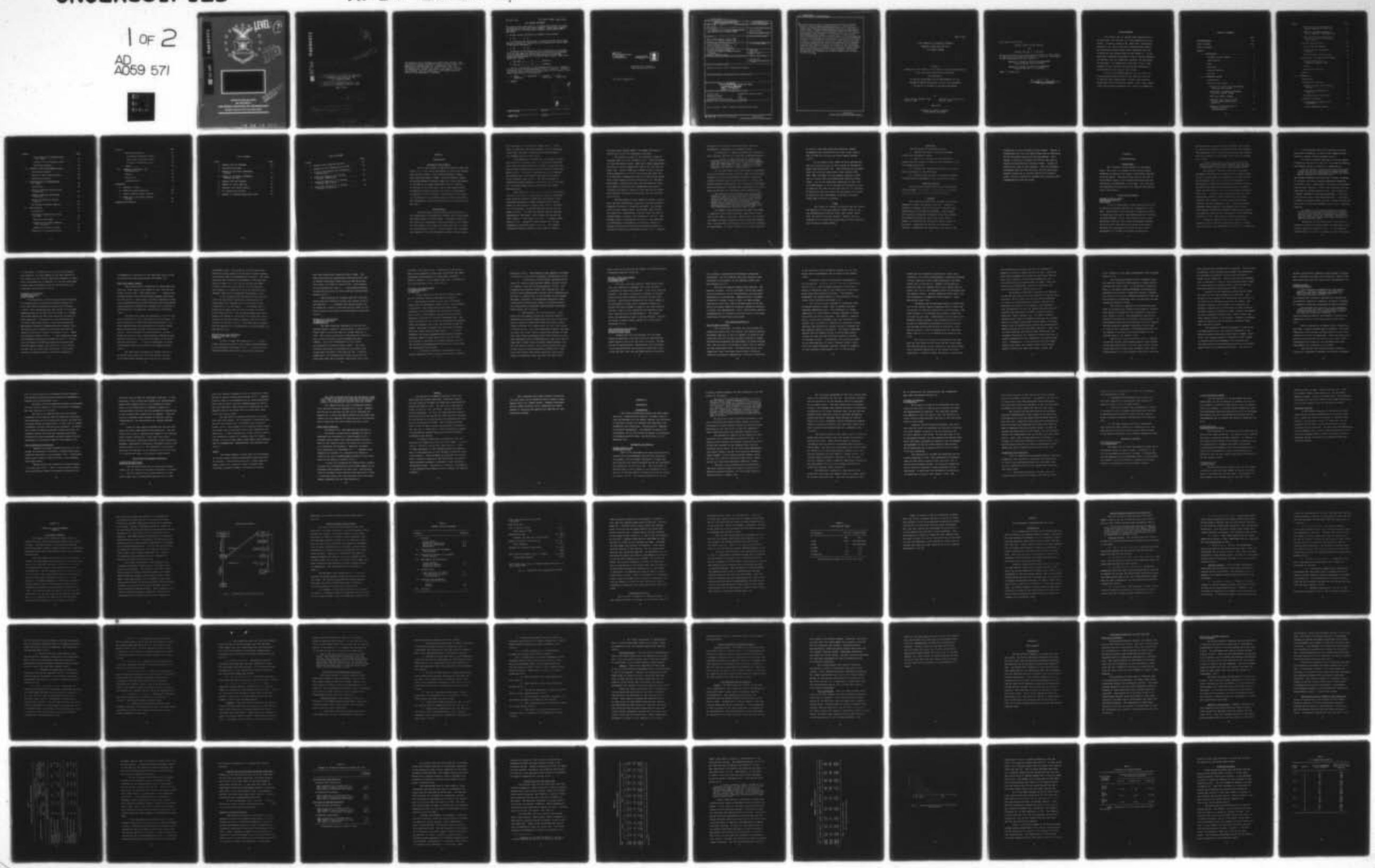

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Wright-Patterson Air Force Base, Ohio

78 09 18 045

(9) Master's thesis,

(6) A COST ANALYSIS ON PROCURING IMPROVED TECHNICAL ORDER DATA FOR THE F-15 WEAPON SYSTEM

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LSSR 27-78A

(11) Jun 78

(12) 152p.

(14) AFIT-LSSR-27-78A

USAF SCN 75-20B AFIT Control Number LSSR 27-78A

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Region#5-11

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 27-78A	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A COST ANALYSIS ON PROCURING IMPORVED TECHNICAL ORDER DATA FOR THE F-15 WEAPON SYSTEM		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Robert Wilmer Bennett, Captain, USAF William D. K. Moravek, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Graduate Education Division School of Systems and Logistics Air Force Institute of Technology		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Research and Administrative Management AFIT/LSGR, WPAFB OH 45433		12. REPORT DATE June 1978
		13. NUMBER OF PAGES 136
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE AFR 190-17.

JERRAL F. GUESS, CAPT, USAF
Director of Information

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Technical Data	Conventional Technical Orders
Break-Even Analysis	F-15
F-15 Avionics Cost	C-141
Proceduralized Technical Orders	Monte Carlo

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

Thesis Chairman: Donald R. Edwards, Lieutenant Colonel, USAF

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The United States Air Force has expressed strong interest in finding methods of reducing weapon system maintenance cost. One method is to increase the productivity of maintenance personnel by providing better technical data. High maintenance personnel cost makes it imperative that a more efficient, improved, proceduralized TO (PTO) format be developed and utilized. Due to the inherent advantages of PTOs, the F-15 Technical Order Management Agency manager is in the process of evaluating the cost of converting the F-15 TOs to the PTO format. A cost versus benefits analysis of the advantages and disadvantages of PTOs has been accomplished to assist top level management in deciding the appropriate type TO option to procure. To accomplish the analysis this thesis identifies the steps in the TO procurement process, explains the techniques used by McDonnell-Douglas Aircraft Company to develop cost estimates for the F-15 weapon system TOs, describes the advantages of procuring the F-15 weapon system TOs in the PTO format, and estimates where possible the monetary savings derived from the advantages of the improved PTO format. This thesis concludes that the F-15 weapon system technical data should be procured in the PTO format.

LSSR 27-78A

A COST ANALYSIS ON PROCURING IMPROVED TECHNICAL ORDER DATA FOR THE F-15 WEAPON SYSTEM

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degrees of Master of Science in Facilities Management

and Master of Science in Logistics Management

By

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June 1978

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and

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has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degrees of

MASTER OF SCIENCE IN FACILITIES MANAGEMENT
(Captain Robert Wilmer Bennett)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(Captain William D. K. Moravek)

DATE: 14 June 1978

Donald R Edwards
COMMITTEE CHAIRMAN

ACKNOWLEDGMENTS

The authors wish to express their appreciation to all those who have assisted us in the preparation of this thesis. A special thanks to Mr. Chuck Feely (Continuing Education), Mr. Jack Wilsom (F-15 System Program Office), and Lieutenant Colonel Eugene Jones (AFIT/LSG) who gave us direction and guidance when we most needed it. We are especially indebted to Lieutenant Colonel Donald R. Edwards, our advisor, for the leadership, patience, and motivation he displayed. Our appreciation also goes to Mrs. Linda Pearson for her interest and professional competence in the preparation and typing of this thesis.

Finally, and perhaps most of all, we would like to acknowledge and pay tribute to our families, who put up with the many frustrations, failures, and successes encountered while writing this thesis. Their love, inspiration, and frequent assistance will always be remembered.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The Air Force needs an improved technical order (TO) format (15:7). The recent development of Logic Tree Troubleshooting Aids (LTTAs), Fault Isolation Manuals (FIMs), Fault Reporting Manuals (FRMs), Job Guide Manuals (JGMs), and System Schematics Manuals (SSMs) is a major improvement in the quality of weapon system TOs (19:1-3). However, an analysis of the additional cost of procurement versus the potential savings generated by these TO improvements is required (19:48). Therefore, the purpose of this thesis is to determine if the economic benefits derived from these new developments in the TO format exceed the higher procurement cost.

Justification

For many years, there has been strong interest in the conservation of Department of Defense (DOD) funds within the United States Air Force (USAF). Personnel costs have been taking an increasingly larger percentage of the overall Air Force budget which limits the funds available for other Air Force programs (26:150). Recent studies have indicated that manpower costs for maintenance personnel alone account for 15 percent of the Air Force budget (18:2). If the level of operations and effectiveness is to be maintained in the USAF, new ways of improving the effectiveness of its personnel must be found (24:2).

The complexity of present Air Force weapon systems and the steadily increasing cost of maintaining these systems, despite current austerity programs, require that new ways of reducing maintenance costs be identified and implemented (18:1). "One way of reducing cost is to increase the productivity of maintenance personnel by providing better technical data [18:1]." The desired result is reduced maintenance manhours, improved quality of the product, increased weapon system availability, and lower operating cost.

The results of *A Study of the Air Force Maintenance Technical Data System*, accomplished in 1962, by the Behavioral Sciences Laboratory emphasized the problem of the increased complexity of weapon systems and the growing number of TOs required to support them (2:44). According to a 1974 estimate, the 83,609 USAF TOs had 875,451,189 pages (27:A7-6). "In 1940 the average aircraft required approximately 1000 pages: while today, the average aircraft requires 53,000 pages [27:p.1-1]." A weapon system similar to the proposed B-1 would require a TO system approaching one million pages (27:p.1-1). The rapidly increasing volume of technical data needed to support advanced weapon systems makes it extremely difficult to effectively utilize the information available.

The acquisition cost of the increasing volume of technical data is on the increase (19:1). The F-15 Technical Order Management Agency (TOMA) has a budget approaching $100 million with an expenditure rate of $1.1 million per month (36). The F-16 TOMA has a budget of $167.1 million with an expenditure of $1.8 to $3 million per month (22). A-10 TOMA has an expenditure rate of $.5 million per month with a total budget ceiling of $20 million (9). The enormous budgets, expenditure rates, and the potential financial impact of procuring and implementing new types of technical data make it imperative that the decision makers have accurate information available on the cost and benefits (19:13).

The development of more usable TO systems is desirable, and the technological capability required to develop improved TO systems is currently available. The conventional TO (CTO) system format, MIL-M-25098, does not meet the operational requirements of the Air Force in terms of responsiveness, accuracy, and flexibility (2:22-23). The present system is outdated, and it fails to take advantage of technological developments in providing a means of readily identifying and displaying the data necessary to accomplish individual maintenance actions (31:1). Products provided to the user are often inaccurate, unwieldy, unresponsive, confusing, and incomplete (36:2).

A 1974 draft of a Required Operational Capability (ROC) indicated that the TO system was outdated because it:

> . . . failed to take advantage of technological developments in providing a means of rapidly identifying and retrieving the data necessary to accomplish individual maintenance actions. There is an urgent need for a new technical order system which is more responsive to users [*sic*] needs [31:1].

At the level where actual maintenance is performed, the use of systems-oriented technical data will help ensure maximum utilization of maintenance personnel, which will improve efficiency and reduce cost (18:2). In 1976, the Systems Research Laboratories, under contract to the Human Resouces Laboratory, evaluated the effectiveness of various types of TOs used to troubleshoot system malfunctions.

> The results of the experiment evaluation clearly demonstrate that the use of proceduralized troubleshooting [logic tree] approach led to significantly better troubleshooting than the use of the [conventional] TO. This finding is consistent for . . . proportion of problems solved and spares consumed. Nearly twice as many good parts were unnecessarily replaced when the TO was used than when LTTAS [Logic Tree Troubleshooting Aids] were used [19:86].

In summary, high maintenance personnel cost makes it imperative that a more efficient, improved TO format, such as the LTTA, be utilized. Additionally, the increasing number of weapon systems and their complexity demands that a system within the capabilities of present technology be established. For these reasons, the 1976 study sponsored by the Air Force Human Resources Laboratory (AFHRL) recommended that consideration be given to the development of LTTAs for existing and future weapon systems (21:17).

At the present time, LTTAs are being procured for the F-16 aircraft as part of the original TO information based under MIL-M-83495 (22). The technical data procured under this military specification also includes FIMs, FRMs, JGMs, and SSMs; and the complete package is referred to in this study as proceduralized technical orders (PTOs). Due to the significant advantages of PTOs, the F-15 TOMA manager is in the process of evaluating the cost of procuring the PTOs for the projected F-15 C/D aircraft. An analysis of the cost versus the advantages is required to assist top level management in deciding the appropriate type TO option to procure.

Scope

This thesis is limited to analyzing the cost versus the benefits of procuring technical orders (TOs) in the new proceduralized technical order (PTO) format, MIL-M-8345, for the F-15 series aircraft. However, the conclusions of this study may be applicable to the TO procurement of similar weapon systems.

Objectives

The objectives of this thesis are to:

1. Identify the steps in the TO procurement process for new weapon systems.

2. Explain the technique used by McDonnell-Douglas Aircraft Company to develop cost estimates for the F-15 weapon system TOs.

3. Describe the advantages of procuring the F-15 weapon system TOs in the PTO format.

4. Estimate where possible the monetary savings derived from the advantages of the improved PTO format.

Research Question

The following research question was established for this study: *Should the F-15 weapon system technical data be procured in the PTO (MIL-M-83495) format?*

Overview

The following chapters are arranged in a logical sequence to answer the research question. Chapter II contains a thorough literature review of technical data systems and cost estimating techniques. This chapter also contains background information about data systems and computer applications used later in the thesis. Chapter III describes the methodology which consists of two parts: background for analysis and approach to analysis. Assumptions and limitations that apply to the methodology are also included in this chapter. Chapter IV accomplishes the first two thesis objectives by describing the TO procurement process and costing methods. Next, Chapter V carefully evaluates the positive and negative aspects of proceduralized technical orders. Chapter VI contains two types of data analysis. The first compares performance data for CTOs and PTOs, and the second uses computer techniques to forecast future F-15 logistics costs. Finally, Chapter VII presents the conclusions and recommendations from this study.

CHAPTER II

LITERATURE REVIEW

Introduction

The literature review consists of three major areas. The first is a summary of the various studies conducted to determine the types of improvement required in the TO system. The second area gives an overview of the different types of cost estimation/analysis and the limitations and advantages of each type. The third portion describes the data source and computer applications used in this thesis.

Technical Data System

A Study of the Air Force Maintenance Technical Data System

In 1962 a comprehensive study identified the need to improve maintenance and material information in the USAF. Unfortunately, the TO system in general use today is essentially the same as the system which was identified as being obsolete in 1962. This study of the Air Force maintenance technical data system recommended immediate action to revise and improve the system by developing new media for presentation of technical data (2:44). Development of a system for storing and retrieving maintenance data requires a highly refined coding system to identify and describe each discrete task and procedure. "The magnitude of this task further suggests that development action should be undertaken at the earliest possible date [2:44]."

> It would seem that no time should be wasted in addressing ourselves to this problem, and that the solution could be applied to sophisticated equipment on the ground as well as vehicles in space [2:44].

The purpose of the 1962 study was to evaluate management and operating procedures and to identify weaknesses in content and in utilization of Air Force maintenance technical data (2:1). The 2,300 responses to a field survey of nineteen organizations provided a factual and definitive basis for the identification of problem areas and deficiencies in Air Force maintenance technical data (2:14). Organizations surveyed included base level maintenance personnel, depot maintenance technicians, technical data managers, military and civilian staff officers, and unit commanders (2:2). There was general agreement among technical data managers that the Air Force had not effectively developed technical data within its capability based on the requirements of the individual technician (2:10). Questionnaire responses suggested ". . . a need for changes in the size, structure and content of TOs to make them more useful both as a training text and as a job performance aid [2:16]." Furthermore,

". . . it was apparent that lack of detailed, accurate and current information in TOs not only impedes maintenance but retards training progress [2:12]."

In order to simplify the task of locating needed information required to do the job, a revised TO numbering and indexing system is essential to modernization.

> The one subject concerning TOs on which the maintenance man was most positive and voluble pertained to the difficulties encountered in finding the information required to do the job [2:32].

The average respondent indicated that he spent 30 percent of his total job time in seeking necessary information in the TOs (2:32). Additionally, 30 percent said information was very difficult to find, and 47 percent felt that there must be a better system (2:32). The following is a typical response by maintenancé personnel: "You can't go to any one place in the TO and find out *all* about how a system or component works--you get a little bit here and go dig out a little bit somewhere else [2:22]." Generally speaking:

> It appears to the research team that a subject of overriding importance to effective use of maintenance technical data was identification of methods and techniques to make the necessary information for specific tasks more readily available, and easier to identify and find [2:33].

Respondents to the questionnaire identified the following categories of deficiencies or complaints in the physical aspects of technical data: (1) the numbering system created difficulty in finding required information;

(2) the amount of refer-backs in the textual procedures was excessive; (3) large numbers of TOs were required to do a single job; (4) the TOs contained inadequate or incomplete troubleshooting information; (5) the size and weight of data used was excessive; and (6) the data were late, inaccurate, and unrevised (2:22-23).

Maintenance Information Automated Retrieval System (MIARS)

The Department of the Navy studied the feasibility of converting Navy aeronautical component manuals to a Fault Tree Isolation System using 16mm film cartridges in 1967. Their objectives were very similar to the recommendations made by the 1962 Air Force study. On 7 October 1968 OPNAV Instruction 4790.1 was issued by the Chief of Naval Operations. The purpose of this instruction was to provide additional support to the newly established Maintenance Information Automated Retrieval System (34:1). The initial goal of MIARS was to utilize the 16mm film system to reduce the volume of TO manuals (35:11). MIARS was the Navy's answer to the ". . . ever-increasing volume of maintenance and material information [34:1]." In the last five years, the technical base for all first-line aircraft weapon systems, such as the A-7, F-14, and P-3, has been set up in the logic tree format. This format provides an effective means of retrieving appropriate troubleshooting information in the same basic style as the Air Force's Military Specification MIL-M-83495 (21).

PIMO Final Report Summary

The Presentation of Information for Maintenance and Operation (PIMO) project was started in June 1966 and completed in April 1969. PIMO studied the ". . . complex relationship between qualified maintenance manpower and technical data [23:2]." Specifically, the test attempted to prove that a proceduralized job guide technical order system would reduce maintenance manhours and increase the reliability of troubleshooting for apprentice (three-level) technicians (23:2).

The PIMO field study was conducted on the C-141 aircraft at Charleston, Dover, and Norton Air Force Bases. It was a follow-up to a 1965 study made by Serendipity, Inc., which concluded that the proceduralized job guide concept would, without doubt, improve technician performance (23:10). When evaluating the effectiveness of proceduralized job guides on more complex systems, Serendipity compared the complexity of the UH-1F helicopter to the C-141 aircraft and stated ". . . that the improvement in system effectiveness would be even greater for complex systems [23:3]."

The PIMO study concluded that through the use of job guides there would be a 50 to 100 percent increase in the maintenance manpower availability for productive maintenance labor. The reduction in maintenance labor would be a direct result of being able to reduce on-the-job training (OJT) by approximately 25 percent. The study concluded that unscheduled maintenance at the home base could be reduced 27 to 44 percent and that the operationally ready rate would increase 38 to 40 percent. This equates to a reduction of 30 to 39 percent of the manpower required for unscheduled maintenance (23:15).

It was estimated that through just the reduction in OJT for the 431X1E technician, proceduralized job guides would save (depending on the life-time of the C-141A fleet) 22 to 100 times ". . . more money than it would cost to expand the job guide to cover the entire C-141A fleet [23:15]." The job guide manuals were estimated to be capable of increasing the C-141A fleet effectiveness by the same amount as adding 16.44 more C-141A aircraft to the fleet (23:15). The PIMO report estimated that the benefits of a proceduralized job guide manual far outweigh the cost.

Evaluation of C-141 Job Guide Manuals (JGM) PRAM Project #29475-02

In 1976, a study was conducted to ". . . objectively evaluate the worth of the already procured manuals in an operational environment [11:1]." A comparison was conducted between bases which utilized JGMs and those that used conventional technical orders (CTOs). The study concluded that inexperienced technicians were able to perform maintenance tasks using the JGMs which they were unable to accomplish using the CTO. Additionally, it was concluded that JGMs ". . . significantly enhance the proficiency portion of the on-the-job training (OJT) program [11:2]."

When analyzing the "economic pay-off" the study group could not establish a direct cost savings (11:4-5), but they were ". . . confident that future savings will be accrued as a result of the data and the effect it will have on existing and future C-141 maintenance technicians [11:5]."

Evaluation of Three Types of Technical Data for Troubleshooting

The Human Resources Laboratory of the Air Force Systems Command sponsored a special study to evaluate different types of technical data for trouble shooting in 1976. This study evaluated the troubleshooting effectiveness of Fully Proceduralized Troubleshooting Aids (FPTAs), Logic Tree Troubleshooting Aids (LTTAS), and Conventional Technical Orders (CTOs). The study indicated that better troubleshooting was accomplished using either the FPTA or LTTA than the CTO. A greater proportion of the problems were solved, using less aircraft parts when the maintenance technicians used either the FPTA or the LTTA (19:86). Additionally, the performance of the apprentice technicians using FPTAs and LTTAs approached the performance of experienced personnel. However, because of the extremely high cost, the FPTAs are not being procured at this time (19:87).

Technical Data Requirements for Weapon Systems--14 June 1977

Initial Technical Order Project Findings, part one of a two-part study to determine the cause of ". . . the alarming increase in the cost of technical orders (TOs) on new weapon systems [14:1]," was completed in June 1977. The study covered five major areas: increases in TO requirements, TO cost drivers, assessment of user's requirements, potential TO acquisition management improvements, and other recommendations. The study evaluated the four areas and discussed the possible effect the elements had on the effectiveness of the TO system. The study concluded that "the whole TO system cries for firmer direction and control . . . [29:38]." Therefore, the study recommended that specific actions should be taken to assure that quality Air Force TOs are acquired in the most cost effective manner (29:2-9). The following recommendations/conclusions are those that are applicable to this study:

1. Any hope of effective implementation will require additional funds as well as high level, positive,

aggressive action. Modification of many peoples' attitudes and behavior is required for successful implementation (29:4).

2. In references to MIL-M-83495, advocates of the latest TO military specification (AFHRL, various TO council members) claim the following benefits (29:23). The proceduralized Technical Order (PTO) reduces cost; simplifies training/maintenance actions; uses a numbering system that is international in use; bridges the gap between designers, engineers, and maintenance personnel; establishes better configuration control of aircraft wiring; and establishes an integrated organizational maintenance specification set (29:23-24).

3. Additionally, the Job Guide Manuals (JGMs) and/or the PTO package provide the following benefits: technicians can perform tasks using this type of data when they are unable to perform the same tasks using conventional tech data; it is much easier for first term airmen to follow and use; they allow productivity sooner with less training; they reduce time in search and retrieval of tech data; they reduce maintenance error rate--removing serviceable components during troubleshooting; they can be used by lower skill levels; they can reduce troubleshooting time, OJT, and formal training; they increase maintenance capability; they can reduce maintenance manhours per flight hour; they improve operational readiness; they provide higher in-commission rates; and they can reduce spare

parts inventory by reducing the number of serviceable parts erroneously replaced (29:24-25).

Technical Data Requirements
for Weapon Systems--
9 September 1977

Part two, the Final Technical Order Project Findings, was completed in September 1977; and the report is prepared in three major sections: F-15, F-16, and C-141 aircraft. The report is basically a summary of the most current TO cost data presently available for the three aircraft. Each section addresses TO cost data, number of TOs and number of pages; and a comparison between the initial and final findings is made for the three specific aircraft. Most of this information was obtained by personal interview with the TOMA managers. The results verify two observations made in earlier studies: The cost and volume of modern weapon system TOs is continuously increasing (30:1).

User Acceptance and Usability
of the C-141 Job Guide
Technical Order System

Between June 1975 and February 1977 the Human Resources Laboratory conducted a study to determine the latest status of the C-141 Job Guide TO system. Through the use of questionnaires, observations, and interviews, it was determined that the program was successful (15:1). It was felt that "The JGMs and LTTAs generally have been well accepted, although some resistance to change was encountered. The new technical data have generally been considered to be superior to the technical orders that they replaced [15:1]."

Positive and negative factors were observed. The positive included: size of the books, clarity and organization of materials, use of illustrations, and dual-level presentation of instructions. Negative factors included: resistance to change, errors in data, too many volumes required for some jobs, lack of storage space for the TOs, easily torn pages, method of locating information difficult to master, and implementation (15:1). Additionally, specific recommendations for possible corrective action of the above noted negative observations were given.

Cost Estimating/Analysis

Cost Estimating Methods

Cost estimations, no matter how sophisticated the estimating process used, are actually only educated guesses. Government agencies, as well as industry, extrapolate from historical data the planning estimates required to answer the questions concerning the development of future programs. Thus, the real basis for estimating future costs is comparison with experienced costs. The methods for making cost comparisons range from expert opinion down to detailed industrial engineering computations. The primary differences in the continuum of cost estimating methods are the techniques used to extrapolate from the known to the unknown (7:45).

In general, there are three basic approaches to cost estimating: *Analogous Systems, Industrial Engineering* and *Parametric*. Each of these approaches to cost estimating is frequently used in the preparation of cost estimates during the acquisition process. The strengths, weaknesses, and appropriateness of each technique are discussed in the following paragraphs (7:3).

The *Analogous System* approach of estimating costs by drawing analogy to other items is probably the most prevalent methodology used. This technique is a direct comparison of a new program or program component to one or more recent and similar projects. This method is used to obtain a broad cost assessment (ball park estimate) of a program cost; and when it is applied in a carefully planned, detailed, and conscientious manner, analogy is perhaps the most powerful method of estimating. The greatest advantage derived from this method is that it can be made quickly without the time and cost otherwise required to develop an in-depth analysis. Unfortunately, the analogous system is too often applied in a quick, haphazard manner; therefore, the system frequently receives a skeptical reception. It only considers technological costs if the analogous system used for comparison accounted for those costs. Ironically, the primary disadvantage of analogous estimates is their simplicity; and a great advantage is the same simple ease of application. However, the estimate is sometimes based on "guesses" with little factual data to support the cost of new components which are different from the compared system. Analogy comparison often tends to be less acceptable to prospective users because it lacks statistical tests (7:4).

Estimators use the analogous system to predict the cost of the unknown items by comparing them to items that are similar in function, construction, and technology. The final estimate is strengthened when several comparisons for each item are made. Concentration on the largest cost elements becomes necessary, and determined efforts must be used to comprehensively document the entire approach and overcome preconceived notions of inadequacy in the analogy approach. After a system enters the conceptual phase, the *Analogous System* method is not normally used (7:4).

The *Industrial Engineering* approach can be used when the item design is well known and well established. This approach begins with an analysis of the work proposed and an extensive description of the system and design requirements. Manhours (labor) and material requirements are accumulated and costed, and then the elements are summed to arrive at a total cost for the job. Since this method uses standards built from time and motion studies, Gantt Chart analysis, critical-path scheduling, etc., detailed production operations must be known. After the standards are established, current or historical cost factors are applied to the analysis (7:5).

The greatest difficulty in applying this approach is that the Air Force is not the producer of technical data; therefore, the Air Force does not have direct knowledge or control of the manufacturing process. Without this knowledge and control at his disposal, the estimator's only alternative is to use the limited data available and personal past experience to roughly price the cost of materials, labor, overhead, etc. He cannot, however, estimate direct labor or overhead costs with any reliable degree of accuracy since these factors depend, to a great extent, upon the manufacturing process and accounting procedures utilized by the individual contractor. Thus, the Air Force estimator must rely on cost factors and cost estimates provided by the contractor because there are no industry standards for the computation of technical data costs. Consequently, if the contractor does not submit accurate cost data, the estimator must either develop general factors that lump direct labor, burden, and profit together or must apply undocumented "rule-of-thumb" factors (7:5).

The engineering method of cost estimating works best when the production configuration is known and most problems have been solved. It has definite limitations early in the weapon system development cycle because of procedural difficulties in handling "unknowns." However, the *Industrial Engineering* method represents the most precise approach to estimating, and it is the basis for most production contracts (7:506).

The *Parametric* approach to cost estimating produces an estimate which predicts costs based on relationships between variables such as performance characteristics, physical traits, and developmental distinctions derived from experience on logically related systems. The relationships stem from cost histories of similar systems, thus the parametric approach evaluates the new system in light of past experience. This method seems most useful whenever a new item is not totally similar to the existing items in all aspects (7:48).

The *Analogous System* and the *Parametric* approach are similar because they generally require large amounts of the same kind of data. The data must include specifications and costs of previously purchased items, and an understanding of all the conditions under which the items were developed and produced must be acquired. Once the data are defined, ratios derived from a number of procurements are analyzed to determine if significant statistical trends can be identified. After putting the data together, cost is expressed in terms of the performance and/or physical characteristics obtained earlier, and this data now form Cost Estimating Relationships (CERs) (7:6).

Analysis is then required to establish what CERs are valid for the cost estimate being developed. The validity of the estimate will depend upon the relevance of the CERs and the confidence placed on the trends. The parametric approach also includes such intangibles as schedule slippages due to limitations on funds, technical problems, changes in production rates, contract performance failures, management inefficiencies, labor strikes, and other unknown factors in the program. Parametric estimates should be logically and statistically evaluated rather than routinely accepted.

The parametric estimating approach is required by DOD Memorandum for all cost estimates presented to the Defense Systems Acquisition Review Council (DSARC). Basically, this approach permits a blending of known changes in system acquisition management and technology with the uncertainties of system design during the early development phase of the acquisition process. The *Parametric* estimate (periodically updated by known changes in management, technology, and data) can be used as a check on the more definitive *Industrial Engineering* cost estimate (7:7).

Purposes of Cost Estimating/Analysis

> Cost estimates are required for three general purposes: Planning, Budgeting, and Contracting. These purposes should represent milestones in a continuous estimating process [7:7].

For planning cost estimates, detailed cost analyses are not generally feasible or essential; therefore, analogous or parametric estimating techniques are usually employed.

> The estimates are rough but, in most instances, sufficient since the lack of a satisfactory base for accurate estimating in the planning stage dictates the shunning of detailed techniques [7:7].

Rules-of-thumb developed by the parametric method can be competently applied at this early stage in many cases (7:7).

After a decision to go forward with a program has been made, a budget estimate must be prepared. The budget computation should reflect the best estimate of the total program at the date of procurement. Since the budget preparation process precedes contracting by at least a year, estimating errors caused by the time factor and vague requirements are introduced at this point.

The contract cost estimating process normally includes an Independent Government Cost Estimate prepared prior to solicitation and a Government Contract Negotiation Objective resulting from an analysis of proposals in response to the solicitation (7:8).

Obviously, the cost estimating process is continuous from the initial planning to the solicitation of proposals and final awarding of a contract.

The lack of an adequate data base for accurate estimating in the planning stage dictates that as the program progresses into the acquisition process, new data will inevitably become available which, in turn, lead to changes, refinements, and more realistic cost estimates. Therefore, until better estimating techniques become available, the estimator and the Air Force must recognize that early estimates are rarely meaningful and must proceed with the development of procurement based on that premise (7:8).

Cost Estimating Uncertainties

"Whenever an analyst estimates the cost of a new system, he encounters a multitude of problem areas which introduce uncertainty in his estimate [7:9]." Uncertainty occurs, and it plays a vital role even in the seemingly most simple tasks.

"Making useful cost estimates of future programs is no easy task [7:10]." Thus, it can be safely stated that uncertainties cannot be accurately forecasted, and provisions must be made for unforeseen situations. A risk situation is one in which the outcome is an uncontrollable random event stemming from a *known* probability distribution; on the other hand, an uncertain situation is characterized by the fact that the probability distribution of the uncontrollable random event is unknown. "This distinction, sometimes leads analysts to describe risks as 'known-unknowns' and uncertainties as 'unknown-unknowns' [7:11]."

There are many types of methods that the cost estimator may turn to when dealing with uncertainty. The following list is only a representative sample of the techniques used to manage uncertainty: Monte Carlo Simulation; Fortiori Analysis; Sensitivity Analysis; Range of Estimates Approach; Supplemental Discounting; Adjustment Factors; and Special Studies (7:11-13). The successful cost estimator must plan for unknowns, or his estimates will not be valid in a "Real World" which is filled with uncertainties.

Data Source and Computer Techniques

Increase Reliability of Operation Systems (IROS)

The Increase Reliability of Operational Systems (IROS) uses the Industrial Engineering approach to estimate ". . . logistic support costs, systems downtime, flight safely [sic] data in quantitative displays such as rank orders for technical managers to use in decisions on where and how to improve system effectiveness [28:2]." Implementation of IROS is in accordance with Air Force Regulations 400-46 and Air Force Logistics Command Regulation 400-16. IROS data provides a rank ordering of information for each component down to the lowest work unit code (WUC) level within each weapon system.

The IROS data are generated quarterly in the Air Force K051 data system. The information is collected daily from Air Force Manual 66-1 Maintenance Data Collection System, the Air Force Manual 65-110 Equipment Status Reporting System, and various depot level repair management systems (13:2). "IROS transforms day to day logistics activities reported in support of a weapon system to support dollars in terms of BASE LABOR, DEPOT LABOR, DEPOT MATERIAL, COST OF CONDEMNATIONS, TRANSPORTATION, AND PACK/SHIP COST [28:2]."

SIMFIT

The SIMFIT computer program tests the distribution of raw data against twelve distributions contained within the program. These distributions are: Erlang; Weibull; Gamma; Pearson XI; Lognormal; Normal; Uniform; Beta; Triangular; Poisson; Binomial; and Negative Binomial.

The SIMFIT program calculates the parameters needed to determine the probability distribution from the input data. The input data are divided into cells and compared to the theoretical value for each cell [6:85].

The computer program uses the Kolmogorov-Smirnov (K-S) and the Chi-square goodness-of-fit tests. However, the K-S test is the only one that can be used when the sample size is relatively small because the Chi-square statistics are only computed for that portion of the distribution in which the cell size criteria are met (32:14).

Monte Carlo Technique

The Monte Carlo technique has been defined as ". . . that branch of experimental mathematics which is concerned with experiments on random numbers [12:2]." Although random numbers and random processes have been used for more than 250 years, the Monte Carlo simulation is a relatively new technique. Basically, the Monte Carlo simulation is a technique to ". . . determine some probabilistic property of a population of objects or events by the use of random sampling applied to the components of the objects or events [1:175]."

In most cost estimating the probabilistic property of total cost is determined by using random samples of the components which comprise the total cost. Such applications of the Monte Carlo technique have been used so often in simulation models that the term Monte Carlo has almost become synonymous with the word simulation.

Summary

The problem of inadequate technical orders was identified over fifteen years ago. Additional studies recently conducted by AFHRL and AFLMC have reconfirmed the observations made in 1962. The need for an improved TO format in terms of size, structure, content, and detail is well documented. In 1976, the Human Resources Laboratory field tested two new formats which had been developed for the purpose of correcting the well documented deficiencies in the present TO format. The increased cost and value of TOs for modern weapon systems makes it essential that the cost of converting to a new TO format be compared to the potential savings resulting from the advantages provided by that system.

In general, three basic approaches to cost estimating are in common use in the Air Force today: *Analogous Systems*, *Industrial Engineering*, and *Parametric*. Each of these approaches to cost estimating plays an important part in the preparation of cost estimates during the acquisition process. These estimates are required for the purpose of planning, budgeting, and contracting; and each of these purposes represents a milestone in the continuous estimating process. Uncertainty is inherent to estimating, so the estimator must develop a plan to manage the "unknown-unknowns."

IROS transforms day-to-day logistics activities into data which can be stored and used to predict future support costs for a weapon system. Computer techniques such as SIMFIT and Monte Carlo simulation are useful methods of analyzing and applying the IROS data to cost estimating problems.

CHAPTER III

METHODOLOGY

Introduction

This thesis methodology contains two major areas. The first, "Background for Analysis" includes a definition and discussion of the nature, sources, and collection of the data; criteria for research and comparison; and assumptions and limitations. The second area, "Approach to Analysis" encompasses: the sequence of steps in TO procurement; the TO cost estimation method; an evaluation of proceduralized TOs (PTOs); and the forecast of F-15 logistics cost.

Background for Analysis

Nature, Sources, and Collection of Data

Data for TO procurement are based upon historical records of past procurements from the same contractor. For example, the F-16 budget information is based upon data obtained from General Dynamics during the development and acquisition of the F-111 (26). The actual cost of various types of TOs is based on the contractor's estimate of the average number of manhours required to produce one page of the TO. The various categories of TOs are assigned different manhours per page depending on the complexity of the manual.

> The cost of any given TO is largely a *contractor* derived product, usually computed on the *contractor's* estimate of the number of original and change pages in the TO, hours required to prepare those pages and cost per hour. These estimates in turn may be based on a variety of factors such as contractor developed page and illustration standards (hours per unit) for writing, graphics and production; historical data; surveys of existing TOs; complexity of the system; and, of course, interpretation of the applicable MIL Specs (28:32-33].

The validity of the contractor's estimates is normally established by comparing that company's previous performance on similar weapon systems and similar manuals. Additionally, the contractor's claims are compared to other contractors within the aerospace industry (22).

The sequence of steps in the TO acquisition were extracted from a comprehensive literature review. In addition, many telephone and personal interviews were conducted with personnel in the technical data business including the Air Staff; the Air Force Plant Representative Office (AFPRO); the Air Force Logistics Management Center (AFLMC); the Air Force Logistics Command (AFLC); the A10, F-15, and F-16 Systems Program Offices (SPOs); and the Air Force Human Resources Laboratory (AFHRL).

The data on the advantages and disadvantages of PTOs were primarily based on a study initiated by the Advanced Logistics Division, Air Force Human Resources Laboratories, Inc., Dayton, Ohio.

Two electronic subsystems of the C-141 aircraft were used as the foundation for the test. The systems selected were the AN/APN-147 and the AN/ASN-35 which are both part of the doppler radar. They were chosen for the following reasons: the equipment was readily available; the CTOs were representative af current technical data; the Air Training Command Course 3ABR32834 (Inertial and Radar Navigation System Specialist) addresses these systems as "typical" types of Air Force equipment; and the systems were complex enough to provide a realistic test, but small enough to be able to procure the technical data at a reasonable cost (19:4,24).

The identification of the support costs for the F-15 weapon system was based on the most current data found in the K051 data base. These data are based on quarterly information from the AFR 66-1 Maintenance Data Collection System (MDC). The K051 is a "high burner list" which tracks the scheduled and unscheduled general support cost of the various components and end items of a weapon system. This tracking system represents a key part of the Air Force Logistic Command's (AFLC's) Material Improvement Program and provides specific data for the Increase Reliability of Operational Systems (IROS) program (8).

The K051 data, displayed on 16mm microfilm and microfiche, break down the support costs of a weapon system by the Work Unit Code (WUC). The cost indicated for each

WUC is generated at the organizational and intermediate base level maintenance function (8).

Criteria for Research and Comparison

The Sequence of Steps in TO Procurement were analyzed with the intent of making them as factual, accurate, and comprehensible as possible. The steps were written with emphasis on the cost aspect; thus, any omissions or errors that one might encounter were due to the cost orientation of this study.

Likewise, TO Cost Estimating Methods, were developed with the intent of accurately and factually reflecting the actual methods currently in use by contractors and Air Force experts in the field. As with the steps in the TO procurement process, the cost methods were obtained from those indiviudals recognized as experts in the procurement and management of the Air Force technical data systems. The ultimate goal was to portray the *real world* in terms of TO cost estimating.

The Evaluation of the PTOs was conducted with two primary questions in mind: What advantages and disadvantages of PTOs have an impact on the life cycle cost of maintaining the weapon system? Can realistic present day dollar values be assigned to these advantages and disadvantages? In some cases the information available was too subjective to assign cost figures. Also, some conclusions relevant to PTOs used on the C-141 aircraft are not applicable to the F-15. Consequently, for the sake of objectivity, only those advantages and disadvantages that were quantifiable and analogous to the F-15 were used to predict the dollars saved over the F-15 life cycle.

The criteria for the Cost Analysis of the Advantages and Disadvantages of PTOs hinged on the nature and characteristics of the maintenance data obtained from the K051 data base. These data were analyzed to determine the extent to which valid application of these data could be made in computing life cycle dollar values. In order to maintain the objectivity of this thesis, the cost analysis portion was accomplished based on the K051 data base information. Again, some of these data were irrelevant or incapable of quantitative analysis in terms of cost. Only the data which satisfied the specific objectives of this thesis were used to develop the life cycle cost (LCC).

Assumptions and Limitations

Prior to conducting the proposed analysis, some basic assumptions were required to facilitate the research and to clarify any misinterpretations that the reader might perceive. Therefore, the following assumptions/limitations were established:

1. The studies conducted by project PIMO, the Systems Research Laboratories/AFHRL, and AFLMC are valid

indications of the acceptability, usability, advantages, and disadvantages of PTOs.

2. Advantages and disadvantages of PTOs exist that lend themselves to quantitative cost analysis by assigning dollar values to these factors.

3. The cost estimates for procurement of various TO options for the F-15 weapon system which were provided by McDonnell-Douglas Aircraft Corporation are accurate based on current technology and experience with PTOs and CTOs.

4. The data obtained form AFLC's Maintenance Data Collection (MDC) systems are reasonably valid, and these data can be used to place realistic dollar values on the factors identified in the studies conducted on PTOs.

Approach to Analysis

The Sequence of Steps in TO Procurement

The exact flow of the TO procurement process varies from weapon system to weapon system. A synthesis of the F-15 TO procurement process will be made. A diagram showing the sequence will be established using a proceduralized step method. This will provide a conceptual and visual display of the technical data procurement process.

TO Cost Estimation Method

Once the sequence for TO procurement has been established, it will be possible to identify the various cost elements in technical data costing; such as manhours, pages, and category. A decision matrix showing the alternate procurement selection possibilities will be developed. This matrix will show the alternative decisions and the corresponding cost to procure the technical orders for the F-15.

An Evaluation of Proceduralized TOs (PTOs)

The evaluation of the PTOs will be divided into the positive and negative factors. The factors will be defined, evaluated, and quantified where possible. An analysis of the various effectiveness and efficiency measurements will be accomplished to determine the overall improvement in maintenance performance. This PTO percentage savings index will be depicted on a scale from pessimistic to optimistic with the most likely value being the midpoint of the two extreme points.

Forecast of F-15 Logistics Cost

The operating cost of the F-15 will be categorized according to work unit codes (WUCs) using the last three years of data from the K051 data base. To determine the most probable cost distribution for each WUC, three techniques will be used. These techniques are: time-data graphs; Simple Linear Regression; and the SIMFIT computer program. Finally, the Monte Carlo cost forecasting method will be used to provide the probable distribution of the total logistics cost for the applicable WUCs.

Break-Even Analysis

A cost benefit analysis of the PTO will be made using the dollar values established in the previous section. Break-even charts will be used to indicate, where possible, at what point in time the additional cost of procuring the TOs under the PTO format would be offset by dollars saved using PTOs. The same logic and methodology will be extended for a portion of the projected life cycle of the F-15 weapon system in order to predict the total potential savings of procuring the technical data base in the PTO format.

CHAPTER IV

TECHNICAL ORDER PROCUREMENT PROCESS

Procurement Sequence

The acquisition of technical orders (TOs) is a complex and ever changing task which evolves over a period of years. The exact method of initially procuring TOs varies from weapon system to weapon system and is controlled and maintained by the System Project Office (SPO) technical order division.

The major weapon system source selection process includes the requirement for the contractor to provide negatives of the applicable technical data (based on the military specification stated in the contract) to the DOD representative. The DOD representative in the case of the F-15 is the Air Force Plant Representative Office (AFPRO) located at the major contractor's plant in St. Louis, Missouri. The AFPRO assembles the negatives, performs a quality control check, and forwards the negatives to a contractor designated by the Government Printing Office (GPO). The technical order division of the SPO provides authorization to the Air Force Systems Command (AFSC/DAR) who in turn obligates the funds to the GPO designated contractor upon completion of the required printing.

The contractor returns the negatives to the AFPRO and distributes the formal copies of the technical orders directly to the USAF field units through the TO distribution system. However, preliminary technical orders are not distributed through the distribution system but are sent directly to the SPO, which in turn distributes them as required. The AFPRO returns the negatives to the weapon system contractor, who is responsible for maintaining the negatives until program transfer (Appendix A) or directed by the System Program Office. At this time the negatives are officially transferred to the prime Air Logistics Center (ALC), which assumes responsibility. Figure 1, F-15 Technical Data Acquisition Cycle, displays the sequence of events in the cycle (36).

The actual acquisition of the technical data includes considerable coordination in the form of contracts and agreements. The process is initiated in the SPO by issuing a Contract Data Requirement List (CDRL) which defines the weapon system technical data requirements. The CDRL consists of the Technical Order Publication Plan H-101/M, the Technical Manual CFAE/CFE notices H-105/M, the Aircraft and Training Equipment H107-1/M, and the Validation Record H-108/M. These elements of the contract establish delivery conditions, specification requirements, and validation/verification (Appendix A)

ACQUISITION PROCESS

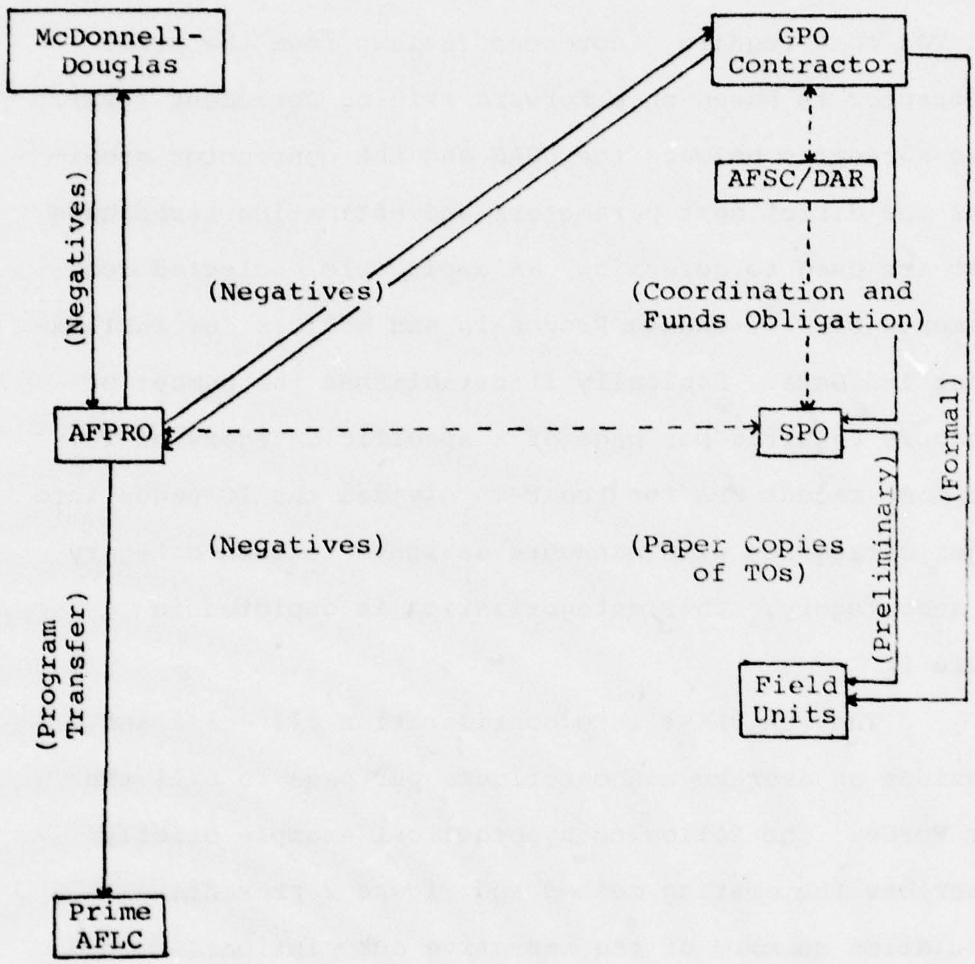

Fig. 1. Technical Data Acquisition Cycle

guidelines for the entire technical data/order acquisition (36).

Technical Order Costing Method

The cost of providing the technical order (TO) negatives to the USAF on contract furnished equipment (CFE) and TOs that require inprocess reviews from the prime contractor is based on a Forward Pricing Agreement (FPA). This agreement between the USAF and the contractor specifies the direct cost parameters and estimating techniques that are used to determine, as applicable, selected cost elements of F-15 Change Proposals and Notices for Publications and Data. Basically it establishes the number of manhours required per page of a specific category of TO. The most recent FPA for the F-15 divides the TO pages into major categories with manhours assigned to each category or subcategory. This categorization is depicted in Table 1.

The FPA takes into consideration *all cases* and provides an average manhour figure per page to bill the Air Force. The following hypothetical example briefly describes the costing method and Figure 2 presents a tabulation summary of the narrative description.

For example, a three page instruction is required to correct a deficiency noted in maintenance technical data for the weapon system. This Time Compliance Technical Order

TABLE 1

FORWARD PRICING AGREEMENT

Category	Manhours
I. Airframe	
Flight Manual	5.0
Mechanical Maintenance	5.3
Electrical Maintenance	4.5
Non-Nuclear	10.0
II. Contractor Furnished Equipment (CFE) Manuals	
III. Contractor Furnished Air Equipment (CFAE) Manuals	
IV. Development Program Manuals	
Flight Manuals	4.0
Inspection Manuals	2.6
Mechanical Manuals	
V. Retrofit Data	
Time Compliance TO (TCTO)	24.6
Time Compliance Directive (Test Aircraft)	14.5
VI. Inprocess Review Manuals (per each CFE TO only)	
Change	7.0
Initial	59.0
VII. Planning	4.9

Pages with deficiencies requiring correction	3
TCTO Title Page	1
List of Affected Pages	1
Total pages in TCTO	5
Manhours per page	x 24.6
Manhours per TCTO per aircraft model	123.0
Models of aircraft (F-15A/B/C/D)	x 4
Total Manhours	492.0
Manhours for planning requirement	+ 4.9
	496.9
Test aircraft manhours (14.5 x 5 pages)	+ 72.5
Grand Total Manhours	569.4

569.4 times labor rate per manhour equals total cost of the proposed TCTO.

Fig. 2. Summary of Cost Computation for TCTO

(TCTO) correction would fall into Category V, Retrofit Data; and five separate pages would be required. The five pages are: the TCTO title; a page listing the affected pages in the TO; and the three pages of corrected maintenance instructions. Assuming there are four versions of the weapon system (F-15A, B, C, and D) that are affected by the TCTO, a separate TCTO would be published for each aircraft at a cost of 24.6 manhours per page. Therefore, the five pages would require 123 manhours. Since there are four versions of the aircraft, the 123 figure multiplied by four yields 492 manhours. An additional 4.9 manhours must be added for planning requirements to arrive at a total of 496.9 manhours for the TCTO. To compute the actual total cost of producing the TCTO, the 496.9 manhours is multiplied by the current labor rate per manhour. In cases where special test aircraft are in the system, an additional 14.5 manhours per page are added to accommodate these aircraft. Thus, 72.5 manhours (14.5 manhours times 5 pages) are added to 496.9 prior to multiplying the cost per manhour to arrive at the "grand total" cost of researching, modifying, and making the required TCTO negatives.

Cost-Decision Matrix

The F-15 SPO is faced with a complex problem. All new technical orders are required to be procured under the proceduralized TO format, MIL-M-83495 (16). Since the F-15A TOs were procured under the old format, MIL-H-25098, the U.S. Air Force has the option of using either the old or new format for future procurements. Therefore, the cost versus benefits of the proceduralized TOs must be analyzed to determine what tradeoffs exist.

The F-15 SPO anticipated the requirement for cost data for the various alternatives and requested *Ball Park* cost figures from McDonnell-Douglas for the possible procurement options. Table 2 is a cost-decision matrix based on the cost data provided by McDonnell-Douglas (10:1).

The major significance of the cost-decision matrix is that it indicates an estimated savings of $1.78 million can be achieved by procuring the F-15 A/B/C/D aircraft TOs as a package in the PTO format. This savings is realized when comparing the estimated cost of procuring the PTOs in separate packages. This difference in cost represents the required initial cost of converting the available technical data of the F-15A into PTO format. After the initial conversion has been accomplished, the future cost of procuring the PTO would be approximately the same as the cost of procuring additional copies under the CTO format. The printing cost of PTOs would be slightly higher because they generally contain more pages than a CTO.

TABLE 2

COST-DECISION MATRIX

A/C Package	Cost by TO Format Type*	
	CTO	PTO
F-15A	None	Not Available
F-15B	.2	Not Available
F-15A/B	.2	4.8
F-15C/D	1.65	5.28
F-15A/B/C/D	1.85	8.3

*In millions of dollars for FY 1977 base year.

There is a point in the F-15 production schedule where the option to procure the PTO will result in higher cost because it will not be possible to design and procure the PTO prior to the actual F-15 C/D field requirement. This case will require the procurement of the CTO as an interim measure while the PTO is being developed. This procurement will result in higher LCC cost, because total cost must include not only the additional cost of the CTOs, but also the opportunity cost incurred by sacrificing any savings that might have been achieved due to the inherent advantages of the PTO.

CHAPTER V

AN EVALUATION OF PROCEDURALIZED TOs (PTOs)

Introduction

It is appropriate at this time to restate and evaluate the postive and negative factors of PTOs. Each factor will be evaluated to determine if it is feasible to quantify the potential cost related to that factor using the K051 data base. Those factors elected for further analysis will be categorized according to Work Unit Code (WUC) in order to extract the pertinent data from the K051 data base. These cost data will be subjected to Monte Carlo simulation to determine the approximate distribution of the total cost of the applicable WUCs.

Actually, there are two broad categories of positive and negative factors for job guide manuals (JGMs) which are the proceduralized technical orders (PTOs) being considered for the F-15 weapon system. The first category, Factors Affecting Usability and Acceptance, deals with how individual maintenance personnel, the users, viewed PTOs during actual "hands-on" application in their work environment. The second category, Factors Affecting Maintenance Capability, relates to how PTOs interact with the entire weapon system maintenance concept to change mission performance and maintenance costs.

Factors Affecting Usability and Acceptance

The 1977 Air Force Human Resources Laboratory (AFHRL) study of the use of JGMs and logic tree troubleshooting aids (LTTAs) produced some interesting results.

> It had been established that the use of JGMs and LTTAs could improve maintenance efficiency. However, it was not known how well the new proceduralized data would be accepted by the users or what problems would be encountered in implementing and using the data in an operational environment [15:1].

Positive Factors. The following positive factors of PTOs were noted by maintenance personnel who participated in the study.

1. *Size of Job Guide Manuals.* With few exceptions, technicians agreed that the smaller size made the JGMs easier to carry and use (15:15).

2. *Procedures are easy to read and understand.* The clear, concise manner of writing in the JGMs was clearer and often more thorough than CTOs (15:15).

3. *Presentations of Instructions.* Technicians especially liked the impact conditions page which tells how to prepare for the job, the step-by-step instructions which tell them exactly what to do, the illustrated parts breakdown for parts information, and the follow-on maintenance instructions (15:15).

4. *Illustrations.* The job guide's foldout illustrations, which are a key part of the maintenance procedures, were well accepted by most technicians (15:15).

5. *Dual-Level Presentation.* Experienced technicians greatly appreciated the general instructions which enabled them to complete familiar jobs without referring to the detailed instructions provided for the inexperienced technicians. This dual-level format helped reduce experienced personnel resistance to the change to JGMs (15:16).

6. *Format.* "Most users agreed that the format makes the TO easier to read, understand, and use, especially for the inexperienced [15:25]."

7. *Reading Level.* "By far, the predominant opinion was that the job guides are very easy to read, to understand, and to follow [15:25]." This factor was most important to inexperienced people, but even the experienced people seemed to appreciate the ease of reading and understanding (15:25).

Negative Factors. C-141 aircraft maintenance technicians who participated in the study also detected negative factors of the PTOs. The following list is a summary of the negative factors affecting usability and acceptance.

1. *Resistance to Change.* "There is a natural tendency to resist anything new that alters one's normal everyday way of doing things [15:16]." However, this resistance to change does not appear to be significant or long lasting. "A surprising number of those who expressed

dislike or indifference to the data indicated that the problem was primarily a matter of resistance to change and that they will probably like the data after they [are] used to it [15:16]."

2. *Errors in the Data.* As with any new TO, errors and omissions in data are a serious problem in gaining acceptance of the data. "However, the error rate did not appear to be any greater than would be expected for any new TO [15:16]." Because of the nature of PTOs, errors are more critical, especially when the PTO is used by inexperienced technicians. The prevailing attitude among most technicians was that they will have to live with the errors until they can be corrected through the AFTO Form 22 system (15:16).

3. *Problems in Implementation.* There were four major implementation problems which had an impact on acceptance of the PTOs.

a. A significant communications problem was encountered when the normal chain of command was relied upon as the major means of getting information to the working technicians. A mass briefing on the purpose of the study and participation required from the technicians would have been more effective (15:16).

b. "Adequate instruction on the use of the data was not provided [15:16]." The job guides themselves were not difficult to use; however, since the technicians did not adequately understand what is contained in the job guides and how to find the information, their effectiveness was decreased (15:16).

c. Policies for use of the JGM dual-level feature were not adequately explained to the technicians. Again, failure to communicate effectively resulted in uncertainties among maintenance personnel concerning MAC policy on use of the dual-level feature (15:17).

d. "Adequate provisions were not made for storing the JGMs on the aircraft [15:17]." An effective means of storing the manuals on the aircraft and making them readily available are essential to encouraging maximum use (15:17).

4. *Number of Volumes Required.* "The most frequently heard complaint at both bases [Charleston and Norton Air Force Bases] was that too many books are required to do a job [15:18]." This is directly contrary to the original concept that all information required to do a job would be provided in one job guide and that job guides would be packaged to keep the number of volumes required for related tasks at a minimum. Air Force agencies procuring JGMs for other weapon systems should give special consideration to this problem (15:18).

5. *Durability.* "A problem has been encountered with the pages tearing out of the job guide manuals [15:18]." The problem stems from three factors: poor paper; rough edges on binder rings, and holes punched at the very edge of the page. All of these deficiencies should be corrected to prevent possible serious problems caused by lost pages (15:18).

6. *Illustrations.* Some illustrations were found to be poor, primarily because of the printing quality, not because of the content (15:19).

7. *Locating Procedures.* Technicians experienced serious indexing problems with the new technical data system because some data contained inadequate index and table of contents, and some technicians did not adequately understand the indexing system. Due to the differences from the CTO indexing system, training on locating information should be an integral part of the daily implementation.

8. *Ineffective Procedures.* "Technicians complained that some procedures were ineffective or inefficient [15:19]." The two most common complaints were:

a. Experienced technicians complained that checkout procedures are sometimes too long. The quick checks used with the old TOs were removed and replaced with new, longer checkouts in some cases.

b. The technicians said that the new procedures require the use of far more danger tags than the CTOs. "Since danger tags are a controlled item, any unnecessary use of the tags presents an unnecessary administrative requirement and a substantial increase in maintenance time [15:19]."

9. *Omitted Procedures.* Although the new data cover many more tasks than the CTOs, technicians report that some tasks have been omitted. It is likely that some procedures were in fact omitted while others simply were not found by the technicians (15:19).

10. *Manpower Requirements.* "Procedures sometimes require more men than are normally used or available [15:19]."

11. *Incomplete Troubleshooting Data.* "Many common malfunctions were not included in the malfunction indexes or covered by troubleshooting trees [15:20]." Again, the verification and validation phases must be thorough enough to insure that the troubleshooting data are fully capable of serving the intended purpose.

Summary. Obviously, both the positive and negative factors affecting usability and acceptance of the PTOs are often highly subjective in nature because they relate to individual user preferences. Consequently, any attempts to quantify and assign dollar values to these factors would be futile. Certainly, these factors in some way affect maintenance costs; unfortunately, there is no practical method of measuring their effect. In the long range the overall effect should result in cost savings; but, for the purpose of this thesis, it is assumed that the positive and negative factors will at worst negate each other.

> Most of the shop supervisors interviewed spoke well of the concept and the potential of the job guides. They recognized the problems, especially the errors and sometimes lengthy checkout procedures, but overall they indicated that the job guides were much better than the original TOs. The officers and senior NCOs, almost without exception, were optimistic about the long-range impact of the job guides upon C-141 aircraft maintenance [15:28].

<u>Factors Affecting Maintenance Capability</u>

The primary source of factors affecting actual maintenance capability and performance is the 1976 Air Force Human Resources Laboratory (AFHRL) Evaluation of Three Types of Technical Data for Troubleshooting. The results of this experimental evaluation clearly demonstrate that the use of PTOs resulted in significantly better troubleshooting than the use of CTOs (15:2).

<u>Positive Factors</u>. The analysis of the data collected in the AFHRL study indicated that, given technically accurate PTOs of high quality, the following positive factors can be identified.

1. Apprentice electronics technicians with no field experience are able to troubleshoot moderately

complex electronic systems effectively (19:90).

2. Technicians with more than six months experience on moderately complex electronic systems are able to troubleshoot more effectively with PTOs than the standard CTOs at the intermediate level of maintenance (19:90).

3. Apprentice technicians with no field experience using PTOs are able to troubleshoot as effectively or more effectively at the intermediate level than technicians with some experience (less than six months) using standard CTOs (19:90).

4. The use of PTOs results in significantly fewer "good" parts being replaced unnecessarily than when CTOs are used. Use of PTOs at the intermediate maintenance level in an operational environment could result in significant cost savings due to reduced spare parts consumed (19:90).

5. Even for experienced technicians, troubleshooting at the intermediate level is performed significantly faster when PTOs are used (19:90).

6. Experienced technicians believe that the PTOs are less difficult to understand than the CTOs (19:91).

7. Experienced technicians prefer the PTOs over the CTOs for use in troubleshooting at all levels of complexity from flightline to intermediate maintenance to depot repair (19:91).

8. "Although the present study was limited to electronic maintenance, it is highly probable that similar results would be obtained in other maintenance areas [19:91]."

9. A greater proportion of the maintenance problems were solved using the PTOs (19:66).

10. In addition to the proven advantages of PTOs documented during actual field testing, the Air Force Logistics Management Center reported some additional positive aspects of PTOs in their Initial Technical Order Project Findings. These positive factors are briefly summarized below.

a. PTOs can reduce long range maintenance cost (29:23).

b. PTOs simplify training and maintenance actions (29:23).

c. The new TO system uses a numbering system that is in use internationally (29:23).

d. The gap between designers, engineers, and maintenance personnel is bridged by PTOs (29:23).

e. PTOs establish better configuration control of aircraft wiring (29:23).

f. Time spent in search and retrieval of technical data is reduced by the proceduralized system (29:24).

g. The overall consequence of implementing PTOs is reduced maintenance manhours per flight, higher in-commission rates, and improved operational readiness (29:25).

Negative Factors. The most glaring disadvantage of PTOs is the higher acquisition cost compared to the older CTOs. The significantly higher cost of PTOs has retarded the development of an improved technical order system.

Summary. Many of the advantages of PTOs cited by the Air Force Logistics Management Center are theoretical in nature and unproven. However, the conclusions of the AFHRL study are backed by actual controlled comparison tests of CTOs and PTOs, and these documented positive aspects of PTOs can be used to determine the possible maintenance cost savings of this new technical order format.

Except for higher acquisition cost, the negative factors associated with PTOs are related to ineffective implementation and management of the technical order system. These types of problems are characteristic of all new as well as established technical data systems. Officers and senior NCOs involved in technical data agree that after the PTOs are fully integrated into the maintenance system, management problems will not create any greater costs than the present CTOs. These immeasurable management variables are not expected to be any more counterproductive than the problems currently being experienced with CTOs.

Factors Selected for Further Analysis

Positive Factors. The AFHRL field study which compared three types of technical data for troubleshooting generated very quantitative and rigorous statistics relevant to number of problems solved, performance of apprentice and experienced technicians, number of spare parts consumed, and time required to troubleshoot when both PTOs and CTOs were used for electronic maintenance troubleshooting. These positive factors are used in the following chapter as the basis for computing the cost savings which might be achieved using the PTOs instead of the CTOs currently in use.

The Analogous Systems Approach

Method. The AFHRL study was limited to two electronic subsystems of the C-141 aircraft as a foundation for comparison tests of three types of technical data for troubleshooting. The subsystems selected were the AN/APN-147 and the AN/ASN-35 which are both parts of the doppler radar. Consequently, a strong analogy to the F-15 avionics subsystems can be established. If the advantages of PTOs are valid for the test subsystems (the AN/APN-147 and the AN/ASN-35), then the magnitude of these advantages is expected to be at least as great or even greater for the more complex F-15 avionics systems. Therefore, the following seven work unit codes (WUCs) were selected to develop the F-15 potential cost savings: 51XXX-Instruments; 52XXX-Autopilot; 57XXX-Integrated Guidance and Flight Control System; 63XXX-IFF System; 71XXX-Radio Navigation; and 74XXX-Fire Control System. The K051 file data extracted for these WUCs represents the cost of maintaining the F-15 avionics subsystems.

The analogy between C-141 and F-15 avionics maintenance is useful in developing cost data for two reasons. First, avionics electronic subsystems constitute the highest maintenance cost for the F-15 weapon system. Second, if cost savings using PTOs can be documented for the C-141 aircraft, it is reasonable to assume that those cost savings would also be valid for the more complex F-15 avionics subsystems.

Data Limitations. There are three primary limitations to the data gathered to draw the analogy between the C-141 and F-15 systems. First, there are many positive aspects of the PTOs that cannot be quantified in terms of dollars saved. Although there is no way to estimate these savings, they are expected to act as *hidden multipliers* and create significant savings in maintenance dollars (29:23). Second, the AFHRL study compared PTOs and CTOs only on a limited application to two avionics subsystems. The effect of job guide manuals on the entire C-141 aircraft will not be known until more data on maintenance costs after the implementation of PTOs can be gathered and analyzed. Finally, critics of the K051 data system point out that the figures are in error because they consistently underestimate the actual cost of each WUC. However, if a cost savings is realized despite the conservative (low) K051 cost data values, then the actual savings should be even greater than estimated by this thesis.

CHAPTER VI

DATA ANALYSIS

Introduction

The Data Analysis chapter is divided into three main parts. The first, Performance Comparison for CTOs and PTOs, deals with estimating the potential percentage savings which can be achieved utilizing PTOs instead of CTOs. The second part, Forecast of F-15 Logistics Cost, uses three years of F-15 maintenance cost data extracted from the IROS K051 data file to predict the future cost of avionics maintenance. This forecast represents the projected cost of using CTOs; thus, the estimated dollar savings for PTOs can be computed by applying the percentage savings factors obtained in the first part of the data analysis. The third part contains an analysis of three break-even charts. These charts display the predicted break-even points (the points in time where savings generated by PTOs equal the increased cost of acquiring the PTOs) for the anticipated savings derived from the improved technical data.

Performance Comparison for CTOs and PTOs

Measuring Performance

As defined by Robert N. Anthony, performance consists of two dimensions (3:377). The first, effectiveness, expresses how well a maintenance technician accomplishes the job measured in terms of planned and actual output. The ratio of actual jobs accomplished to total jobs assigned yields the technicians percentage of effectiveness. The second dimension of performance, efficiency, deals with the consumption of input resources to accomplish the job. Therefore, efficiency is stated as the ratio of inputs (parts or time) consumed to outputs (jobs) achieved.

The evaluation of three types of technical data for troubleshooting conducted by the AFHRL tested three performance measures of maintenance personnel. One effectiveness measure and two efficiency measures of the performance of these technicians were recorded during the experiment. Mean proportion of problems solved is an effectiveness measure, while mean number of parts used incorrectly and mean time to troubleshoot and repair are efficiency measures. The combination of these three measures can be used to estimate the improvement in overall performance as a result of using proceduralized technical data.

Results of the AFHRL Technical Data Evaluation

The effectiveness of technical data was evaluated by measuring the ability of technicians to troubleshoot representative faults in the test systems using each type of data. Job performance was used to indicate trouble-shooting ability. Each test was administered by inserting a bad component into the system and observing the performance of the technician as he used one of the three types of data to identify the bad component. Data was recorded regarding whether the fault was correctly isolated, the number of spare parts used, and the time required to troubleshoot (20:9).

Data were collected from personnel in three categories: recent technical school graduates (no field experience), technicians with six months or less experience on the equipment, and technicians with more than six months experience. An analysis was conducted on each category of technicians separately, and then the combined results were studied to determine the total improvement in maintenance performance using PTOs.

Apprentice Technicians. Eighteen airmen who had just graduated from Keesler Technical Training Center (KTTC) Course No. 3ABR32834 served as subjects for the study (20:9). They were randomly assigned to two groups; one group used FPTAs first and the other used PTOs first.

The apprentice technicians performed one-half of the problems with FPTAs and one-half with PTOs. A controlled sequence of problem assignment ensured that each problem was performed an equal number of times with each type technical data. This sequence also ensured that each problem was controlled for possible order effects in the experiment. These technicians were not tested using CTOs since this level technician is not expected to be able to troubleshoot effectively using the CTOs (18:9).

Despite this apparent lack of capability with CTOs, the apprentice technicians performed extremely well with PTOs. As indicated in Table 3, the effectiveness and efficiency of apprentice technicians using PTOs approached the performance measures for experienced technicians using CTOs. This initial capability to complete the job without on-the-job training should have a great effect on personnel and training requirements. Consequently, the performance capability of the apprentice technicians would probably result in significant savings.

<u>Technicians with Six Months or Less Experience</u>. Thirty-six technicians in the Military Airlift Command served as subjects in the two experienced categories. Eighteen had six months or less experience on the equipment and eighteen had more than six months experience (18:9). The subjects included both military and civilian

TABLE 3

SUMMARY OF THE AFHRL EXPERIMENT RESULTS

Performance Measures	Category of Technician					
	Apprentice		6 Months or Less Experience		More than 6 Months Experience	
	CTO	PTO	CTO	PTO	CTO	PTO
Operational Level of Maintenance						
Mean proportion of problems solved	NC*	77.8	100	100	100	95.8
Mean number of parts used incorrectly	NC	1.0	.5	.33	.5	.17
Mean time to troubleshoot and repair	NC	35.7	16.0	28.4	20.9	30.2
Intermediate Level of Maintenance						
Mean proportion of problems solved	NC	60.0	60.0	89.4	78.8	87.8
Mean number of parts used incorrectly	NC	2.22	2.67	1.05	1.05	1.05
Mean time to troubleshoot and repair	NC	47.5	59.9	34.8	46.7	39.4

*No Capability (NC) with CTOs.

personnel, and the same experimental procedures were used for both groups. A problem assignment procedure similar to that used for the apprentice subjects was used; however, the experienced technicians were tested with all three types of technical data (18:9).

The effectiveness (mean proportion of problems solved) for the technicians with six months or less experience at the organizational level of maintenance was 100 percent for both CTOs and PTOs. Their efficiency (mean time to troubleshoot and repair) was actually better using CTOs; however, a large number of parts were used incorrectly. Parts used incorrectly can become an extremely costly item because of the total logistics cost required to procure, handle, transport, and maintain these items. Thus, significant savings in fewer parts used incorrectly should easily offset an average of 12.4 minutes additional time consumed in troubleshooting using PTOs.

At the intermediate maintenance level the performance using PTOs was superior to all three measurement criteria. Perhaps the most impressive difference in performance was the mean number of parts used incorrectly. The average technician used over 2.5 times as many parts incorrectly when troubleshooting with CTOs. In addition, technicians using PTOs solved 28.8 percent more problems while using an average of 25.1 minutes less time per solution.

Technicians with More Than Six Months Experience. Eighteen of the thirty-six technicians in the 328X4 AFSC had more than six months experience, and these subjects were tested in the same manner as the first group of experienced technicians. It was noted that these more experienced technicians solved more problems in less time using CTOs at the organizational level of maintenance. However, they again used almost three times as many parts incorrectly when troubleshooting with CTOs.

At the intermediate level, performance using the PTOs was as good or better than the performance using CTOs in all three performance measurements.

Summary of Potential Savings

Even without the possible savings due to having apprentice technicians accomplish more tasks, it is reasonable to expect a considerable reduction in the F-15 avionics maintenance costs as a result of improved performance by experienced technicians troubleshooting with PTOs. Table 4 presents a summary of the percentage of savings for each performance measure evaluated during the AFHRL testing of exprienced avionics maintenance personnel. All figures in Table 4 are expressed in percentages.

TABLE 4

SUMMARY OF ESTIMATED PERCENTAGE SAVINGS FOR PTOs

	Percentage Savings
Six Months or Less Experience	
Organizational Maintenance	
Mean proportion of problems solved	0
Mean number or parts incorrectly used	34.0
Mean time to troubleshoot and repair	-77.5 *
Intermediate Maintenance	
Mean proportion of problems solved	28.8
Mean number of parts incorrectly used	60.7
Mean time to troubleshoot and repair	41.9
More than Six Months Experience	
Organizational Maintenance	
Mean proportion of problems solved	- 4.2 *
Mean number of parts incorrectly used	66.0
Mean time to troubleshoot and repair	-44.5 *
Intermediate Maintenance	
Mean proportion of problems solved	9.0
Mean number of parts incorrectly used	0
Mean time to troubleshoot	15.6

*Percentage savings in favor of CTOs.

The original data for mean proportion of problems solved were already expressed in percentages; therefore, it was possible to make a direct comparison of the effectiveness of CTOs and PTOs. The numbers opposite the Mean Proportion of Problems Solved in Table 4 represent the percentage difference in effectiveness between the two types of technical data.

The experimental data for mean number of parts incorrectly used and for mean time to troubleshoot and repair were not expressed as percentages. By using the CTO efficiency as a standard for comparison, the data were converted to percentages which reflect the improvement in efficiency derived from using PTOs. The negative figures shown in Table 4 indicate that the potential percentage savings for that specific performance measure actually favors the CTOs.

Although the elements of performance, effectiveness and efficiency, could not realistically be combined to compute an overall average, visual inspection of Table 4 indicated that a significant savings could be anticipated with PTOs. The best approach to the problem was to estimate a realistic range of savings that might be expected. In order to display a greater range of possible savings estimates, the following savings options were selected: "pessimistic" = 3 percent; "most likely" = 15 percent; and "optimistic" = 27 percent. These figures are consistent with the savings expectations expressed by PIMO[1] and other studies covered in the Literature Review. Research psychologists from the AFHRL, who were directly involved in the technical data evaluation project, also supported these figures as reasonable estimates of expected cost savings (5:25).

Forecast of F-15 Logistics Cost

The available data for the seven applicable WUCs (51XXX--Instruments, 52XXX--Autopilots, 57XXX--Integrated Guidance and Flight Control Systems, 63XXX--IFF Systems, 71XXX--Radio Navigation, and 74XXX--Fire Control System) were collected from the K051 (see IROS in Chapter II) data base. The data were expressed in average monthly cost by WUC, by quarter; therefore, simple mathematical calculations were required to express the data in average cost per aircraft per quarter (see Table 5).

For each WUC, cost per aircraft, was plotted over a time horizon. These graphs, found in Appendix C, were used to visually display the general trend of each individual WUC. Simple linear regression was used to find a mathematical trend for future cost. The visual displays and mathematical trends were compared to the

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[1]Compared to the PIMO estimates, 15 percent is a rather conservative estimate of potential savings.

TABLE 5

AVERAGE COST PER AIRCRAFT

WUC	1975				1976				1977			
	1	2	3	4	5	6	7	8	9	10	11	12
51XXX	730	500	580	282	679	767	870	588	492	535	485	550
52XXX	214	89	300	324	1,515	970	695	302	238	183	444	561
57XXX	85	49	132	74	36	73	91	88	1,373	357	407	523
63XXX	1,516	1,073	1,482	1,396	952	1,209	1,389	918	914	563	705	752
65XXX	254	716	1,072	781	1,012	1,068	1,179	1,323	1,132	825	876	1,043
71XXX	2,371	611	1,071	1,102	2,403	2,251	2,402	1,860	3,951	2,639	3,260	3,028
74XXX	4,383	2,296	3,546	83,223	4,845	9,598	11,627	6,241	2,168	14,200	25,106	28,745

NOTE: These figures are the average cost per aircraft per quarter by WUC with FY 1974 as the base year (I).

SIMFIT (see SIMFIT in Chapter II and Appendix C) computer program results. The Kolmogorov-Smirnov (K-S) test was used over the Chi-square test because it is the more appropriate and powerful test when the data base is relatively small (32:14). Additionally, as indicated in Table 6, more than one distribution was acceptable at the 90 percent confidence level. This was not unexpected as the

> . . . Erlang, Lognormal, Gamma, and Weibull distributions are basic in the theory of curve fitting and when the sample is small, it is difficult to clearly distinguish between the various distributions. For example, all four of the distributions may fit the data and, therefore, the researcher has to decide which probability distribution best represents his data [32:6].

Various combinations of acceptable variable distributions were tested to determine their sensitivity to change. It was found that the mean values and the total probability distributions changed insignificantly when the individual WUC distributions were varied. The distributions that were determined to best describe the individual variables (WUCs) were then used in the Monte Carlo (see Monte Carlo in Chapter II and Appendix D) computer simulation program. A total of 4,000 convolutions of the random variable were generated to form the Avionics Maintenance Cost Probability Distribution in Figure 3. Three points on the total cost probability distribution (low, middle, and high) were selected to answer the thesis research question. The high point represents the point

TABLE 6

SUMMARY OF SIMFIT ANALYSIS

WUC	Erlang	Weibull	Gamma	Pearson X1	Lognormal	Normal	Uniform	Beta	Triangular
51XXX	.092	POL	.130	POL	.101	.148	.145	.654	.382
52XXX	.122	.139	.127	POL	.073	.297	.396	POL	.453
57XXX	.357	.295	.320	.310	.260	.530	.580	POL	.526
63XXX	.147	.120	.147	POL	.145	.128	.107	.125	.137
65XXX	.142	.090	.141	POL	.207	.95	.136	.110	.166
71XXX	.243	.191	.240	POL	.294	.153	.159	.194	.214
74XXX	.248	.190	.214	.210	.176	.412	.575	POL	.453

NOTE: T_c for all variables = .338

POL = Parameters Out of Limits

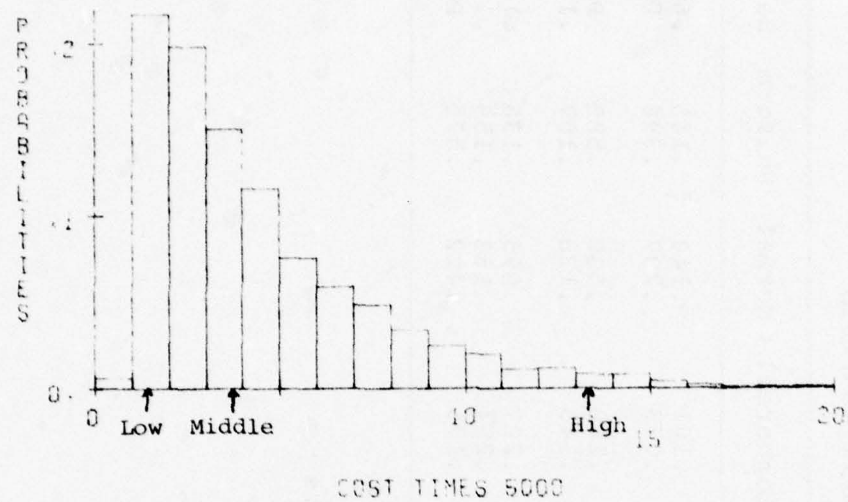

Fig. 3. Avionics Maintenance Cost Probability Distribution

where there is only a 3 percent probability that the future cost would be greater than $67,727. In other words, there is a 97 percent chance that the future cost would be lower than $67,727. The low point indicates that there is a 3 percent chance that the future cost will be lower than $5,513 and a 97 percent chance that it will be higher than $5,513. The middle cost is the point on the probability distribution where there is a 50 percent chance that the future cost will be higher than $17,211 and a 50 percent chance that it will be lower than $17,211.

All of the above figures are for FY 1974; therefore, these figures were adjusted to FY 1977 base year using the *National Defense Budget Estimates for FY 1977*. This publication provides the DOD/MAP composite index which is weighted to include the ratio of civil service pay, military personnel pay, retired pay, and industry purchases for all DOD operations (33:78). The composite FY 1974 index was 77.2, and the adjusted forecast cost figures are (low--$7,141, middle--$22,294, and high--$87,729) per aircraft per quarter.

Table 7 is a matrix summary of the PTO percentage savings options (pessimistic, most likely, and optimistic) and the forecast F-15 logistics (low, middle, and high) cost probabilities. The combination of three options and three probabilities for each option yields nine savings

TABLE 7

POTENTIAL PTO SAVINGS MATRIX

PTO Savings Options (percent)	Forecast Avionics Maintenance Cost Probabilities (percent)		
	Low--3%	Middle--50%	High--97%
Pessimistic 3%	$ 214	$ 669	$ 2,632
Most Likely 15%	1,071	3,344	13,159
Optimistic 27%	1,928	6,019	23,687

NOTE: Figures are FY 1977 dollars per aircraft per quarter.

forecasts which range from $214 to $23,687 per aircraft per quarter for the seven avionics WUCs.

Break-Even Analysis

Three break-even charts were developed from the potential PTO savings shown in Table 7. Since these figures represent dollars per aircraft, it was necessary to obtain a production schedule for the remainder of the production cycle. The F-15 Production Schedule in shown in Table 8 (4). With this information, the savings per quarter were computed by multiplying the theoretical savings per aircraft by the total number of aircraft in the inventory during each quarter. Those aircraft in production during any quarter were not added to the total until the following quarter.

One break-even chart was developed for each PTO savings option. For example, the Pessimistic Break-Even Chart in Figure 4 is based on 3 percent savings. The three savings curves on this chart reflect the effect of 3 percent savings at each of three points on the probability distribution for F-15 forecast avionics maintenance cost. A low, middle, and high cost figure was selected from the distribution as shown in Figure 3. The Most Likely and Optimistic chart were drawn in the same manner. The following paragraphs provide a brief description and analysis of each break-even chart.

TABLE 8

F-15 PRODUCTION SCHEDULE

Fiscal Year	Quarter	Aircraft Scheduled for Production	Total Aircraft at Beginning of the Quarter
79	1	27	334
	2	27	361
	3	27	388
	4	24	415
80	1	24	439
	2	24	463
	3	23	487
	4	17	510
81	1	21	527
	2	21	548
	3	17	569
	4	19	586
82	1	20	605
	2	20	625
	3	19	644
	4	18	663
83	1	18	681
	2	18	699
	3	12	717
	4	...	729

AD-A059 571 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 1/3
A COST ANALYSIS ON PROCURING IMPROVED TECHNICAL ORDER DATA FOR --ETC(U)
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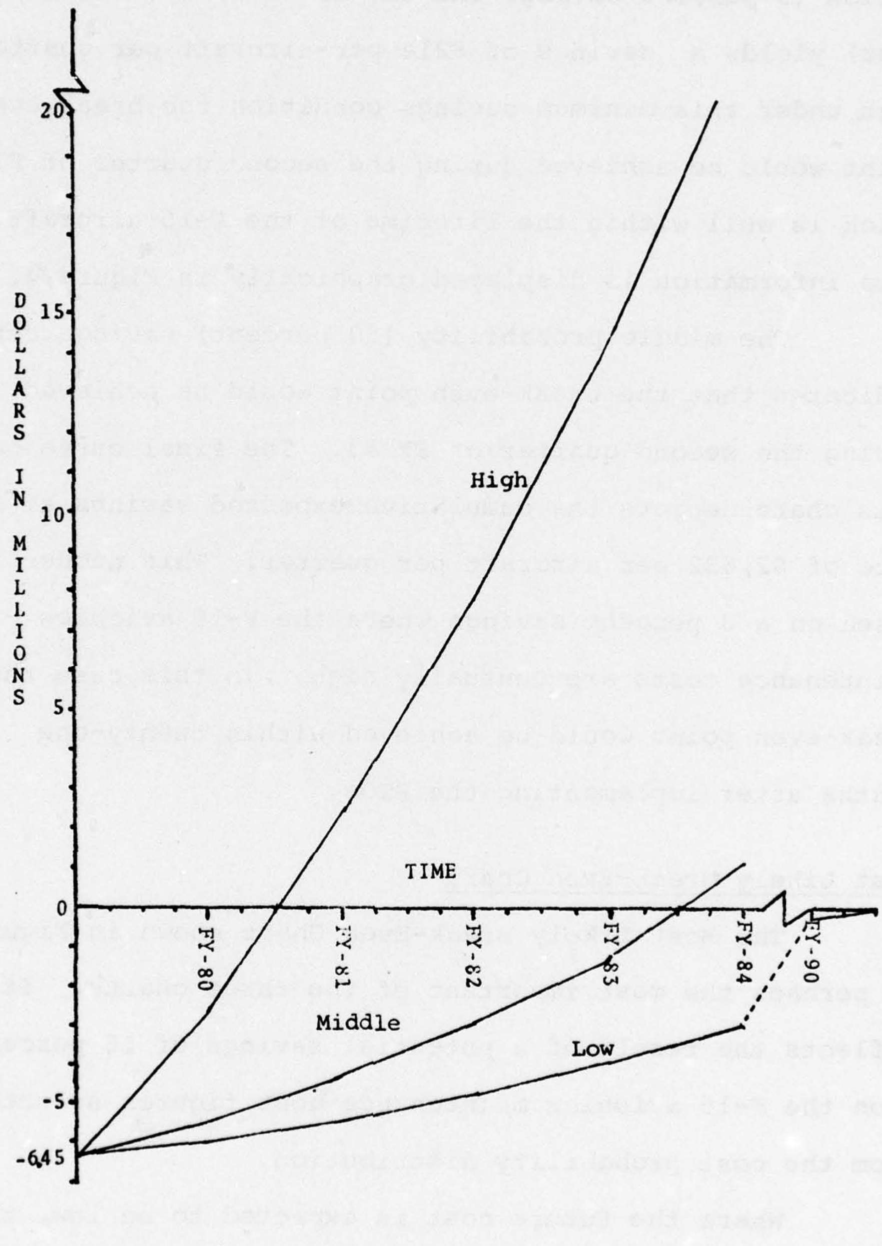


Fig. 4. Break-Even Analysis at 3 Percent Savings (Pessimistic)

Pessimistic Break-Even Chart

Referring to Table 7, the smallest savings condition (3 percent savings and the low avionics maintenance cost) yields a savings of $214 per aircraft per quarter. Even under this minimum savings condition the break-even point would be achieved during the second quarter of FY 90 which is well within the lifetime of the F-15 aircraft. This information is displayed graphically in Figure 4.

The middle probability (50 percent) savings curve indicates that the break-even point would be achieved during the second quarter of FY 83. The final curve on this chart depicts the cumulative expected savings at a rate of $2,632 per aircraft per quarter. This number is based on a 3 percent savings where the F-15 avionics maintenance costs are unusually high. In this case the break-even point would be achieved within twenty-one months after implementing the PTOs.

Most Likely Break-Even Chart

The Most Likely Break-Even Chart shown in Figure 5 is perhaps the most important of the three charts. It reflects the result of a potential savings of 15 percent upon the F-15 avionics maintenance cost figures selected from the cost probability distribution.

Where the future cost is expected to be low, the potential savings is $1,071 per aircraft per quarter. If

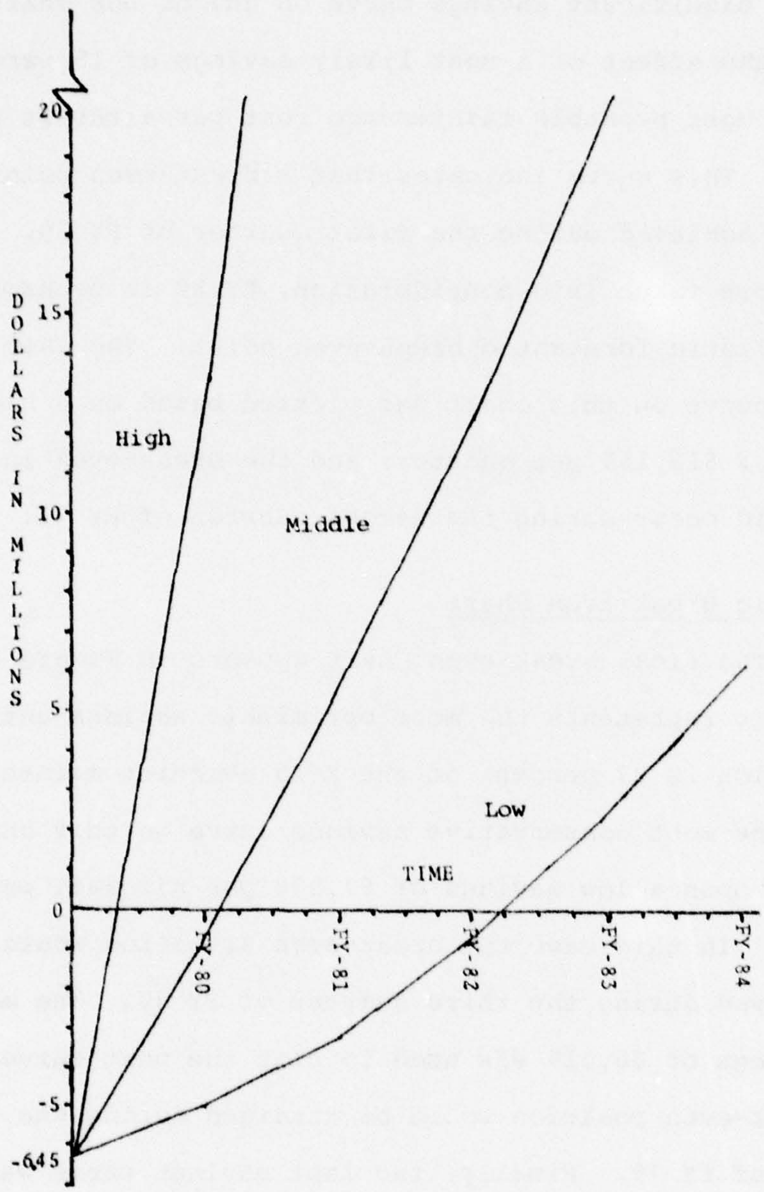


Fig. 5. Break-Even Analysis at 15 Percent Savings (Most Likely)

the F-15 production plan runs on schedule, the break-even point would be reached during the first quarter of FY 82. The most significant savings curve on any of the charts depicts the effect of a most likely savings of 15 percent upon the most probable maintenance cost per aircraft per quarter. This curve indicates that a break-even point would be achieved during the first quarter of FY 80. With all factors taken into consideration, FY 80 is perhaps the most realistic forecasted break-even point. The last savings curve on this chart was plotted based on a high savings of $13,159 per quarter, and the break-even intercept would occur during the second quarter of FY 79.

Optimistic Break-Even Chart

The final break-even chart appears in Figure 6. This chart represents the most optimistic savings anticipated which is 27 percent of the F-15 avionics maintenance cost. The most conservative savings curve on this chart is based upon a low savings of $1,928 per aircraft per quarter. In this case the break-even situation would be achieved during the third quarter of FY 80. The middle savings of $6,019 was used to plot the next curve, and the break-even position would be attained during the third quarter of FY 79. Finally, the last savings curve was based upon the situation where the avionics maintenance cost was extremely high and a 27 percent savings was

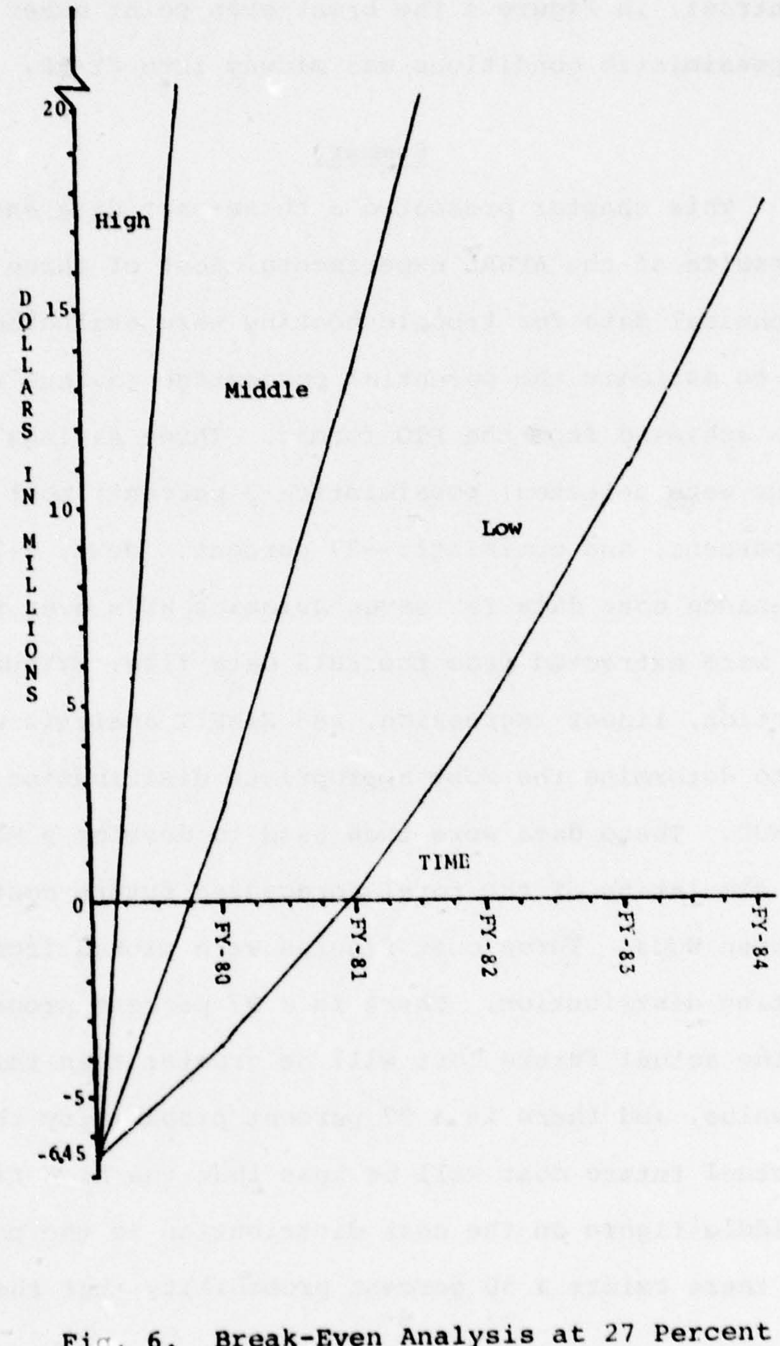


Fig. 6. Break-Even Analysis at 27 Percent Savings (Optimistic)

achieved. In this very optimistic savings case, break-even would be realized during the first quarter of FY 79. In contrast, in Figure 4 the break-even point under the most pessimistic conditions was midway into FY 90.

Summary

This chapter presented a three-part data analysis. The results of the AFHRL experimental test of three types of technical data for troubleshooting were evaluated in order to estimate the potential percentage savings which can be achieved from the PTO format. Three savings options were selected; pessimistic--3 percent; most likely --15 percent; and optimistic--27 percent. Next, F-15 maintenance cost data for seven avionics WUCs over three years were extracted from the K015 data file. Visual inspection, linear regression, and SIMFIT analysis were used to determine the most appropriate distribution for each WUC. These data were then used to develop a Monte Carlo simulation of the total forecasted future cost of the seven WUCs. Three cost figures were picked from the resulting distribution. There is a 97 percent probability that the actual future cost will be greater than the low cost value, and there is a 97 percent probability that the actual future cost will be less than the high figure. The middle figure on the cost distribution is the point where there exists a 50 percent probability that the future cost will be higher and a 50 percent chance that the future cost will be lower.

All dollar values were adjusted to FY 77, and a three-by-three matrix was constructed to visually display the data. Finally, the break-even analysis charts illustrate the forecast points in future time where the savings for each of the nine states of nature equals the additional cost of procuring the PTOs. It was determined that the most likely break-even point would be achieved during the first quarter of FY 80.

CHAPTER VII

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

For many years, the United States Air Force (USAF) has expressed strong interest in finding methods of reducing weapon system maintenance cost. "One way of reducing cost is to increase the productivity of maintenance personnel by providing better technical data [18:1]." The results of "A Study of the Air Force Maintenance Technical Data System," accomplished by the Behavioral Sciences Laboratory in 1962, identified the need for an improved technical order (TO) format in the USAF (2:44). High maintenance personnel cost makes it imperative that a more efficient, improved, proceduralized TO (PTO) format, such as the logic tree troubleshooting aid (LTTA), be developed and utilized.

At the present time, LTTAs are being procured for the F-16 aircraft and all other new aircraft acquisitions as part of the original technical data package (22). Due to the significant advantages of PTOs, the F-15 Technical Order Management Agency (TOMA) manager is in the process of evaluating the cost of converting the TOs for the F-15 to the PTO format. The F-15A model has already been procured with the conventional TOs (CTOs), but there is now an opportunity to purchase the new PTOs for various combinations of the F-15A/B/C/D models. A cost versus benefits analysis of the advantages and disadvantages of PTOs has been accomplished to assist top level management in deciding the appropriate type TO option to procure. Thus, the purpose of this thesis has been to analyze the cost versus benefits of procuring the new PTOs for the F-15 series aircraft.

To accomplish this purpose, the following four objectives were selected: to identify the steps in the TO procurement process; to explain the technique used by McDonnell-Douglas Aircraft Company to develop cost estimates for the F-15 weapon system TOs; to describe the advantages of procuring the F-15 weapon system TOs in the PTO format; and to estimate where possible the potential monetary savings derived from using the improved PTO format. These objectives were established so that it would be possible to systematically provide the background necessary to answer this thesis research question: *Should the F-15 weapon system technical data be procured in the PTO format?*

A comprehensive literature review revealed that the problem of inadequate TOs was identified over fifteen years ago. The most significant study of TO systems since the 1962 study was completed in 1976 by the Air Force Human

Resources Laboratory (AFHRL). AFHRL evaluated three types of technical data for troubleshooting. Fully proceduralized troubleshooting aids (FPTAs), LTTAs, and CTOs were compared in actual performance tests by apprentice technicians, technicians with six months or less experience, and technicians with more than six months experience. The FPTAs are not being considered for procurement due to the extremely high cost of the additional pages required to present technical data in that format.

The F-15 System Project Office (SPO) anticipated the need for cost data for the various alternatives and requested *"Ball Park"* cost figures from McDonnell-Douglas for the possible procurement options. This cost data provided the basis for the cost versus benefits comparison.

Many of the advantages of PTOs cited by the various studies were theoretical in nature and unproven. However, the conclusions of the AFHRL study of three types of technical data for troubleshooting were backed by actual controlled comparison tests of CTOs and PTOs, and these documented positive aspects of PTOs were used to determine possible maintenance cost savings. Four positive factors with statistical relevance were selected for further analysis. They were: performance of apprentice and experienced technicians; number of problems solved; number of parts used incorrectly; and time required to troubleshoot and repair. From the analysis of PTOs three savings options were developed: Pessimistic--3 percent; Most Likely--15 percent; and Optimistic--27 percent.

The analogous systems approach was used to draw a strong analogy between the C-141 avionics subsystem used in the AFHRL study and the F-15 avionics subsystems. Seven applicable work unit codes (WUCs), which make up the F-15 avionics maintenance cost, were selected to provide the foundation for computing the potential cost savings. A Monte Carlo simulation was used to forecast the future F-15 total avionics maintenance cost. Three points (low, middle, and high) on the cost probability distribution were selected to reflect the possible range of future avionics maintenance cost. When these three cost figures were placed into a matrix with the three anticipated percentage savings options, a continuum of nine possible savings per aircraft per quarter was developed. Using these figures and the number of F-15 aircraft projected to be in the inventory, three break-even charts were constructed and used to illustrate the forecast points in the future where the anticipated savings equal the cost of PTOs. Analysis of the break-even charts reveals that the most likely break-even point would be achieved during the first quarter of FY 80.

Conclusions

There are several distinctive aspects of this thesis effort. First, it is important to remember that there are many positive but subjective factors associated with PTOs which cannot be quantified. The effect of these factors on maintenance cost will not be known until more experience is gained from operational use of PTOs.

Second, the forecast break-even points are based only on the savings from the avionic maintenance WUCs. These savings alone would most likely pay the additional acquisition cost for PTOs, and it reasonable to anticipate significant savings in other maintenance WUCs. Although avionics repair is traditionally one of the most expensive individual maintenance areas for advanced weapon systems, this cost is only a fraction of the total F-15 maintenance cost. The total estimated cost of the seven avionics WUCs during the three-year period from 1975 to 1977 is $25.6 million, while in comparison the total F-15 weapon system maintenance cost for the same time period is estimated to be above $60.5 million (13).

Third, this study presents a range of potential savings for PTOs that encompasses all of the realistic states of nature. The continuum of possible savings ranges from a very pessimistic to a highly optimistic figure with appropriate probabilities assigned to the predicted savings. Table 9, Summary of Forecast Break-Even Points,

TABLE 9

SUMMARY OF FORECAST BREAK-EVEN POINTS

PTO Savings Options (percent)	Forecast Avionics Maintenance Cost Potential (percent)		
	Low--3%	Middle--50%	High 97%
Pessimistic 3%	FY 90-2	FY 83-2	FY 80-3
Most Likely 15%	FY 82-1	FY 80-1	FY 79-2
Optimistic 27%	FY 80-3	FY 79-3	FY 79-1

illustrates the broad spectrum of possible break-even points. The most likely break-even time appears to be during FY 80.

Finally, after all factors are considered, the answer to the research question must be: *The F-15 weapon system technical data should be procured in the PTO (MIL-M-83495) format.* This conclusion is consistent with the recent F-15 SPO decision to procure proceduralized technical orders for the entire F-15 weapon system (36).

Recommendations

The following recommendations are an outcome of this thesis effort.

1. After sufficient data is accumulated, the effect of PTOs on C-141 aircraft maintenance costs should be evaluated to determine the actual savings realized. The cost data for the C-141 and other operational aircraft, such as the F-15, A-10 and F-111, which transistion to PTOs should be monitored closely in order to detect any positive or negative trends and to determine the causes of these changes.

2. Beginning with the F-16 weapon system, all new aircraft acquisitions will be procured with the proceduralized technical data package (16). The maintenance cost data for these new "state of the art" weapon systems should be scrutinized closely to detect cost trends that can be attributed to PTOs.

3. The affect of PTOs on those F-15 and F-16 aircraft dedicated to foreign military sales should be studied. The influence of the improved capability of PTOs should enhance these foreign sales and provide better maintenance performance in those countries.

4. The F-15A technical data has already been procured in the CTO format and the F-15B could also be procured in the same format for $0.2 million. Consequently, an extremely valid comparison of the technical orders could be achieved if the F-15 C/D technical data were procured in the PTO format. If this comparison verified the advantages of PTOs, follow-on procurement of the PTOs for the F-15 A/B would increase the total cost of the technical data by only $0.2 million. Actually, less than $200,000 appears to be a small price to pay to validate the savings claimed for PTOs. Afterwards, the transistion to PTOs for other weapon systems could be approached with greater confidence in the potential of PTOs to reduce maintenance costs.

APPENDIXES

APPENDIX A

GLOSSARY OF TERMS

MIL-M-25098. Conventional TO (CTO) procurement specification. TOs procured under this military specification (Mil Spec) contain a description of the equipment and most of the information required to troubleshoot the equipment. However, the TOs are prepared assuming that the technician has adequate training and experience in using test, in locating most parts within the equipment, and in interpreting schematic diagrams (29:92). Some troubleshooting information is provided, but the steps are not fully proceduralized (see Appendix B).

MIL-M-38800. The primary difference between this specification and MIL-M-25098 is the requirement for organizational manuals to be Job Guide Manuals (JGMs). These JGMs are the new style Logic Tree Troubleshooting Aids (LTTAs) which provide a step-by-step procedure (see Appendix B) for troubleshooting (29:92).

MIL-M-83495. This specification expands upon MIL-M-38800 by requiring Fault Isolation Manuals (FIMs), Fault Reporting Manuals (FRMs), and System Schematics Manuals (SSMs). These manuals are used to identify, isolate, and report discrepancies found by aircrew members and maintenance personnel. The indexing system used in these manuals (see Appendix B) identifies the specific JGM required to troubleshoot the malfunctioning system.

MIL-STD-863A. The manuals above are tied to engineering through MIL-STD-863A which provides specific guidance for the preparation of schematic diagrams (see Appendix B) contained in the System Schematic Manuals (SSMs).

TOMA. A Technical Order Management Agency (TOMA) is an integral part of each Systems Program Office (SPO). This agency is tasked with monitoring the procurement, validation, and verification of technical orders during the acquisition phase of new weapon systems.

VALIDATION. Contractor's test of a new TO. Prior to delivery of each new weapons system component, the contractor is required to validate the accuracy of each supporting TO (29:92).

VERIFICATION. Air Force's test of a new TO. AFR 8-2 requires verification of "selected" (but unspecified) TOs prior to the TOs being formalized and accepted by the Air Force. Presently, there is no stated criteria on what constitutes a verification; therefore, each SPO develops its own policy in regard to verification (29:16).

FPTA. The fully proceduralized troubleshooting aid (FPTA) provides complete step-by-step instructions for both checkout and troubleshooting, and they are designed for use by both experienced and inexperienced technicians. FPTAs are more proceduralized than LTTAs, and the keyed illustrations provided with the text make the much more expensive (18:5).

CTO. See MIL-H-25098.

PTO. As used in this thesis, the term proceduralized technical orders (PTOs) include those manuals required by MIL-M-38800, MIL-M-83495, and MIL-STD-863A.

WUC. Work unit codes are the common denominator in the IROS program and is similar to the Work Breakdown Structure (MIL-STD-881) used by the prime weapon system contractor. By using work unit coding there is a complete identification from the major functions of the system (landing gear, bomb/NAV, etc.) down to its lowest level component (27:8).

ROC. The Required Operational Capbility (ROC) is now referred to as a Statement of Operation Need (SON) and at one time was referred to as a General Operational Requirement (GOR). It is the primary vehicle for stating a Major Air Command need (17:9).

PROGRAM TRANSFER. The point in time when the responsibility for a weapon system is transferred from the Air Force Systems Command to the Air Force Logistics Command.

APPENDIX B

TECHNICAL ORDER COMPARISON

CHECKOUT AND TROUBLESHOOT CONTROL INDICATOR C-3819A/ASN-35 (CONT)

Inspect Control Indicator.

CAUTION

If returning to this page from a troubleshooting step, be sure:

a. All disconnected wires and cables are reconnected.
b. All removed components are reinstalled.

1. Open foldout (p. 1-59).

NOTE

Do not overlook importance of visual inspections. If you do not know how to inspect components, refer to T.O. MSIM GENL.

Replace defective components, as discovered, and continue checkout. Refer to IPB (T.O. 5N5-12-2-4) for part number.

2. Perform thorough visual inspection of control indicator (12). Look for:

   a. Burned or scorched components.
   b. Cracked, disconnected, and broken wires.
   c. Bent, broken, and missing pins (13) and terminals (14).

3. Inspect control indicator (12) for foreign matter. Remove foreign matter, as required.

Check Counter Assemblies.

NOTE

Be sure to rotate L/R counter assembly (6) through its full count 999 LEFT and RIGHT 999.

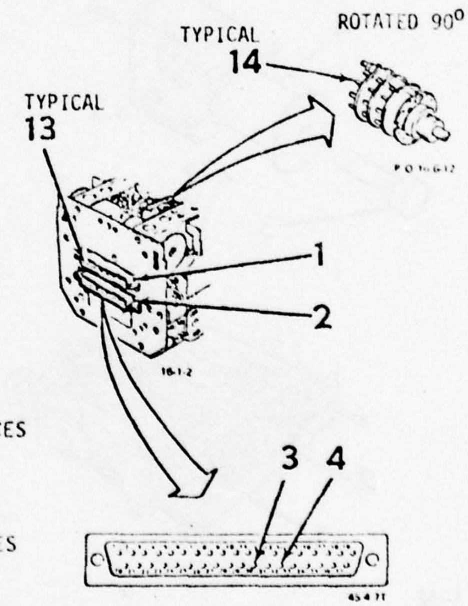
4. Operate controls (7), (8), and (11) to rotate counter assemblies (6), (9), and (5) through their full count. Check that counters (6), (9), and (5) rotate freely. If not, inform supervisor.

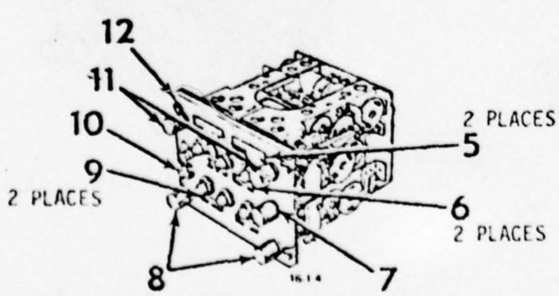
Check Torque Transmitter Continuity.

5. Disconnect P5405 (15). Using VOM, check that resistance between P5401-30 (3) and P5401-32 (4) is 8 to 10 ohms. If not, go to p. 1-12 (malfunction No. 1).

6. Connect P5405 (15). Disconnect P5406 (16).

7. Using VOM, check that resistance between P5401-30 (3) and P5401-32 (4) is 8 to 10 ohms. If not, go to p. 1-12 (malfunction No. 2).





1-6

Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

CHECKOUT AND TROUBLESHOOT CONTROL INDICATOR C-3819A/ASN-35 (CONT)

Troubleshoot Malfunction No. 37 (Cont).

4. Check that right counter magnet assembly K5405 (4) adjustment is good. If not, go to step 11. If adjustment is good, go to next step.

5. Check that right counter magnet core K5405 (3) adjustment is good. If not, go to step 12. If adjustment is good, go to next step.

6. Inform supervisor malfunction is mechanical and located in L/H along track counter assembly (2).

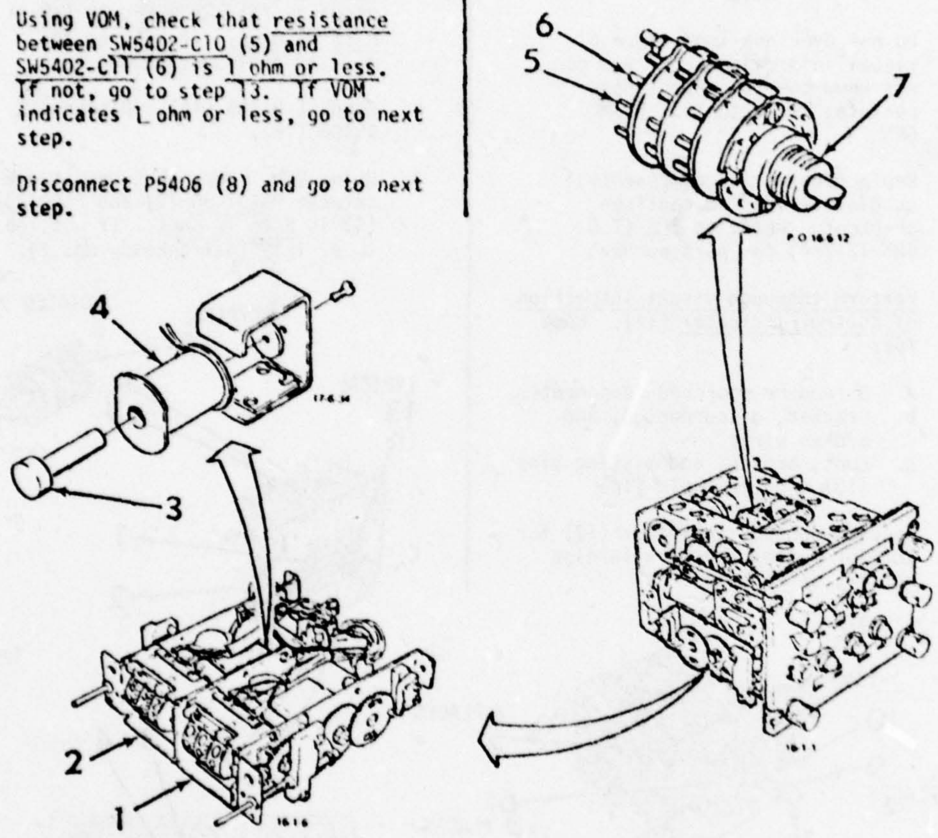
7. Using VOM, check that resistance between SW5402-C10 (5) and SW5402-C11 (6) is 1 ohm or less. If not, go to step 13. If VOM indicates 1 ohm or less, go to next step.

8. Disconnect P5406 (8) and go to next step.

9. Using VOM, check that resistance between J5406-J (10) and J5406-F (9) is 60 to 80 ohms. If not, go to step 14. If VOM indicates 60 to 80 ohms, go to next step.

10. Using control indicator wiring diagram (vol. 6) check wiring. Repair or replace defective wires and go to p. 1-1.

11. Adjust right counter magnet assembly K5405 (4) (vol. 6, p. 5-1) and go to step 15.



Example Page from FPTA Checkout and Troubleshoot Procedures for Navigational Computer AN/ASN-35

T.O. 5N1-3-8-2-TS-1

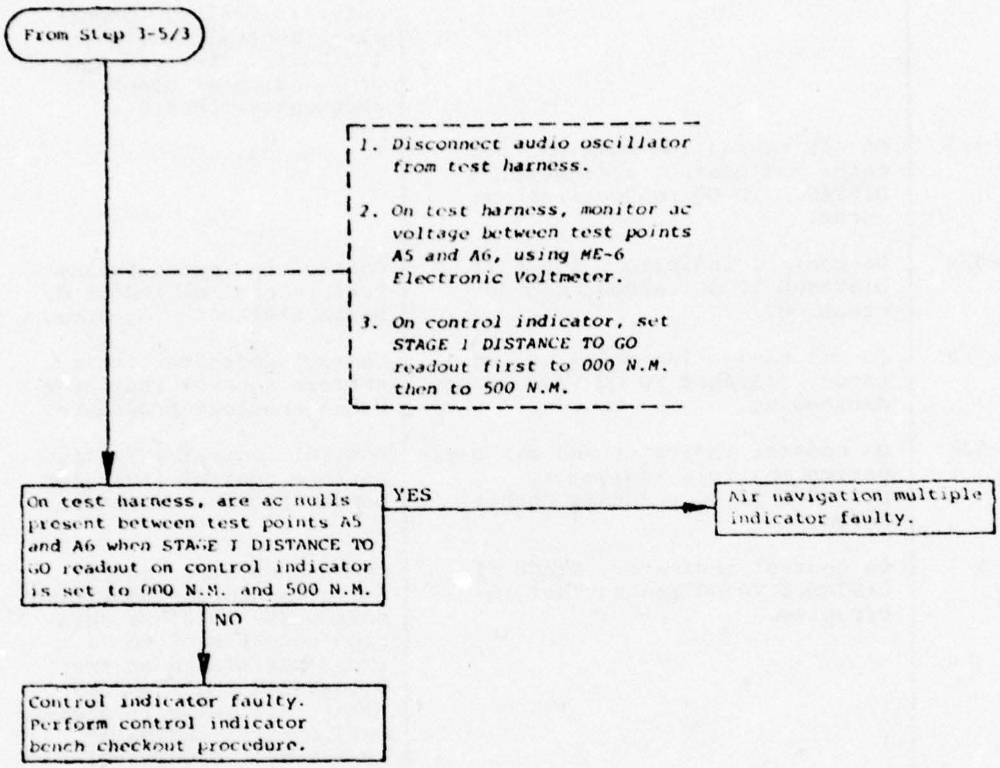


Figure 3-3. Computer Set Troubleshooting for Failed Bench Checkout Procedure 3-5/3

Example Page from LTTA Bench Checkout and Troubleshooting Procedures for Computer Set AN/ASN-35 (Section 3 of LTTA)

Computer Set AN/ASN-35 Troubleshooting Crossreference
(Continued)

STEP FAILED	INDICATION	PROCEDURE
3-5/2 Cont'd		If all ac voltages are present and vary, air navigation multiple indicator is faulty. Otherwise, control indicator is faulty. Perform control indicator bench checkout procedure.
3-5/3	On air navigation multiple indicator and control indicator, DISTANCE TO GO readouts do not agree.	Figure 3-3.
3-5/4	On control indicator, STAGE II DISTANCE TO GO readout not decreasing.	Control indicator faulty. Perform control indicator bench checkout procedure.
3-5/5	On air navigation multiple indicator, DISTANCE TO GO readout not decreasing.	Control indicator faulty. Perform control indicator bench checkout procedure.
3-5/6	On control indicator and air navigation multiple indicator, DISTANCE TO GO readouts do not agree.	Control indicator faulty. Perform control indicator bench checkout procedure.
3-5/7	On control indicator, STAGE II DISTANCE TO GO readout not increasing.	On test harness, check for a 15- to 35-V positive pulse, 35- to 85-ms duration occurring 9 to 11 times per minute at test points E12 (hot) and E5 (rtn). If pulse is present, control indicator is faulty. Otherwise, navigational computer track resolver drive 300 is faulty. Perform track resolver drive bench checkout procedure.
3-5/8	On control indicator, STAGE I DISTANCE TO GO readout not increasing.	Control indicator faulty. Perform control indicator bench checkout procedure.

Example Page from LTTA Bench Checkout and Troubleshooting Procedures for Computer Set AN/ASN-35

Step	Test Point	Test Equipment	Control Settings and Instructions	Normal Indication	If Indication Is Normal	If Indication Is Abnormal
8	Terminals A-13, A-14, A-11, and A-12 on test harness	Audio oscillator and AVO-8	With the audio oscillator as in step 7 and the heading track simulator set to zero, set the DESIRED TRACK ANGLE counter between 000.0 and 180.0 degrees. Connect the frequency meter across test points A-11 and A-12 (common)	DISTANCE CROSS TRACK counter reading increases LEFT or decreases RIGHT.	Proceed to step 9.	If there is no "left" pulse input at A-11 and A-12, check for faulty connections or fault in computer. Check pawl and star wheel. Check gear train for signs of jamming.
9	Terminals A-13, A-14, A-10 A-12 on test harness	Audio oscillator and AVO-8	With the audio oscillator and the heading track simulator set as in step 8, set the DESIRED TRACK ANGLE counter between 180° and 359.9 degrees. Connect the frequency meter across test points A-10 and A-12.	DISTANCE CROSS TRACK counter reading decreases LEFT or increases RIGHT.	Proceed to step 10.	If there is no "right" pulse input at A-10 and A-12, check for faulty connections or fault in computer. Check pawl and star wheel. Replace relay K5404 if faulty.
10	Terminals A-13, A-14, D-6 and D-7 on test harness	Audio oscillator and AVO-8	With the audio oscillator and the heading track simulator as in step 8, set the DESIRED TRACK ANGLE (STAGE I and STAGE II) counters to 45°. Turn the AUTO-MAN switch to OFF. Set the DISTANCE TO GO STAGE I counter at 50 miles and the DISTANCE CROSS TRACK counter at 50. miles LEFT. Turn the AUTO-MAN switch to MAN.	Readings on both counters should remain identical while decreasing from 50 to 0 miles.	Repeat the step, but using the DISTANCE TO GO STAGE II counter.	a. If readings differ, check for 0° actual track input from the heading track simulator at test points D-6 and D-7. If voltage is other than zero, simulator is faulty. b. If voltage is zero, repeat the step, but using the DISTANCE TO GO STAGE II counter. If readings of the DISTANCE CROSS TRACK and DISTANCE TO GO counters correspond for stage I but not for stage II, the STAGE II DISTANCE TO GO counter is faulty.

Figure 8-2. Table of Control-Indicator Trouble Analysis (Sheet 3 of 6)

CTO: Example from TO Field Maintenance Instructions for Computer Set, Navigational (continued on page 106)

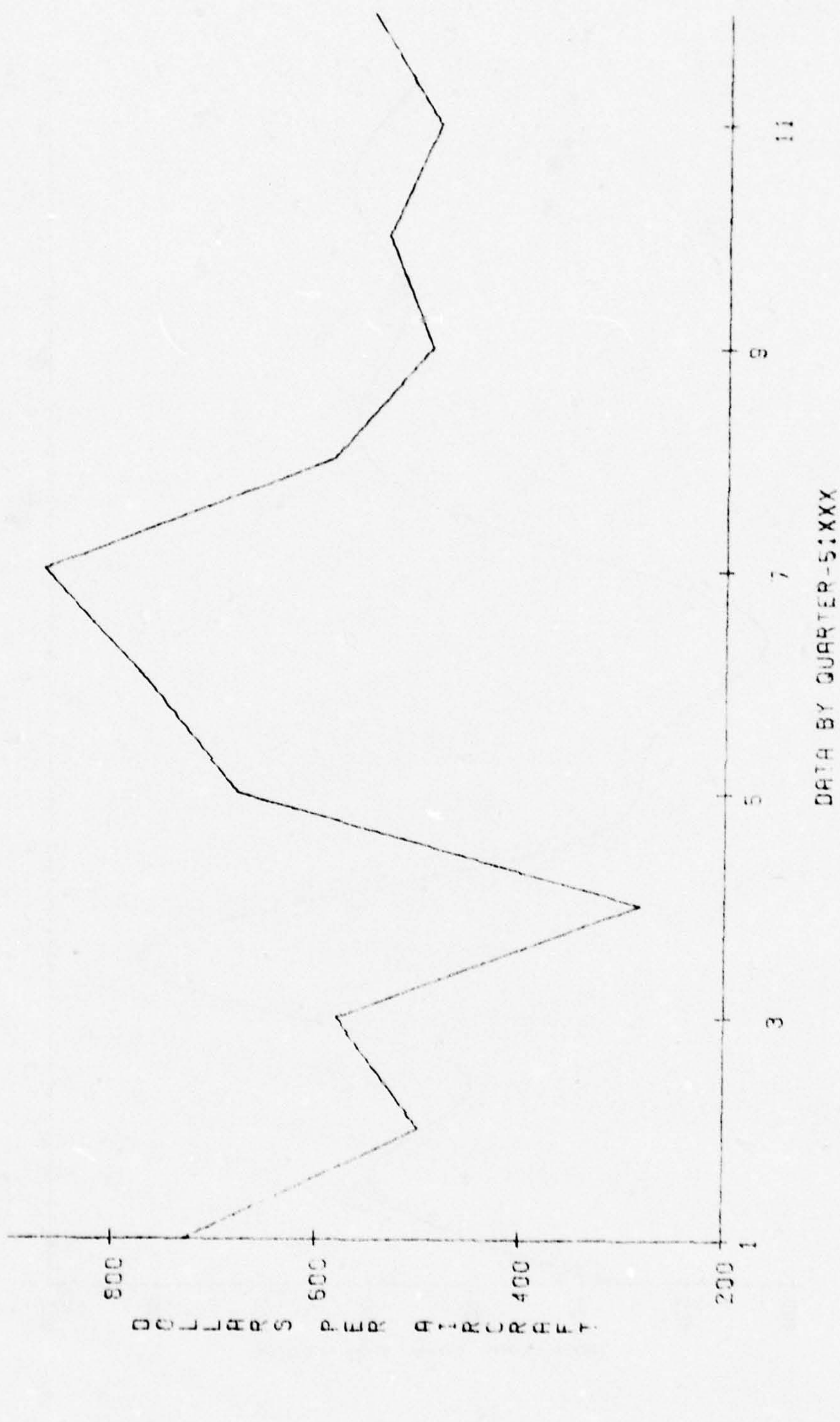
Step	Test Point	Test Equipment	Control Settings and Instructions	Normal Indication	If Indication Is Normal	If Indication Is Abnormal
10 (cont)						If they correspond for stage II but not for stage I, the STAGE I DISTANCE TO GO counter is faulty. If they do not correspond for either stage, the DISTANCE CROSS TRACK counter is faulty.
11	Terminals C-4, C-5, B-18, B-19 on test harness	Electronic voltmeter ME-6( )/U	Connect meter to C-4 and C-5. Set the DISTANCE CROSS TRACK counter to 3 miles RIGHT or LEFT. Adjust R124 in the computer to obtain a meter reading of ±150 mv. Reset the counter to 15 miles RIGHT or LEFT, and readjust R124 until meter again reads ±150 mv.	When DISTANCE CROSS TRACK counter reads LEFT, the voltage at C-4 is positive and at C-5 is negative. When the counter reads RIGHT, the polarities are reversed.	Cross track d-c potentiometer R5401 is functioning correctly.	Check for 12 volts dc at B-19 and B-18 (gnd). If voltage absent, apply 12 volts dc to B-19 and B-18, and repeat the step. If the specified normal indication is obtained, the fault is in the computer. If the normal indication is not obtained, replace R5401. Check diode limiters CR5404 and CR5405 for short circuit; replace if defective.

Figure 8-2. Table of Control-Indicator Trouble Analysis (Sheet 4 of 6)

CTO: Example Page from TO Field Maintenance Instruction for Computer Set, Navigational (concluded)

APPENDIX C

SIMFIT COMPUTER PROGRAM RESULTS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7
9
11
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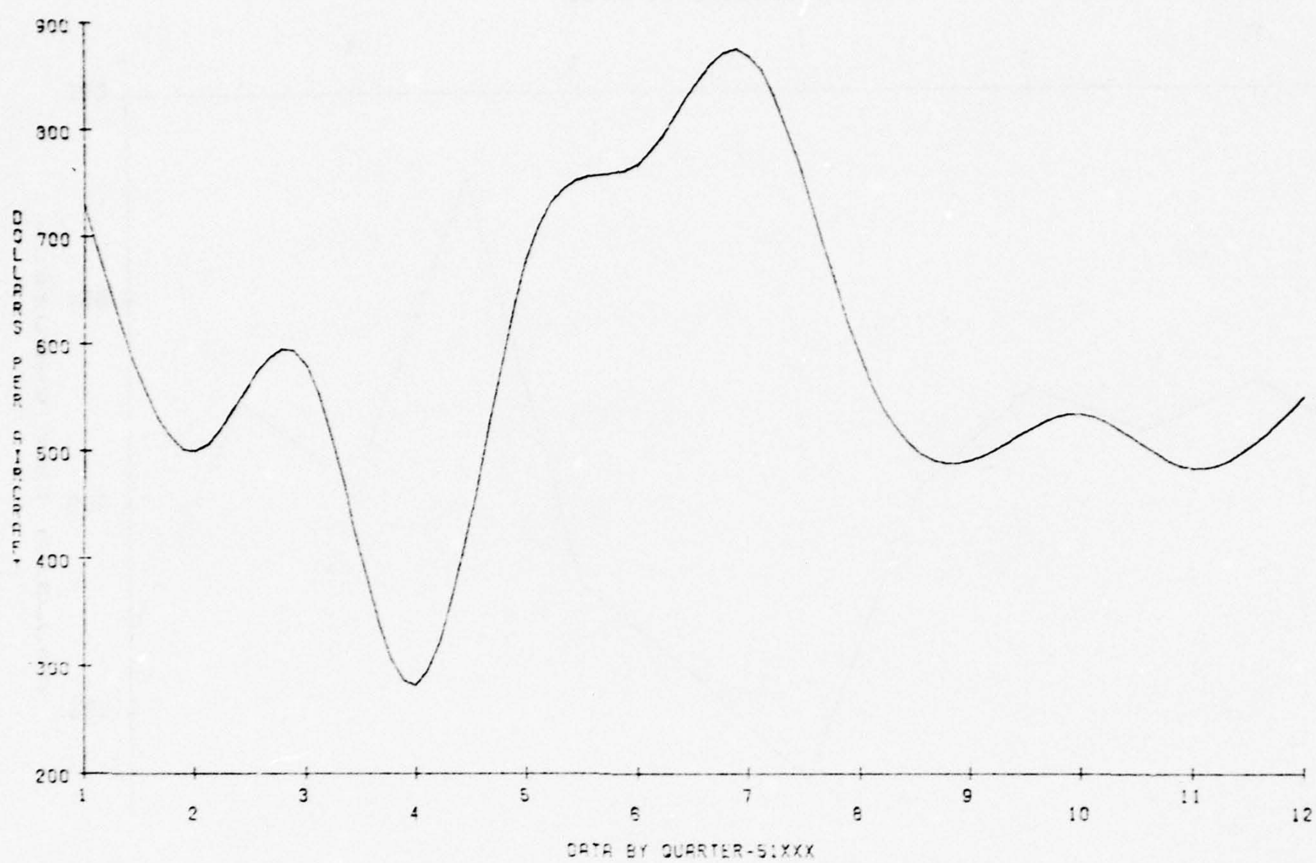
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11
12
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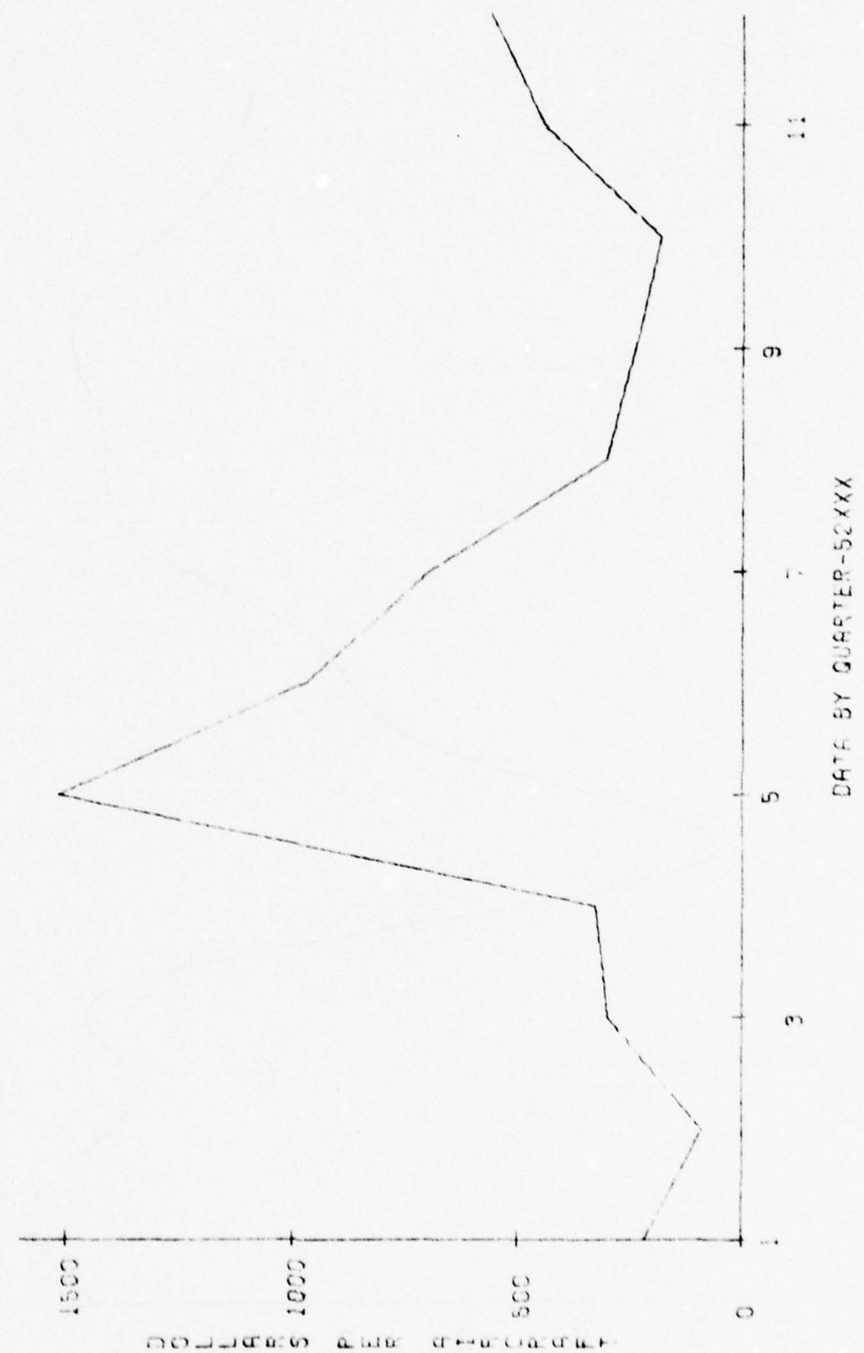
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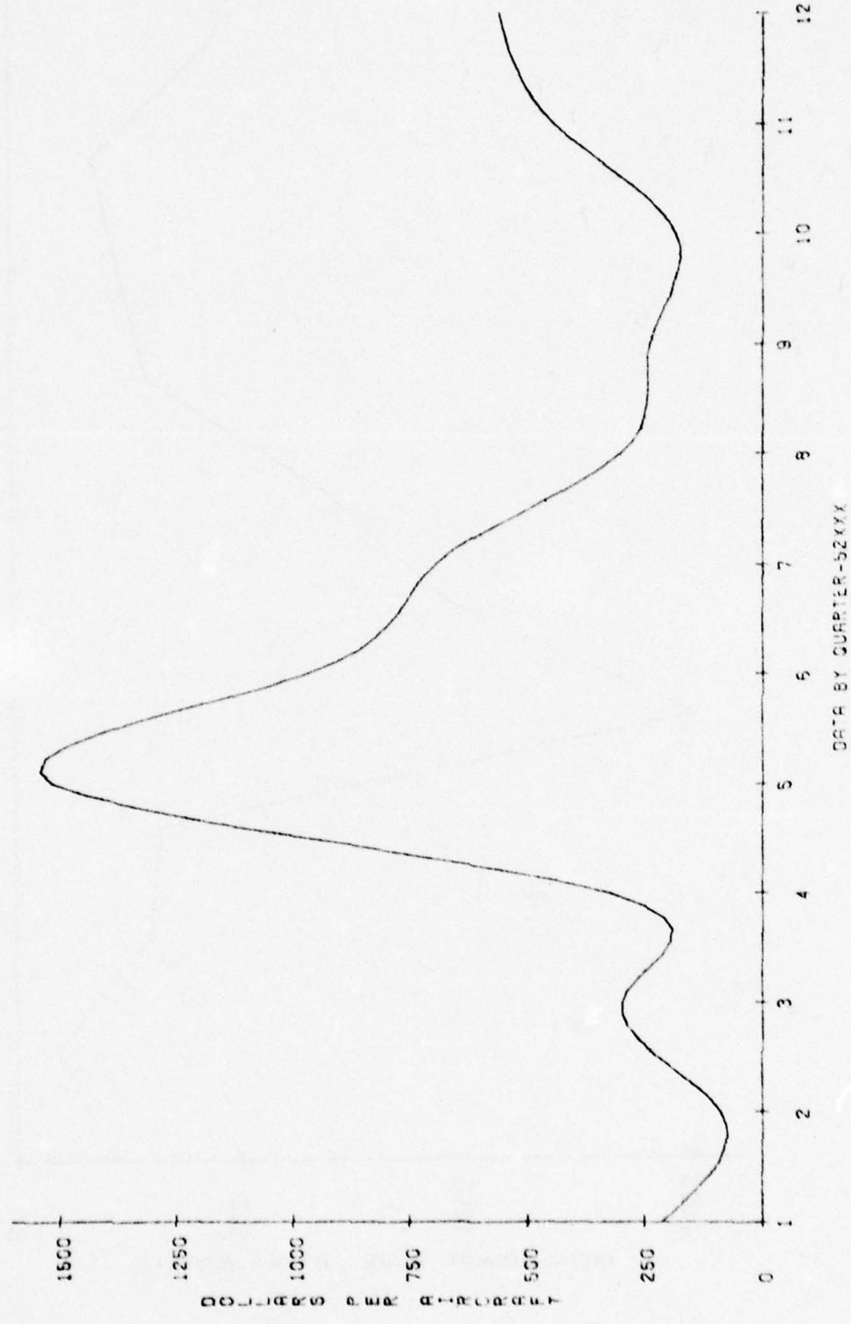
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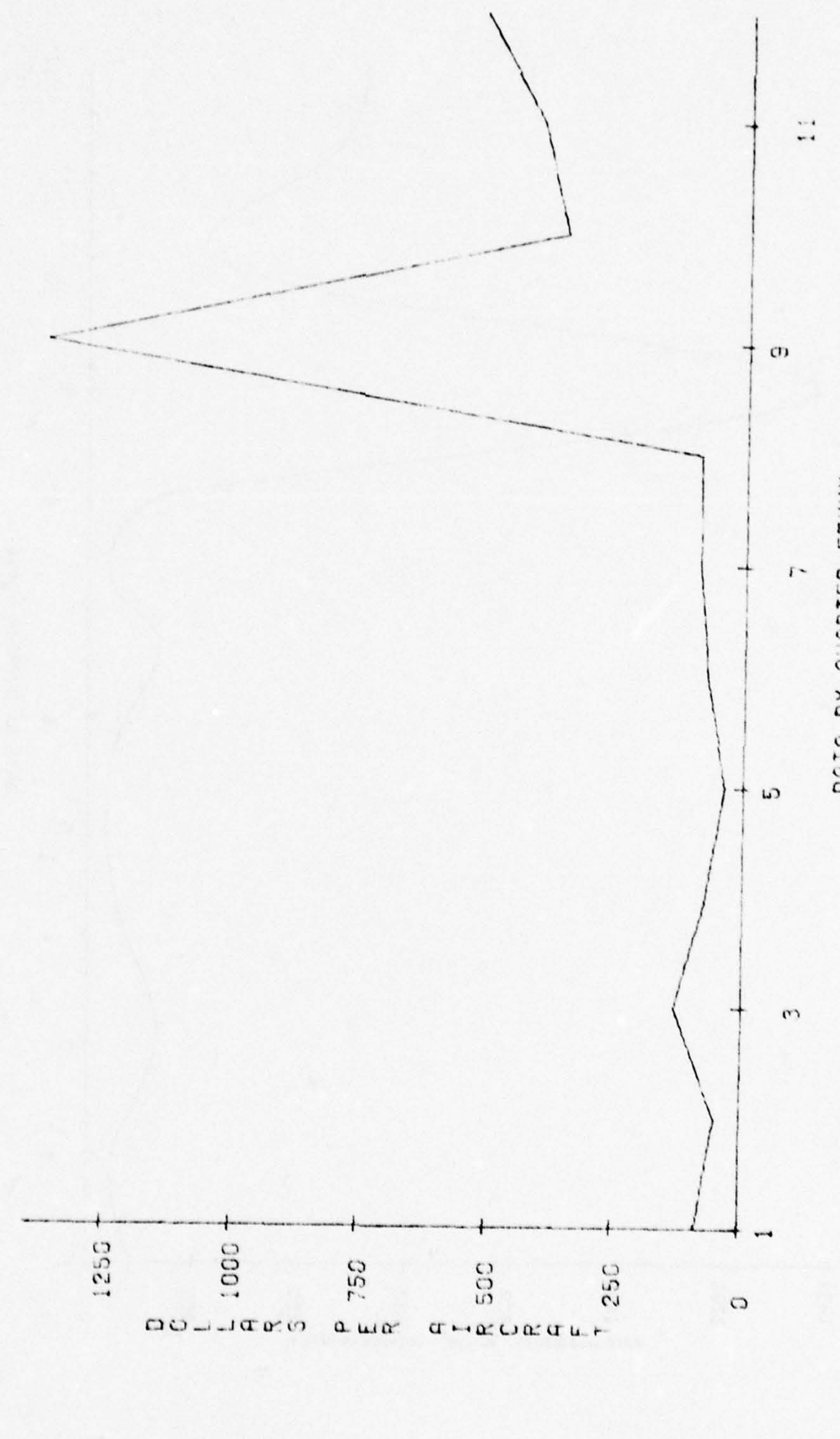

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5
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9
11
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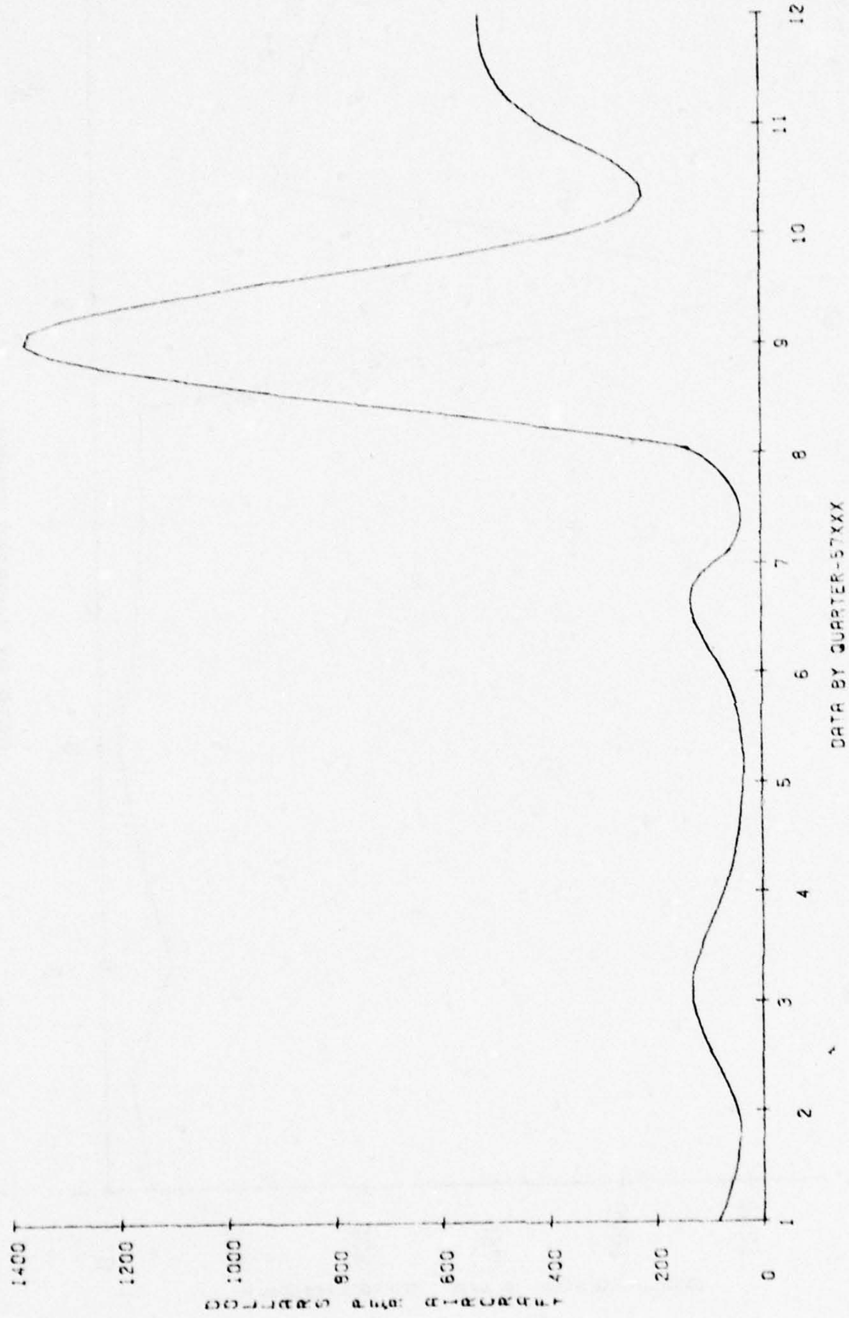
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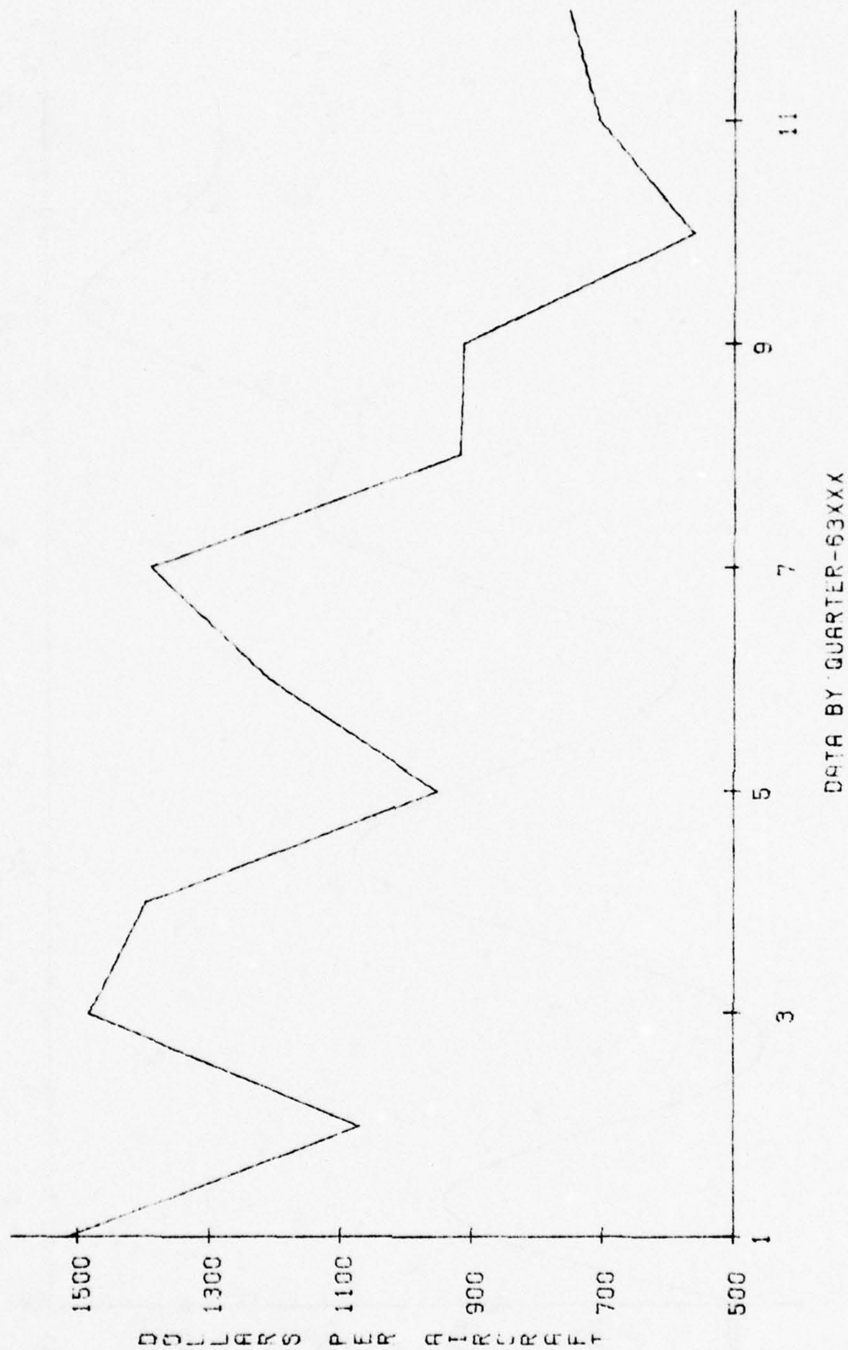
8
9
10
11
12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3
5
7
9
11
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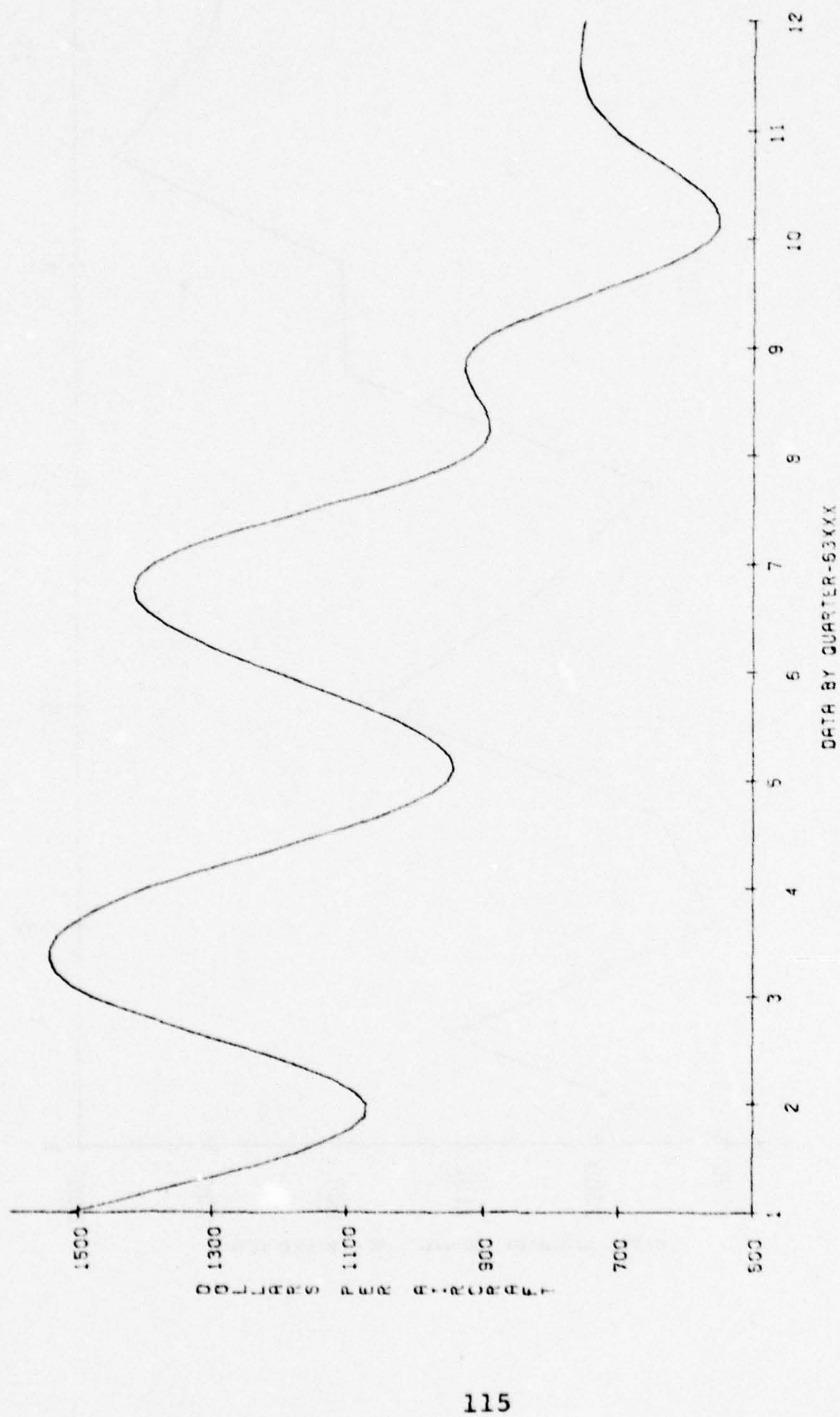
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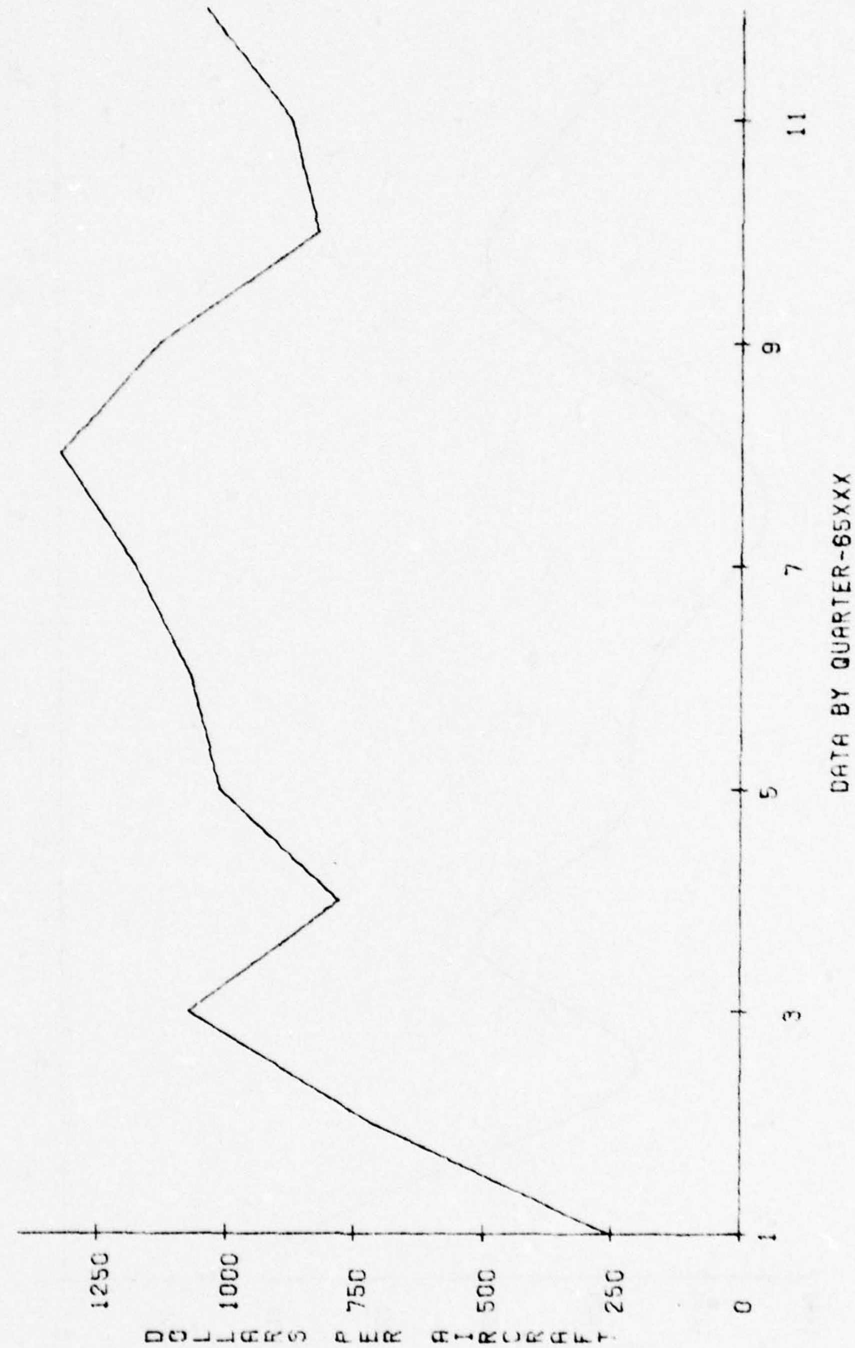
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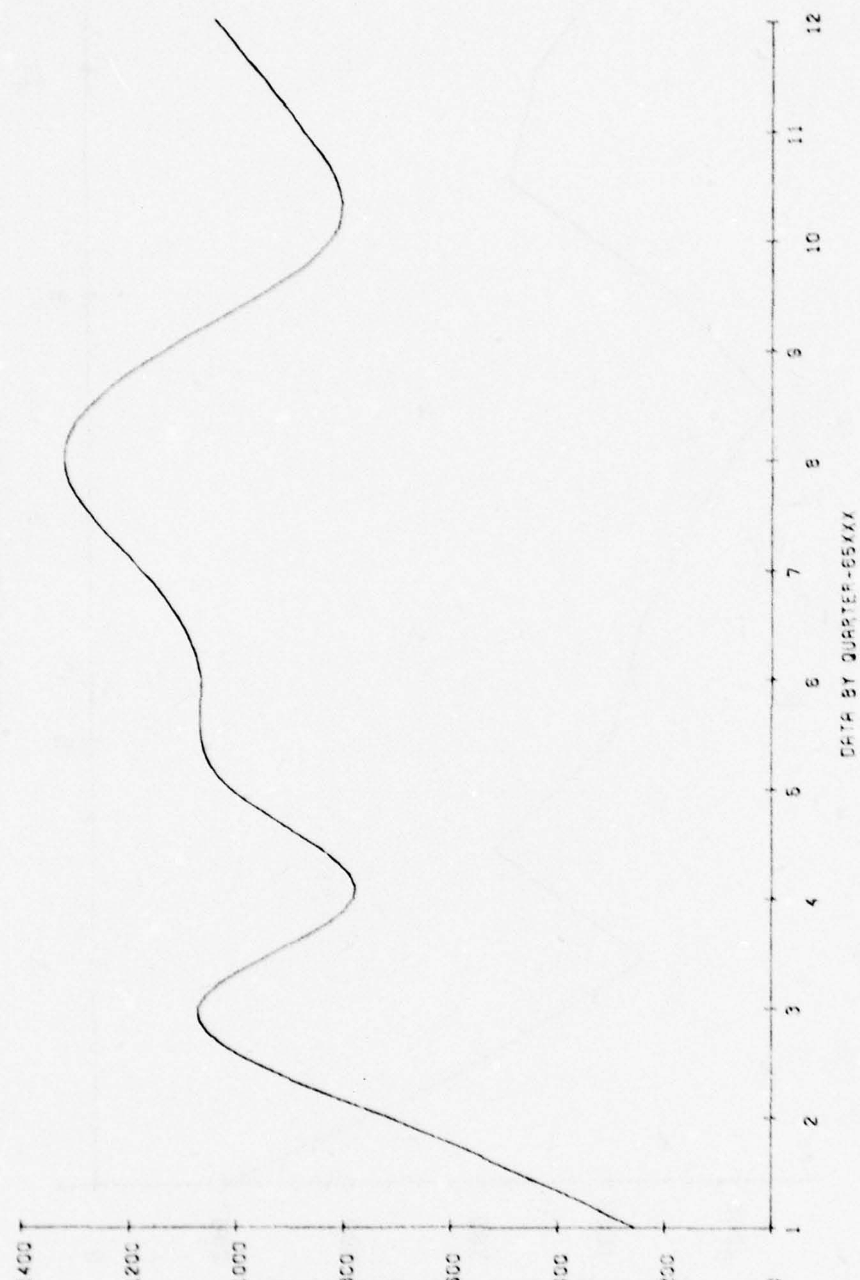

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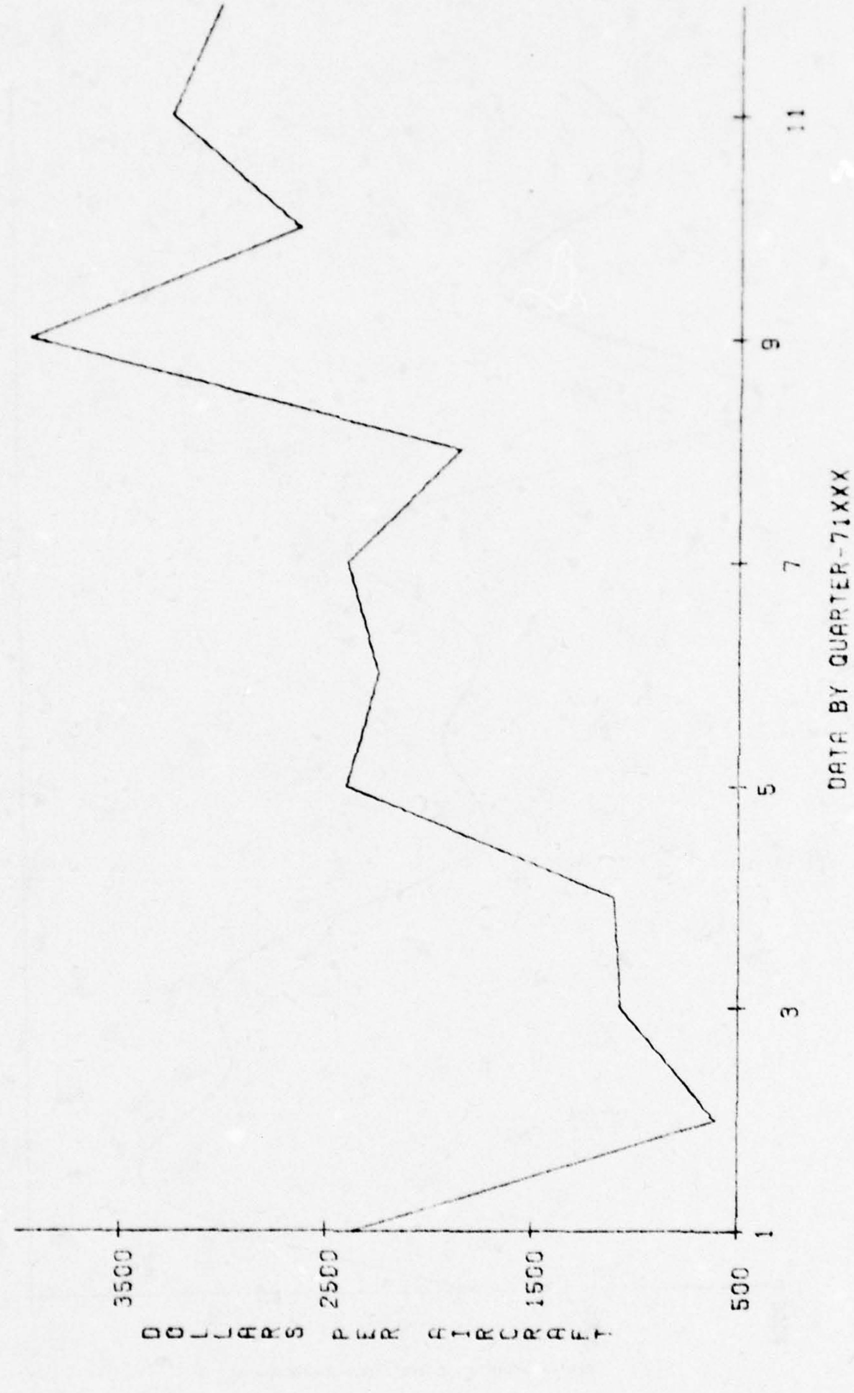
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3
5
7
9
11
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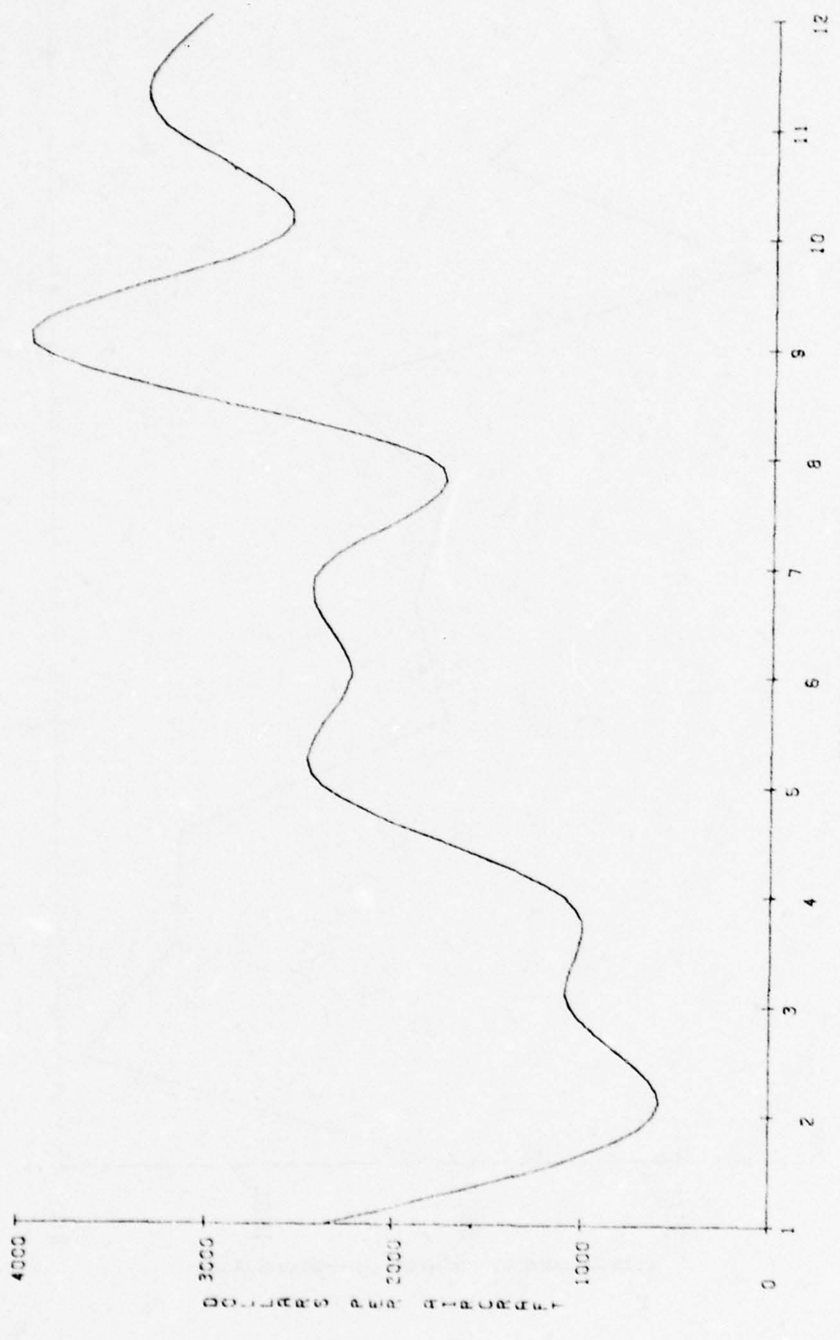

DATA BY QUARTER-71XXX
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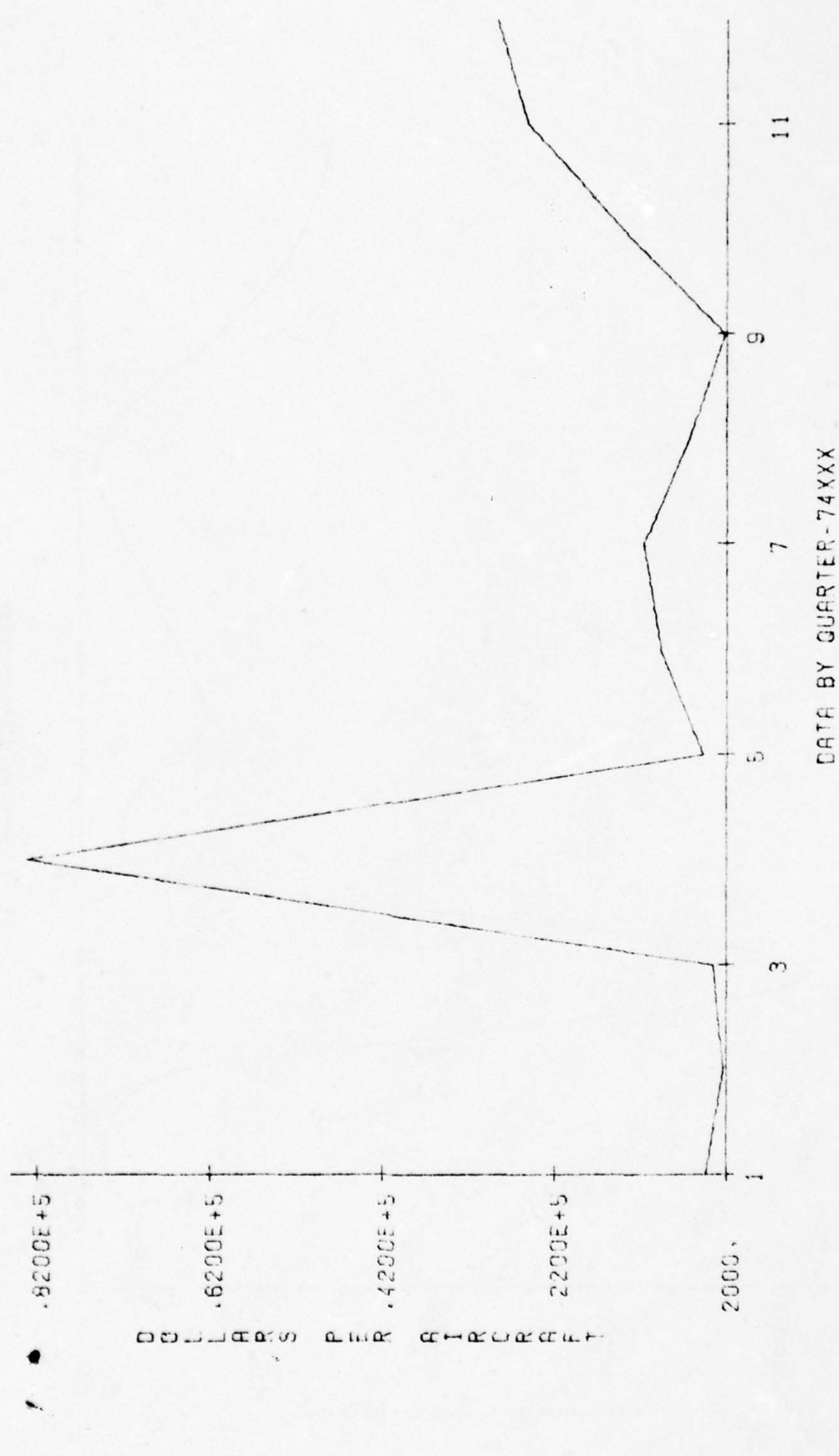
6
7
8
9
10
11
12
0
1000
2000
3000
4000


DOLLARS PER AIRCRAFT
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.2200E+5
2000.
1
3
5
7
9
11
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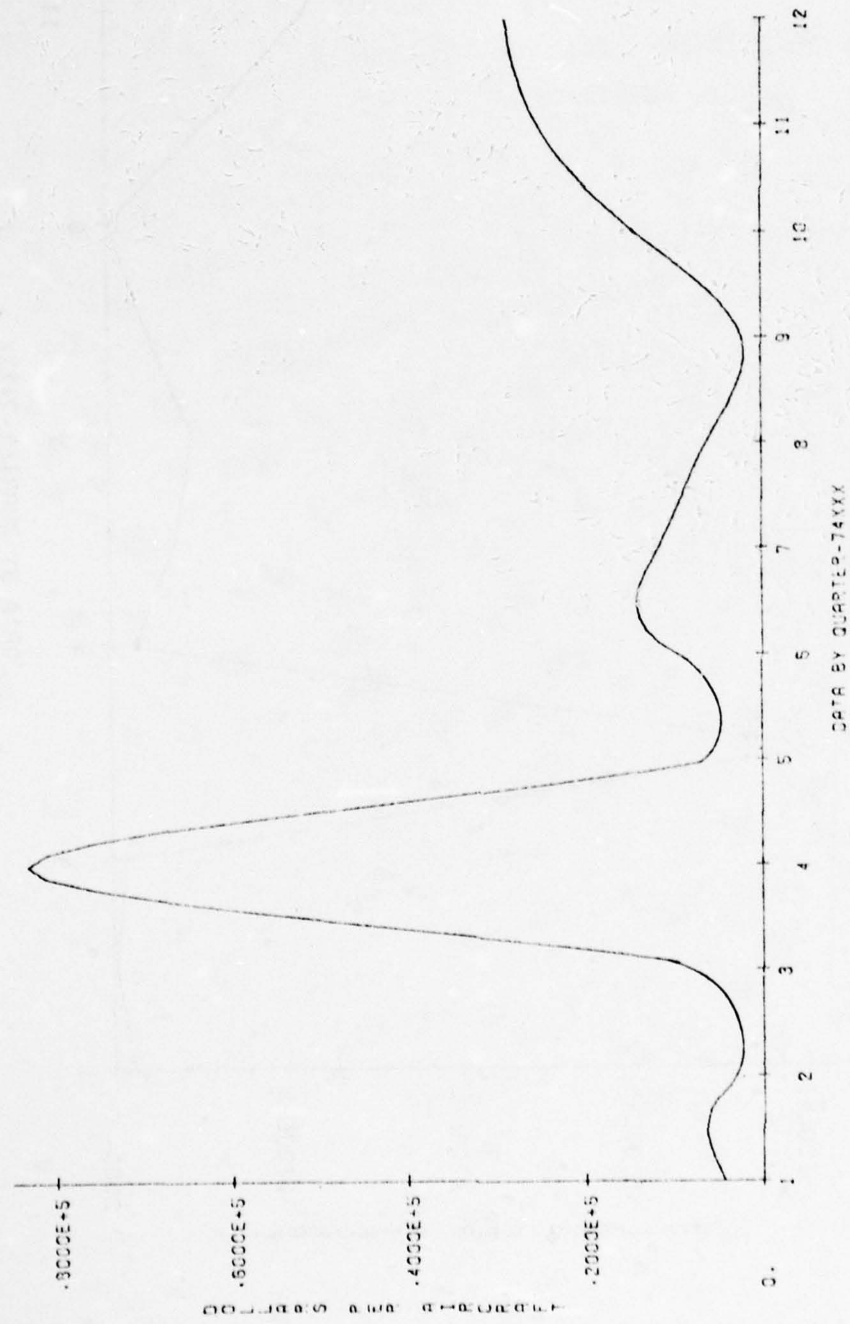
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DOLLARS PER AIRCRAFT
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3
4
5
6
7
8
9
10
11
12
DATA BY QUARTER-74XXX

APPENDIX D

MONTE CARLO SIMULATION COMPUTER PROGRAM

MONTE CARLO PROGRAM

```
001*#RUN *=(ULIB)GRADLIB/TSS,R;LIBRARY/APPLIB,R;
002*#OCNE.LIB/LIBRARY,R;AF.LIB/BLIBRARY,R
010 DIMENSION Y(5000)
020 CALL ATTACH (10, "78A71/CET1A;",3,0)
030 DO 20 J=1,4000
035C
040 X1=UNIFORM(282.,870.)
050 X2=LOGNORM(486.25,407.182)
060 X3=LOGNORM(274.0,382.102)
070 X4=UNIFORM(563.,1516.)
080 X5=XNORMAL(940.,279.)
090 X6=LOGNORM(2245.75,966.597)
095 X7=EXPONT(16332.)
097C
100 Y(J) = X1+X2+X3+X4+X5+X6+X7
110 WRITE(10,105) J, Y(J)
120 105FORMAT(I4,2X,F12.1)
125 20 CONTINUE
130 ENDFILE 10
140 REWIND 10
150 STOP "FILE 10 IS COMPLETE"
160 END
170 FUNCTION LOGNORM(U,SD)
180 LOGNORM=EXP(XNORMAL(ALOG(U)-.5*ALOG((SD/U)**2+1.),
190& ALOG((SD/U)**2+1.)**.5))
200 RETURN
210 END
```

SAMPLE OF DATA FROM
MONTE CARLO PROGRAM

1	13142.8
2	20179.7
3	22030.2
4	65977.7
5	9884.0
6	53411.1
7	15518.3
8	9276.7
9	29626.4
10	45057.7
11	13811.8
12	5555.5
13	63973.8
14	15667.1
15	36895.7
16	7713.0
17	39482.7
18	23828.3
19	22782.1
20	20111.8
21	17521.0
22	35065.0
23	8286.8
24	8450.4
25	20028.5
26	46092.0
27	21623.0
28	26365.0
29	15349.9
30	19820.5
31	11864.2
32	14873.3
33	18834.3
34	8980.2
35	24833.9

PROBABILITY DISTRIBUTION PROGRAM

```
10##NORM,R(SL)
20$:IDENT:WP1308,AFIT/LSG(MORAVEK STD 78A71 WP1308) GRAPH01 PLOT
30$:MSG2:1,SEND PLOT TAPE TO PLOTTER**USE BLACK INK**(MORAVEK,WP1308)
40$:OPTION:FORTRAN,NOMAP
50$:FORTY:NFORM,NLNO
60 DIMENSION DAT(5000)
70C
80C      PROGRAM (PLOTFREQ) FOR DATA (DAT(K)) SCALED (LINE 430)
90C      BETWEEN ZERO AND TEN. PARAMETER IV = 1 GIVES
100C      PROBABILITIES; IV = 0 FREQUENCIES (CHANGE LABELS)
105C      PARAMETER JK = 1 GIVES 3 BY 5 PLOT; 5 BY 8 OTHERWISE.
110C      PROGRAM SKIPS LINE NUMBERS; X0 IN READ IS
120C      VALUE FOLLOWING LINE NUMBER; CHANGE READ LIST
130C      FOR CONFORMITY TO FILE BEING READ.
135C      CHANGE XMIN,XMAX AS DESIRED
136C
140 PARAMETER IV = 1; JK=1; XMAX = 20; XMIN = 0.
150 REAL YVAL(200)
160 CHARACTER CAUSE*1, ALPHA*1
170 CHARACTER TITLE1*34/'   DISTRIBUTION OF COMPUTED  \'/
180 CHARACTER TITLE2*37/'         AVIONICS COST-TOTAL  \'/
190 K=1
200 TLO=999999.
210 THI=-999999.
220 SUM=0.
230 SQU=0.
240 5READ(5,1001,END=50)  X0
250 DAT(K) = X0
260 1001 FORMAT(V)
270 IF(DAT(K).GE.THI) THI=DAT(K)
280 IF(DAT(K).LE.TLO) TLO=DAT(K)
290 SUM=SUM+DAT(K)
300 SQU = SQU + DAT(K)**2
310 K=K+1
320 GO TO 5
```

```
330 50 CALL USTART
340 CALL UDIMEN(8.,33.,"CAPT MORAVEK 78-A\")
350 K=K-1
360 CALL USET("SMALL")
370 CALL UDAREA(0.,12.,0.,12.)
380 Y = K
390 DO 100 J = 1,30
400 100YVAL(J) = 0
410 YMAX = 0.
420 DO 200 J = 1,K
430 INDX = DAT(J)/5000. + 1
440 IK = MAX1(IK,INDX)
450 YVAL(INDX) = YVAL(INDX) + 1
460 IF(YVAL(INDX).GT.YMAX) YMAX = YVAL(INDX)
470 200CONTINUE
480 YMAX = (YMAX/10. + 1.)*10.
490 AVE = SUM/Y
500 IF (IV.NE.1) GO TO 206
510 DO 107 M = 1,IK
520 YVAL(M) = YVAL(M)/Y
525 PRINT 999, YVAL(M)
527 999 FORMAT(1X,F6.3)
530 107CONTINUE
540 YMAX = YMAX/Y
550 206PRINT 1011, (DAT(M),M=1,IK), YMAX,  FLOAT(INDX)
560 1011FORMAT(3X, 10F6.2)
570 SIGMA=SQRT((SQU-(SUM**2)/Y)/(Y-1))
580 TMED=(TLO+THI)/2.
590 CALL USET("DASH")
600 CALL UWINDO(0.,100.,0.,100.)
610 CALL UMOVE(0.,0.)
620 CALL URECT(100.,100.)
630 CALL USET("LINE")
640 IF(JK.EQ.1)CALL UDAREA(2.0, 7.0, 3.0, 6.0)
650 IF(JK.NE.1)CALL UDAREA(2.0,10.,3.,8.)
```

```
660 CALL UPSET("YLABEL","PROBABILITIES \")
670 CALL UPSET("XLABEL","COST TIMES 5000\")
680 CALL USET("XBOTHLABELS")
690 CALL USET("YBOTHLABELS")
700 CALL USET("OWNSCALE")
710 CALL UWINDO(XMIN,XMAX,0.,YMAX)
720 CALL UAXIS(XMIN,XMAX,0.,YMAX)
730 DO 300 J = 1,30
740 X = J -1
750 CALL UMOVE(X,0.)
760 CALL URECT(X+1,YVAL(J))
770 300CONTINUE
780 CALL USET("DEVICE")
790 CALL UMOVE(2.25,9.85)
800 CALL UPRNT1(TITLE1,"TEXT")
810 CALL UMOVE(2.25,9.85)
320 CALL UDOIT("LF01")
830 CALL UPRNT1(TITLE2,"TEXT")
840 CALL UMOVE(5.9,9.25)
850 CALL UPRNT1("MEAN  =\","TEXT")
860 IF(Y.NE.0.) GO TO 250
870 CALL UPRNT1("NO DATA\","TEXT")
880 GO TO 490
390 250 CALL UPRNT1(AVE,"REAL")
900 CALL UMOVE(5.9,9.25)
910 CALL UDOIT("LF01")
920 CALL UPRNT1("ST DEV=\","TEXT")
930 IF(Y.EQ.1.) SIGMA=0.
940 CALL UPRNT1(SIGMA,"REAL")
950 CALL UMOVE(5.9,9.25)
960 CALL UDOIT("LF02")
970 CALL UPRNT1(Y,"REAL")
980 CALL UPRNT1(TMED,"REAL")
990 CALL UMOVE(5.9,9.25)
1000 CALL UDOIT("LF03")
```

```
1010 CALL UPRNT1("HI PCT=\","TEXT")
1020 CALL UPRNT1(THI,"REAL")
1030 CALL UMOVE(5.9,9.25)
1040 CALL UDOIT("LF04")
1050 CALL UPRNT1("LO PCT=\","TEXT")
1060 CALL UPRNT1(TLO,"REAL")
1070 CALL UMOVE(1.05,9.45)
1080 CALL UPRNT1("BENNETT/MORAVEK\","TEXT")
1090 490 CALL USET("VIRTUAL")
1100 500 CONTINUE
1110 CALL UEND
1120 STOP
1130 END
1140$:LIBRARY:A1,A2,A3
1150$:EXECUTE
1160$:LIMITS:,39K
1170$:PRMFL:A1,R,R,GRAPHICS.LIB/GCS/GCS3.0
1180$:PRMFL:A2,R,R,GRAPHICS.LIB/GCS/CALC3.0
1190$:PRMFL:A3,R,R,AF.LIB/CALLIB
1200$:FFILE:27,FIXLNG/80,BUFSIZ/81
1210$:TAPE:27,X1D,,,,PLOT-TAPE/WR
1220$:DATA:I*
1230$:SELECTA:78A71/CET1A,R
1240$:ENDJOB
```

SIMFIT PROGRAMS--SAMPLE

```
010##S,R(SL) :,8,16;;,61
020$:IDENT:WP1308,AFIT/MORAVEK 78A/LSG
030$:OPTION:FORTRAN,NOMAP
040$:SELECT:SIMFIT/SFO-DECK
050$:EXECUTE
060$:LIMITS:05,,,5000
070$:DATA:05
080$:SELECTA:SF1
090$:DATA:09
100$:SELECTA:WUC1
110$:ENDJOB
```

```
10   1 2 3 4 5 6 7 8 9 10 11 12 0 0 0
020  .10 4 1 0 0
030  .75 282.0 163.3333 4 0.0 0 0 0 0.0
040   TEST OF WUC 51XXX
050   TEST NO.1
060   ;1
070   (V)
080   -99.99
```

```
010    588   870   767   679
020     730    282   580    500
030     550    485    535    492
040     -99.99     00      00      00
```

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Ackoff, Russeell L., Leonard E. Arnoff, and West C. Churchman. Introduction to Operations Research. New York: John Wiley and Sons., Inc., 1957.

2. Allen, R. H. and others. "A Study of the Air Force Maintenance Technical Data System." Technical documentary report No. AMRL-TDR, 62-85, Behavioral Science Laboratory, Wright-Patterson AFB, Ohio, 1962.

3. Anthony, Robert N. Management Accounting Principles. Revised ed. Homewood IL: Richard D. Irwin, Inc., 1970.

4. Bryan, Lieutenant Colonel Jack B., USAF. Chief, Manufacturing Division F-15 Systems Program Office, AFSC/ASD, Wright-Patterson AFB OH. Personal interview. 4 May 1978.

5. Campbell, Wendy. Research Psychologist, Personnel and Training Branch, AFHRL/ASR, Wright-Patterson AFB OH. Personal interview. 5 May 1978.

6. Crowe, Captain Lowell R., USAF, and Captain Levi D. Lowman, Jr., USAF. "An Analysis of the Exponential Function as the Underlying Distribution for Describing Failures in Inertial Measurement Units." Unpublished master's thesis. SLSR 22-77A, AFIT/SL, Wright-Patterson AFB OH, June 1977. AD A044189.

7. Davis, Major Guy Williams, USA. "The Dilemma of Uncertainties Associated with Cost Estimating in the Project Management Office." Unpublished study project report. PMC 76-1, Defense Systems Management School, May 1976.

8. Feeley, Charles R. Professor of Management Systems, AFIT School of Continuing Education, Wright-Patterson AFB OH. Personal interview. November 1977 - February 1978.

9. Fritz, SMSgt. Chief, Technical Order Management Agency, A-10 System Program Office, AFSC/ASD, Wright-Patterson AFB OH. Telephone interview. 13 February 1978.

10. Gouy, J. W. Air Force Plant Representative Office, St. Louis MO. Message, subject: F-15 Technical Order Cost, to F-15 SPO/TOMA, 26 August 1977.

11. Hamilton, Colonel E. C., Jr. Directorate PRAM Program Office, HQ AFSC. Letter, subject: Evaluation of C-141 Job Guide Manuals (JGMs) PRAM Program #29475-02, to AF;LGYE, 29 July 1976.

12. Hammersley, J. M., and D. C. Hadscomb. Monte Carlo Techniques. New York: John Wiley and Sons., Inc., 1965.

13. Hayes, Elis. IROS Data Management Specialist, HQ AFLC, Wright-Patterson AFB OH. Personal interview. 31 January 1978.

14. Hines, Colonel William H. Vice Commander, Air Force Logistics Management Center, Air University. Letter, subject: Technical Data Requirements for Weapon Systems, to HQ USAF/LG, 14 June 1977.

15. Johnson, Robert C. and others. "User Acceptance and Usability of the C-141 Job Guide Technical Order System." Technical documentary report No. AFHRL-TR-77-31, Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson AFB OH, June 1977.

16. Litke, Lieutenant Colonel Donald P. Director of Material Management, Air Logistics Center, Robins AFB GA. Message, subject: F-15 Technical Manuals to AFALD/SD/PT, 1 February 1978.

17. McCarthy, Dyke and Thomas Valore, Major, USAF. "The Acquisition of Major Systems." Unpublished research report, unnumbered, AFIT, Wright-Patterson AFB OH, April 1978.

18. Potter, Norman R. and Donald L. Thomas. An Evaluation of Proceduralized Troubleshooting Aids for Maintenance of Eelctornic Systems. Dayton: Systems Research Laboratories, Inc., September 1976.

19. ________. _Evaluation of Three Types of Technical Data for Troubleshooting: Volume I Results and Project Summary_. AFHRL-TR-76-75-(I), Brooks AFB TX: Air Force Human Resources Laboratories, September 1977.

20. ________ and others. _Evaluation of Three Types of Technical Data for Troubleshooting: Methodology for Field Evaluation_. AFHRL-TR-76-74 -(II), Brooks AFB TX: Air Force Human Resources Laboratories, September 1977.

21. Richardson, James. Director Publications, Naval Rework Facilities, Jacksonville FL. Telephone intervew. 22 November 1977.

22. Royal, Lettie. Chief, Technical Order Management Agency, F-16 Systems Program Office, AFSC, ASD, Wright-Patterson AFB OH. Personal interview. 4 November 1977. Telephone interview, 13 February 1978.

23. Serendiptiy Incorporated. _PIMO Final Report Summary_. AD-852 101, Norton AFB CA, May 1969.

24. Strebeck, Lieutenant Colonel George E., USAF, and Major Peter J. Scrivano, USAF. "Effect of Constraints on Management of an Economic Order Quantity Type Stock Fund." Unpublished master's thesis. SLSR 22-73B, AFIT/SL, Wright-Patterson AFB OH, December 1973. AD 769156.

25. Thomas, Don L. Research Psychologist, Personnel and Training Branch, AFHRL/ASR, Wright-Patterson AFB OH. Personal interview. 5 May 1978.

26. "United States Air Force--Facts and Figures," _Air Force Magazine_, Volume 56, No. 5 (May, 1973), pp. 146-158.

27. U.S. Department of the Air Force, Air Force Logistics Command. "Automated Text Composition System: A Service Test Evaluation." Unpublished research report, unnumbered, Oklahoma Air Logistics Center/ACDT, 16 December 1974.

28. ________. Air Force Logistics Command. _Increased Reliability of Operational Systems Regulation 400-16_. Wright-Patterson AFB OH, January 1974.

29. ________. Air University, Air Force Logistics Management Center. "Initial Technical Order Project Findings." Unpublished research report, unnumbered, Gunter AFB AL, June 1977.

30. ________. "Technical Data Required for Weapon Systems." Unpublished research report, unnumbered, Gunter AFB AL, 9 September 1977.

31. ________. HQ USAF/LGYE. "Automated Technical ORDER System." Draft of Required Operational Capability (ROC) No. AF-74, undated.

32. ________. Users Guide for SIMFIT. IACOMMG Phamphlet 100-20, 22 October 1975. First Aerospace Communications Group--Command, Offut AFB NE, 1975.

33. U.S. Department of Defense, Office of the Assistant Secretary of Defense (Comptroller). National Defense Budget Estimates for FY 1977. Washington: Government Printing Office, 1977.

34. U.S. Department of the Navy. Maintenance Information Automated Retrieval System (MIARS): Evaluation and Development of. OPNAV Instruction 4790.1, Washington: Government Printing Office, 7 October 1968.

35. ________. "Technical Manual Program." Unpublished research report, unnumbered, Naval Air Technical Services Facility, Philadelphia PA, 28 February 1967.

36. Wilson, Jack. Chief, Technical Order Management Agency, F-15 Systems Program Office, AFSC/ASD, Wright-Patterson AFB OH. Personal interview. 15 November 1977.

B. RELATED SOURCES

Eaton, Colonel E. P., Jr. Chief, Engineering and Support Division, HQ USAF. Letter, subject: Mechanized Preparation of Technical Orders, to AFLC/MMOM, August 1974.

Forrester, Jay W. Industrial Dynamics. Cambridge MA: Massachusetts Institute of Technology Press, 1977.

Greenberger, Martin, Matthew A. Crenson, and Brian L. Crissey. Models in the Policy Process. New York: Russell Sage Foundation, 1976.

Hyson, John. Logistics Management Specialist, AFALD, Wright-Patterson AFB OH. Personal interview. 19 October 1977.

Keys, Bernard and Howard Leftwich. The Executive Simulation. Dubuque IA: Kendall/Hunt Publishing Company, 1977.

Mezydlo, Master Sergeant G., USAF. Specialist, Technical Order Management Agency, F-16 Systems Program Office, HQ AFLC, Wright-Patterson AFB OH. Personal interview. 4 November 1977.

Mihram, G. Arthur. Simulation Statistical Foundations and Methodology. New York: Academic Press, Inc., 1972.

Morrison, Chief Master Sergeant F., USAF. Specialist, Technical Order Management Agency, F-16 Systems Program Office, HQ AFLC, Wright-Patterson AFB OH. Personal interview. 4 November 1977.

Nie, Norman H., and others. Statistical Package for the Social Sciences. New York: McGraw-Hill Book Company, 1975.

Ostwald, Phillip F. Cost Estimating for Engineering and Management. Englewood Cliffs NJ: Prentice-Hall, Inc., 1974.

Park, William R. Cost Engineering Analysis: A Guide to Economic Evaluation of Engineering Projects. New York John Wiley and Sons, Inc., 1973.

Post, Brigadier General Gerald J. DCS, Material Management, HQ AFLC. Letter, subject: Mechanized Preparation of Technical Orders, to Oklahoma City ALC/MM, 15 October 1974.

Ragoma, Ralph. International Logistics Specialist, Naval Air Technical Service Facility, Philadelphia PA. Telephone interview. 18 October 1977.

Schoderbek, Peter P., Asterios G. Kefalas, and Charles G. Schoderbek. Management Systems Conceptual Considerations. Dallas TX: Business Publications, Inc., 1975.

Smith, Lieutenant Colonel Larry L., USAF. "The Use of Index Numbers in Defense Contract Pricing." Unpublished research report No. AU-AFIT-SL-1-76, Air Force Institute of Technology, Wright-Patterson AFB OH, November 1976.

Streight, Ronald W. Technical Order and Engineering Data Branch, HQ AFLC/LOLM. Letter, subject: Trip Report Naval Air Station, Jacksonville, FL, to HQ AFLC/LO, 11 November 1976.

U.S. Department of the Air Force, Air Force Institute of Technology. Understanding and Evaluating Technical Data Prices. School of Systems and Logistics LS-24, Wright-Patterson AFB OH, 1977.

__________. Air Force Logistics Command. "Air Force Automated Technical Order System (ATOS): Data Automation Requirement (DAR)." Unpublished research report, unnumbered, Oklahoma Air Logistics Center/ACDT, 14 May 1976.

Wright, Jerry. Air Force Plant Representative Office, St. Louis MO. Telephone interview. 26 August 1977.