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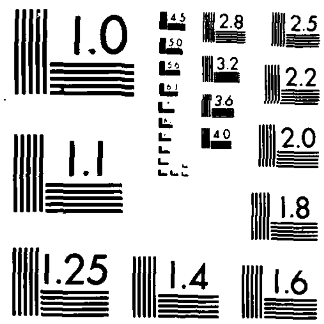

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A STUDY OF THE AIR FORCE DEPOT MAINTENANCE COST ALLOCATION FOR COST FACTOR DEVELOPMENT

THESIS

Patricia M. Larson
Captain, USAF

AFIT/GSM/LSM/86S-13

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Wright-Patterson Air Force Base, Ohio

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AFIT/GSM/LSM/86

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AFIT/GSM/LSM/86S-13

A STUDY OF THE AIR FORCE
DEPOT MAINTENANCE COST ALLOCATION
FOR COST FACTOR DEVELOPMENT

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 Degree of

Master of Science in Systems Management

Patricia M. Larson, B.A.

Captain, USAF

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Preface

This thesis is a benchmark in the investigation of depot maintenance costs allocations to flying hours and primary aircraft authorized, yet it is only a starting point. It is the result of many years of the Air Force Directorate of Cost's attempt to find verifiable depot maintenance costs proportions for the development of cost factors used in decrementing and incrementing the Air Force Budget and in decision making studies.

New techniques, such as ridge regression and the "hunt and peck" method are used to determine the proportions found. Due to time constraints, only cargo aircraft are used in the study. Considerable work must still be accomplished to develop the proportions for all Air Force aircraft. This thesis has produced a consolidated aircraft data base for use in future studies.

The completion of this study would not have occurred without the guidance and assistance from cost experts across the Air Force and close friends.

I am greatly indebted to Mr. Roger Steinlage of AFLC/ACC, whose unending assistance helped guide me through the depths of WSCRS and the AFLC systems. Also, much appreciation goes to the Classroom Support Computer Systems Manager, Janet, who put up with my extremely large data base. Her support was tremendous. And to my typist, Jackie McHale, I extend my appreciation for the late nights and miracle turn-around. Also, ridge regression sounded like a war maneuver until Mr. Rich Murphy explained its use. I wish to thank him for his assistance in completing this effort. Also, I cannot thank my thesis advisor, Major "Bud" Bowlin, enough for his patience, encouragement, quick turn-around, and push. I demanded a lot of him and tested his patience regularly these past few months. I greatly appreciate his assistance.

A special thanks to the friends who helped me through a truly unlucky 30th year. It would take another chapter to thank them all, yet without the help of Sylvia Wardley-Niemi, Don Walters, John Golden, and Chris Bolan, this thesis would not have been completed. I thank Sylvia for taping the many classes I missed and providing delivery service for homework, papers, and best of all, food; Don for the many favors, the cheer after PT and use of his car; John for the transportation and delivery service; and Chris for giving me someone to blame when the work wasn't done.

Many thanks to the Wright-Patterson medical personnel on Ward 2-South, in Physical Therapy and Orthopedics, whose enthusiasm and push put me back on my feet to complete this year. A special thanks to Dr. Ruda, who put my knee back together, and to my physical therapist, Tim Arndts, for "ripping" it apart!

Of course, I wouldn't be where I am today without the love and support of my family: Dad, Trish, Mike, Sheryl, Matt, Monica, Greg, Doug, Fred, Juli-Anne, and Billie Elizabeth.

Finally, I dedicate this effort to my late mother, Joayn. She made me realize I can do anything. I wish she could be here to share it.

Patricia Larson

Table of Contents

List of Figures

List of Tables

Abstract

This ~~investigation~~ attempts to determine the proportion of depot maintenance costs for cargo aircraft that is flying hour related and the proportion that is inventory related. Currently arbitrary proportions, such as 65 percent to flying hours and 35 percent to inventory, are used. Air Force Directorate of Cost (AF/ACC) uses these allocated costs to prepare life cycle cost and budget year factors for Air Force Regulation (AFR) 173-13, USAF Cost and Planning Factors. Budget factors are used annually in the budget development cycle and directly affect aircraft operating budgets. Life cycle cost factors provide aircraft average yearly operating costs over the lifespan of each aircraft and are used extensively in decision making studies.

The analysis is accomplished using ordinary least-squares regression and ridge regression analyses on nine years of actual depot maintenance costs from the Air Force Logistics Command (AFLC) Weapon Systems Cost Retrieval System (WSCRS) for cargo aircraft.

As a result, the cargo aircraft fleet, excluding overhauls, is found to have a proportion of 76 percent of depot maintenance costs to flying hours and 24 percent to inventory. Aircraft overhauls result in a proportion

of 35 percent of depot maintenance costs to flying hours and 65 percent to PAA. A proportion for engine overhauls cannot be determined. Also, a complete data base is available for further analysis of remaining aircraft.

A STUDY OF THE AIR FORCE DEPOT MAINTENANCE COST ALLOCATION FOR COST FACTOR DEVELOPMENT

I. Introduction

General Issue

Air Force Regulation (AFR) 173-13, USAF Cost and Planning Factors, contains life cycle and budget year cost factors for all active Air Force aircraft. These factors are used for estimating resource requirements (e.g., budgets) and associated costs for Air Force programs. The regulation is updated at least annually to reflect the latest program costs. The depot maintenance costs included in this regulation contain all "elements of expenditures incurred by the Depot Maintenance Service, Air Force Industrial Fund to inspect, repair, overhaul, or perform other aircraft maintenance not performed at base level" (4:3).

Depot maintenance costs are expected to be either usage (i.e., flying hour) or inventory (i.e., primary aircraft authorized) driven (6:78). Depot maintenance cost factors are currently developed by first identifying costs by work breakdown structure (WBS). Then, the WBS costs are allocated to flying hours (FH) and the number of primary aircraft authorized (PAA) using the percentages listed in

Table 1. However, the allocation percentages in Table 1 are unverifiable. The only known documentation of these allocations is an undated and unsigned paper (approximate time frame of 1974) found at Headquarters Air Force, Directorate of Cost (AF/ACC). Therefore, AF/ACC has requested a study to determine an appropriate and scientifically verifiable allocation of depot maintenance costs to flying hours and primary aircraft authorized by each aircraft WBS.

TABLE 1

AIRCRAFT DEPOT MAINTENANCE COST ALLOCATIONS
BY WORK BREAKDOWN STRUCTURE

WBS Category	Percent Cost Flying Hour Related	Percent Cost Inventory (PAA) Related
Aircraft Overhaul	0	100
Engine Overhaul	100	0
Engine Accessories	100	0
Aircraft Accessories	65	35
Avionics Instrumentation	65	35
Avionics Communication	65	35
Avionics Navigation	65	35
Armament	65	35

(6:78)

Budget factors, in AFR 173-13, are used annually in the budget development cycle and directly affect aircraft operating budgets. Likewise, life cycle cost factors provide the average yearly operating costs over the lifespan of each aircraft and are used extensively in tradeoff or other decision making studies. Thus, USAF/ACC is constantly searching for ways to develop more accurate cost factors (4:i-4).

Specific Problem

For each aircraft work breakdown structure, what proportion of depot maintenance costs are flying hour related and what proportion are inventory related? For this research, cargo aircraft will be examined.

Definition of Key Terms

Appendix A contains a listing of abbreviations used in this study. Definitions of key terms can be found in the Glossary in Appendix B.

Background

Depot Maintenance. Weapon system maintenance is performed either at the base or the depot. Base maintenance includes organizational and intermediate maintenance. Depot maintenance is the responsibility of Air Force Logistics Command (AFLC) and includes:

> inspection, test, repair, modification, alterations, modernization, conversion, overhaul, reclamation or rebuilding of parts, assemblies, subassemblies, components, equipment, end items, . . . manufacture of critical nonavailable parts and providing technical assistance to the base maintenance shops. (6:82)

Depots have more extensive shop facilities and equipment, plus highly skilled and specialized personnel.

Depot maintenance is either organic (performed in-house), contract, or interservice. Organic depot maintenance is performed by five Air Logistics Centers (ACs) and at Newark Air Force Station (AFS). These depots are Ogden ALC, Oklahoma City ALC, Sacramento ALC, San Antonio ALC, Warner Robins ALC and the Aerospace Guidance and Meteorology Center, Newark AFS. Contract and interservice depot maintenance augment the Air Force's organic capabilities (9:Section I).

Depot Maintenance Cost. For cost collection purposes, depot maintenance is performed by work performance categories (WPCs) and identified by work breakdown structure. The work breakdown structure system is used in depot maintenance cost collection and factor development to categorize or classify costs. Costs are reported by both WBS and WPC in the maintenance accounting systems. Also, through the WPC code, depot maintenance costs, such as those from Class IV modifications, Class V modifications, Interim Contractor Support (ICS) and Contractor Logistics Support (CLS), can be identified. Relevant WPCs are listed in Appendix C.

The WBS category, aircraft overhaul, refers to programmed depot maintenance (PDM) performed on aircraft at specific calendar intervals; modifications for safety reasons, to correct a deficiency or for mission changes; analytical condition inspection and rework; or on-condition maintenance. Likewise, engine overhaul usually refers to scheduled maintenance based on the operating hours of the propulsion system. The overhaul repair categories exclude repair of aircraft and engine accessories and components. The repair of these accessories and components is included in the WBS categories: aircraft accessories, engine accessories, avionics communication, avionics instrumentation, and avionics navigation (3:1-2).

Data Collection Systems. AFLC depot maintenance operations are tracked through thirty-one data systems which interface through an intricate network. These systems can be grouped into five general categories: four requirements systems, three material systems, seven production systems, seven cost systems, and ten other interfacing systems (7:4). The requirements systems forecast item buy and repair quantities, plus the budget for these items. The material systems track the items and repair demands. The production systems support the depot maintenance facility by scheduling, tracking job orders, tracking work loads, etc. The cost systems collect and track the depot maintenance costs, such as material, labor and overhead. The other systems include such reports on the maintenance facility master plans and maintenance engineering data (7:55). Only five data systems directly affect this study. These five systems are described below.

The primary requirements system for recoverable items subject to depot repair is the D041, Recoverable Consumption Requirements System. The D041 consolidates historical usage and failure data and provides quarterly computations. These computations project buy and repair requirements, determine termination and excess quantities, and forecast budget requirements. At least thirteen systems outside of the depot maintenance system network feed into the D041, and the D041 feeds into at least twelve other information systems (8:24-27, 7:4-18; 16).

The G033J, Past Program Data System, is one of the systems that feeds into D041. The G033J maintains a thirty-month usage file of information such as aircraft flying hours and inventory for each Mission Design Series (MDS). It also serves as a cross reference for engine applications to MDS (6:7).

One of the systems the D041 feeds into is the D097, Interchangeability/Substitution (I&S) Data Maintenance System. The D097 contains a National Stock Number (NSN) Cross-Reference File to relate the I&S stock numbers to master stock numbers (6:7).

The total depot maintenance costs from each ALC feed into the H036B, DMS, ASIF Cost Accounting Production Report. The H036B consolidates the organic cost data, contract cost data, and weapon systems support costs from each ALC. This aggregration is at the "end item and aircraft serial number level" (7:49).

One ultimate end user of all the data from the depot maintenance systems network is the HO36C, Weapon Systems Cost Retrieval System (WSCRS), maintained by HQ AFLC, Directorate of Cost (AFLC/ACC). WSCRS contains historical depot maintenance and condemnation costs for most active aircraft and engines since FY75 and missiles since FY78. For this reason, it is the primary system used for developing weapon system cost factors (6:4).

Cost Factor Data Base. Currently, depot maintenance cost factors for AFR 173-13 are developed using the AFLC WSCRS data base, and this is the data base used in this research. WSCRS is the only historical data base "providing one consistent source of historic cost information" (6:4) for depot maintenance activity.

WSCRS is a flexible system in which data can be requested and expressed in different formats depending upon the level of detail the requester needs. For example, detailed quantity and cost data can be requested for specific National Stock Number (NSN) stock items. This data can be summarized at various levels such as the Federal Stock Class (FSC); the mission (e.g., Cargo, Fighter, etc.); the design (e.g., C-5 or C-141); and the series (e.g., C-5A or C-5B). The data can also be summarized by the work breakdown structure for depot maintenance (as listed previously in Table 1 with the addition of support equipment). Lists of data elements tracked in WSCRS are provided in Appendices D and E.

WSCRS includes information obtained from its interfaces with several AFLC data systems described in the previous section. For example, the D041, Recoverable Consumption Requirements System, provides WSCRS with nomenclature, unit prices, number of condemnations, and the quantity of all stock items used for each Mission Design Series (MDS) (e.g., F-16A, C130H, B-52G). The G033J, Past Program Data System, "provides the actual flying hours and inventory months" (6:7) for each MDS. The H036B, DMS, ASIF Cost Accounting Production Report, provides the annual depot maintenance costs (6:6-7). Figure 1 shows the information flow and process WSCRS undertakes each year. A list of the data element sources for WSCRS is also found in Appendices D and E.

In summary, WSCRS is a flexible cost data information system in which data can be requested in detail or summary by WBS, cost aggregation (Mission Design Series), fiscal year, work performance category, etc.

Cost Factor Guidance. Direction for the development of cost factors is found in three places. AFR 173-4, Aircraft and Missile Depot Maintenance Cost Factors, directs how depot maintenance cost factors are developed

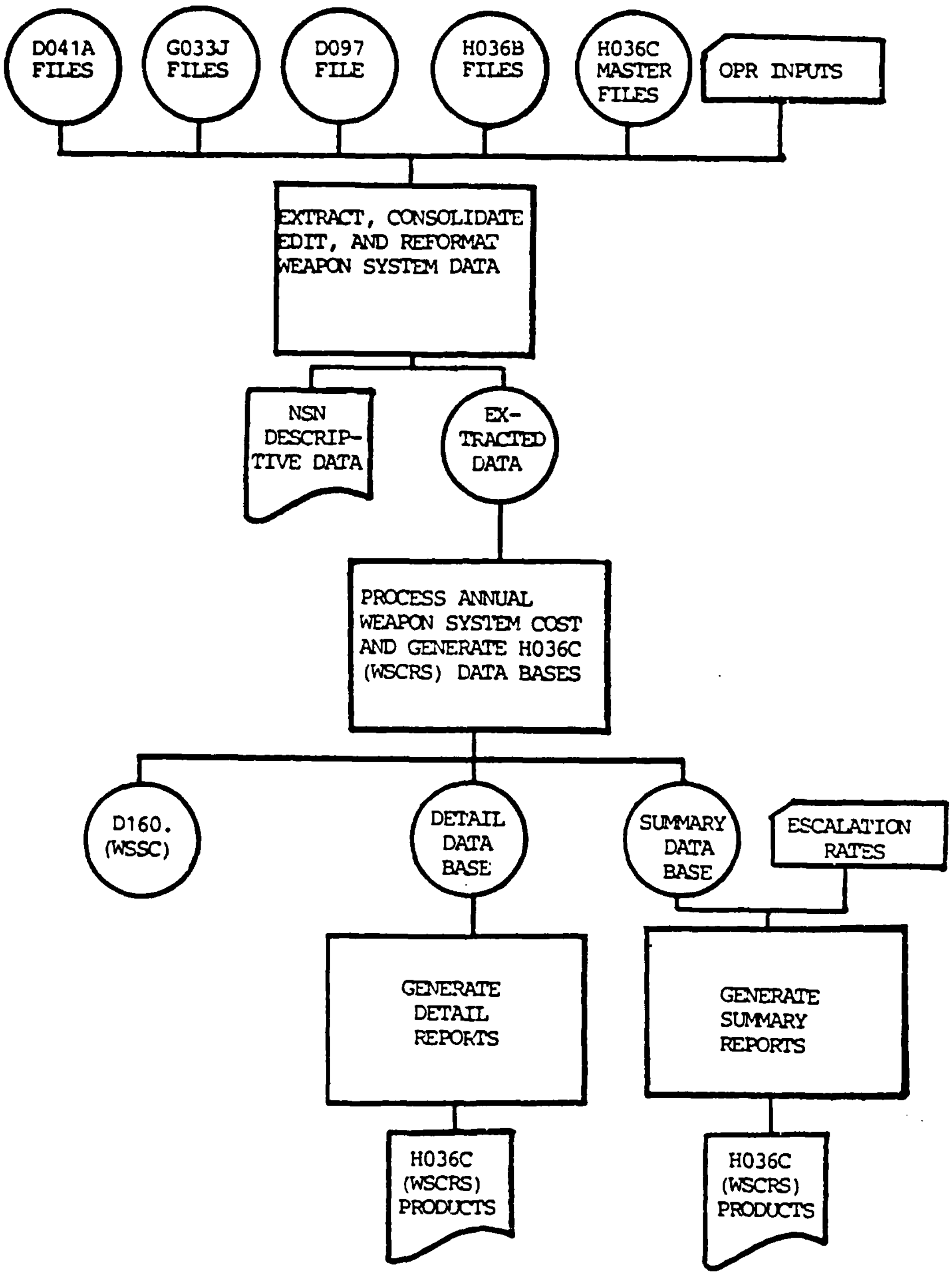


Figure 1. WSCRS Annual Processing

By direction of this regulation, aircraft depot maintenance cost factors are by flying hours and inventory (3:1). AFR 173-13, <u>US Air Force Cost and Planning Factors</u>, contains all official cost and planning factors and prescribes direction for their use. Cost factors are developed for life cycle and budget year. Life cycle cost factors are generated for a weapon system to capture the average yearly expected costs for its economic life. For example, the economic life of cargo aircraft or bombers is 25 years, and the life cycle cost factor is the expected average yearly cost over that 25-year period. Life cycle cost factors are used for cost studies such as economic analyses, cost/benefit analyses, or lease versus buy studies. Budget year factors are only used by the Air Force and represent the expected budget impact for the current budget year only. These factors are used to decrement and increment the budget for changes in force structure or the flying hour program (4:1-2, 3:1).

The Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG) has guidance specifying operating and support (O&S) cost elements, to include depot maintenance. The guidance states that even though

> estimated O&S costs may not be the same as programming or budgeting costs . . . many of the cost elements from those O&S cost analyses should be compatible with approved Program, Planning and Budgeting System (PPBS) costs, and can be used to derive the impact of alternative aircraft choices on programs and budgets. (15:2-3)

The Department of Defense (DOD) budget process assesses changes in terms of changes in the flying hour program or in force structure.

In summary, in accordance with the above regulations and guidance, depot maintenance cost factors must be related to flying hours and inventory.

Cost Factor Generation and Use. HQ USAF/ACC provides overall guidance for cost factor development and use. HQ AFLC/ACC maintains the historical cost data base needed to generate the depot maintenance cost factors. HQ Air Force Accounting and Finance Center, Comptroller Support, Directorate of Cost (AFAFC/CWC) develops the cost factors for each MDS aircraft and missile based upon guidance from HQ USAF/ACC and data inputs from AFLC/ACC and other Air Force organizations (3:3).

The cost factors for each WBS within a Mission Design Series (MDS) are calculated as follows (6:78):

$$\text{WBS Depot Maintenance Cost per Aircraft} = \frac{(\text{WBS Variable Cost}) * (\%)}{\text{PAA}} \qquad [1]$$

$$\text{WBS Depot Maintenance Cost per Flying Hour} = \frac{(\text{WBS Variable Cost}) * (\%)}{\text{FH}} \qquad [2]$$

where: % = the percent application found in Table 1
PAA = Primary Aircraft Authorized Inventory
FH = Flying Hours

Approach and Presentation

This thesis is divided into five primary phases: identification of the problem and its background, literature search of existing studies on this problem, selection of techniques to solve the problem, identification and analysis of the data base, and conclusions and recommendations.

Chapter I presented the problem with depot maintenance cost factor development and provided a general background to the subject. First, depot maintenance was described, followed by a discussion of the AFLC data collection systems. This chapter closed with a summary of cost factor regulation, generation, and use. Chapter II is the background literature search. Four studies are reviewed and discussed as they pertain to this thesis. Chapter III is the methodology. This chapter provides the primary approach used in this thesis for solving the problem. It also presents alternative approaches attempted. Chapter IV is the analysis. Chapter V provides the conclusions and recommendations of this study.

II. Literature Review

Overview

This chapter reviews four studies that address either estimating or allocating depot maintenance costs. Two of these studies directly address the problem of depot maintenance cost allocation for factor development. These two studies limit their scope to using flying hours and primary aircraft authorized (PAA) as cost drivers of depot maintenance. The other two studies estimate weapon system life cycle operating and support (O&S) costs using aircraft physical and performance (P&P) characteristics to develop cost estimating relationships (CERs). Also, the latter two studies provide models for estimating O&S costs on new weapon systems in the development or production phase. However, depot maintenance cost factors are developed only for deployed Air Force weapon systems. The following discussion addresses each of these four studies.

Depot Maintenance Cost Allocation Studies

A 1984 unpublished Air Force Institute of Technology (AFIT) thesis specifically addresses the allocation of depot maintenance costs by flying hours and primary aircraft authorized (PAA) using WSCRS as its primary source for data (1:13-14). First Lieutenant Ron Clayton and Mr. Ron Stuewe use the WSCRS Summary Cost Reports by work breakdown structure (WBS) for each Mission Design Series (MDS) to determine if a causal relationship exists between depot maintenance WBS costs and flying hours and PAA. They conclude that "any method of prorating depot maintenance WBS costs to develop cost factors based solely on flying hours and inventory explanatory variables is not appropriate" (2:74).

A limitation of their study is their use of summary cost data from WSCRS vice the WSCRS detailed data base. Relationships, if any exist, may be at the component level which can only be determined from the detailed data base. A discussion of the advantages of using the detailed data base vice the summary cost data base can be found in Chapter III, Methodology.

Clayton and Stuewe also point out the multicollinearity due to the relationship that exists between flying hours and inventory. The number of aircraft in inventory can affect the number of hours a unit is authorized to fly. For example, if five aircraft are added to a unit's PAA, then flying hours will probably increase to accommodate the five new aircraft. Multicollinearity can skew a cost estimating relationship (CER) that is developed based on these two variables. For this reason, and because of insignificant findings in their data, Clayton and Stuewe feel that "other factors may be responsible for impacting on total depot maintenance costs in addition to flying hours and inventory" (2:79).

In a June 1985 USAF/ACMC (now USAF/ACCC) study, Captain Andrew Sherbo addresses the "Depot Maintenance Percentage Allocation for Work Breakdown Structure (WBS) Cost Category" (16). Captain Sherbo, acting on the results of Clayton and Stuewe's thesis, conducted a cursory study using ten observations (aircraft) "in an attempt to find what allocation might exist between FH [flying hours] and PAA" (16). He limits his study to flying hours and inventory "as independent variables since we [USAF] program and budget on these two factors" (16). Captain Sherbo concludes that a possible 65 percent flying hour/35 percent PAA allocation exists in a few aircraft. However, he also finds that "PAA may not be an appropriate independent variable. Other causes may exist" (16). Specifically, the A-10A and the F-4C/D/E averaged a 65 percent FH/35 percent PAA split, but the remaining eight observations (B-52G/H, FB-111A, C-5A, KC-135A, C-141A, F-15A, F-111A/D/E/F, T-38A) show little or no relationship. In fact, the PAA variable has a negative relationship with depot maintenance costs in seven observations. This negative relationship may be caused by the multicollinearity between flying hours and PAA.

Despite the findings of these two studies, the Office of the Secretary of Defense (OSD) Cost Analysis Improvement Group (CAIG) clearly specifies the cost factors must be compatible with the programming and budgeting process. This means the factors must be related to flying hours and PAA for incrementing or decrementing the Air Force budget (15:2-3, 4:1-2).

Weapon Systems Life Cycle Cost Studies

Mr. Kenneth Marks and Mr. Garrison Massey of RAND Corporation have developed a "Model for Estimating Aircraft Cost of Ownership (MACO)" (12:1) in 1981. This model is for estimating operating and support (O&S) costs during the full scale development and production phases of a new weapons system. However, it does not address depot maintenance cost allocation. MACO estimates O&S cost as "a function of aircraft component level maintainability and reliability characteristics plus other aircraft design, logistics, operational and deployment variables" (12:iii).

The following discussion compares the cost drivers used in the MACO model with the current method used in WSCRS and in depot maintenance cost factor development (described in Chapter I).

The MACO model uses inventory and calendar time intervals to estimate the cost for aircraft programmed depot maintenance (PDM). The cost for PDM is collected in WSCRS under the WBS category, aircraft overhaul (refer to Table 1). Recall, for the development of cost factors, aircraft overhaul costs are allocated 100 percent to PAA.

MACO uses flying hours to determine the cost for engine overhauls. WSCRS collects costs for engine overhauls under the WBS category, engine overhaul. Again, for the development of cost factors, engine overhaul costs are allocated 100 percent to flying hours (refer to Table 1).

The MACO model has a category, "exchangeable item repair," which includes the remaining depot maintenance WBS categories under which costs are collected in WSCRS (refer to Table 1): engine accessories, aircraft accessories, avionics instrumentation, avionics communication, avionics navigation, and armament. Again, recall for the development of cost factors engine accessory costs are allocated 100 percent to flying hours. Also, the depot maintenance costs of the remaining five categories are allocated 65 percent to flying hours and 35 percent to PAA. The MACO model does not use flying hours or inventory to calculate these "exchangeable item repair" depot maintenance costs. The cost estimating relationship (CER) in MACO determines the number of exchangeable items in a year by using: component failure rates, not reparable this station (NRTS) rates, demand rate from PDM or engine overhaul, and the depot condemnation rate (12:51). Then MACO applies a labor factor. This factor is developed by allocating the total maintenance workload to each work center by sortie rate and inventory for each work center (12:13).

To summarize the above discussion, the MACO model uses inventory and flying hours to calculate PDM and engine overhaul depot maintenance costs, respectively. These are the variables used to develop depot maintenance cost factors. MACO uses a CER for the remaining depot maintenance cost categories that uses other physical and performance characteristics as cost drivers. However, flying hours and PAA are used by the Air Force for cost factor development of these same depot maintenance cost categories.

Marks and Massey do not provide statistical evidence of the CERs they have developed for MACO, which are basically allocations of expected O&S costs for a new weapon system. However, they do point out a limiting factor of the model that needs to be addressed for improvement in estimating maintenance costs, which is:

> the lack of an integrated historical data base at the aircraft component level. Historical information on component reliability and maintainability relevant to base maintenance is generally reported by work unit code, while depot-level maintenance and recoverable spares information is recorded by stock number. Unfortunately, there is no standard reference to relate the two recording systems. (12:vii)

This problem of tracking depot maintenance work reported by work unit code (WUC) to stock numbers still exists today (17).

In a separate 1981 study entitled, Estimating Aircraft Depot Maintenance Costs, Mr. Kenneth Marks and Mr. Ronald

Hess develop parametric equations by WBS for estimating costs for new aircraft, i.e., aircraft currently in development and production. Marks and Hess use three years of data (FY75-FY77) from WSCRS. They use various physical and performance (P&P) characteristics they found peculiar to each WBS to develop cost estimating relationships. Marks and Hess analyze the WSCRS data "in conjunction with data on potential explanatory variables at both the system and subsystem levels [WBS]" (11). They offer that "the information contained in the equations can enhance understanding of the factors that affect depot maintenance cost" (11:93). A problem with their study is the use of only three years of data. Also, accounting methods changed in FY77, discounting the use of FY75 and FY76 data.

Summary

This chapter reviews four studies that have addressed either allocating or estimating depot maintenance costs. Two studies directly address the allocation problem. One allocation study concludes flying hours and PAA are not appropriate variables for explaining depot maintenance costs. The second allocation study finds PAA is not appropriate. The other two studies offer CERs for estimating O&S costs based on possible cost drivers. These two studies show other possible explanatory variables of depot maintenance costs.

Two problems surfaced from these four studies: 1) variables other than flying hours and inventory probably drive depot maintenance costs, and 2) more information is needed in relating specific component or item level maintenance as potential cost drivers of depot maintenance. However, the OSD CAIG guidance specifies the need for using factors related to flying hours and PAA for use in Air Force budget exercises. Appropriate and scientifically supported factors need to be developed.

Chapter III will present the methodology to be used to solve the problem of depot maintenance cost allocation to flying hours and to inventory.

III. Research Method

Overview

The purpose of this study is to investigate the relationship between depot maintenance costs and flying hours and primary aircraft authorized (PAA) by work breakdown structure (WBS). This chapter presents the alternate methodologies suggested to solve the problem of allocating depot maintenance costs to flying hours and to PAA, and the selection of the primary methodology. The data base is described, followed by a list of the ground rules and limitations of this method. Finally, discussions of the development of a consolidated data base using WSCRS data and of the analysis methods used in this study are presented.

Alternative Approaches

Three approaches to the problem have been suggested:

Analysis of WSCRS Data. One approach is to study the detailed WSCRS data to as low a level as the Federal Stock Group (FSG) level to determine if a relationship exists by stock group between the depot maintenance cost and the flying hours and PAA variables. Unlike the Clayton and Stuewe thesis, this would be a detailed analysis of the data and would contain two more years of data. One result of such an analysis may be a cost estimating relationship

(CER) for determining the cost allocations for each aircraft mission. The CERs can then be incorporated into the WSCRS computer system. For example, this procedure may yield for a cargo aircraft the following depot maintenance cost allocations for the WBS category, aircraft accessories:

Federal Stock Group	Nomenclature	FH	PAA
15	Aircraft and airframe structure components	80%	20%
26	Tires and lubes	70%	30%
41	Air conditioner and air circulation components	35%	65%

Repair Generations. From discussions with Mr. Roger Steinlage of AFLC/ACC and the Marks and Massey O&S Cost studies discussed in Chapter II, it is apparent many factors other than flying hours and PAA may relate to depot maintenance costs. However, as discussed in Chapter I, OSD CAIG and HQ USAF/ACC guidance dictates the use of flying hours and PAA. One suggestion is to examine the not-reparable-this-station (NRTS) quantities. When an item is declared NRTS at a base, it is forwarded to the depot. At the depot, the item is declared reparable or condemned. Depot maintenance occurs in the inspection of all items and in the repair of items that are not condemned. It is suggested that the NRTS quantity may be more implicative by flying hours or PAA than costs. Depot maintenance costs include Air Logistics Centers' (ALCs) specific overhead, indirect costs, and cost per manhour factors. Fluctuations in the costs may distort their relationships with flying hours and PAA. In this approach, the NRTS quantities can be split by flying hours and PAA, then the costs of the items that are not-reparable-this-station can be assigned accordingly (17).

Items in repair at the depot are generated from the bases (i.e., NRTS), or they may be generated at the depot during periodic or other maintenance. Thus, NRTS and depot repair generations will need to be studied. WSCRS collects "quantity repaired;" however, the reporting of these quantities are not considered accurate (17). NRTS and depot repair generations quantities can be found in the AFLC D041 system (as discussed in Chapter I). However, D041 maintains only a two-year historical base.

Time and data availability constraints prevent this study from further examining NRTS and depot repair generations. This is an approach that should not be discounted at this time. It needs to be further examined. AFLC is procuring a new data base system called RDB (Requirements Data Base). When the RDB is "up and running," systems such as the D104 and D143 will go away. The RDB is supposed to contain a better history, to include more years of NRTS data. However, this capability is still "many years down the road" (17).

Sample Approach. Another suggested approach to determining the appropriate allocation of depot maintenance cost to flying hours and PAA is to perform a sample. Stock items repaired at the depot can be sampled to determine the cause of the components' malfunctions, then categorize the reasons for the malfunction by usage (i.e., flying hour) or time and inventory (i.e., PAA), total the depot repair costs, and determine the percentages. For example, a corroded item would be considered to be time related and an item damaged by bird strike may be flying hour related.

The sampling approach requires extensive preparation and research better performed by a team. Also, this approach requires subjective reasoning in determining whether certain malfunctions are flying hour or inventory related.

Primary Approach

Since the purpose of this study is to address the relationship between depot maintenance costs and flying hours and PAA, the primary approach selected is to use the WSCRS data base (the first approach discussed) to examine the depot maintenance costs and the relationships between costs and flying hours and PAA. Time and data availability constraints prevent following the other two approaches.

Data Base

As outlined in Chapter I, the Weapon System Cost Retrieval System (WSCRS) is appropriate for this research. WSCRS has the history of depot maintenance costs for most Air Force weapon systems since FY75. WSCRS is a consolidation of other AFLC data information systems created specifically for cost studies. It is the most complete and consistent cost data base available. WSCRS provides the only matching of depot maintenance costs of each National Stock Number (NSN) item to a particular weapon system (i.e., Mission Design Series) and then to a work breakdown structure (WBS) category. However, using WSCRS does present limitations discussed in the next section. A list of cost elements included in WSCRS is in Appendix D, and a list of other elements included WSCRS is in Appendix E.

Ground Rules, Assumptions, Limitations

1. Time limitations prevent analyzing missile and all aircraft data. Only cargo aircraft included in WSCRS are examined. However, a complete aircraft data base is created to further analyze all aircraft.

2. The data is analyzed at the mission (e.g., attack, cargo, bomber, etc.) level. Time limitations prevent examining modified fleet, such as EC-135 or KC-135, which may be significant.

3. The data is examined as low as the Federal Stock Group (FSG) level if needed. FSGs are two-digit codes for grouping components and items. The FSGs are listed at Appendix F. Again, time limitations prevent analyzing the data at the Federal Stock Class (FSC) level which is a further breakout of the FSGs into four-digit codes. FSC level data is available in the data base created for this study.

4. Base level support equipment (SE) costs are excluded. SE repair for base and depot is evaluated separately by AFAFC/CW.

5. WSCRS has historical depot maintenance data back to FY75. However, changes in accounting methods in FY77 voids the use of FY75 and FY76 data bases because they will be incompatible with post FY77 data. Therefore, nine years of data are used in this study, FY77 through FY85 (11:92).

6. Reparable items may be repaired in batches at the depot, instead of individually, because repairing in batches is more economical. Thus, an item from a particular aircraft sent to the depot for repair may not be the same item that is returned to that aircraft. The costs for items repaired in batches are not specifically attributed to a particular MDS, and must be proportionately allocated. If an item is sent to the depot in one fiscal year, placed in a batch and fixed the following fiscal year, its costs are reported in the fiscal year in which it

is repaired (6:15). This reporting may cause costs to be high in one year and low in another (6:76).

7. WSCRS is constrained by the information it receives from existing systems. "Few existing systems collect costs directly by MDS" (6:8). Therefore, WSCRS must allocate the costs which are common to more than one MDS to each MDS. These allocations are based on flying hour and PAA ratios. Such factors as the mission or environmental conditions effect on cost are not considered. This is of concern to the validity in using the costs from WSCRS for this study. Deleting these costs can skew the relationship just as well as including these costs. Including or excluding these costs will affect an average of 30 percent of the total depot maintenance costs. Allocations that occur within the fleet will not affect this study because this study is evaluating the data at the mission (i.e., cargo in this example) level. For example, $10,000 in depot maintenance cost is performed on an air conditioning unit found in the C-5A, C-5B, C135A, and C-135B. The allocation of the $10,000 by PAA will not affect this study because the entire $10,000 will be allocated to cargo. However, if the air conditioning unit is also used in the B-52G and B-52H, the allocation by PAA may skew this study since the $10,000 will be split between cargo and bomber based on the number of primary aircraft authorized. For this study, only the items that

are mission peculiar are analyzed. The data base created for this study includes and identifies common items used across the missions (e.g., cargo and bombers) for use in future analysis (6:8,75).

8. The detailed WSCRS data base has three "record types" to accommodate incidents of poor maintenance data collection. Record type 1 is the most complete in which costs are tracked to the National Stock Number (NSN). Type 2 records identify costs only to the Federal Stock Class (FSC). Type 3 records contain overhaul cost (aircraft and engine) and other records in which costs are not identified by <u>any</u> stock number (such as NSN, FSC, or FSG). Costs in type 3 records are trackable to the MDS and WBS levels. Only the type 1 records, type 2 records, and overhaul costs from type 3 records are evaluated in this study. Since the other costs in type 3 records cannot be tracked to FSG, these records are not used in this study. Deleting these records omits 3 percent of total depot maintenance costs.

9. Interim Contractor Support (ICS) and Contractor Logistics Support (CLS) costs are excluded from this study. ICS/CLS costs cannot be identified to a particular WBS, and are subjectively allocated in WSCRS (6:8).

10. WSCRS contains actual expenditures vice using standard costs of all depot maintenance costs. An exception is ICS/CLS costs. ICS/CLS costs in WSCRS are the obligations from the contracts (6:8).

11. Class IV modifications (for safety and deficiencies) and Class V modifications (for mission changes) costs are not included in this study since they are not directly attributed to maintenance costs. However, modification installations performed in conjunction with "scheduled Programmed Depot Maintenance (PDM) or overhaul aren't always tracked separately" (6:8). Thus, the WBS category, aircraft overhaul, may contain costs for modification installations.

12. WSCRS currently uses an inventory number equivalent to total active inventory instead of primary aircraft authorized (PAA). HQ USAF/ACC directed AFLC/ACC to change WSCRS to use PAA in July 1984 (1). Using PAA meets the requirements for developing budget and life cycle cost factors, and for using the cost factors in cost studies and the budget process. AFLC/ACC completed this change manually in June 1986, and is currently updating the WSCRS historical data base. This study uses the corrected PAA quantities.

Preparation of WSCRS Data Base

This study requires using specific information found in the WSCRS data base. Several steps are taken to prepare a consolidated data base for use in analyzing the data.

Tapes with the entire WSCRS data base for FY77 through FY85 are provided by AFLC/ACC. The Air Force Institute of Technology (AFIT) Classroom Support Computer (CSC) is used to manipulate the appropriate WSCRS information needed for this study. The CSC is a minicomputer and requires large jobs to be processed in batches. Four batches are required for one year of WSCRS data. The entire data base is screened to remove support equipment and elements without depot maintenance costs using a Fortran program to load the appropriate data elements into the CSC. Then, the depot maintenance costs and flying hours are consolidated by WBS, FSC/FSG, and mission using the Statistical Analysis System (SAS) package.

Five data bases are created. Their descriptions are as follows:

1. <u>Complete</u>

a. Contains all type 1 and type 2 records. Type 3 records are excluded, thus does not contain overhaul records.

b. Current and base year FY85 costs are summed and sorted by fiscal year, WBS, FSC, and MDS. The number of data base records in each sorted category is included.

c. Class IV modifications, Class V modifications, ICS, and CLS costs are excluded.

2. <u>Fleet Common</u>

a. Contains type 1 and type 2 records for items common to the fleet (e.g., cargo, bomber, fighter) only. Items common across the fleets are excluded. Type 3 records are excluded, thus does not contain overhaul records.

b. Current and base year FY85 costs are summed and sorted by fiscal year, a commonality code, WBS, FSC, and MDS. The number of data base records in each sorted category is also included.

c. Class IV modifications, Class V modifications, ICS, and CLS costs are excluded.

3. Mods and Contracts

a. Contains Class IV modifications, Class V modifications, Interim Contractor Support, and Contractor Logistics Support data.

b. Current and base year FY85 costs are summed and sorted by WPC, fiscal year, WBS, FSC, and MDS. The number of observations in each sorted category is also included.

4. Type 3 Records

a. Contains type 3 records only. This includes the two overhaul categories, aircraft overhaul and engine overhaul.

b. Current and base year FY85 costs are summed and sorted by fiscal year, WBS, and MDS. The number of observations in each sorted category is also included.

5. Flying Hours

a. Contains the fleet flying hours and an inventory quantity equivalent to total active inventory (TAI) minus the numbr of aircraft presently in the depot (as reported in WSCRS).

b. Flying hours and WSCRS inventory are summed and sorted by year and MDS.

A copy of these programs can be obtained from the author.

Cost data are converted to constant FY85 dollars using OSD Raw Inflation Indices as of 4 January 1986 (issued by USAF/ACC on 6 January 1986 and received by AFLC/ACC on 24 February 1986). The operating and maintenance inflation indices are shown in Table 2.

TABLE 2

OPERATIONS AND MAINTENANCE
RAW INFLATION INDICES

Fiscal Year	Index
77	.562
78	.606
79	.661
80	.725
81	.812
82	.886
83	.930
84	.965
85	1.000

The primary aircraft authorized (PAA) data base is not yet available in WSCRS (refer to Ground Rules, No. 12). Thus, a separate PAA data base is obtained from AFLC/ACC and a sixth data base is created in the CSC. These files must be merged for the data analysis.

Examination of the Data

Multiple linear regression is used to evaluate the data for determining the relationships that exist between depot maintenance costs and flying hours and PAA. Regression analysis is defined as "a statistical tool that utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other, or others" (14:23). Least-squares-best-fit regression analysis fits a line to the observed data so as to minimize the sum of the squared deviations between the observed data and the fitted line (14:10). The steps in analyzing the data are as follows:

Identification. The independent variables are predetermined to be flying hours and PAA. This is per OSD CAIG guidance, AFR 173-4 and AFR 173-13 as explained in Chapter I. Due to the multicollinearity problem identified by Clay and Stuewe in their AFIT thesis, an examination of the relationship between flying hours and PAA needs to be performed. Multicollinearity occurs when two or more of the independent variables (in this case, flying hour and PAA) are related to each other, thus containing redundant information. This redundancy can cause instability in the solutions of a regression when the related variables are used.

> Collinearity reduces the statistical reliability of the regression coefficients by increasing the variances of the sampling distribution from which the coefficients are drawn. This effect increases the probability that a given sample will produce regression coefficients which differ substantially from the parameters they are trying to estimate. (13:10)

Flying hours and PAA may be related because flying hours usually are increased when more aircraft are added to the inventory. A possible solution is to convert total flying hours to flying hours per PAA (AVFH) to reduce the multicollinearity problem.

Specification. Plots of the raw data are used to visually examine the relationships between the dependent (i.e., depot maintenance costs) and independent variables (i.e., flying hours, PAA, and AVFH). Plots will be examined to determine if a relationship exists and if that relationship is linear or nonlinear. If the relationship appears to be nonlinear, then the variables may need to be transformed so as to perform the linear regression.

In this study, five models will be looked at. All five models use the dependent variable, depot maintenance costs. Three models will use each of the independent variables – flying hours, PAA and AVFH – alone. The fourth model will use both flying hours and PAA as independent variables. The last model will use AVFH and PAA as the independent variables.

Analysis. Analysis of the regressions is presented in Chapter IV. It includes examining the model's coefficient of determination, independent variable's coefficient, significance, residuals, possible outliers, and multicollinearity. First, the coefficient of determination (R^2) describes the proportion of the total variation in the observed dependent variables (Ys) that is explained by the regression line. This is often referred to as the goodness of fit. The higher the R^2, the better the fit (14:96-97).

Another analysis technique is to test for the possibility of a regression coefficient being zero. A t-test is used for this. If a regression coefficient has a probability of being zero, given a specified confidence level, then that independent variable may be incorrectly specified. Also, it may not be a significant cost driver or collinearity may exist between that variable and another independent variable. A coefficient of zero will cause that particular variable to drop out of the model because there is no linear relationship between that independent variable and the dependent variable (14:67-68).

Another test is the F-test. The F-test is a test of the model significance. The F-value is obtained by taking a ratio of the explained variation around the regression line to the unexplained variation around the regression line. This value is tested against an F-distribution at a certain level of confidence. The higher the calculated

F-value is, the better the model may be. A probability value can also be obtained to give a probability of the model being insignificant, thus a linear relationship between the independent variables and the dependent variable probably does not exist. The model may be incorrectly specified (14:86-87, 92-94).

Residual analysis involves examining the residuals (of the fitted line to the observed values) to see if there is 1) random scatter, 2) normal distribution, and 3) constant variance. Condition 1 should exist if the model is correctly specified. Usually condition 2 exists if the model is correctly specified. If condition 3 does not hold, and the variance is changing, a condition known as heteroscedasticity exists.

> When heteroscedasticity prevails but the other conditions of the model . . . are met, the estimators b0 and b1 obtained by ordinary least squares procedures are still unbiased and consistent, but they are no longer minimum variance unbiased estimators. (14:170)

A plot of the residuals will provide this information visually (14:111-122).

The residuals are also examined for possible outliers — "extreme observations" (14:114). Outliers may cause a misleading fit. An outlier may be an observation that is not supposed to be in the data set, or it may be correctly in the data set, but affected by an extraordinary occurrence or perhaps a new way of doing things, thus affecting the future observations. This may mean the outlier has significant information to add to the model (14:114-115). Residuals are examined to determine if outliers exist, and if outliers should remain in the data set or be removed. Residual analysis for outliers is accomplished through studentized, studentized deleted (rstudent), leverage, and the cooks distance measure (cooksd) methods of evaluation.

The studentized and studentized deleted (rstudent) residuals are used to determine if outliers exist with respect to the dependent variable. The studentized residuals are calculated by taking each residual and dividing it by its own standard error. The rstudent residuals are calculated the same as student residuals, except the particular observation the rstudent is being calculated for is omitted. Thus, the omitted variable cannot influence the fit of the observed data. "A deleted residual corresponds to the prediction error . . . when predicting a new observation from the fitted regression function based on earlier observations" (14:406). These two calculations are compared with a t-statistic to determine if the observation may be an outlier (14:404-406). In this study the t-statistic is calculated at 95 percent confidence.

The leverage value measures the distance between the independent variable values of an observation and the mean (center) of all of the observations (14:402). It is used to determine if there is an outlier with respect to the independent variables. A rule of thumb is to compare the calculated leverage values with two times the number of parameters in the model divided by the number of observations (14:402-403).

The cooks distance measure (cooked) is used to determine whether or not outliers identified by the student, rstudent and leverage values are "influential in affecting the fit of the regression function" (14:407). Cooksd is "an overall measure of the impact of the i_{th} observation on the estimated regression coefficients" (14:407).

> Cook's distance measure . . . may be viewed as reflecting in the aggregate the differences between the fitted values for each observation when all n observations are used in the data base and the fitted values when the i_{th} observation is deleted. (14:409)

A rule of thumb for using cooksd values is a percentage greater than 50 percent may imply the observation has a significant impact on the regression line. A percentage less than 20 percent indicates little apparent influence. The range in between 20 percent and 50 percent is discretionary. Usually an analyst will look at all (studentized, studentized deleted, leverage and cooks distance measure) measures to determine the existence of outliers and their influence on the regression function (14:407-409).

Since multicollinearity appears to be an inherent problem between flying hours and PAA, a ridge regression method will be used to deal with it. Ridge regression analysis is a technique used when it is suspected that collinearity is present between two or more independent variables. This technique allows the use of both independent variables in the model when, in fact, each variable may be a significant depot maintenance cost driver. In a National Estimator article, Mr. Richard Murphy explains ridge regression:

> The presence of collinearity among two or more independent variables increases the variance of the sampling distributions of the regression coefficients. . . . Ridge regression introduces a bias into the estimates of the regression coefficients so that, on an average, they will not equal the parameters being estimated. . . . ridge regression coefficients will also have much smaller variances. What this means is that if the reduction in variance can be achieved without introducing too much bias, the overall accuracy of the regression coefficients can be significantly enhanced. (12:11)

In regression analysis, the population parameters we are estimating is fixed and unknown. In this study we are trying to estimate B_0, B_1, and B_2 in the following equation:

$$\text{Depot maintenance cost} = B_0 + B_1 \text{ FH} + B_2 \text{ PAA} \quad [3]$$

where

B_0 = the Y-intercept

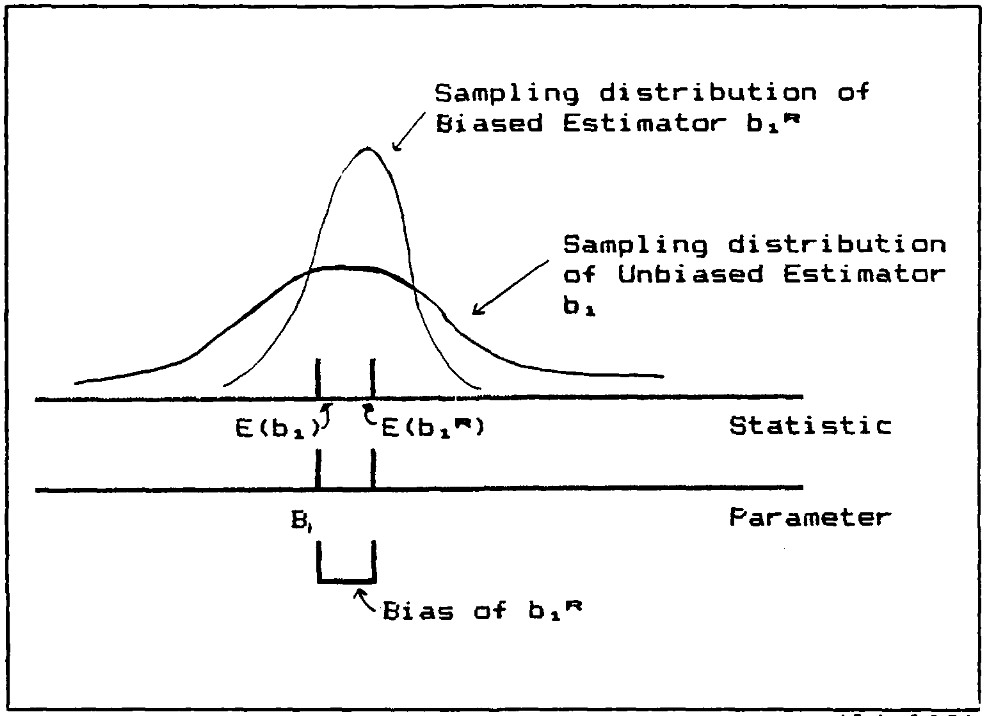
FH = flying hours

PAA = primary aircraft authorized

B_1 & B_2 = the population parameters; the regression coefficients indicating "the change in the mean of the distribution of Y [depot maintenance cost] per unit increase in X [flying hours or PAA]" (13:33)

Least-squares-best-fit regression is used to estimate these parameters. A property of the estimates of these parameters, referred to as b_0, b_1 and b_2, is that they are unbiased. Thus, the expected values of the parameter estimates are the population parameters "so that neither estimator tends to overestimate or underestimate systematically" (14:39). These parameter estimates are not fixed. They are random variables with their own distributions (see Figure 2). If different observations from the same population are used to estimate the parameters, the estimate of the parameters may be different. The means of the respective distributions are equal to the population parameters. Through adding observations (equal to the number of independent variables in the model) with very small values to the current set of standardized observations, small bias is entered into the parameter estimates of the model. When bias is introduced into the estimates of the parameters, the estimates are no longer equal to the population parameters (see Figure 2). Yet, the variances are reduced as bias is introduced.

When an estimator has only a small bias and is substantially more precise than an unbiased estimator, it may well be the preferred estimator since it will have a larger probability of being close to the true parameter values. (14:394)



(14:395)

B is the population parameter

$E(b_1)$ is the unbiased estimate of the population parameter B,

$E(b_1^R)$ is the biased estimation of the population parameter B,

Figure 2. Biased and Unbiased Distribution

There is a point where the variance reduction becomes insignificant as more bias is introduced. At this point the analyst chooses the amount of bias to ideally enter into the model. This point is a judgement call based on the analyst's evaluation of the variance reduction.

Model Selection. Once the five models are analyzed, the "best" model is chosen. To determine the appropriate percentages of flying hours and PAA to depot maintenance costs, two methods will be used.

The first method will force a zero intercept, leaving only the independent variables, flying hours and PAA, in the model. Then, the means of both flying hours and PAA will be used to calculate the depot maintenance costs. The proportion of each independent variable in terms of contribution to depot maintenance costs will then be calculated.

The second method is a "hunt and peck" approach. This procedure regresses various proportions of depot maintenance costs against flying hours and PAA, separately, to see if one proportion has better statistics or the least squared error. For example, depot maintenance costs may be $100 K. Various proportions are applied, such as 60/40 or 20/80, and regressed against flying hours and PAA, respectively. Under the 60/40 split, $60 K will be regressed against flying hours and $40 K will be regressed against PAA. Then, under the 20/80 split, $20 K is regressed against flying hours and $80 K is regressed against PAA. The results of these regressions (and other proportions) are compared to determine the split with the best statistics or lowest squared error.

This method is similar to the current procedure used to develop depot maintenance cost factors. The total depot maintenance costs are apportioned by the appropriate percentage (refer to Chapter I, Table 1) for flying hours and PAA, then the factors are calculated.

Summary

The primary method chosen for this study is to examine the WSCRS data base for possible relationships between depot maintenance costs and three independent variables — flying hours, PAA and flying hours per PAA. Using the WSCRS data base presents some limitations as outlined in this chapter. However, WSCRS is the only data base with nine years of validated depot maintenance cost data. Two other approaches are suggested: 1) examine repair generations, and 2) perform a sample. However, time and data availability constraints prevent using these approaches at this time.

Least-squares-best-fit regression analysis will be used to examine the data. Chapter IV will provide the results.

IV. Analysis

Overview

This chapter addresses the analysis of cargo aircraft depot maintenance cost data. The objective is to determine whether a relationship exists between depot maintenance costs and flying hours and primary aircraft authorized (PAA).

This chapter will proceed as follows: First, the cargo fleet common data set is examined, which excludes overhauls (data set B in Chapter III). The data is plotted and examined visually to see what relationships may exist. This first step includes an analysis of the correlation between flying hours and PAA. Then, a least-squares-best-fit regression analysis is performed. Second, the cargo aircraft data set is partitioned by the work breakdown structure (WBS) categories and plotted. Then, regression analysis is performed on the respective WBSs, including overhauls. Third, ridge regression analysis, a regression method used when it is believed multicollinearity is present, is performed. In the fourth step an analysis is performed on using a forced zero intercept vice the intercept found under least-squares-best-fit regression. The final step takes an approach that looks at the changing relationships between flying hours and PAA as the percentage of depot maintenance costs change.

Analysis of the Cargo Aircraft Fleet Common Data Set

General Discussion. For this study, only cargo aircraft are examined. The fleet common data set (data set B in Chapter III) includes items common to a mission and excludes items common to more than one Mission Design Series (MDS) (reference ground rule #7). The WBS categories included are aircraft accessories (AA), armament (AR), engine accessories (EA), avionics communication (VC), avionics instrumentation (VI), and avionics navigation (VN). Two WBS categories, aircraft overhaul (AO) and engine overhaul (EO) are not included in this data set and are excluded in the fleet analysis. The nine years of depot maintenance costs, flying hours, and PAA for this scenario are shown in Table 3.

TABLE 3

CARGO FLEET COMMON SUMMARY

Fiscal Year	Cargo DM Cost (FY85 dollars)	Flying Hours	PAA
77	166,316,927	929,407	1,699
78	220,566,134	959,304	1,699
79	223,361,796	960,295	1,673
80	202,195,453	945,684	1,735
81	258,168,906	1,007,217	1,762
82	300,815,043	1,025,850	1,798
83	375,175,293	1,032,251	1,801
84	401,839,530	1,046,559	1,825
85	359,502,875	1,056,249	1,853

Plots and Collinearity Assessment. The plot of depot maintenance costs to flying hours shows a positive, linear relationship, as shown in Figure 3. Likewise, the plots of cost to PAA and flying hours to PAA show positive, linear relationships (see Figures 4 and 5).

An analysis of the correlation between flying hours and PAA reveals a pearson correlation coefficient of .92753. This 93 percent correlation means flying hours and PAA are highly correlated and confirms the relationship shown in Figure 5. Thus, a possible problem with multicollinearity, as addressed in Chapter III, may occur. This can further be seen in the results from performing singular and multiple regressions which are discussed below.

As mentioned in Chapter III, a possible way to eliminate multicollinearity is to transform the independent variable, flying hours, to average flying hours per PAA (AVFH). The results are shown in Table 4.

Average flying hours (AVFH) show little change, except in FY77 and FY80, when AVFH drops significantly. Since there is not much variability in AVFH, using it as an explanatory variable may be insignificant. Also, note that AVFH has its limitations as an explanatory variable since costs could increase, yet AVFH could remain constant as a result of both flying hours and PAA increasing. For the regression analysis, both flying hours and AVFH are examined.

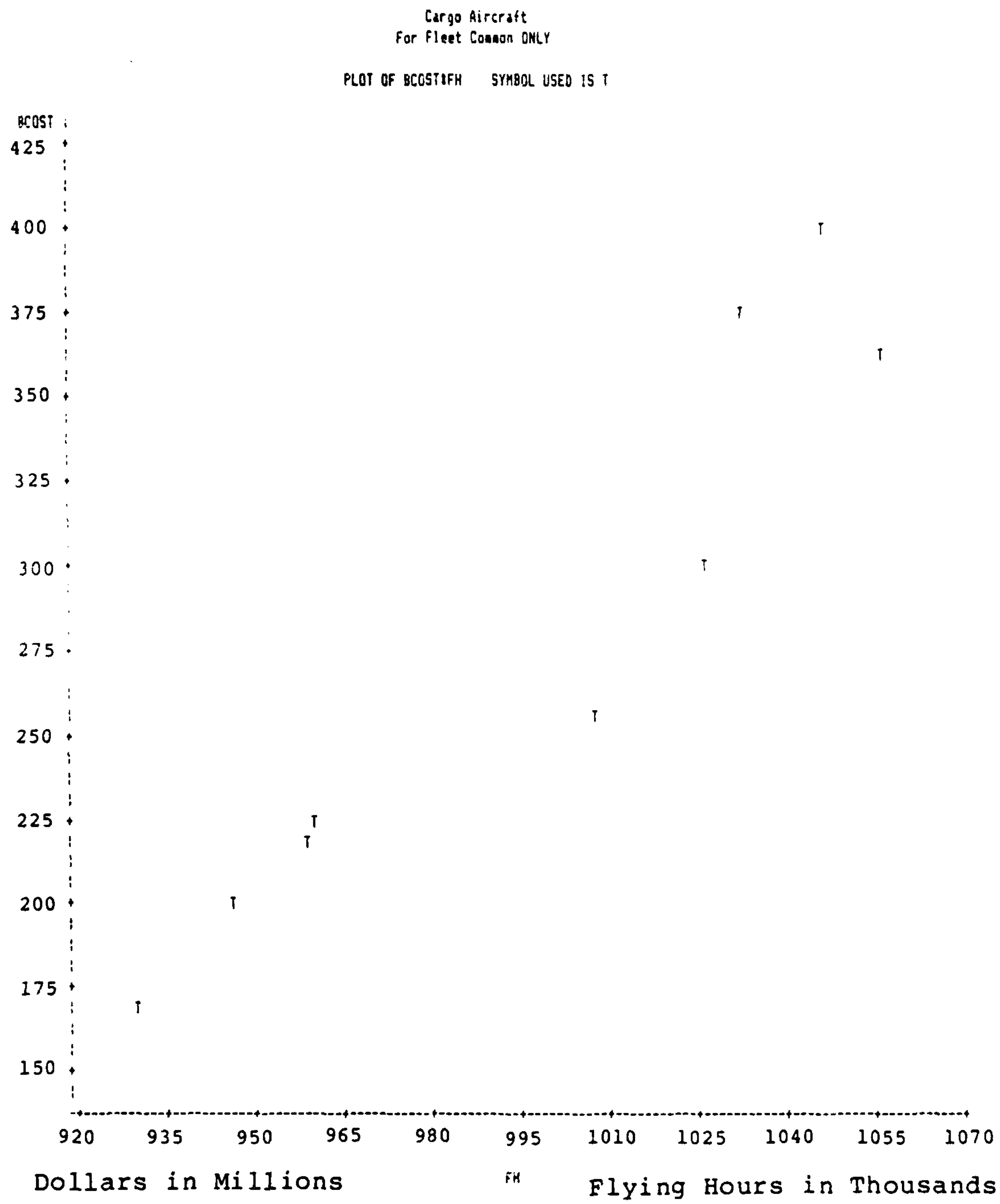


Figure 3. Plot for Cargo Aircraft Depot Maintenance Costs to Flying Hours (FH)

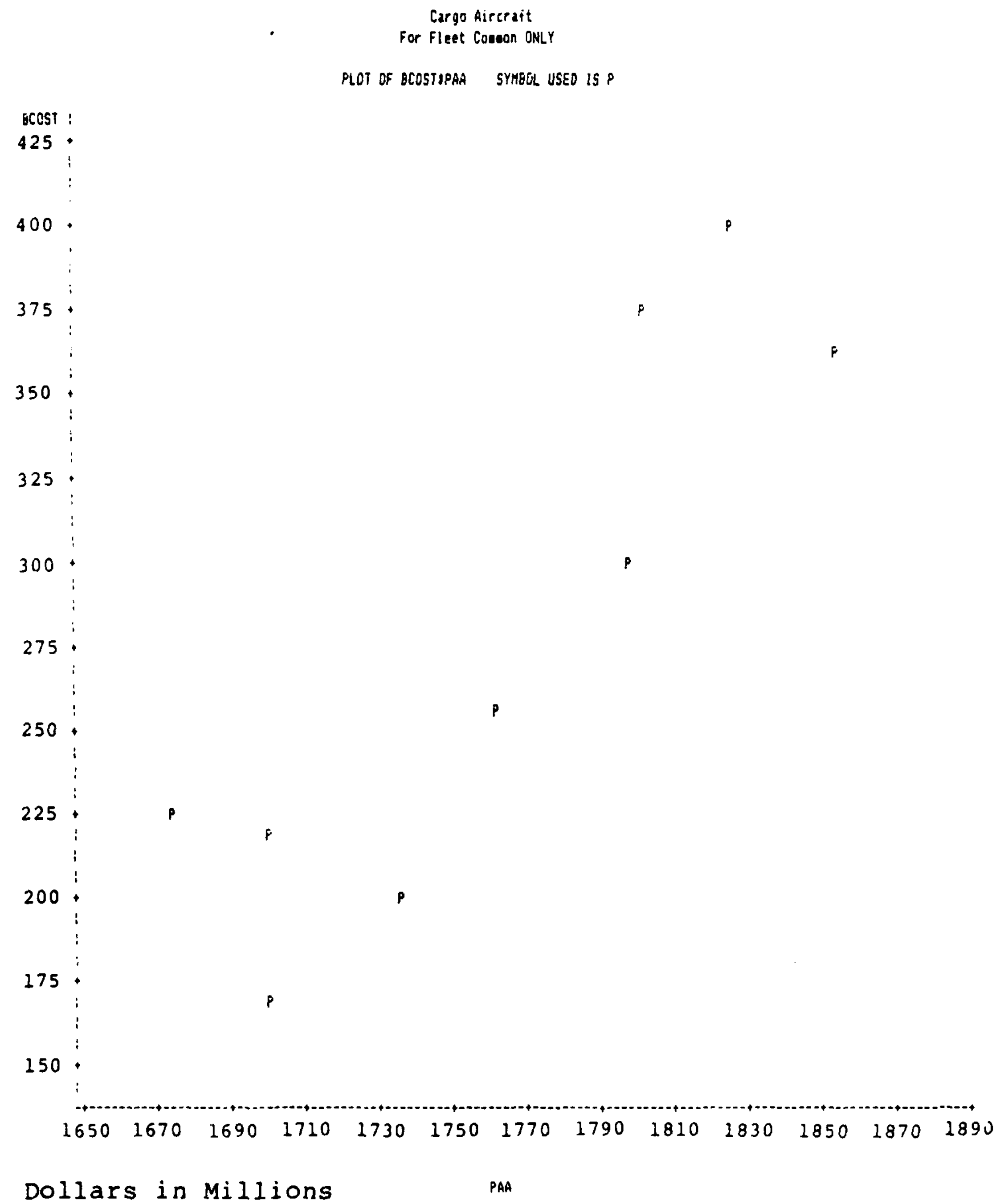


Figure 4. Plot for Cargo Aircraft Depot Maintenance Costs to Primary Aircraft Authorized (PAA)

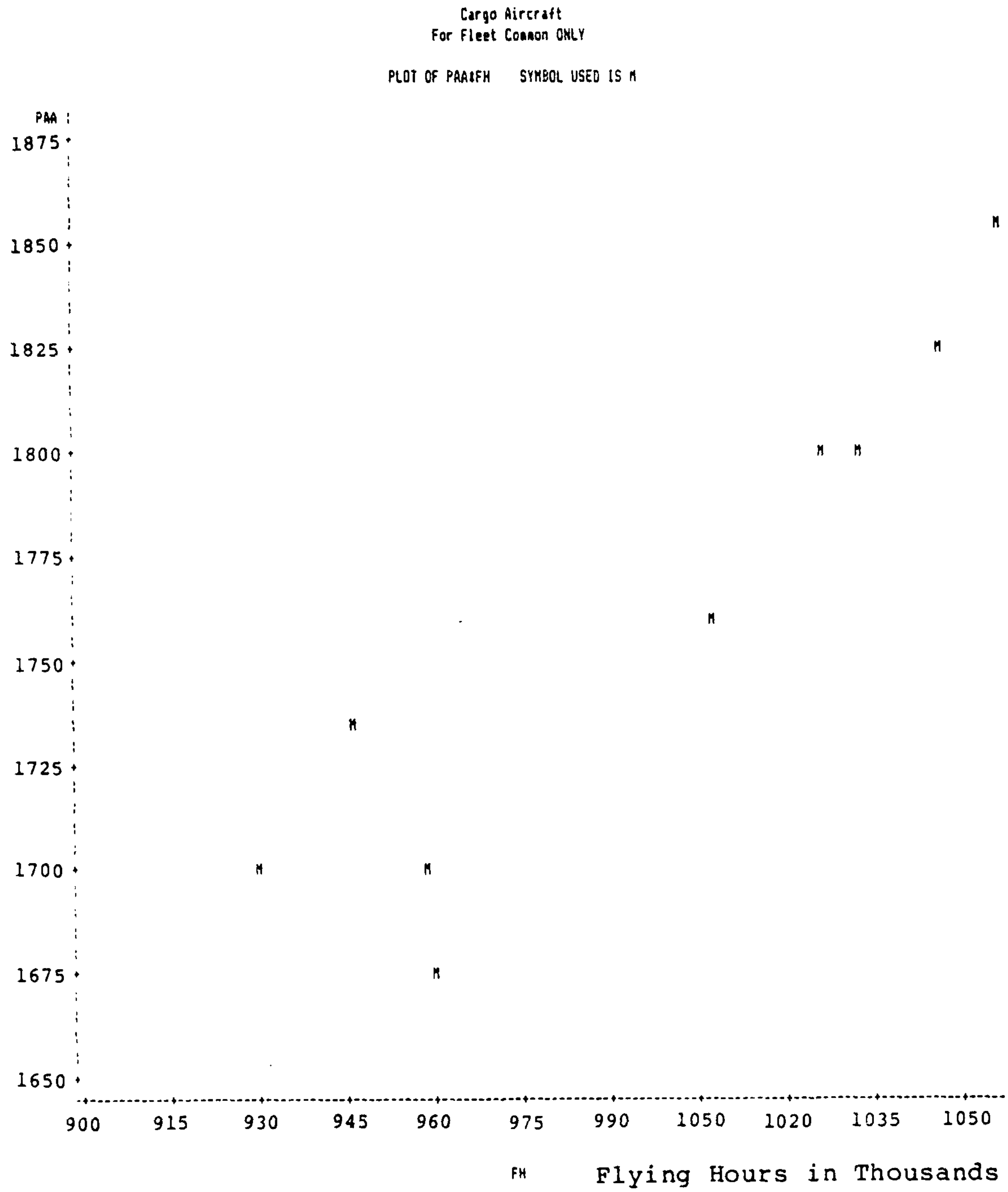


Figure 5. Plot for Primary Aircraft Authorized (PAA) to Flying Hours (FH)

TABLE 4

INDEPENDENT VARIABLES

Fiscal Year	Flying Hours	PAA	AVFH
77	929,407	1,699	547.03
78	959,304	1,699	564.63
79	960,295	1,673	574.00
80	945,685	1,735	545.06
81	1,007,217	1,762	571.63
82	1,025,850	1,798	570.55
83	1,032,251	1,801	573.15
84	1,046,559	1,825	573.46
85	1,056,249	1,853	570.02

Regression Analysis. Table 5 displays the statistical results of the regression analyses. There are five analyses, all with cargo aircraft depot maintenance cost as the dependent variable. Three of the analyses have a single independent variable — flying hours, PAA, and AVFH. Two analyses have two independent variables — flying hours and PAA, and AVFH and PAA.

The R^2 is the coefficient of determination. It describes the proportion of the variation in depot maintenance costs that is explained by the developed regression line. The higher the percentage explained, the better the fit of the regression line (14:96-97). Here, flying hours alone explain 90 percent of the variation in depot maintenance costs. PAA explains 78 percent. Yet, the model that combines flying hours and PAA still explains only 90

TABLE 5

CARGO FLEET COMMON SUMMARY REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.90	64.35	.0001	8.02	.0001
PAA	.78	24.54	.0017	4.95	.0017
AVFH	.48	6.32	.0401	2.51	.0401
FH	.90	27.58	.0009	2.75	.0332
& PAA				.03	.9807
AVFH	.90	27.30	.0010	2.73	.0342
& PAA				5.08	.0023

percent. This is probably due to multicollinearity between flying hours and PAA.

The t-statistic is a test to determine if a particular independent variable even belongs in the model. This statistic tests the probability of the coefficient of that variable actually being zero, thus dropping out of the model (13:67). In the flying hours and PAA model, PAA has a 98 percent chance of having a zero coefficient. Thus, PAA is an insignificant variable in this combined model. This is also probably due to multicollinearity between flying hours and PAA.

The F-value shows the overall model significance. It is the ratio of the explained variation in depot maintenance costs to the unexplained variation in depot maintenance costs. The higher the F-value, the better the regression model may be (14:92-96). In this model, the independent variable, flying hours, alone, has the highest F-value of 64.35. When flying hours and PAA are combined, the model significance drops considerably to 27.58. This F-value change and the t-statistic for PAA in the combined, flying hours and PAA, model show that flying hours alone is the best explanatory variable for changes in depot maintenance costs.

The independent variable, AVFH, explains 48 percent of the variation in depot maintenance costs. When this variable is combined with PAA, the model explains 90 percent of the variation (R^2 = .90) in depot maintenance costs. However, this model is not as significant as flying hours alone. Its F-value (27.30) is slightly lower than the F-value of the flying hours and PAA model. Yet, the t-statistics indicate both variables are significant to the model and would stay in the model. In fact, the AVFH variable is less significant than PAA.

The residual analysis shows no significant problems except signs of an increasing variance. Tables 6 through 9 found at the end of this discussion display the statistics used in residual analysis. The increasing variance, known as heteroscasticity, for all models except the PAA model, becomes a problem because it may skew some of the statistical tests. However, the parameter estimates are unaffected. The statistical tests are skewed because the estimators are "no longer minimum variance in biased estimators" (14:170). For example, smaller variances will cause us to accept the F-value and t-statistic tests of significance when in fact we should have rejected them (14:67-70, 84-90).

Also note the "jump" in the residuals (except in the PAA model) between FY80 and FY81. This may indicate two different populations of depot maintenance costs. Perhaps a change in depot maintenance methods or practices or a change in cost data collection has taken place. As more years of depot maintenance cost data are collected, this should be assessed. Deleting the first four years of data leaves only five years of data for analysis, so no change to the data base is made for this research.

The remaining residuals analysis examines the possibility of outliers. As discussed in Chapter III, the studentized and studentized deleted (rstudent) residuals are used to determine if outliers exist with respect to the dependent variable. The studentized residuals are calculated the same as student residuals, except the particular observation the rstudent is being calculated for is omitted. These two calculations are compared with a t-statistic to determine if the observation may be an outlier (14:404-406). In this study the t-statistic is calculated at 95 percent confidence. For the one independent variable model the t-statistic is 1.943. For the two independent variables model the t-statistic is 1.895. Notice in Tables 6 through 9 all calculated studentized and rstudent residuals are within the t-statistic determined above.

The leverage value measures the distance between the independent variable values of an observation and the center of all the observations. Recall that leverage values are used to determine if there are outliers with respect to the independent variables. The rule of thumb is to compare the calculated leverage values with two times the number of parameters in the model divided by the number of observations (13:402-403). In this study the calculated leverage values of the models with one independent variable (thus two parameters since the intercept is a parameter to be estimated) is .4444. The two independent variables models will compare the calculated leverage values with .6667. All values in Tables 6 through 9 are within this rule of thumb.

The cooks distance measure (cooksd) is used to determine whether or not outliers identified by the student, rstudent and leverage values are "influential in affecting the fit of the regression function" (14:407). It measures the overall impact of a particular observation to the regression line. Recall from Chapter III a percentage greater than 50 percent indicates strong influence, and under 20 percent indicates a small impact. In Tables 8 and 9, the cooksd statistics are above 50 percent for FY79 and FY80. However, the studentized, rstudent and leverage values are all very small, indicating these two years are not outliers, yet influential in the regression function.

In summary, analysis of the residuals indicates an increasing variance in all models except the PAA model. This increasing variance may cause some of the statistical tests to be skewed; however, the coefficients will still be unbiased estimators. Also, no outliers appear to be found in the data set.

TABLE 6

RESIDUAL ANALYSIS FOR MODEL USING INDEPENDENT VARIABLE FH

FY	Residual	Student Residual	Rstudent Residual	Cooksd Stat	Leverage
77	- 512,426	- .023	- .021	.000	.3551
78	3,430,896	.135	.126	.002	.1850
79	4,559,062	.179	.166	.004	.1810
80	7,976,088	.326	.305	.178	.2502
81	-39,586,657	-1.494	-1.675	.150	.1182
82	-28,293,149	-1.094	-1.113	.115	.1608
83	35,296,523	1.385	1.504	.216	.1842
84	37,885,549	1.553	1.776	.409	.2530
85	-20,755,887	- .887	- .872	.179	.3125

TABLE 7

RESIDUAL ANALYSIS FOR MODEL USING INDEPENDENT VARIABLE PAA

FY	Residual	Student Residual	Rstudent Residual	Cooksd Stat	Leverage
77	-39,568,497	-1.063	-1.074	.170	.2309
78	14,680,710	.394	.369	.023	.2309
79	48,215,184	1.412	1.546	.545	.3534
80	-46,251,403	-1.169	-1.207	.104	.1318
81	-22,199,023	- .555	- .525	.019	.1112
82	-22,114,318	- .567	- .537	.030	.1554
83	48,699,146	1.254	1.318	.153	.1628
84	46,989,096	1.272	1.343	.259	.2424
85	-28,450,895	- .852	- .833	.224	.3812

TABLE 8

RESIDUAL ANALYSIS FOR MODEL USING INDEPENDENT VARIABLES FH AND PAA

FY	Residual	Student Residual	Rstudent Residual	Cooksd Stat	Leverage
77	- 742,634	- .033	- .030	.000	.4450
78	3,624,046	.137	.125	.002	.2482
79	5,066,527	.269	.247	.039	.6179
80	7,560,610	.367	.339	.053	.5430
81	39,442,639	-1.406	-1.568	.119	.1534
82	28,301,052	-1.013	-1.016	.066	.1609
83	35,344,613	1.287	1.381	.128	.1881
84	37,859,065	1.438	1.622	.235	.2542
85	-20,968,536	- .880	- .861	.165	.3892

TABLE 9

RESIDUAL ANALYSIS FOR MODEL USING INDEPENDENT VARIABLES AVFH AND PAA

FY	Residual	Student Residual	Rstudent Residual	Cooksd Stat	Leverage
77	- 123,069	- .005	- .005	.000	.4535
78	3,785,978	.143	.130	.002	.2487
79	4,863,741	.258	.237	.037	.6223
80	6,661,223	.318	.293	.038	.5324
81	-39,417,790	-1.399	-1.556	.118	.1536
82	-28,401,060	-1.013	-1.015	.066	.1611
83	35,616,739	1.290	1.385	.128	.1873
84	38,265,039	1.446	1.635	.236	.2533
85	-21,250,801	- .888	- .869	.167	.3887

Summary of the Cargo Fleet Analysis. The independent variable, flying hours, appears to be the sole significant variable. Yet, the ground rules of this investigation state a need for appropriate allocations of depot maintenance cost to flying hours and PAA. The results lead to further investigation in the use of a technique that works with multicollinearity. In this study ridge regression is used. Before explaining the ridge regression analysis, an examination of the depot maintenance costs by WBS breakout is made.

Analysis of Cargo Fleet Common WBS Data Set

General Discussion. The WBS analysis uses the same fleet common aircraft data set as in the previous section. However, for this analysis cargo data is sorted and summed by the WBS categories: aircraft accessories (AA), armament (AR), engine accessories (EA), avionics communication (VC), avionics instrumentation (AI), and avionics navigation (VN). In addition, the two WBS categories, aircraft overhaul (AF) and engine overhaul (EO), found in the type 3 records data base are examined. The independent variables, flying hours, PAA, and AVFH (flying hours per PAA), remain the same. Table 10 contains the total depot maintenance costs by WBS.

<u>Plots and Regression Analysis</u>. The plots of the WBS data (in the same format as the plots of the fleet data) show mixed results. These plots are in Appendix G. The WBS categories, AA, AF, EA and VC, are the only categories that show possible linear relationships for the independent variables, flying hours and PAA. The remaining WBS categories show random scatter for all independent variables.

The regression analysis results show strong relationships in only the WBS categories: aircraft accessories (AA), aircraft overhaul (AF), and engine accessories (EA). The results of the regressions are in Tables 11 through 18, found at the end of the following discussion. These tables follow the same format as Table 4.

Three WBS categories, aircraft accessories (AA), engine accessories (EA), and avionics navigation (VN), have a large number of repair quantities and the highest depot maintenance costs in the group (refer to Table 10).

TABLE 10

CARGO FLEET COMMON WBS COST SUMMARY

(FY85 Dollars)

FY	AA	AR	EA	VC
77	70,886,352	0	74,160,374	2,420,210
78	111,491,264	78,627	85,872,224	2,457,179
79	107,772,843	27,041	96,244,726	1,715,963
80	90,534,821	65,866	94,651,589	1,264,036
81	125,737,976	30,868	114,664,375	1,676,317
82	140,708,357	66,600	137,275,055	3,046,998
83	172,721,175	17,072	178,861,451	2,432,982
84	191,719,801	102,094	185,147,594	3,417,532
85	183,813,885	31,003	157,406,928	3,249,247

FY	VI	VN	AF	EO
77	1,939,892	16,910,099	176,928,880	49,937,074
78	3,725,213	16,941,627	222,473,080	33,487,192
79	3,313,896	14,287,327	202,810,297	31,703,399
80	2,822,155	12,856,986	277,490,889	27,551,754
81	2,094,002	13,965,368	352,988,392	35,561,475
82	3,167,931	16,550,102	423,810,280	53,309,247
83	3,433,779	17,708,834	429,481,143	75,439,561
84	3,587,015	17,865,494	574,532,858	38,059,510
85	2,738,124	12,263,688	556,322,311	37,110,580

Yet, AA and EA appear to be the driving force in the relationships found in the cargo fleet common aircraft data set, as discussed in the previous section. (The overhaul categories, AF and EO, are excluded in the fleet analysis.) The depot maintenance costs for both aircraft accessories and engine accessories show strong relationships to flying hours, as shown by the R^2 values in Tables 11 and 12. (VN shows no relationship at all with R^2s of less than .05.) PAA alone also shows a strong relationship with depot maintenance costs for these WBSs, but it is not as strong as flying hours. However, when both PAA and flying hours are used in the regression model, PAA is insignificant, as it is with the fleet common data base. This insignificance is probably due to the multicollinearity of flying hours and PAA.

Interestingly, aircraft accessories show a stronger relationship to flying hours than engine accessories, which conflicts with the allocation factors currently used. Currently, depot maintenance cost factors for aircraft accessories are based on a 65 percent flying hours/35 percent PAA ratio. Depot maintenance cost factors for engine accessories are currently allocated 100 percent to flying hours.

The WBS category, avionics communication (VC), exhibits weak relationships between depot maintenance costs and FH, PAA, and AVFH (refer to Table 13). The remaining

WBS categories, armament (AR), avionics instrumentation (VI), and avionics navigation (VN), show no relationships between costs and either FH, PAA, or AVFH (refer to Tables 14 through 16). As can be seen from Table 10, the depot maintenance costs for these WBS categories appear to be more cyclic than linear. This can be due to the quantities repaired in batches. As mentioned in Chapter III (ground rule #6), the costs for some items repaired in batches are collected in the year of the repair. This may cause depot maintenance costs to be higher in one year and lower in the next year. Another possible reason for this lack of relationship may stem from the missing items due to using the fleet common data base. As discussed in Chapter III (ground rule #7), the fleet common data base excludes all items common to more than one mission. Several items in these WBS categories may be common items to other aircraft missions and are absent from the fleet common data base. For example, if a navigational item is used on the C-135 and the B-52, then the depot maintenance costs for that item are not in this data base. The complete data base (as described in Chapter III) must be used for examining all items in each WBS. Time constraints prevent this study from further analysis using the complete data base.

The WBS category, aircraft overhauls (AF), is the only category that shows a strong relationship to PAA alone (refer to Table 17). The R^2 is .95. The F-value of 116.98

is the highest seen in this analysis. Yet, the relationship of depot maintenance costs to flying hours is also strong with an R^2 of .91 and an F-value of 69.53. The combined, flying hours and PAA, model loses significance when compared to the PAA model above. In this combined model, the flying hours variable becomes slightly insignificant with a t-statistic of 1.78. Thus the probability of its coefficient being zero is 12.5 percent. The significance of PAA in this category supports the current method for developing depot maintenance cost factors, which is to allocate 100 percent of depot maintenance costs to PAA.

The lack of any relationships found in the WBS category engine overhauls (EO) is surprising because engine overhauls are scheduled on an operating hour basis (refer to Table 18). As can be seen by the F-value and its associated probability, there are no significant models. The best model is the one using flying hours as the independent variable and there is a 39 percent chance no relationship exists between flying hours and engine overhaul costs. This lack of a relationship may be due in part to engines being scheduled for overhaul based on operating hours vice flying hours. The lack of relationship may also be due to overhauls actually being performed in a different year than the one in which they are pulled for overhaul. The costs would be reported in the year of the overhaul, not in the year of removal from the aircraft. Finally, the lack of a relationship may be due to misspecification of the model. The relationship may be other than linear or other independent variables, such as a "lagged" variable reflecting the time delay in accomplishing overhauls, may be needed. Because of this lack of relationship, engine overhauls are not further examined in this study.

Due to time constraints, further analysis of the WBS data base is not accomplished. Specifically, the residuals have not been examined for the WBS categories, aircraft accessories, and engine accessories. Also, the WBS categories, in entirety, should be analyzed for possible relationships. Perhaps relationships exist across the WBS in which the data is not skewed by the allocations by flying hours and PAA to the MDSs.

Summary of Cargo Fleet WBS Analysis. Only the depot maintenance costs in WBS categories — aircraft accessories, engine accessories, and aircraft overhauls — show a relationship to any of the independent variables. Aircraft accessories and engine accessories show a strong relationship to flying hours only. Likewise, aircraft overhauls exhibit a stronger relationship to PAA alone. The task of finding appropriate allocations of depot maintenance costs to flying hours and PAA is not solved. The problem of multicollinearity between flying hours and PAA still exists

TABLE 11

AIRCRAFT ACCESSORIES REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.93	87.74	.0001	9.37	.0001
PAA	.77	23.73	.0018	4.87	.0018
AVFH	.53	7.82	.0267	2.80	.0267
FH	.93	38.37	.0004	3.59	.0116
& PAA				- .34	.7472
AVFH	.93	38.11	.0004	3.57	.0118
& PAA				5.73	.0012

TABLE 12

ENGINE ACCESSORIES REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.86	41.84	.0003	6.47	.0003
PAA	.78	24.18	.0017	4.92	.0017
AVFH	.40	4.68	.0673	2.16	.0673
FH	.86	18.46	.0027	1.91	.1052
& PAA				.39	.7116
AVFH	.86	18.34	.0028	1.89	.1073
& PAA				4.43	.0044

TABLE 13

AVIONICS COMMUNICATION REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.46	6.01	.0440	2.45	.0440
PAA	.45	5.79	.0471	2.41	.0471
AVFH	.17	1.43	.2710	1.20	.2710
FH	.47	2.71	.1449	.50	.6331
& PAA				.38	.7145
AVFH	.47	2.69	.1465	.48	.6488
& PAA				1.86	.1125

TABLE 14

ARMAMENT REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.004	.03	.8753	-.16	.8753
PAA	.002	.01	.9207	.10	.9207
AVFH	.07	.46	.5214	-.68	.5214
FH	.08	.23	.8060	-.66	.5362
& PAA				.65	.5427
AVFH	.09	.23	.7995	-.68	.5284
& PAA				.28	.7936

TABLE 15

AVIONICS INSTRUMENTATION REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.08	.57	.4759	.75	.4759
PAA	.01	.08	.7864	.28	.7864
AVFH	.22	2.02	.1988	1.42	.1988
FH	.23	.91	.4530	1.31	.2371
& PAA				-1.11	.3105
AVFH	.23	.92	.4496	1.32	.2347
& PAA				- .29	.7843

TABLE 16

AVIONICS NAVIGATION REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.01	.02	.8801	.16	.8801
PAA	.00	.003	.9583	-.05	.9583
AVFH	.03	.21	.6606	.46	.6606
FH	.04	.14	.8737	.52	.6197
& PAA				-.50	.6321
AVFH	.04	.12	.8862	.49	.6390
& PAA				-.25	.8080

TABLE 17

AIRCRAFT OVERHAUL REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.91	69.53	.0001	8.34	.0001
PAA	.95	116.98	.0001	10.82	.0001
AVFH	.29	2.81	.1377	1.68	.1377
FH	.96	78.19	.0001	1.78	.1254
& PAA				2.98	.0248
AVFH	.96	78.26	.0001	1.78	.1250
& PAA				10.49	.0001

TABLE 18

ENGINE OVERHAUL REGRESSION STATISTICS

Independent Variable	R^2	F-Value	Prob > F	T-Stat	Prob > T
FH	.11	.85	.3880	.92	.3880
PAA	.10	.78	.4077	.88	.4077
AVFH	.05	.33	.5825	.58	.5825
FH	.11	.37	.7077	.25	.8129
& PAA				.08	.9412
AVFH	.11	.36	.7109	.23	.8266
& PAA				.65	.5416

and affects the model using both flying hours and PAA. The next section will address a technique for using models with multicollinearity — ridge regression. The cargo fleet common data base (excluding overhauls) and the aircraft overhaul data base are used for further analysis.

Ridge Regression Analysis

General Discussion. Recall that a ridge regression analysis is a technique used when it is suspected that collinearity is present between two or more independent variables. This technique allows the use of both independent variables in the model when in fact each variable may be a significant depot maintenance cost driver. As explained in Chapter III, ridge regression introduces bias into the estimates of the population parameter, i.e., b_1 and b_2. When bias is introduced into the estimates of the parameters, the estimates are no longer equal to the population parameters. Yet, the variances are reduced as bias is introduced. There is a point where the variance reductions become insignificant as more bias is introduced. This point is a judgement call based on the analyst's evaluation of the variance reduction. Figures 6 and 7 show the change in the beta coefficients as more "bias" is introduced into the cargo fleet data set regression and the aircraft overhaul data regression. Notice the two variables, flying hours and PAA, are moving towards each other as more bias is introduced. If these variables

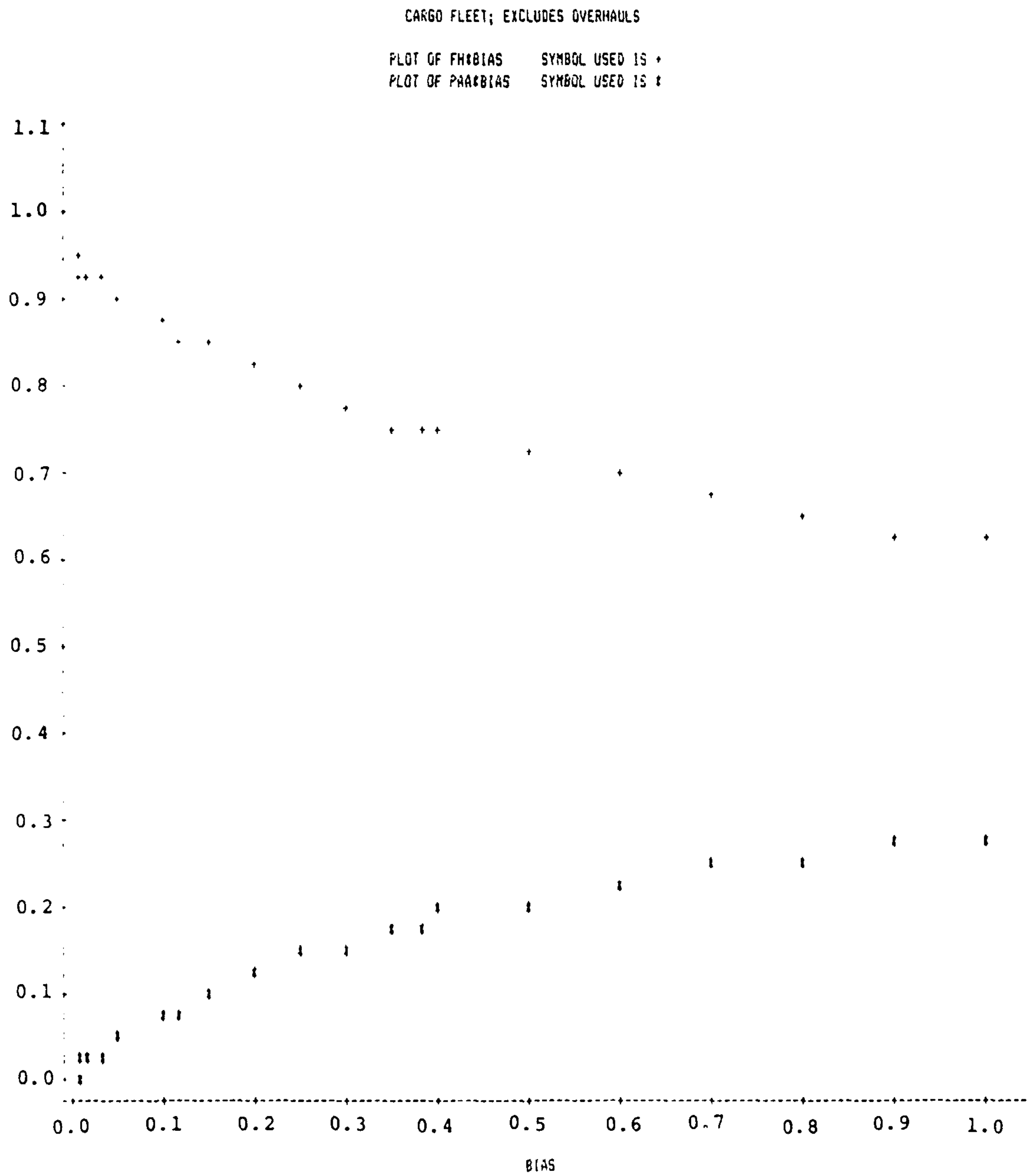


Figure 6. Plot of Coefficients as Bias is Introduced into the Model for Cargo Fleet

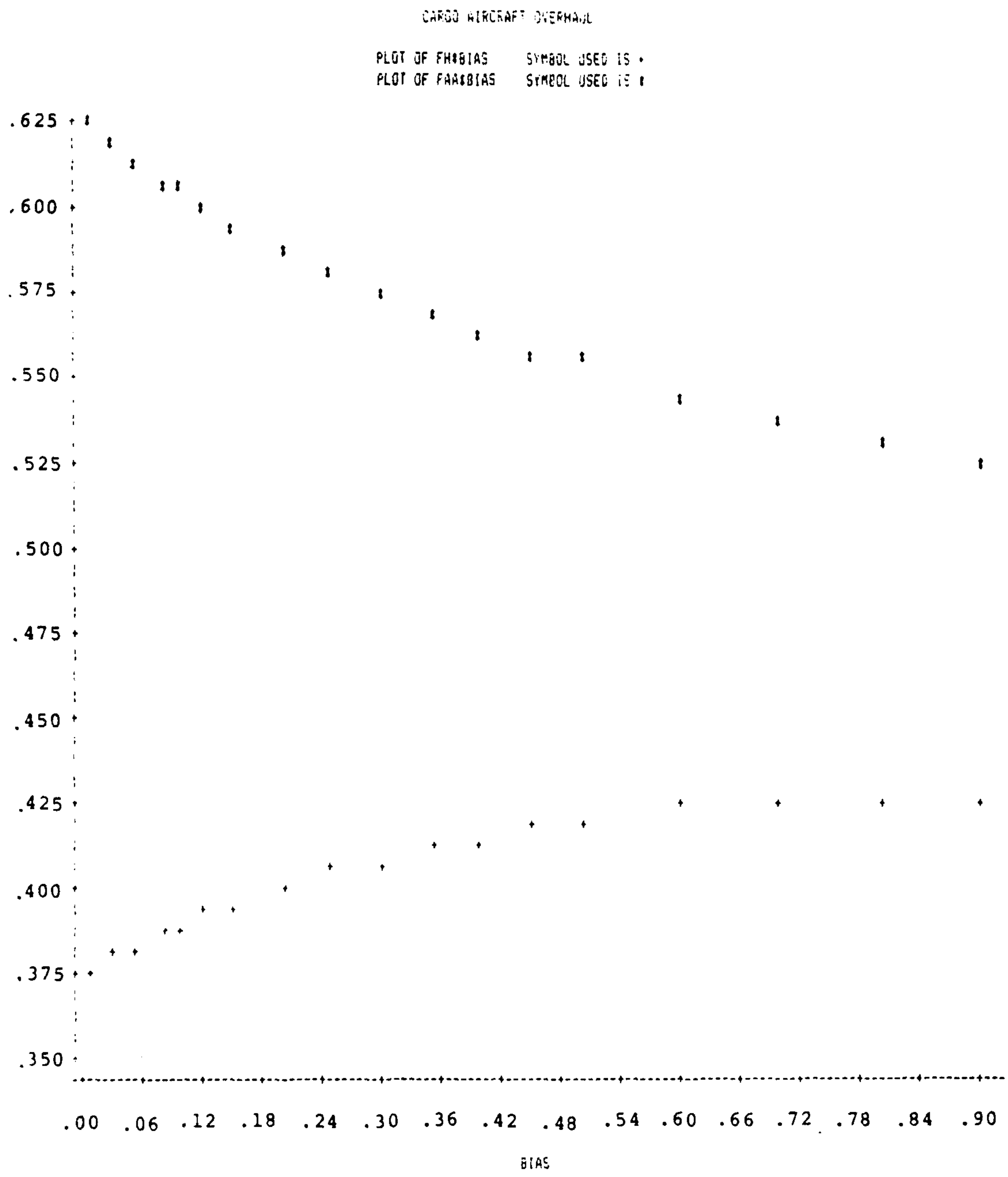


Figure 7. Plot of Coefficients as Bias is Introduced into the Model for Aircraft Overhaul

are not related, i.e., little or no collinearity is present, then the plots of the coefficients would show little change. The points where the plots start to level (again, an analyst's judgement call) are the amount of bias to ideally enter into the model (13).

Two sets of ridge regression are accomplished for this study. One uses the cargo fleet common data which includes all WBS categories except overhauls. The second uses the aircraft overhaul data from type 3 records. Engine overhauls are not examined due to the lack of any relationship in depot maintenance costs to either flying hours or PAA. The combined, flying hours and PAA, model is used for this ridge regression.

Ridge Regression of the Cargo Fleet Data. In the cargo fleet summary, the plots start to level near the introduction of a bias of .35 (refer to Figure 6). The beta coefficients for the model regressed with a .35 bias introduced are: FH = .7575748 and PAA = .1753938. To convert these beta coefficients back for use in the combined flying hours and PAA model, they are multiplied by the standard error of the estimate and divided by the standard error of the variable. Table 19 contains the descriptive statistics and regression coefficients for the cargo fleet common data base.

TABLE 19

SIMPLE STATISTICS AND REGRESSION COEFFICIENTS FOR CARGO FLEET COMMON SUMMARY

(Excludes Overhauls)

Var	Mean	Std. Dev.	FH & PAA Model Coefficient	Beta Coefficient .35 Bias	Converted Coefficient
Cost	278,660,217	84,287,663	-	-	-
FH	995,869	47,572	1,668.48	.7575748	1,342.27
PAA	1,761	63	11,549.31	.1753938	235,069.69

The results of the ridge regression performed on the cargo fleet common data set show PAA to be more significant than it is in the original unbiased regression. The PAA coefficient is 11,549.31 in the unbiased regression, then it increases to 235,069.69 after using the ridge regression. Likewise, the flying hours coefficient is 1,668.48 in the unbiased regression and drops to 1,342.27 after using ridge regression. Ridge regression has allowed the PAA independent variable to contribute more to the depot maintenance costs.

In terms of proportions of each other in contributing to the depot maintenance costs (i.e., ignoring the intercept value), flying hours contribute 99 percent in the original model and drop to 76 percent in the biased model.

Likewise, PAA contributes 1 percent in the original model and increases to 24 percent in the biased model. These percentages use the independent variables' means found in found in Table 19 and are calculated using the equations:

Original model:

$$\text{DM Cost} = 1,403,259,090 + 1,668.48\ \text{FH} + 11,549.31\ \text{PAA} \qquad [4]$$

Biased model:

$$\text{DM Cost} = 1,403,259,090 + 1,342.27\ \text{FH} + 235,069.69\ \text{PAA} \qquad [5]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

The mean flying hours is 995,869 and the mean PAA is 1,761. By substituting these values in equation [4], we get (rounded to the millions) for the original model:

$$\text{DM Cost} = -1,403.33\text{M} + 1,661.59\text{M} + 20.34\text{M}$$

Thus, flying hours contribute 1,661.59M to total depot maintenance costs and PAA contributes only 20.34M, for a total of 1,681.93M before subtracting the zero intercept. The percentages are calculated:

Flying Hours: 1,661.59 / 1,681.93 = 99%

PAA: 20.34 / 1,681.93 = 1%

The biased model calculations using equation [5] are as follows:

DM Cost = -1,403.33M + 1,336.73M + 413.96M

Thus, flying hours contribute 1,336.73M to total depot maintenance costs and PAA contributes 413.96M, for a total of 1,750.69M before subtracting the zero intercept. The percentages are calculated.

Flying Hours: 1,336.73 / 1,750.69 = 76%

PAA: 413.96 / 1,750.69 = 24%

Ridge Regression of the Cargo Aircraft Overhaul Data. The plots of the aircraft overhaul ridge regression data start to level near the introduction of a bias of .40 (refer to Figure 7). The beta coefficients for this model are: FH = .4145682 and PAA = .5631253. Table 20 contains the simple statistics and regression coefficients information for aircraft overhauls. Using ridge regression with an introduction of a bias of .40 causes the independent variable, flying hours, to become a more significant depot maintenance cost driver than it is in the original unbiased regression model. The flying hours coefficient in the original model is 1,169.80, then it increases to 1,297.71 in the biased model. PAA becomes a less significant depot maintenance cost driver in the biased model. Its coefficient drops from 1,479,392 to 1,333,493.

TABLE 20

SIMPLE STATISTICS AND REGRESSION COEFFICIENTS
FOR CARGO AIRCRAFT OVERHAULS

Var	Mean	Std. Dev.	FH & PAA Model Coefficient	Beta Coefficient .35 Bias	Converted Coefficient
Cost	35,742,645,849	1,489,130,520	-	-	-
FH	995,869	47,572	1,169.80	.4145682	1,297.71
PAA	1,761	63	14,793.92	.5631253	1,333,492.9

An interesting finding is that the proportions of flying hours and PAA in contributing to depot maintenance costs are 35 percent and 65 percent, respectively, in the biased model. These percentages use the independent variables' means found in the second column of Table 10 and are calculated using the same procedures followed for the fleet data with the following equation:

Biased model:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}297.71\ \text{FH} + 1{,}333{,}492.9\ \text{PAA} \tag{6}$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

This conflicts with the current allocation percentage for aircraft overhaul, which is considered to be 100 percent

PAA related (see Table 1, Chapter I). Also note that the proportion of flying hours to PAA in contributing to depot maintenance costs for the original unbiased model is 69 to 31. This is calculated using the equation:

Original model:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}169.80\ \text{FH} + 1{,}479{,}392\ \text{PAA} \qquad [7]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

Finally, this proportion does not change as much from the unbiased (original) model to the biased model as the cargo fleet data proportions. Apparently, the aircraft overhauls are not affected by the multicollinearity as much as the cargo fleet.

Summary of Ridge Analysis. Ridge regression has allowed the two independent variables to stay in the model, despite the multicollinearity. The new biased model for the cargo fleet is:

$$\text{DM Cost} = 1{,}403{,}259{,}090 + 1{,}342.27\ \text{FH} + 235{,}069.69\ \text{PAA} \qquad [5]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

The proportion of flying hours to PAA in terms of contributing to the cost is 76 to 24. However, the intercept is ignored in this proportion. The new biased model for aircraft overhaul is:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}297.71\ \text{FH} + 1{,}333{,}492.9\ \text{PAA} \quad [6]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

The proportion of flying hours to PAA (ignoring the intercept) in contributing to depot maintenance costs is 35 to 65.

Through ridge regression two models are available for use in estimating depot maintenance costs. However, the proportions that flying hours and PAA contribute to depot maintenance costs is still not solved. The calculated proportions above do not take the intercept into consideration. As can be seen, the intercepts have extremely large negative values. Further methods need to be investigated to determine the proportions of flying hours and PAA that contribute to depot maintenance costs. Two methods are addressed below. The first method is an attempt to force the intercept to zero. The second method explores a concept of "hunt and peck" by regressing various proportions of depot maintenance costs to see if one proportion has the better statistics or least squared error.

Forced Zero Intercept

The purpose of this study is to find appropriate allocations of depot maintenance costs to flying hours and PAA. The independent variable, flying hours, appears to be a significant explanatory variable for depot maintenance costs in the fleet cargo aircraft data set. Flying hours are also significant in two of the WBS categories, aircraft accessories and engine accessories. PAA appears to be a significant explanatory variable for the WBS category, aircraft overhauls. As discovered above, the ridge regression analysis allows both variables that are highly related to each other, flying hours and PAA, to be used in the model. Ridge regression introduces bias in the model, providing biased coefficients for both independent variables. Thus, both independent variables can be used in the model to determine the proportional contribution of each to depot maintenance costs.

One method to determine the proportion is to first solve the regression model for specific flying hours and PAA; then, calculate the proportion of the estimated depot maintenance costs that is attributed to flying hours and the proportion that is attributed to PAA. The problem with this method is that the Y-intercept cannot be apportioned to flying hours or to PAA. If the Y-intercept can be forced to zero, then this method could be usable. A forced zero intercept can only be performed if the intercept coefficient is found to be insignificant. This significance is tested via the t-test used earlier to determine the significance of the independent variables. In the cargo fleet common aircraft models the intercept is very significant (refer to Table 21). Also notice the large intercept coefficients. These large coefficients are probably due to the large number of flying hours and PAA which do not vary much. The intercept may be compensating for this lack of variance.

TABLE 21

Y-INTERCEPT STATISTICS

Independent Variable	Intercept Coefficient	T-Stat	Prob > T
FH	-1,397,027,934	-6.68	.0003
PAA	-1,802,777,689	-4.29	.0036
AVFH	-2,605,153,369	-2.27	.0574
FH & PAA	-1,403,259,090	-4.19	.0058
AVFH & PAA	-3,037,323,596	-5.58	.0014

Forcing the intercept to zero would alter the regression equation considerably, thus losing the true relationships and the model significance. As depicted in Figure 8, a forced intercept model can only be used for a specific range of flying hours and PAA. This range

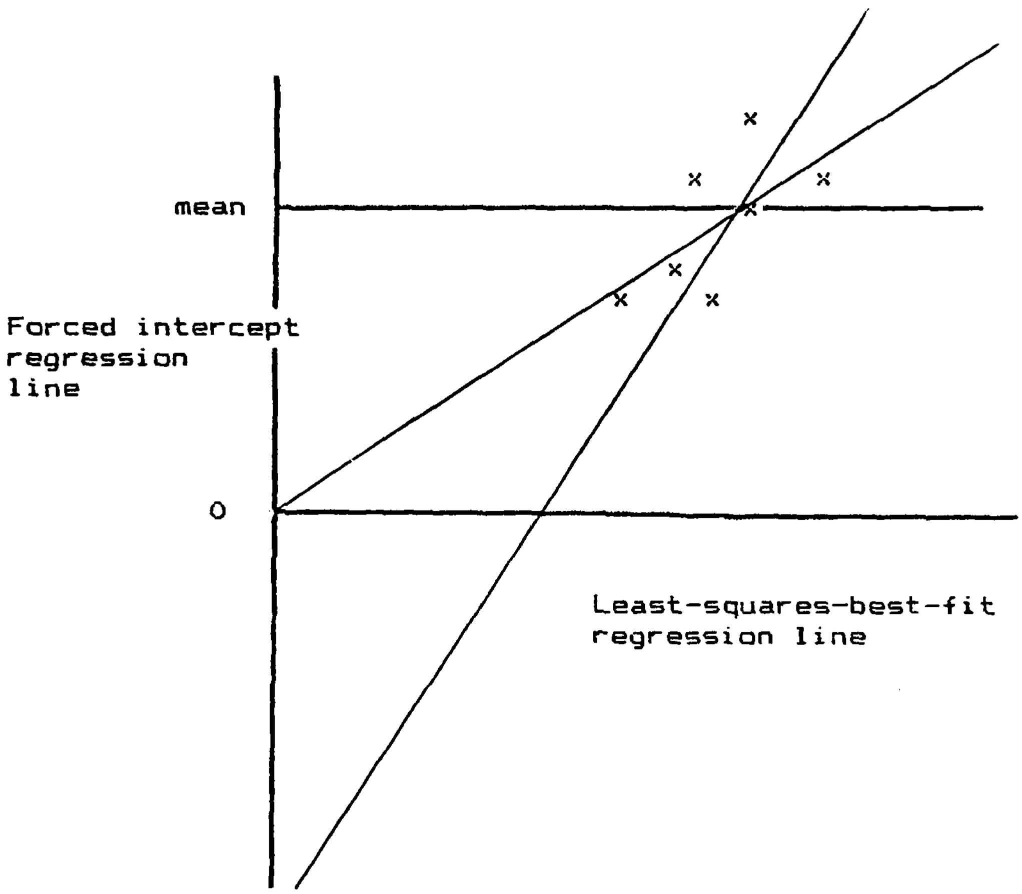


Figure 8. Example of the Skewness in Forcing a Zero Intercept

would be near the mean of the dependent variable, depot maintenance costs, where the two regression lines will intersect. In following this theory, an equation can be developed to determine the range of flying hours and PAA in which the developed proportions would apply. This appears to be a viable solution. However, the forced intercept model results in a negative PAA coefficient of -1,407,115 (see Table 22). This negative coefficient implies the depot maintenance costs go down as PAA increases. In actuality, the PAA independent variable is probably compensating for the large, negative intercept coefficient.

TABLE 22

REGRESSION COEFFICIENTS FOR CARGO FLEET COMMON AIRCRAFT WITH FORCED ZERO INTERCEPT

Variable	Coefficient
FH	2,768.70
PAA	-1,407,115

In summary, an attempt to apportion the depot maintenance costs by forcing a zero intercept and determining the proportion of the cost attributed by flying hours and that portion attributed by PAA will not work. The negative PAA coefficient obtained when the intercept is forced to zero implies depot maintenance costs decrease as

AD-A174 443 A STUDY OF THE AIR FORCE DEPOT MAINTENANCE COST ALLOCATION FOR COST FACTO..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST.. P M LARSON 2/2

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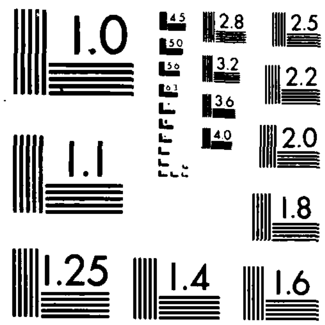


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

PAA increases, while depot maintenance costs increase as flying hours increase. Another attempt to apportion the costs must be made.

Alternating the Proportions of Depot Maintenance Costs

A second method to determine the proportion of depot maintenance costs attributed to flying hours and the proportion attributed to PAA is to "hunt and peck." As discussed in Chapter III, this procedure regresses various proportions of depot maintenance costs against flying hours and PAA, separately, to see if one proportion has better statistics or the least squared error.

The results of this method reveal the statistics do not change. Every R^2, F-value, and t-statistic is the same. However, the coefficients, the sum of the squared errors, and the parameter standard deviations do change. Least-squares-best-fit regression analysis minimizes the sum of the unexplained squared error (SSE). This proposed method uses the same premise of finding a combination of flying hours and PAA where the combined SSE is the least. The results of this procedure are in Tables 23 and 24. For the cargo fleet data set, the minimum SSE occurs at the 69 percent flying hours/31 percent PAA mix. Recall, the ridge regression results in a flying hours to PAA ratio of 76 to 24.

The aircraft overhaul minimum SSE occurs at 38 percent flying hours/62 percent PAA (see Table 23). This ratio

TABLE 23

REGRESSION RESULTS OF DEPOT
MAINTENANCE PROPORTIONED COSTS
CARGO FLEET SUMMARY

Independent Variable	Proportion of DM Cost	SSE[1] ($ in Trillions)	Total SSE[1] ($ in Trillions)
FH	.25	348.50	
PAA	.75	7,096.48	7,444.98
FH	.50	1,394.00	
PAA	.50	3,153.99	4,547.99
FH	.60	2,007.36	
PAA	.40	2,018.55	4,025.91
FH	.65	2,355.86	
PAA	.35	1,545.46	3,891.32
FH	.68	2,578.35	
PAA	.32	1,291.87	3,870.22
FH	.69	2,654.74	
PAA	.31	1,212.39	3,867.13*
FH	.70	2,732.24	
PAA	.30	1,135.44	3,867.68
FH	.75	3,136.50	
PAA	.25	788.50	3,925.00
FH	.80	3,568.65	
PAA	.20	504.64	4,073.29
FH	.90	4,516.57	
PAA	.10	126.16	4,642.73

[1] SSE = sum of the unexplained squared error

* The least combined unexplained error

TABLE 24

REGRESSION RESULTS OF DEPOT MAINTENANCE PROPORTIONED COSTS AIRCRAFT OVERHAULS

Independent Variable	Proportion of DM Cost	SSE[1] ($ in Trillions)	Total SSE[1] ($ in Trillions)
FH	.25	1,014.20	
PAA	.75	5,633.91	6,648.11
FH	.35	1,987.82	
PAA	.65	4,231.69	6,219.51
FH	.37	2,221.50	
PAA	.63	3,975.29	6,196.70
FH	.38	2,343.20	
PAA	.62	3,850.09	6,193.29*
FH	.39	2,468.15	
PAA	.61	3,726.89	6,195.04
FH	.40	2,596.34	
PAA	.60	3,605.70	6,202.04
FH	.50	4,056.78	
PAA	.50	2,503.96	6,560.74
FH	.60	5,841.72	
PAA	.40	1,602.53	7,444.25
FH	.80	10,385.40	
PAA	.20	400.63	10,786.03

[1] SSE = sum of the unexplained squared error

* The least combined unexplained error

comes closer to the ridge regression ratio of 35 percent flying hours to 65 percent PAA. These slight differences in the proportions determined between the two methods may be attributed to the analyst's judgement call in choosing the bias introduced in the ridge regressions.

In summary, the "hunt and peck" method provides a means to allocate depot maintenance costs to flying hours and PAA. It is interesting to note the proportions of flying hours and PAA to each other in the ridge regression provide similar results to the "hunt and peck" method. Through the ridge regression technique a model for estimating depot maintenance costs is available. Through the "hunt and peck" method, the proportions flying hours and PAA contribute to depot maintenance costs for developing depot maintenance cost factors is available.

Summary

The analysis starts with an examination of the fleet cargo data set. The data is regressed and analyzed. The independent variable, flying hours, appears to be the sole significant variable. An analysis of the fleet cargo WBS data is then performed. Only three of the eight WBS categories show a relationship to any of the independent variables. Aircraft accessories and engine accessories appear to be related solely to flying hours. Likewise, aircraft overhauls exhibit a sole relationship to PAA.

It is realized these results may be due to the multicollinearity between flying hours and PAA, thus a technique for handling collinearity among the independent variables — ridge regression — is used to see if both flying hours and PAA can remain in the model. Performing ridge regression does allow both independent variables to remain in the models. The biased model for the fleet data set is:

$$\text{DM Cost} = 1{,}403{,}259{,}090 + 1{,}342.27\ \text{FH} + 235{,}069.69\ \text{PAA} \quad [5]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

The proportion of flying hours to PAA in terms of contributing to the cost is 76 to 24 (the intercept is ignored in this proportion). The new biased model for aircraft overhauls is:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}297.71\ \text{FH} + 1{,}333{,}492.9\ \text{PAA} \quad [6]$$

where

DM Cost = depot maintenance cost
FH = flying hours
PAA = primary aircraft authorized

The proportion of flying hours to PAA (ignoring the intercept) in contributing to depot maintenance costs is 35 to 65.

However, the task of finding the proportion of depot maintenance costs to flying hours and PAA is not completed with performing ridge regression, since the Y-intercept is ignored in computing these ratios from the ridge regression. Two methods are attempted. First, the Y-intercept is forced to zero. By forcing the intercept to zero, flying hours and PAA can be calculated and the proportions contributing to depot maintenance cost can be determined. However, the independent variable, PAA, has a negative coefficient in this regression. This negative coefficient implies depot maintenance costs decrease as PAA increases, thus this procedure does not appear to be viable.

The second method uses a "hunt and peck" approach. Under this approach, various proportions of depot maintenance costs are regressed against flying hours and PAA, separately. The proportional mix with the summed least squared error is chosen as the best proportion. The summed least squared error occurs at the 76 percent flying hours and 24 percent PAA mix for the fleet data set and at 35 percent flying hours and 65 percent PAA for the aircraft overhaul data set.

Chapter V will present the results and recommendations of this study.

V. Conclusions and Recommendations

Overview

This chapter presents the findings, limitations, and conclusions of this study, which are supported by Chapter IV, Analysis. Recommendations for further study follow the conclusions.

Conclusions

The purpose of this study is to find the proportion of depot maintenance costs for cargo aircraft that are flying hours related and the proportion that are inventory (PAA) related. These depot maintenance costs' proportions are used in Air Force cost factor development. According to OSD Cost Analysis Improvement Group and USAF/ACC guidance, depot maintenance cost factors must be compatible with the programming and budgeting process. Thus, the factors must be related to flying hours and PAA for incrementing or decrementing the budget. From discussions with AFLC/ACC personnel and the results of four depot maintenance costs studies, it is recognized that other factors may affect depot maintenance costs; however, these are not examined in this study.

Limitations. Due to time constraints, this study is limited to cargo aircraft. Nine years of data (FY77 through FY85) is extracted from the AFLC Weapon System Cost

Retrieval System (WSCRS) data base. Thus, this study is confined to the limitations of WSCRS, as outlined in Chapter III.

A consolidated data base is prepared for this study using the WSCRS data. WSCRS data is extracted from as low as the Federal Stock Class (FSC) level. However, due to time constraints, only data as low as the work breakdown structure (WBS) is examined. A cursory review of the Federal Stock Group (FSG) level indicates cost data at this level may not be available for all nine years of this study, thus inadequate for analysis.

The results outlined below are limited to the use of the cargo fleet common data base, as outlined in Chapter III. This fleet data includes cost data for items only common across the fleet. It excludes items common to more than one fleet. For example, an avionics item used in cargo aircraft and in bombers is excluded. If the avionics item is used on a C-141 and C-5, it is included. A data base which includes all items is created and available through this study.

The two independent variables for this study are flying hours and primary aircraft authorized (PAA). As shown in the statistical analysis of model [4], inherent in using these two variables is a linear relationship between them. If the number of aircraft authorized is increased, the flying hours will probably be increased to accommodate the additional authorization. This problem, known as multicollinearity, is handled in this study through the use of a technique called ridge regression. This technique allows the use of both independent variables in the model when in fact each variable may be a significant depot maintenance cost driver.

<u>Results</u>. Models for estimating cargo fleet depot maintenance costs, and aircraft and engine overhauls depot maintenance costs are developed using ordinary least-squares regression analysis.

In the cargo fleet model, the independent variable, flying hours, appears to be the sole significant variable. The original model for estimating cargo fleet common depot maintenance costs, excluding overhauls, is:

$$\text{DM Cost} = 1{,}403{,}259{,}090 + 1{,}668.48\ \text{FH} + 11{,}549.31\ \text{PAA} \tag{4}$$

where

DM Cost = depot maintenance costs for cargo aircraft, excluding overhauls
FH = flying hours
PAA = primary aircraft authorized

This model includes the WBS categories: aircraft accessories, engine accessories, armament, avionics communication, avionics instrumentation, and avionics navigation. Two WBS categories, aircraft overhaul and engine overhaul, are excluded. Individual models for the six WBS categories are not developed due to time constraints. However, in examining these WBS categories separately, only aircraft accessories and engine accessories show linear relationships to either flying hours and PAA. The other WBS categories show little or no linear relationships to either flying hours or PAA. The depot maintenance cost relationships to flying hours and PAA found in the fleet common data (used in the model above) are clearly driven by two WBS categories, aircraft accessories and engine accessories.

In the aircraft overhauls model, PAA alone appears to exhibit a stronger relationship than flying hours or the combined flying hours/PAA model to depot maintenance costs. The remaining WBS category, engine overhauls, shows no linear relationship to either flying hours or PAA. Thus, a model for estimating engine overhauls is not developed. The original model for estimating cargo aircraft overhauls is:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}169.80 \text{ FH} + 1{,}479{,}392 \text{ PAA} \quad [7]$$

where

DM Cost = depot maintenance costs for cargo aircraft, excluding overhauls
FH = flying hours
PAA = primary aircraft authorized

In the analysis of these models, the collinearity between flying hours and PAA is examined and is found to be a problem. The problem of multicollinearity between flying hours and PAA exists and affects the model using both flying hours and PAA. Yet, the purpose of this investigation is to find appropriate allocations of depot maintenance costs to flying hours <u>and</u> PAA. Through ridge regression both independent variables, flying hours and PAA, become significant and remain in the model. The biased model for estimating cargo aircraft fleet is:

$$\text{DM Cost} = -1{,}403{,}259{,}090 + 1{,}342.27\ \text{FH} + 235{,}069.69\ \text{PAA} \qquad [5]$$

where

DM Cost = depot maintenance costs for cargo aircraft, excluding overhauls
FH = flying hours
PAA = primary aircraft authorized

Likewise, the biased model for estimating aircraft overhauls is:

$$\text{DM Cost} = -3{,}412{,}095{,}808 + 1{,}297.71\ \text{FH} + 1{,}333{,}492.9\ \text{PAA} \qquad [6]$$

These models are for estimating depot maintenance costs and do not provide proportions of depot maintenance costs to flying hours and PAA. Two methods are used to attempt to find these proportions, which are the objective of this research. The first method is to force the Y-intercept to zero. By forcing the intercept to zero, flying hours and PAA can be calculated and the proportions contributing to depot maintenance cost can be determined. However, the intercept term is found to be very significant in the model, and the independent variable, PAA, has a negative coefficient in this regression. This negative coefficient implies depot maintenance costs decrease as PAA increases, thus this procedure does not appear to be viable.

The second method uses a "hunt and peck" approach. Under this approach, various proportions of depot maintenance costs are regressed against flying hours and PAA, separately. The proportional mix with the summed least squared error is chosen as the best proportion. This method results in the following proportions:

For cargo aircraft, excluding overhauls:	69% flying hours
	31% PAA
For cargo aircraft overhauls:	38% flying hours
	62% PAA

These percentages are supported by the proportions found using equations [5] and [6] above. Using the means for both flying hours and PAA as inputs, the proportions of flying hours and PAA (of each other) are:

For cargo aircraft, excluding overhauls:	76% flying hours
	24% PAA
For cargo aircraft overhauls:	35% flying hours
	65% PAA

in the model, and the independent variable, PAA, has a negative coefficient in this regression. This negative coefficient implies depot maintenance costs decrease as PAA increases, thus this procedure does not appear to be viable.

The second method uses a "hunt and peck" approach. Under this approach, various proportions of depot maintenance costs are regressed against flying hours and PAA, separately. The proportional mix with the summed least squared error is chosen as the best proportion. This method results in the following proportions:

For cargo aircraft, excluding overhauls:	69% flying hours
	31% PAA
For cargo aircraft overhauls:	38% flying hours
	62% PAA

These percentages are supported by the proportions found using [5] and [6] above. Using the means for both flying hours and PAA as inputs, the proportions of flying hours and PAA (of each other) are:

For cargo aircraft, excluding overhauls:	76% flying hours
	24% PAA
For cargo aircraft overhauls:	35% flying hours
	65% PAA

Recommendations

Analysis of fleets other than cargo (e.g., attack, bomber, and fighter aircraft) needs to be accomplished. This study provides a consolidated data base of the WSCRS data base for use in further analysis of depot maintenance costs.

Five WBS categories do not show a relationship to either flying hours or PAA. This can be due to small quantities being fixed in batches, as mentioned in Chapter III (ground rule #6). Or this can be due to the exclusion of items used across the fleets (e.g., an avionics item used on cargo and bomber aircraft). These WBS categories need to be examined using the complete data base, thereby not excluding items used by more than one fleet. Also, these WBS categories can be examined without the breakout by fleet. Perhaps relationships exist across the WBS in which the data is not skewed by the allocations by flying hours and PAA to the MDSs. Another area to be examined is the possibility of relationships that are other than linear. This may be possible, given the increasing variances found in the residuals of all models, except the PAA alone model. Also, the patterns in the statistical results of the five attempted models for each WBS (found in Tables 11 through 18) should be examined for further model development.

Further analysis of true depot maintenance cost drivers, other than flying hours and PAA, should be accomplished. This study is limited to flying hours and PAA because of the need to build cost factors around the budget process. Perhaps other studies which investigate true depot maintenance cost drivers can build a case for "changing the way we do business." These studies should include investigating the use of not-reparable-this-station (NRTS) quantities, as discussed in Chapter III Also, these studies should consider the findings of previous studies, as outlined in Chapter III.

Closing Remarks

This study is a benchmark in the investigation of depot maintenance costs allocations to flying hours and PAA, yet it is only a starting point. Further studies must be accomplished to fulfill the requirement for more accurate depot maintenance cost factors.

Appendix A. Abbreviations

AF	Air Force
AFAFC	Air Force Accounting and Finance Center
AFLC	Air Force Logistics Command
AFR	Air Force Regulation
ALC	Air Logistics Center
AVFH	Average Flying Hours
CAIG	Cost Analysis Improvement Group
CER	Cost Estimating Relationship
CLS	Contractor Logistics Support
CSC	Classroom Support Computer
DOD	Department of Defense
DM	Depot Maintenance
FSC	Federal Stock Class
FSG	Federal Stock Group
FH	Flying Hours
FY	Fiscal Year
HQ	Headquarters
I&S	Interchangeable and Substitutable
ICS	Interim Contractor Support
MACO	Model for Estimating Aircraft Cost of Ownership
MD	Mission Design
MDS	Mission Design Series
NRTS	Not Reparable This Station
NSN	National Stock Number
O&M	Operating and Maintenance
O&S	Operating and Support
OSD	Office of the Secretary of Defense
PAA	Primary Aircraft Authorized
QPA	Quantity Per Application
RDB	Requirements Data Base
SAS	Statistical Analysis System
SE	Support Equipment
SSE	Sum of the Squared Error
TAI	Total Active Inventory
USAF	United States Air Force
WBS	Work Breakdown Structure
WPC	Work Performance Category
WSCRS	Weapon System Cost Retrieval System

Appendix B. Glossary

Backup Aircraft Authorization (BAA):

Aircraft over and above the primary authorized aircraft to permit scheduled and unscheduled maintenance, modifications, and inspections and repair without reduction of aircraft available for the operational mission. No operating resources are allocated for these aircraft in the defense budget. See also primary aircraft authorization (17).

Base Maintenance:

Organizational and intermediate maintenance performed below depot level. It includes contractors performing at this level but excludes depot level maintenance performed at base level (6:82).

Budget Factors:

The budget year operating and maintenance cost of each weapon system.

Class IV Modification:

A modification necessary to correct an equipment deficiency or installation deficiency that affects maintainability, reliability, or inflight safety (6:82).

Class V Modification:

A modification of a system or equipment that will provide:

1. A change in operational requirements or performance which provides an added capability not inherent in the baseline configuration.

2. The capability to accomplish an assigned mission that the basic system or equipment was not originally designed to accomplish.

3. A significant and measurable training or logistic improvement certified essential by the command or the agency primarily concerned (6:82).

Component:

Lowest subassembly located within an equipment (6:82).

Condemned:

The condition of an item or an assembly of items that makes it unsuitable for restoration to a serviceable condition or of no further value to the mission or the functions for which it was originally intended (6:82).

Constant-Year Dollars:

Dollars expressed in an arbitrary base year. The actual expenditures for a fiscal year are inflated or deflated as required to convert to base year equivalents (6:82).

Contract Maintenance:

Any maintenance performed under contract by commercial organizations (including original manufacturers) (6:82).

Contractor Logistics Support (CLS):

The provision of all or portions of organizational, intermediate, or depot maintenance required to support a system by a contractor (vice in-house maintenance) (6:82).

Cost Drivers:

Any process, function, or part which contributes significantly to the cost of a system or operation.

Depot:

An AFLC industrial type facility established to perform accessory overhaul functions or modifications and maintenance in support of field and using organizations. This includes AFLC assigned installations and commercial contractors who are engaged in performing depot level work on weapon systems or equipment under a contract issued and managed by AFLC. This term also includes AFLC depot or contractor field teams that are dispatched to Air Force operating bases or stations for accomplishing depot level work or providing assistance to field and organizational maintenance activities (6:82).

Depot Maintenance:

That maintenance which is the responsibility of and performed by designated maintenance activities, to augment stocks of serviceable material, and to support Organizational Maintenance and Intermediate Maintenance activities by the use of more extensive shop facilities, equipment and personnel of higher technical skill than are available at the lower levels of maintenance. Its phases normally consist of inspection, test, repair, modification, alterations, modernization, conversion, overhaul, reclamation or rebuilding of parts, assemblies, subassemblies, components, equipment end items and weapon systems; the manufacture of critical nonavailable parts; and providing technical assistance to intermediate maintenance organizations, using organizations, and other activities. Depot maintenance is normally done in fixed shops or by depot fields teams (6:82).

Depot Maintenance Cost Factors:

These factors reflect the depot maintenance cost per aircraft, per flying hours, and per missile. They include all the charges of the Depot Maintenance Industrial Fund, such as civilian labor, direct and indirect, overhead, expense material, and other Directorate of Maintenance overhead and contract cost (6:82).

Exchangeable Item:

Investment material such as pumps, electric motors, carburetors, and fuel controls. These items have a potential use of more than once and are economically reparable. These items are also commonly referred to as investment items, reparable items, recoverable items, or component items (6:83).

Intermediate Maintenance:

Base level maintenance which is the responsibility of and performed by designated maintenance activities to support using organizations. Its phases normally consist of calibration, repair or replacement of damaged or unserviceable parts, components or assemblies; the manufacture of critical nonavailable parts; and providing technical assistance to using organizations. Intermediate maintenance is normally accomplished in fixed or mobile shops, or by mobile teams (6:84).

Life Cycle Cost (LCC) Factors:

The average yearly cost of operating a weapon system over its lifespan.

Mission-Design-Series:

The nomenclature designation for both aircraft and missile weapon systems to indicate the prime intended mission, the sequence number of each design, and the series letter indicating significant changes to the logistics support (6:82).

Organizational Maintenance:

Base level maintenance which is the responsibility of and performed by a using organization on its assigned equipment. Its phases normally consist of inspecting, servicing, lubricating, adjusting, and the replacement of parts, minor assemblies, and subassemblies (6:84).

Overhaul:

The disassembly, test, and inspection of the operating components of the basic structure to determine and accomplish the necessary repair, rebuild, replacement, and servicing required to obtain the desired performance (6:84).

Primary Aircraft Authorized (PAA):

Aircraft authorized to a unit for performance of its operational mission. The primary authorization forms the basis for the allocations of operating resources to include manpower, support equipment and flying hour funds. See also backup aircraft authorization (6:84).

Programmed Depot Maintenance (PDM):

Maintenance performed on aircraft and end items on a regularly scheduled basis. PDM also includes nonprogrammed maintenance requirements identified when end items arrive at depot for PDM (6:84).

Reparable Items:

Refer to Exchangeable Item.

Weapon Systems:

Major defense systems such as aircraft, missiles, satellites, ships, tanks, etc.

Work Breakdown Structure (WBS):

Cost categories that define levels of the weapon system structure (6:85).

Work Performance Category (WPC):

One-position code that identifies the type of maintenance work performed (6:85).

Appendix C. Work Performance Categories (WPCs)

Code	Title
A	Overhaul
B	Progressive Maintenance
C	Conversion
D	Activation
E	Inactivation
F	Renovation
G	Analytical Rework
H	Modification
I	Repair
J	Inspection and Test
K	Manufacture
L	Reclamation
M	Storage
N	Technical Assistance
O	Not used
P	Programming and Planning Support
Q	Maintenance Technical and Engineering Support
R	Technical and Engineering Support
S	Technical and Administrative Training
T	Nonmaintenance Work
X	Contractor Logistics Support
Y	Interim Contractor Support

Source: AFLCM 173-264, WSCRS, Attachment 4, p. 88.

Appendix D. WSCRS Cost Elements Obtained from HO36B System

Direct Civilian Labor Cost
Other Direct Civilian Labor Cost
Direct Military Labor Cost
Other Direct Military Labor Cost
Funded Direct Material Cost
Unfunded Direct Material Cost - Investment Items
Unfunded Direct Material Cost - Exchangeable Items
Unfunded Direct Material Cost - Modification Items
Unfunded Direct Material Cost - Expense Items
Funded Other Direct Cost
Unfunded Other Direct Cost
Funded Operations Overhead Cost
Unfunded Operations Overhead Cost
Funded General and Administrative Cost
Unfunded General and Administrative Cost
Contractor/Inservice Cost
Government-Furnished Material - Investment Item
Government-Furnished Material - Exchangeable Item
Government-Furnished Material - Modification Item
Government-Furnished Material - Expense Item
Funded Government-Furnished Services
Unfunded Government-Furnished Services
Funded Organic Maintenance Support Cost
Unfunded Organic Maintenance Support Cost
Condemnation Cost
Contractor Logistics Support Cost
Interim Contractor Support Cost
Direct Civilian Labor Hours
Other Direct Civilian Labor Hours
Direct Military Labor Hours
Other Direct Military Labor Hours

Source: AFLCM 173-264, WSCRS, p. 6.

Appendix E. WSCRS: Other Elements in the Detailed Records

Data Element Name	AFLC System Source
Fiscal Year	HO36B
ALC Site Code	HO36B/DO41A
National Stock Number (NSN)	DO41A
NSN Quantity Per Application (QPA)	DO41A
NSN Percent on Application	
Standard Mission, Design, Series (MDS)	GO33J
Application	GO33J
Application Quantity Per Application on MDS	GO33J
Percent Application on the MDS	GO33J
NSN Operating Hours	GO33J/DO41A
NSN Inventory Months	GO33J/DO41A
NSN Nomenclature	DO41A
NSN Unit Price	DO41A
NSN Base Condemnations	DO41A
NSN Depot Condemnations	DO41A
Weapon System Code	HO36B
Work Breakdown Structure (WBS) Code	HO36B
WBS Group Code	HO36C
Work Performance Category	HO36B
Work Unit Code	HO36C
MDS Flying Hours	GO33J
MDS Inventory Months	GO33J
Production Quantity Completed	HO36B
Average Cost to Repair Rate	HO36C
Depot Maintenance Repair Rate	HO36C
Depot Maintenance Cost Rate	HO36C
Condemnation Rate	HO36C
Condemnation Cost Rate	HO36C

Source: AFLCM 173:264, WSCRS, pp. 24-25.

Appendix F. Federal Stock Groups (FSG)

FSG	Nomenclature
10	Weapons
12	Fire Control Equipment
14	Guided Missiles
15	Aircraft and Airframe Structural Components
16	Aircraft Components and Accessories
26	Tires and Tubes
28	Engines, Turbines, and Components
29	Engine Accessories
30	Mechanical Power Transmission Equipment
31	Bearings
41	Refrigeration, Air Conditioning, and Air Circulation Equipment
43	Fire Fighting, Rescue and Safety Equipment
45	Plumbing, Heating, and Sanitation Equipment
47	Pipe Tubing, Hose and Fittings
48	Valves
49	Maintenance and Repair Shop Equipment
53	Hardware and Abrasives
58	Communications, Detection and Coherent Radiation Equipment
59	Electrical and Electronic Equipment Components
61	Electrical Wire and Power and Distribution Equipment
62	Lighting Fixtures and Lamps
63	Alarm Signal and Security Detection Equipment
66	Instruments and Lab Equipment
67	Photographic Equipment
70	General Purpose ADP Equipment
73	Food Preparation and Serving Equipment
81	Containers, Packaging and Packing Supplies

Appendix G. Work Breakdown Structure (WBS) Data Plots

Attached are two plots for each WBS. The first plot is of depot maintenance costs (Y-axis) to flying hours (X axis). The second is a plot of depot maintenance costs (V-axis) to primary aircraft authorized (PAA) (X-axis). The WBS categories are as follows:

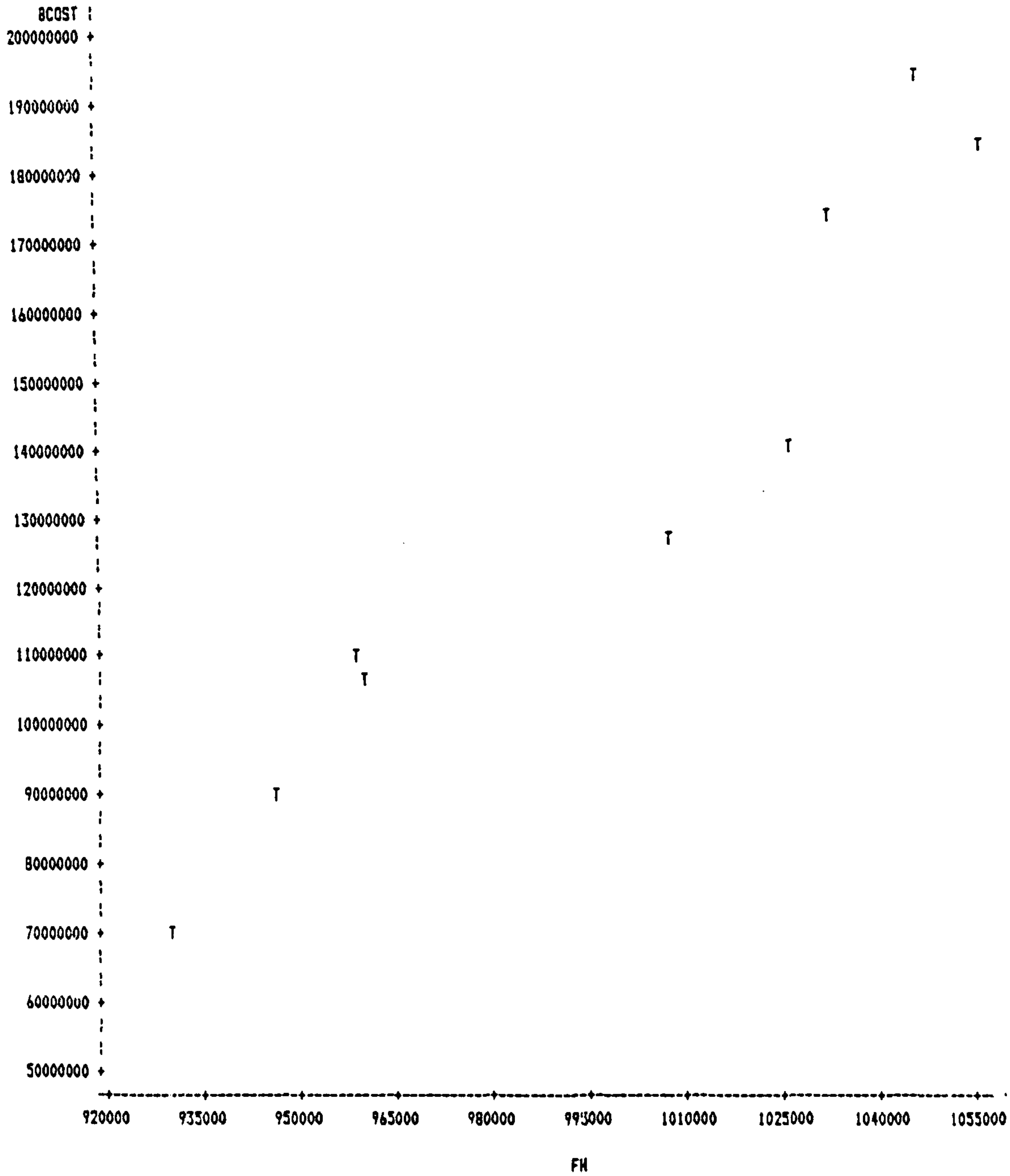
AA	Aircraft Accessories
EA	Engine Accessories
VC	Avionics Communication
AR	Armament
VI	Avionics Instrumentation
VN	Avionics Navigation
AF	Aircraft Overhaul
EO	Engine Overhaul

These plots are used to visually determine the relationship that exists between the dependent and the independent variables that are plotted.

Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=AA

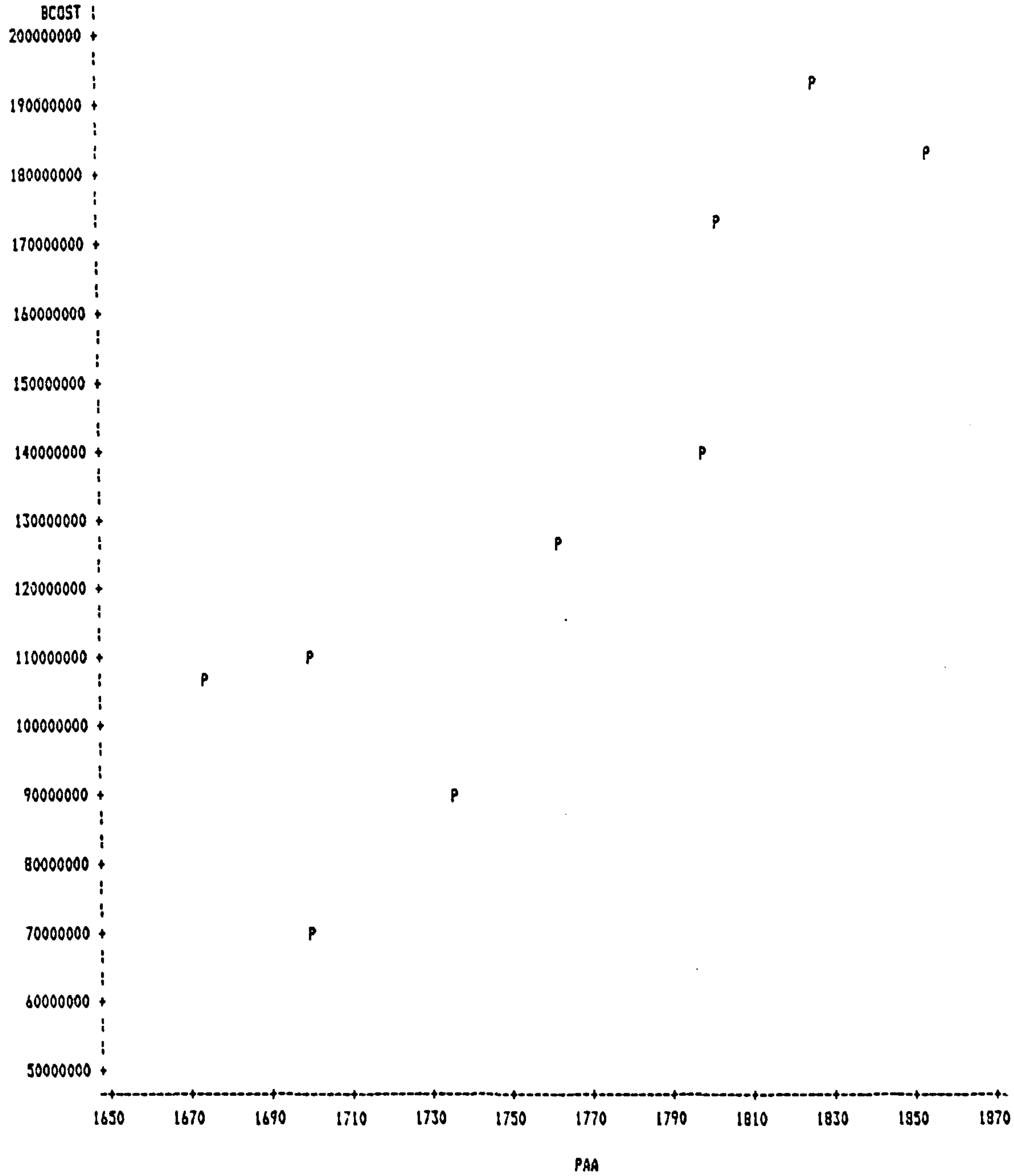
PLOT OF BCOST*FH SYMBOL USED IS T



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=AA

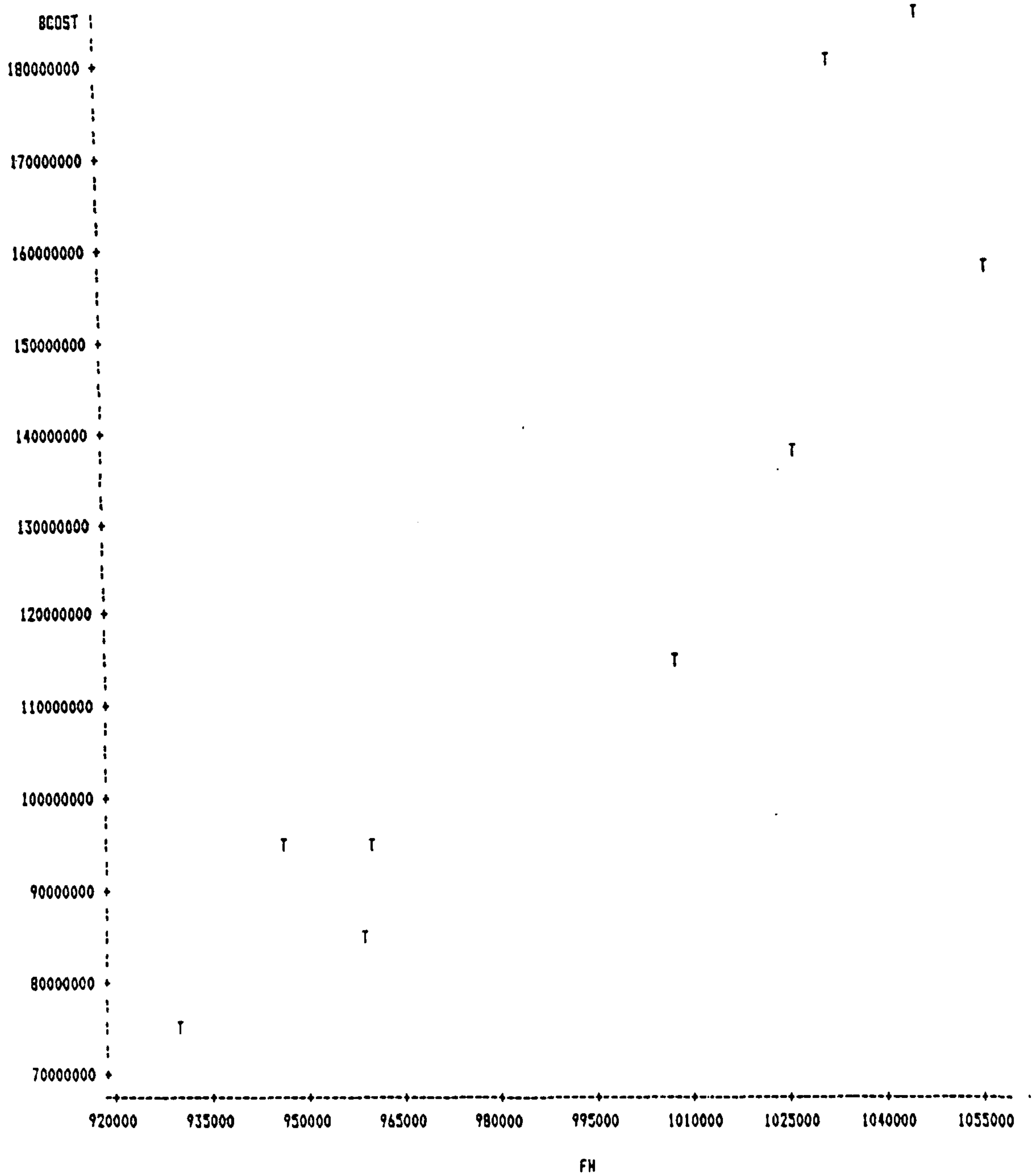
PLOT OF BCOST*PAA   SYMBOL USED IS P



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=EA

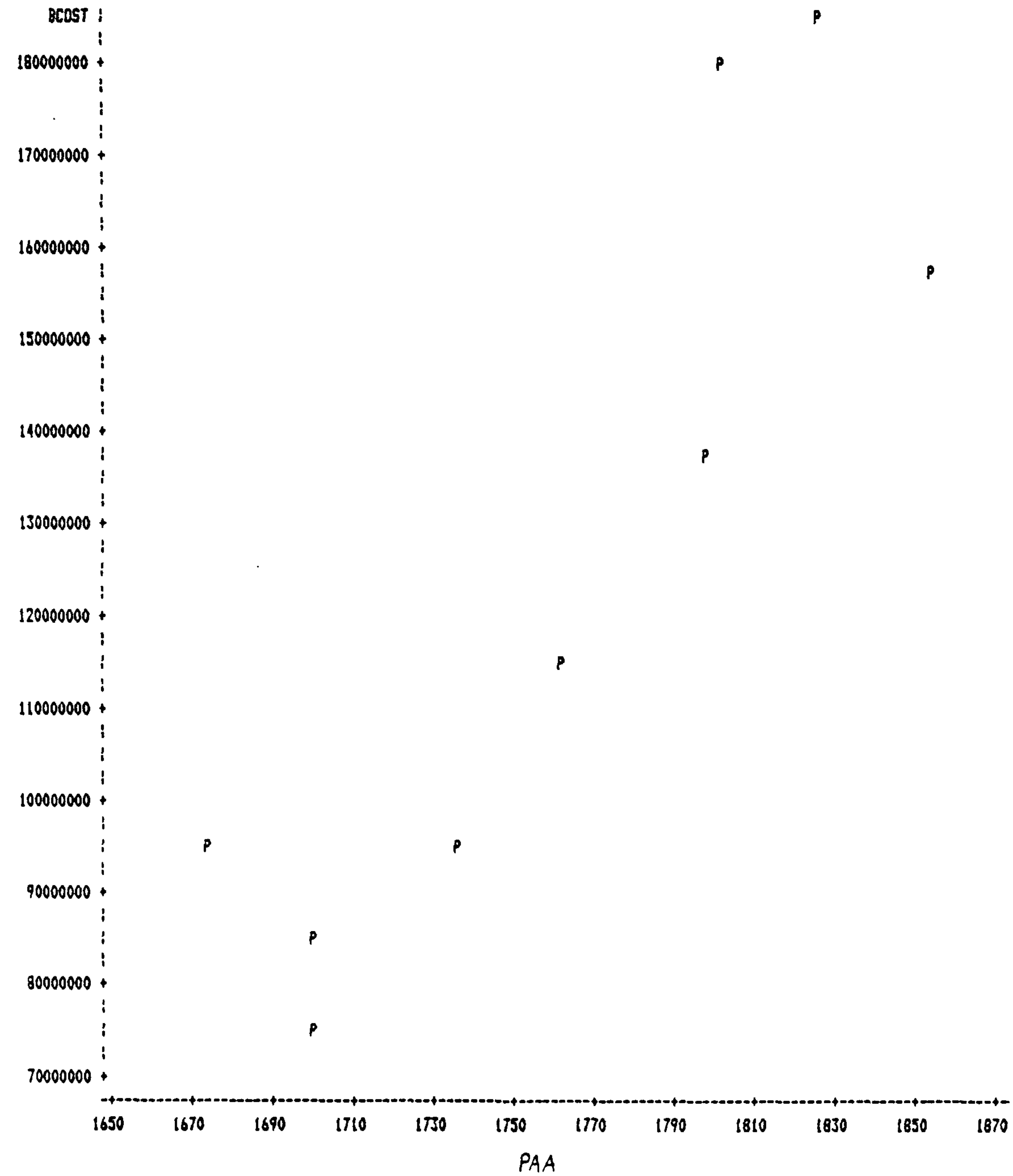
PLOT OF BCOST*FH   SYMBOL USED IS T



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=EA

PLOT OF BCOST*PAA   SYMBOL USED IS P



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=VC

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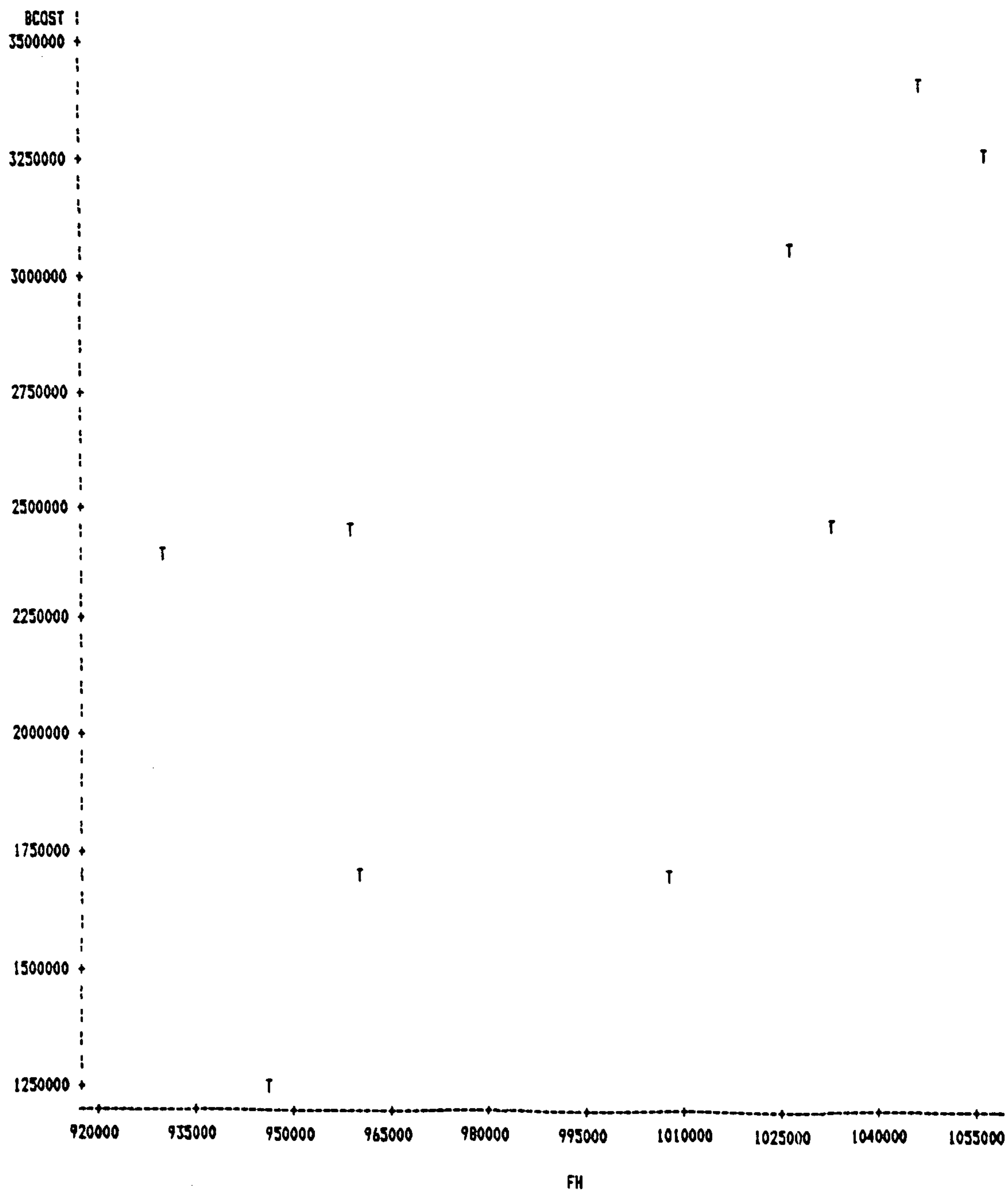
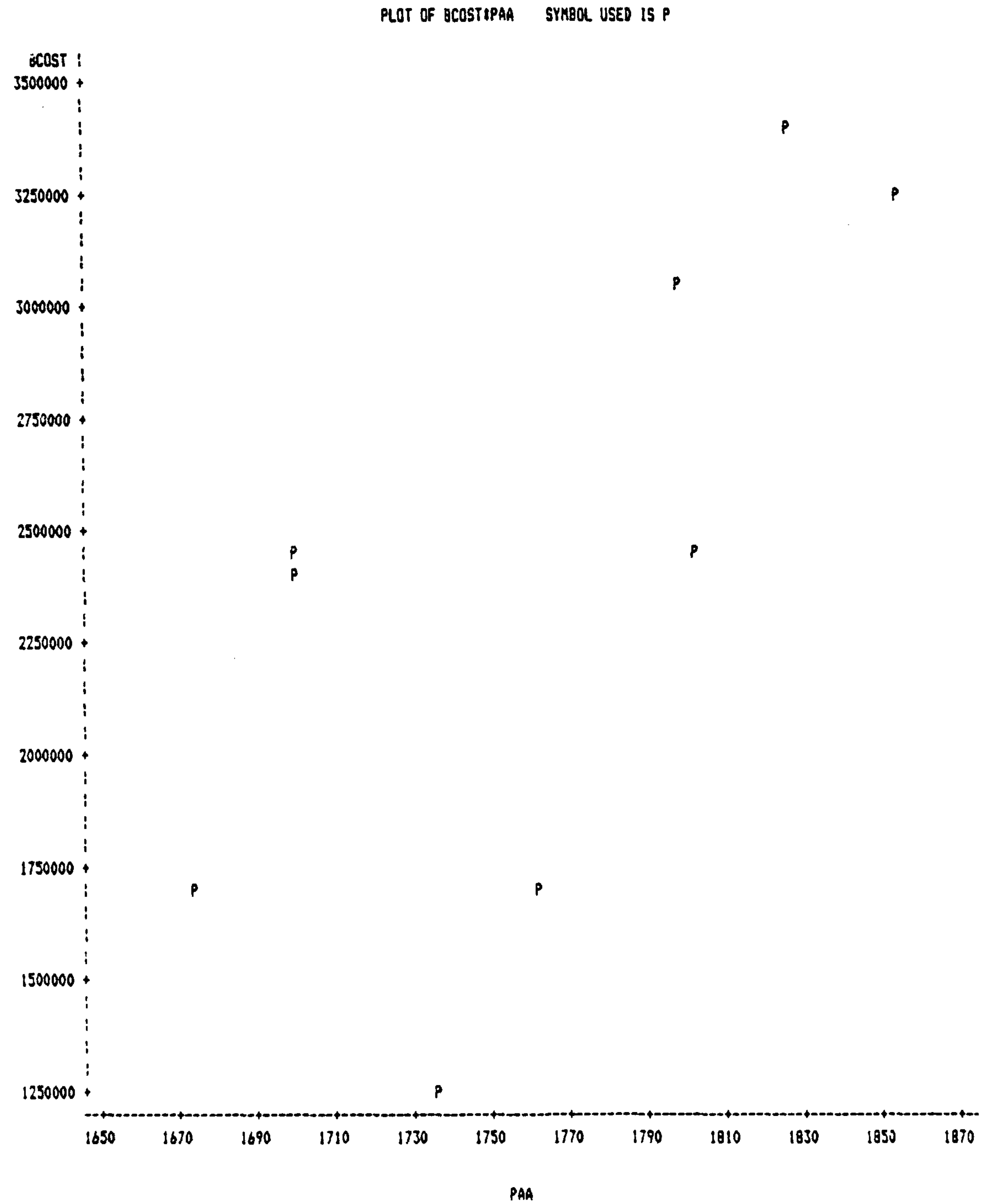


Cargo Aircraft- by WBS
For Fleet Common ONLY

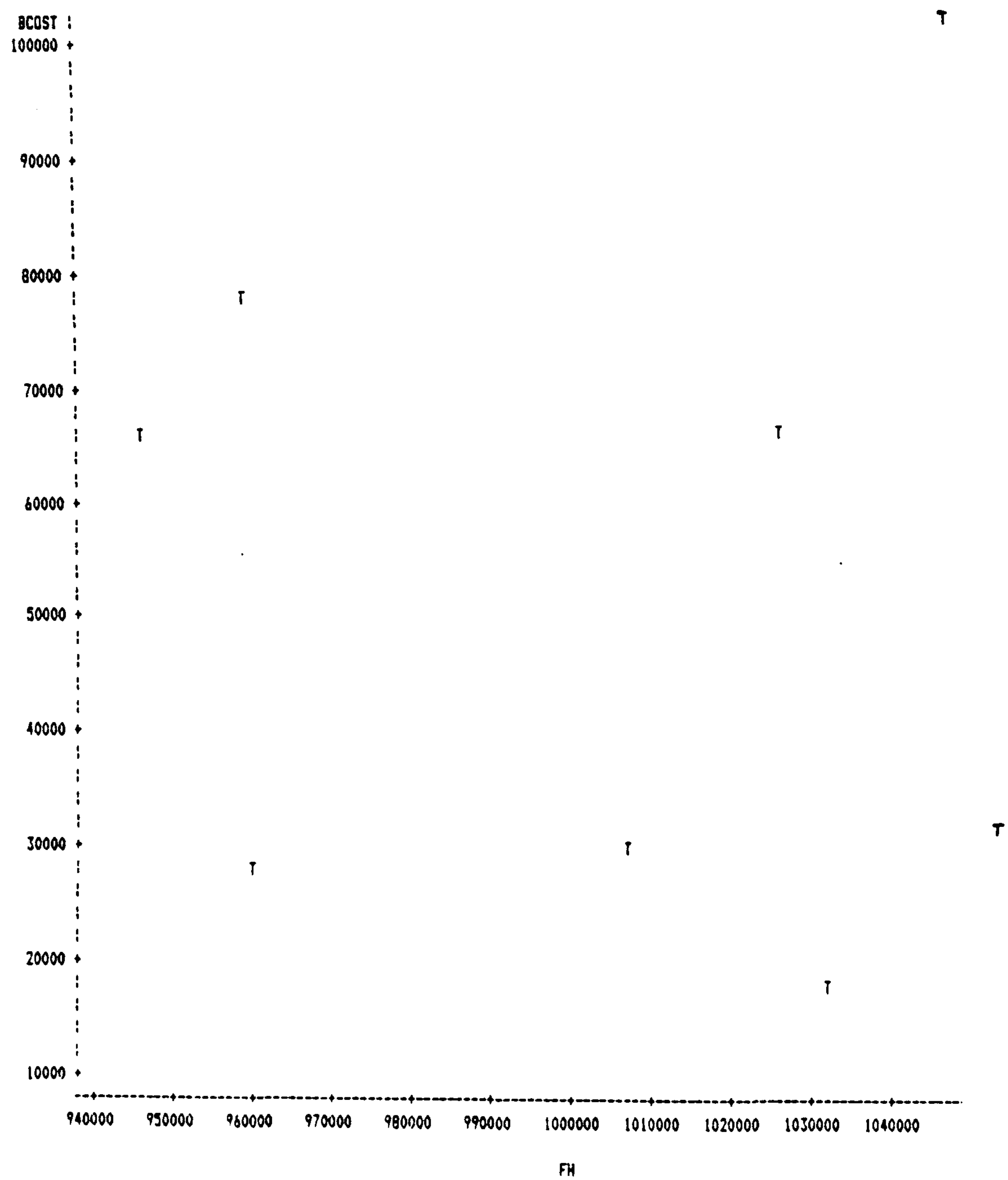
WBS=VC



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=AR

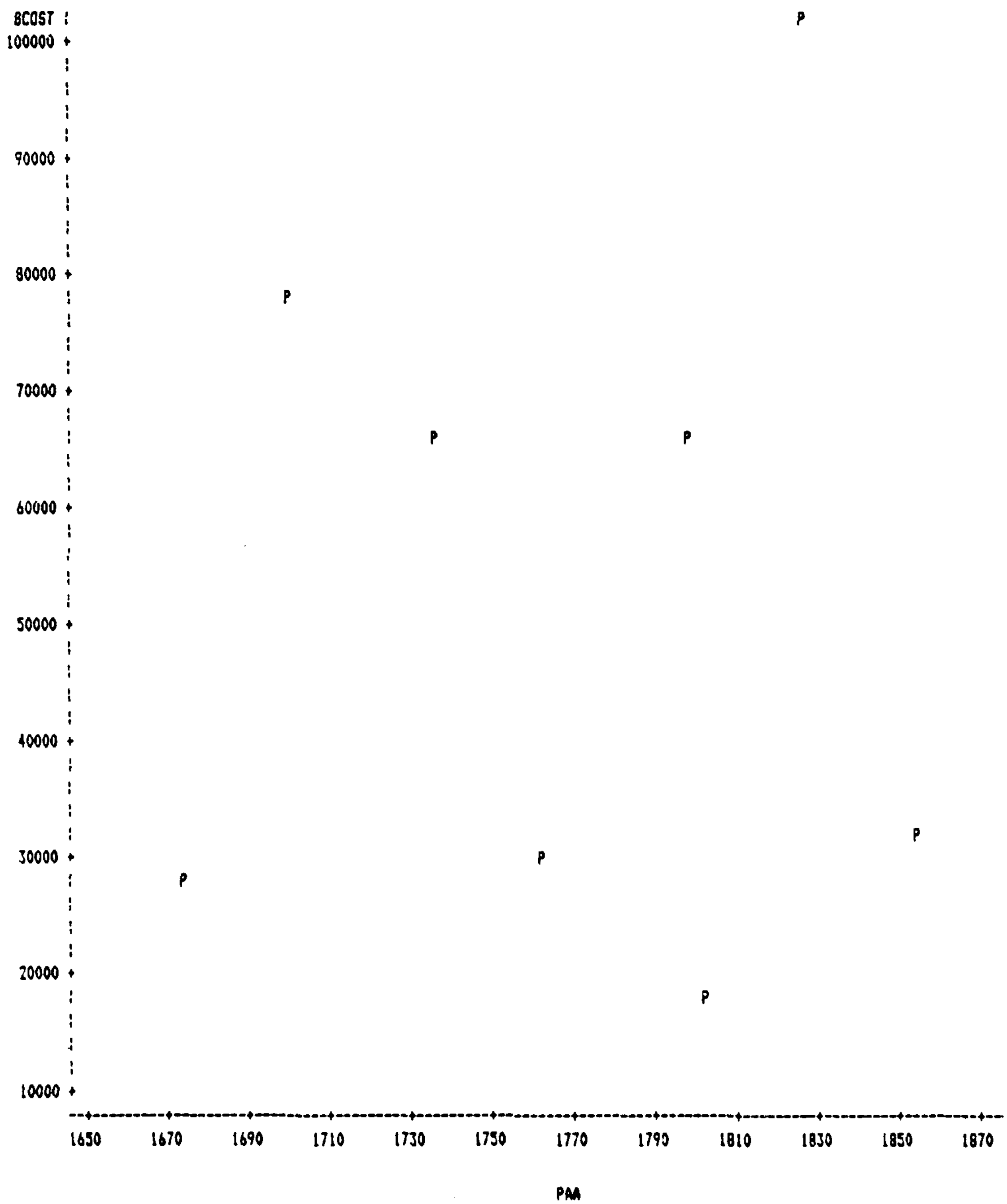
PLOT OF BCOST*FH   SYMBOL USED IS T



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=AR

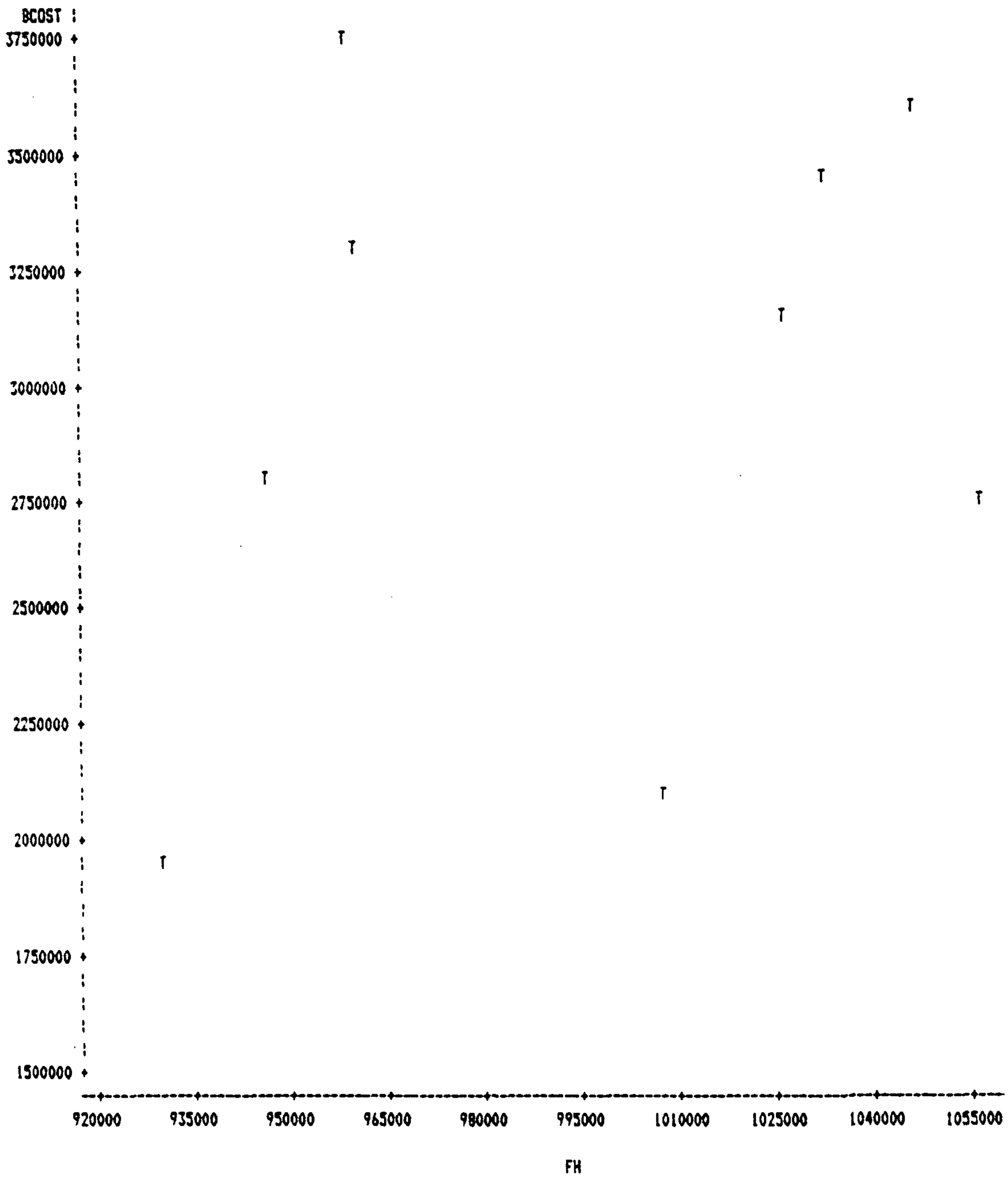
PLOT OF BCOST*PAA SYMBOL USED IS P



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=VI

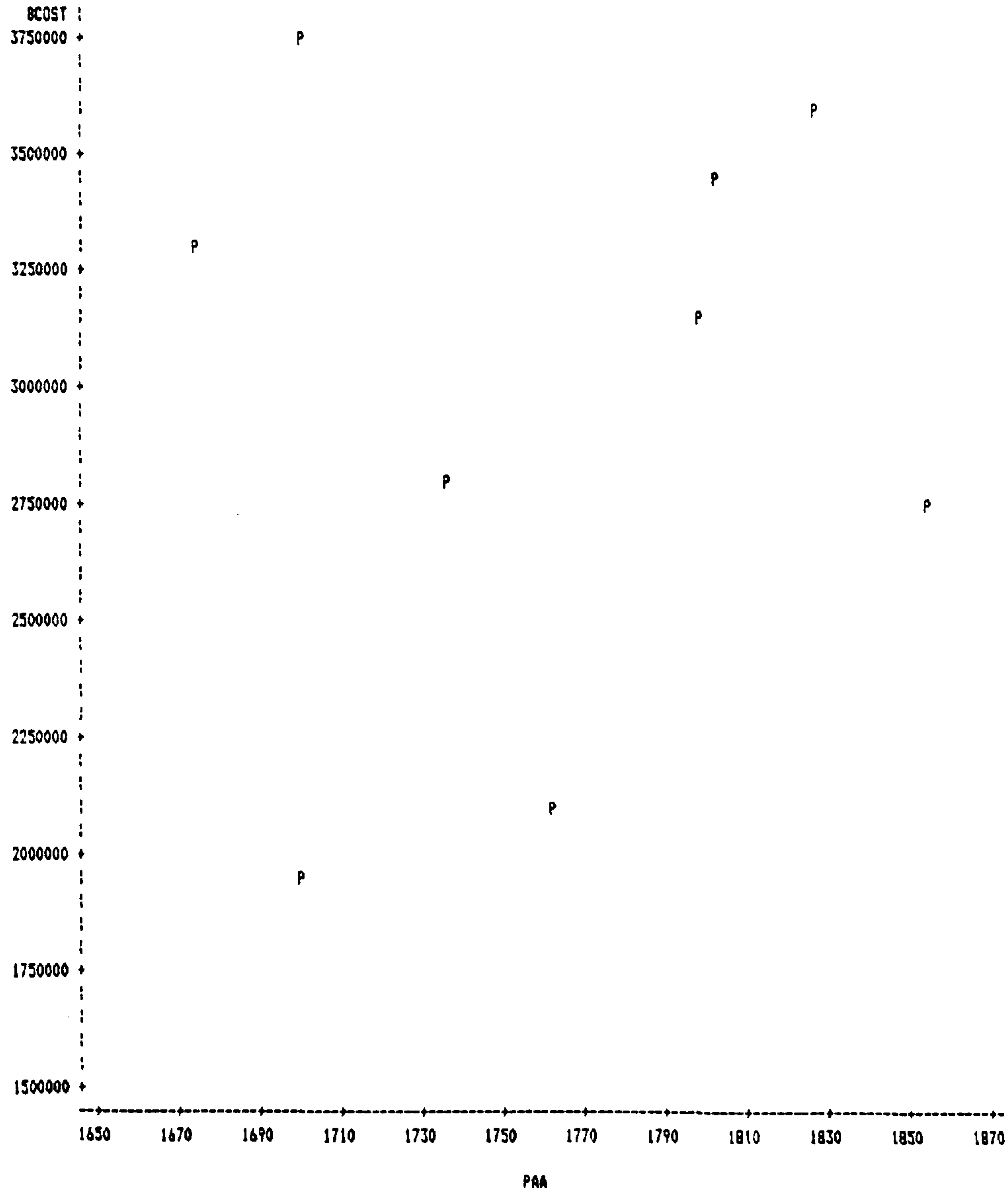
PLOT OF BCOST*FH   SYMBOL USED IS T



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=VI

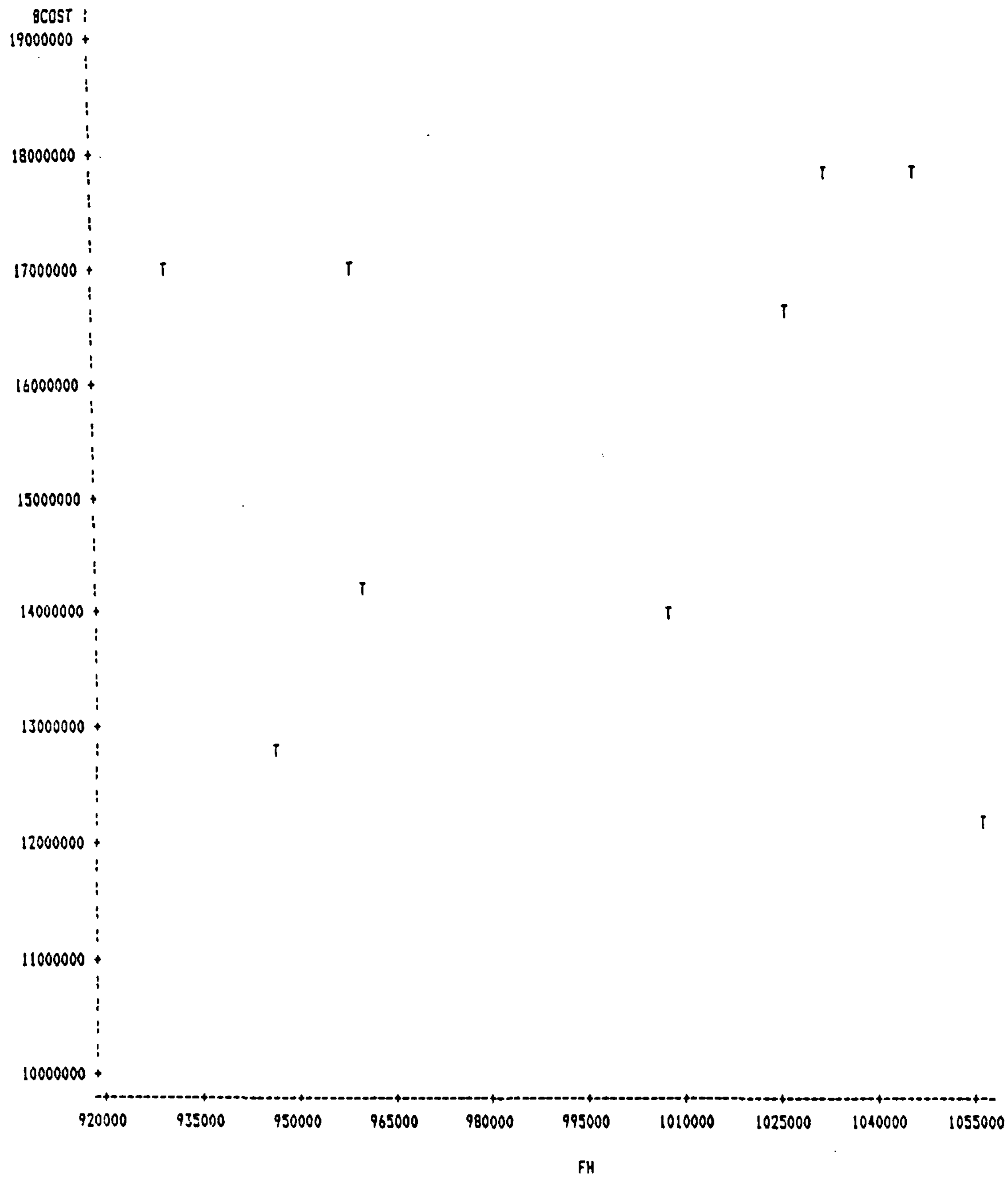
PLOT OF BCOST*PAA   SYMBOL USED IS P



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=VN

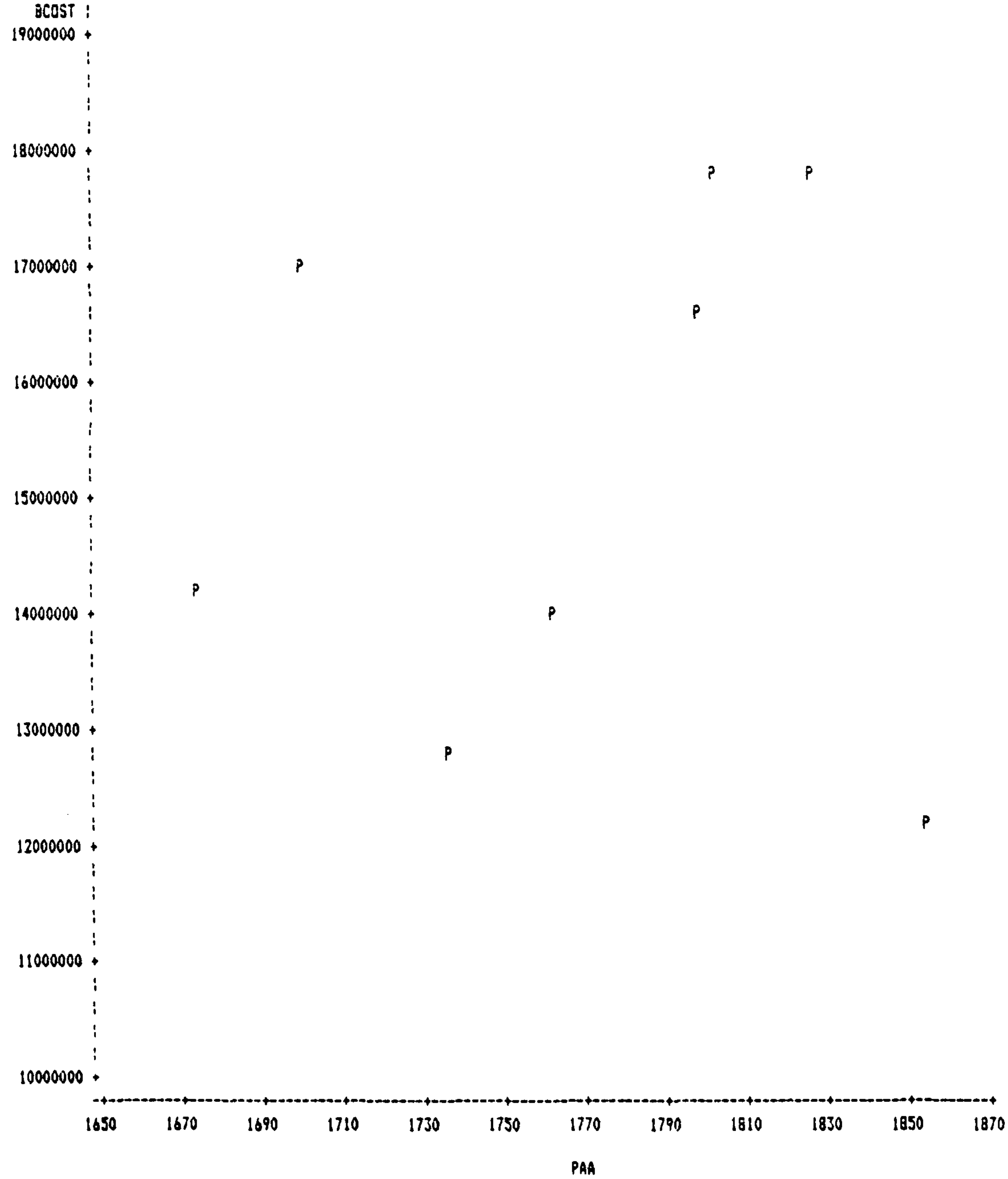
PLOT OF BCOST*FH   SYMBOL USED IS T



Cargo Aircraft- by WBS
For Fleet Common ONLY

WBS=VN

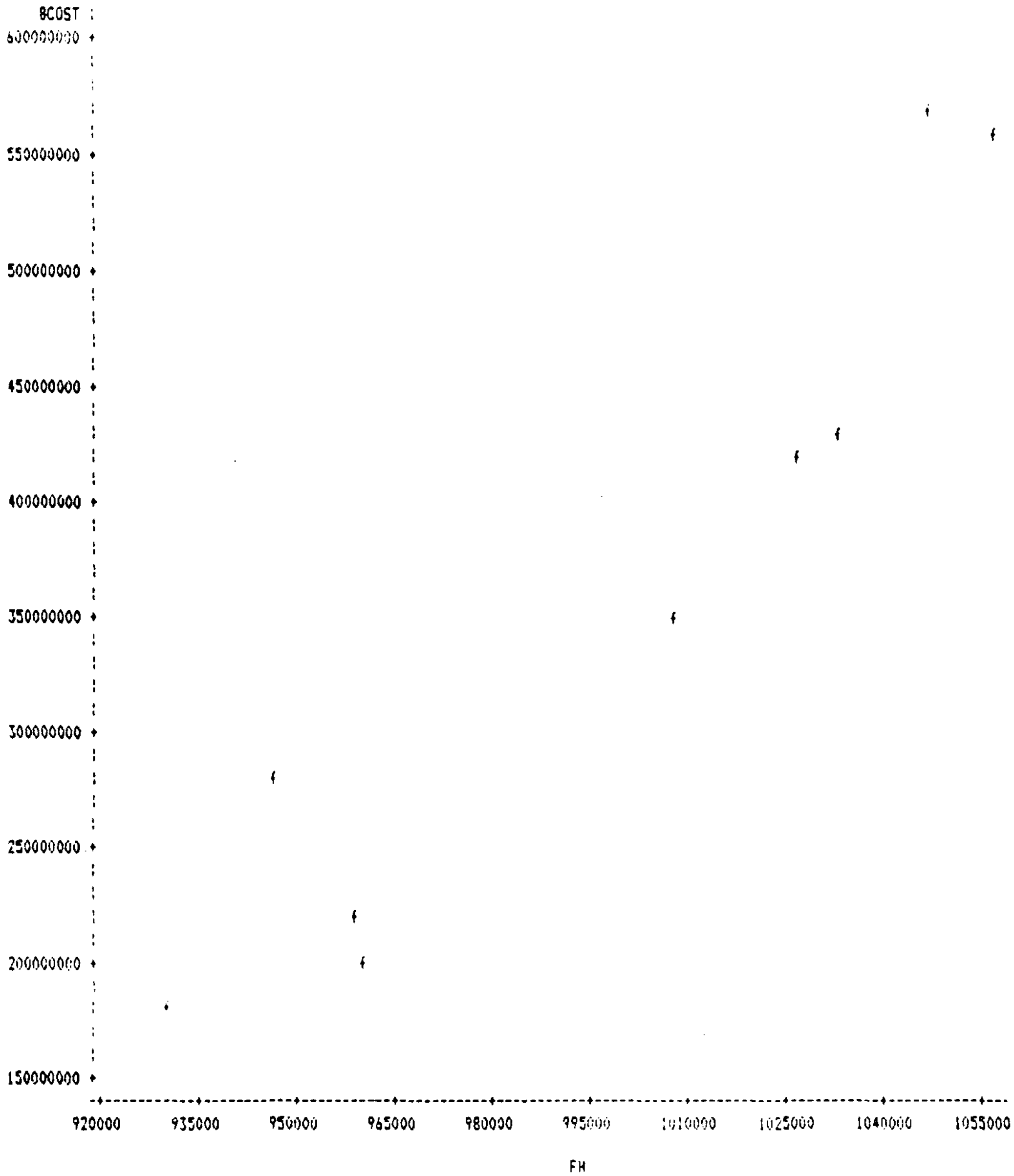
PLOT OF BCOST*PAA   SYMBOL USED IS P



NOTE: 1 OBS HIDDEN

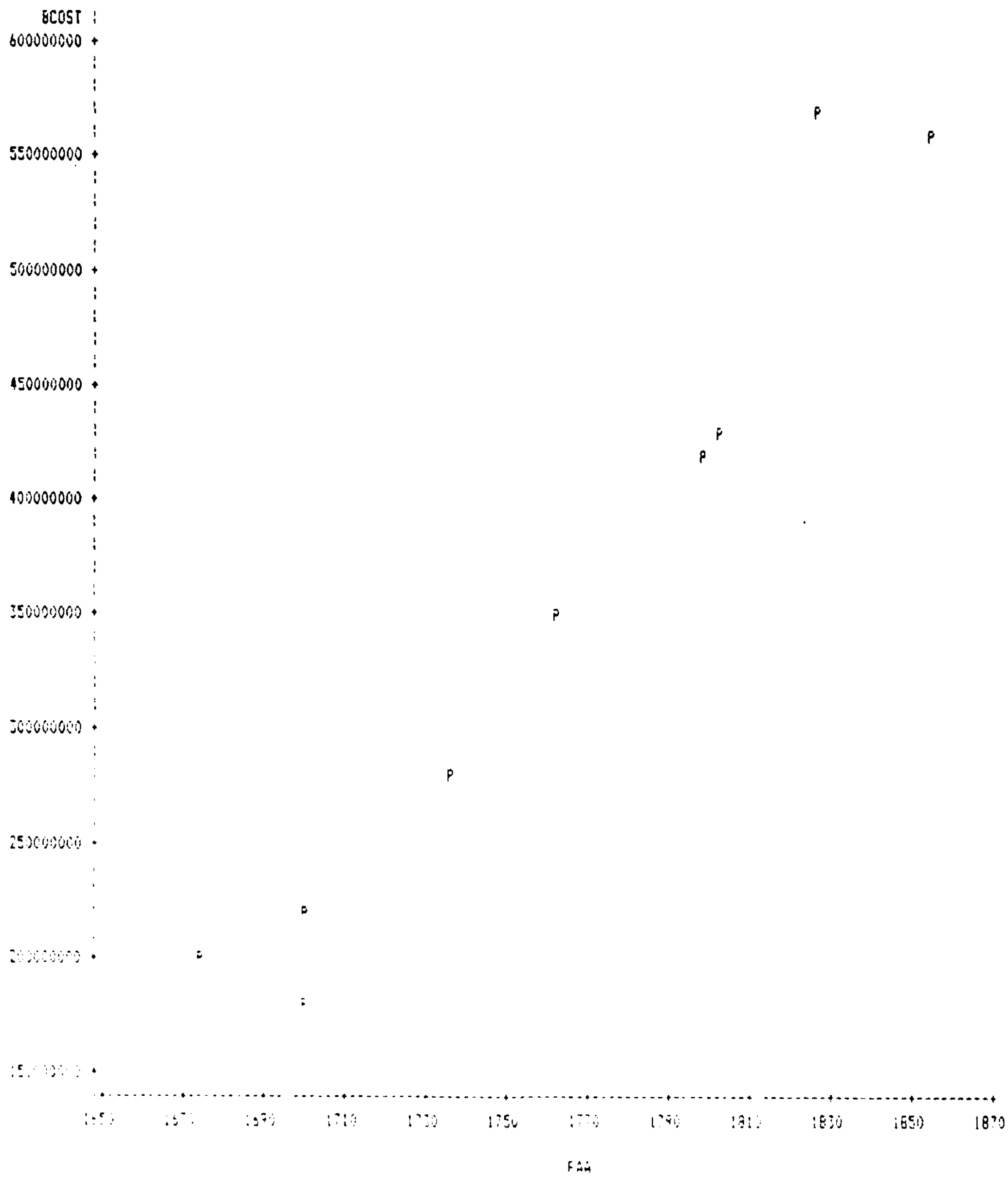
Cargo Fleet Aircraft
Aircraft Overhauls

PLOT OF BCOST*FH   SYMBOL USED IS *



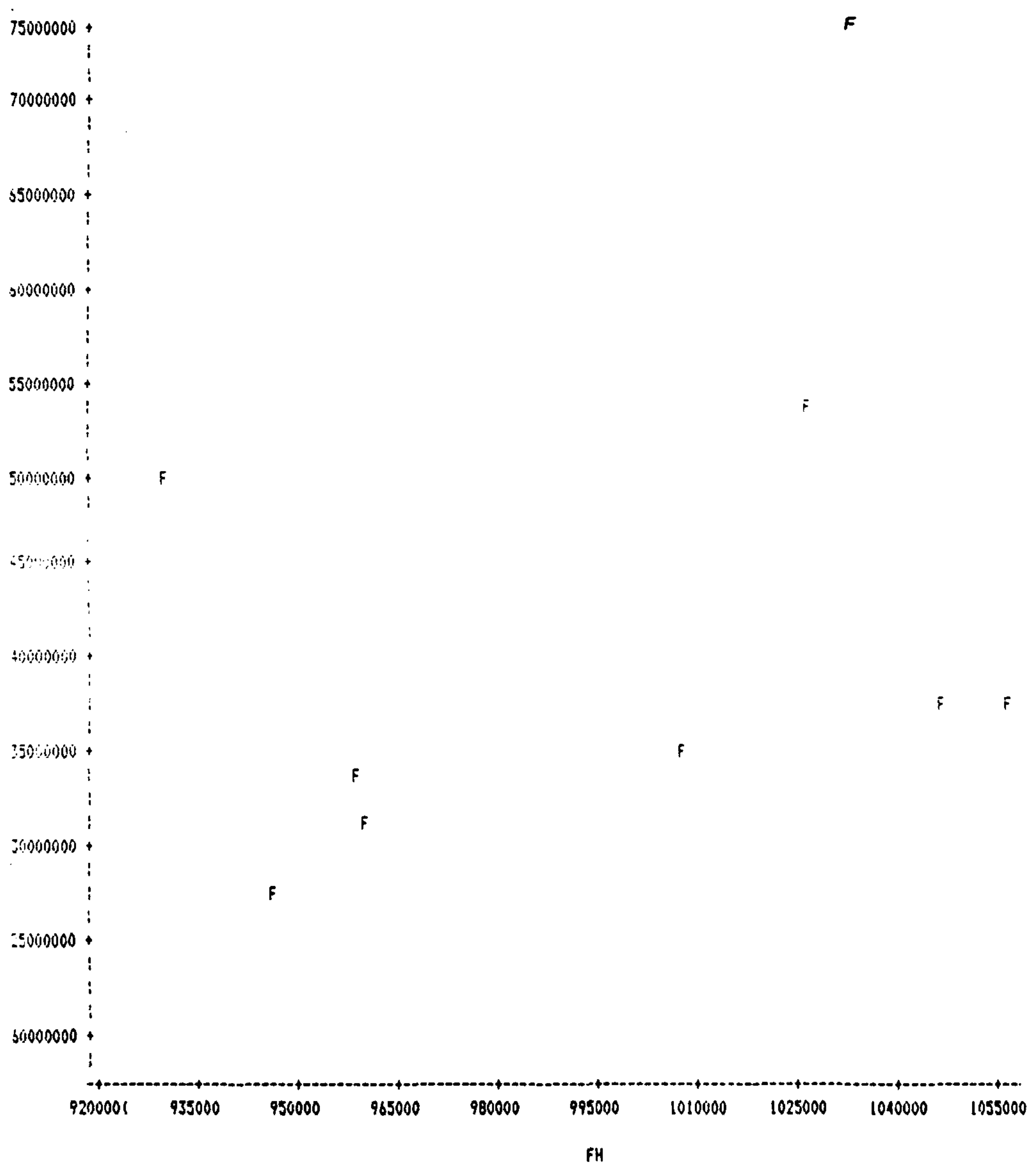
Cargo Fleet Aircraft
Aircraft Overhauls

PLOT OF BCOST*PAA   SYMBOL USED IS P



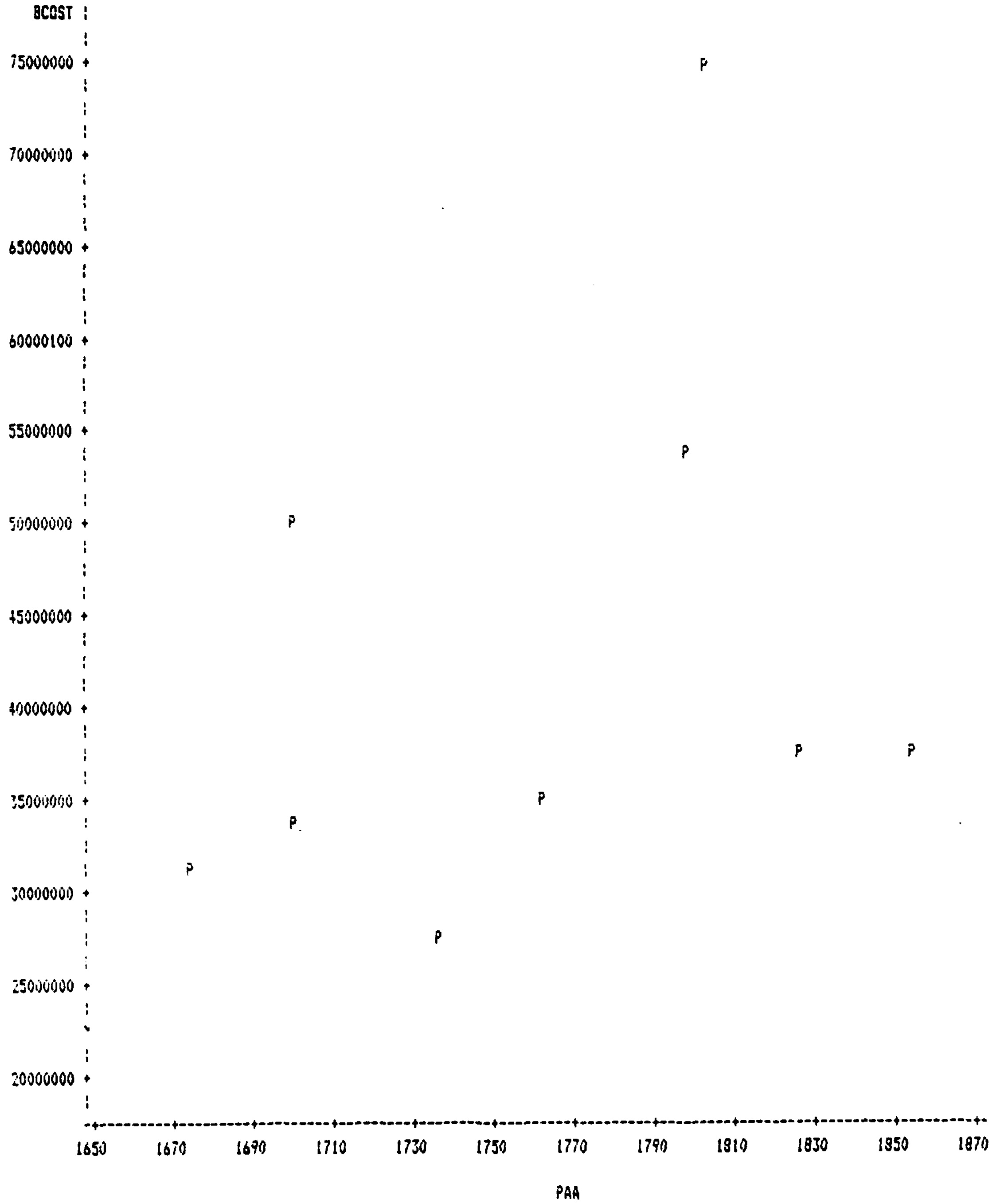
Engine Overhauls

PLOT OF BCOST*FH   SYMBOL USED IS F



Engine Overhauls

PLOT OF BCOST*PAA   SYMBOL USED IS P



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This investigation attempts to determine the proportion of depot maintenance costs for cargo aircraft that is flying hour related and the proportion that is inventory related. Currently arbitrary proportions, such as 65 percent to flying hours and 35 percent to inventory, are used. Air Force Directorate of Cost (AF/ACC) uses these allocated costs to prepare life cycle cost and budget year factors for Air Force Regulation (AFR) 173-13, USAF Cost and Planning Factors. Budget factors are used annually in the budget development cycle and directly affect aircraft operating budgets. Life cycle cost factors provide aircraft average yearly operating costs over the lifespan of each aircraft and are used extensively in decision making studies.

The analysis is accomplished using ordinary least-squares regression and ridge regression analyses on nine years of actual depot maintenance costs from the Air Force Logistics Command (AFLC) Weapon Systems Cost Retrieval System (WSCRS) for cargo aircraft.

As a result, the cargo aircraft fleet, excluding overhauls, is found to have a proportion of 76 percent of depot maintenance costs to flying hours and 24 percent to inventory. Aircraft overhauls result in a proportion of 35 percent of depot maintenance costs to flying hours and 65 percent to PAA. A proportion for engine overhauls cannot be determined. Also, a complete data base is available for further analysis of remaining aircraft.

END

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