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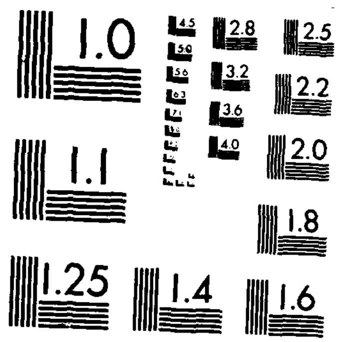

CROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DEPARTMENT OF THE AIR FORCE
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AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF AIR FORCE JET ENGINE WARRANTIES

THESIS

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AFIT/GLM/LSY/86S-4

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THESIS

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Systems and Logistics of the
Air Force Institute of Technology
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Master of Science in Logistics Management

Deborah A. Bielling
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Deborah A. Bielling

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Abstract

With the enactment of Public Laws (P.L. 98-212 and 98-525) warranties must be considered for DOD weapon systems. It is DOD's policy to only obtain cost effective warranties. To determine if a warranty is cost effective a cost-benefit analysis is required. There has been concern by Congress, the General Accounting Office, and the Air Force about the adequacy of the cost-benefit analyses. This thesis effort examined the nature and availability of information needed to conduct cost-benefit analysis of warranties.

A theoretical model of warranty relationships was described and used to identify the information required to assess the benefits and costs of warranties. In order to limit the scope of the research, only jet engine warranties were considered. This thesis effort is useful in that a structure for warranty cost-benefit analysis is provided. In addition, several problem areas involved in evaluating and measuring warranty costs and benefits are identified and discussed.

THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF AIR FORCE JET ENGINE WARRANTIES

I. Introduction

General Issue

Procurement decisions in the Department of Defense (DOD) are made by managers who try to obtain quality products at the least total cost. These decisions have been hampered by the decline in quality (49:6,7) and the ever-tightening budget constraints. For over a decade Congress, users of equipment, and the taxpaying public have been concerned with the following four problems. One, that the defense equipment does not work as advertised. Two, that the equipment takes too long to develop and produce. Three, that the equipment cannot be repaired once it is in the field, and if it can be repaired, spare parts are not available. Four, that the life cycle cost of developing, producing, and maintaining the equipment is too high. With the intent of addressing these concerns various contracting initiatives have emerged.

One of these initiatives has been the use of warranties. Specifically, warranties are used as a method for motivating contractors to assure that the products delivered will work as advertised; and also, for reducing life cycle cost by decreasing operations, maintenance, and support costs (64).

Until fiscal year 1984 and 1985 Congressional action, warranties were used in military production contracts on a selective basis. However, with the passage of Section 794 of the 1984 DOD Appropriation Act (Public Law 98-212) and Section 2403 of the 1985 DOD Authorization Act (Public Law 98-525) the Department of Defense is required to obtain cost effective warranties. Specifically, three warranties (one covering design and manufacturing requirements, one covering defects in materials and workmanship, and one covering essential performance requirements) are required in the procurement of weapon systems with total cost exceeding $10 million or with a unit cost exceeding $100,000 (9:6,7; 23:II-2; 49:47). If the warranty is not cost effective Congress must be notified (23:II-13, II-22-II-25; 49:46; 77:386).

To determine if a warranty is cost effective, DOD guidance requires, prior to procurement, a cost-benefit analysis be conducted (23:II-26; 13:2-3; 49:57; 77:386). In January 1985 a change to the Department of Defense Federal Acquisition Regulation Supplement provided interim guidance for the cost-benefit analysis (32). This guidance was superseded in May 1986 with final guidance that expanded the discussion of what is to be included in the analysis of proposed warranties. Specifically, paragraph 246.770-8 describes the cost-benefit analysis that is required:

> In assessing the cost effectiveness of a proposed warranty, an analysis must be performed which considers

both the quantitative and qualitative costs and benefits of the warranty. Costs include the warranty acquisition, administration, enforcement and user costs, weapon system life cycle costs with and without a warranty, and any costs resulting from limitations imposed by the warranty provisions. Costs incurred during development specifically for the purpose of reducing production warranty risks should also be considered. Similarly, the cost-benefit analysis must also consider logistical/operational benefits expected as a result of the warranty as well as the impact of the additional contractor motivation provided by the warranty (41:947).

Even with the required cost-benefit analysis, both Congress and the General Accounting Office have been concerned about the adequacy of the warranty analyses (21; 23:II-26). In addition, cost-benefit analysis concerns were documented in a 1985 Air Force Institute of Technology masters thesis by Captains Hernandez and Daney,

> USAF people did not know what type of approach/structure to use for a warranty cost-benefit analysis. Instead the USAF people we interviewed relied heavily on the contractor to price the warranty and then analyzed the contractor's methodology instead of preparing an independent estimate for comparison purposes. This is a potentially serious problem since the heart of determining warranty cost effectiveness and affordability should be the cost-benefit analysis, which from our research was not being accomplished independently (49:63).

Also, interest was documented in a January 1986 report prepared by the Air Force Product Performance Agreement Center,

> Questions have been raised regarding the services' compliance with the need [requirement] to determine cost-effectiveness of warranties...a need exists to examine the Air Force approach to warranty implementation with particular emphasis on cost-benefit analysis and related concerns (9:6).

The purpose of this research is to examine the nature and availability of information needed to conduct cost-benefit analyses of warranties. The remainder of this chapter will define the term "warranty" and describe the various types of warranties, review the Department of Defense warranty history, and explain the plan of this thesis.

Definition of Warranty

For the purpose of this research, the term warranty will be defined using the Federal Acquisition Regulation definition. Warranties can also be segregated by types.

Warranty Defined. A warranty is a legal link between the buyer and the seller either after a contract is completed or while the contract is in progress (11:9). Warranty is defined by the Federal Acquisition Regulation as "a promise of affirmation given by a contractor to the government regarding the nature, usefulness, or condition of the supplies or performance of services furnished under the contract" (33:46-9).

Types of Warranties. There are two types of warranties, implied warranties and expressed warranties (11:10-11; 68:14-15). John Rannenberg in his 1984 Naval Postgraduate School masters thesis, Warranties in Defense Acquisition: the Concept, the Context, and the Congress, stated, "implied warranties are 'read in' contracts by common law, even if the specific language is not addressed"

(68:14). Expressed warranties are where "the seller warrants that seller-designed system, accessories, equipment, and parts shall be free from defects in design, material and workmanship and shall conform to the detailed specification requirements over some specified period of time" (68:15).

Six kinds of expressed warranties are used in the Department of Defense:

1) Commercial Warranties - the contractor determines the terms of the liability and the responsibility for correction.

2) Construction Warranty - the contractor agrees to correct any defect in design, material, or workmanship and any nonconformance of work to meet the contract specifications (11:12).

3) Correction of Deficiencies Clause - the contractor agrees to correct any design, material, or workmanship deficiencies which result when the specific item fails to meet specification and contractual requirements (11:11).

4) Reliability Improvement Warranty (RIW) - the contractor agrees, for a specified or measured period of use, to repair or replace defects (subject to specified exclusions if applicable); also, the contractor may be required to enhance the production design and engineering of the system or equipment so as to improve the field/operational reliability and maintainability (11:12).

5) Service Warranty - the contractor agrees to correct services if defects in design or workmanship are found prior to the expiration of a specific event (11:12).

6) Supply Warranty - the contractor is responsible to replace or rework contract items if defects in design, material or workmanship are found prior to the expiration of a specified period of time or before occurrence of a specific event (11:11).

Department of Defense Warranty History

Warranties have been used in defense acquisitions for many years. During the history of the use of warranties in the DOD some significant events and turning points have occurred. The significant events can be divided into three timeframes: prior to 1964, from 1964 through the 1970's, and in the 1980's.

Prior to 1964. Prior to the mid-1960's warranties were frequently used in government contracts (16:4; 45:25; 47:1). However, each military department of the DOD had its own policies (47:34) and its own version of warranty clauses (16:4; 45:25; 47:22). In general, warranties were used to extend the contractor's product liability beyond initial acceptance by the Government. Specifically, warranties were used to:

1) protect the Government where inspection and acceptance test could not assure there was full conformance to the specification (47:50),

2) define the extent of the contractor's liability for latent defects (47:50),

3) give the Government time to conduct the necessary tests required for some complex items (47:51), and

4) assure that contract performance would be accomplished (47:51).

From 1964 Through the 1970's. During the timeframe from 1964 through the 1970's, three significant events occurred relating to warranties. One was that warranties were included in DOD procurement regulations. The second, was that warranty risk issues emerged, resulting in DOD's policy of self insuring. Finally, Reliability Improvement Warranties (RIW's) were introduced. These events are discussed below.

Warranties Appear in Regulation. In 1964, for the first time, the Armed Services Procurement Regulation (now the Federal Acquisition Regulation) established uniform DOD policy for the use of warranties. A comprehensive list of instructions for the use of warranties in fixed price type contracts was published (45:25). Warranties were to be used only where they could be enforced and where the protection for the Government was greater than the potential increase in contract price. Several expansions and clarifications have been made through the years since the introduction of warranties in the DOD regulation (45:25; 13:2-2).

DOD as Self Insurer. In the late 1960's expanded warranty coverage policies added new issues relative to the government and contractor sharing of risk. Specifically, a "Warranty of Construction" clause made the contractor liable for "Consequential Damages" to government property. An incident arose when the Austrialian Government sued Lockheed Aircraft and its subcontractor, Menasco, for the loss of an aircraft and other damages due to an alledged landing gear failure. An out-of-court settlement resulted in Lockheed, Menasco, and the United States Government contributing to the price of a replacement aircraft. The Austrialian incident led to a review of DOD's procurement policy on consequential damages and warranties (23:II-1,II-2; 31:D-1; 45:25).

Subsequently in 1971, DOD announced a procurement policy change aimed at reducing costs by limiting the contractor's risk (31:D-1; 45:25). The change provided, that DOD would generally "act as a self-insurer for loss of or damage to property of the government occurring after final acceptance of supplies delivered to the government and resulting from any defects or deficiencies in such supplies" (45:25-26). Based on DOD's liability policy as a self insurer, the use of warranties were selectively applied to government acquisitions.

Introduction of RIW. In the mid-1960's, an innovative warranty, "Failure Free Warranty", was originally proposed by the Instrument Division of Lear Siegler, Inc. to the Air Force (11:31; 12:1). The "Failure Free Warranty" was different from previous warranties in that (1) all field failures were covered under warranty for an extended time period, (2) risk was shifted so the contractor shared any reward (expanded profit) or penalty (fixed price) with the government, and (3) reliability was measured in field operation after hardware acceptance (50:17). Although the proposal was not accepted, the ground work was laid for what would later be referred to as a Reliability Improvement Warranty (50:17).

In the late 1960's and into the early 1970's, several "Failure Free Warranty" contracts were awarded by both the Navy and the Air Force (11:31; 12:1; 16:4,5; 13:2-2; 53:26). The contracts were for equipment that already existed in the field, which minimized risk for both the contractor and the Government.

In 1973, 1974, and 1975 DOD memorandums were sent to the service secretaries establishing the use of Reliability Improvement Warranties for electronic systems and providing guidelines for their application. The 1974 memo reiterated that the intent of the RIW contracting technique was to realize improved operational reliability and maintainability of DOD systems and equipments for each additional dollar that the contractor uses (50:7; 19:1,2).

The 1975 memo resulted from industries comments to clarify and expand DOD's RIW guidelines. Discussions were held between DOD and industry in which internal and external experiences were used to "refine" DOD's continued application of warranties (45:27).

The result of warranties being included in procurement regulations, DOD's policy of self insuring, and the introduction of RIW's was that warranties were selectively used. By 1979, warranties were estimated to cover one-third of the 4.1 million types of items in DOD inventory (45:26). In addition, about $15 billion of DOD's annual procurements for material included some type of warranty coverage at an annual cost of $300 million (70:1).

In the 1980's. During the 1980's significant occurrences related to warranties continued. Three of these events are discussed. One is that the Air Force took an innovative interest in warranties. The second is that warranties were included as part of the Defense Acquisition Improvement Program (DAIP). Third, Congressional laws were enacted pertaining to warranties.

Air Force Innovations. In August and December of 1979, the Air Force and industry reviewed commercial type warranties for application to military hardware (45:27). There was a movement to change the term "warranty" to the term "product performance agreement" which broadened the review and application. The result of these meetings, was a jointly developed set of principles to guide the efforts of fielding a quality product (45:27). The principles were subsequently published by the Air Force in a Product Performance Agreement Guide (45:27). The Guide described a number of warranty provisions with their applications, advantages, and disadvantages (68:61).

In December 1980, the Air Force initiated an effort to establish the "Product Performance Agreement Center" at Wright-Patterson Air Force Base, Ohio. The Center was to serve as a DOD-Industry clearing house for product performance data and analysis (68:61). The contractor's effort in the solicitation included updating the Product Performance Agreement Guide, risk/cost benefit modeling, and general administrative support (68:61). On 27 September 1982, the Air Force concluded the competitive source selection by selecting a support contractor for the government operated Center (14:1-1).

Warranties as Part of DAIP. In 1981, senior level DOD interest in warranties was seen as one way to enhance the acquisition process. Mr. Carlucci, then the Deputy Secretary of Defense, recognized the importance of reliability in reducing life cycle cost when he proposed his 32 initiatives which became known as the Defense Acquisition Improvement Program (18:5). These initiatives were later consolidated in 1983 by Mr. Thayer (Carlucci's successor) into six initiatives (18:5). One of Thayer's initiative, Improved Support and Readiness, contained Carlucci's original action 16 which stated, "...program management office [should] employ specific contractual incentives focused on designing for reliability and supportability" (18:5,11; 31:D-2). Included in these contractual incentives was the use of warranties (67:1-3,1-4).

Laws Governing Warranties. In 1983, Senator Mark Andrews sponsored a warranty provision as an amendment to H.R. 4185, the fiscal year 1984 DOD Appropriation Act (68:63). At a meeting with industry representatives, the Senator discussed his reasons for developing the legislation. In part, he had a desire to mandate a commercial marketing environment upon the defense acquisition process where both parties would make and enforce stricter commitments (68:64). The amendment became section 794 of the 1984 DOD Appropriation Act, Public Law 98-212. It provided that "no funds would be obligated or expended for the procurement of a weapon system unless the contractor provided certain written guarantees" (1:37). The key features were (1) emphasis of warranting the entire weapon system; (2) having the prime contractor correct defects; and (3) requiring specific performance warranties (23:II-13-II-15; 49:42).

The new law left some questions and caused concern in both industry (23:II-19; 49:44) and DOD (23:II-17-II-19; 68:73-76). It was felt, by both proponents and opponents of the warranty legislation that a rewritten version was necessary (49:44; 68:77). On 31 May 1984, a compromise effort was published as Section 191 of the Defense Authorization Bill, S. 2414 (68:77). The bill was passed on 19 October 1984 as Public Law 98-525, Section 2403 of the 1985 Defense Authorization Act (49:44).

Public Law 98-525 required three specific kinds of warranties to be written in contracts awarded for the production of weapon systems. The law applied to programs with the total cost exceeding $10 million or with a unit cost exceeding $100,000 (9:6,7; 23:II-22; 49:47,48). The three kinds of warranties were described in a report prepared by the Air Force Product Performance Agreement Center:

1) Material/Workmanship warranty requires that the item contracted for, at time of delivery, will be free from all defects in material and workmanship (9:6).

2) Design/Manufacturing warranty requires that the item will conform to the design and manufacturing specifications of the contract (9:6).

3) Performance warranty requires that the item will conform to specific performance criteria under specific conditions. This warranty only applies after manufacture of either the first ten percent of the eventual total production or the initial production quantity, whichever is less (9:6,7).

Plan of This Thesis

The purpose of this research is to examine the nature and availability of information needed to conduct cost-benefit analyses of warranties. In order to limit the scope of the research, only jet engine warranties will be considered. Chapter 2 makes reference to a theoretical model of warranty relationships in order to identify the information required for cost-benefit analysis of warranties. Chapter 3 presents an overview of the history of Air Force engine warranties. Also in Chapter 3 the jet engine warranty environment, particularly, selected Air Force procedures relating to engine warranties are presented. In addition, the specific engines used in the research are identified. In chapter 4, the feasibility of obtaining the information required for assessing the costs and benefits of engine warranties will be discussed. The nature and availability of the information required along with the problems involved with measuring the costs and benefits of engine warranties are considered. Chapter 5 presents the summary, conclusions, and recommendations of this thesis effort.

II. Theoretical Considerations

The purpose of this chapter is to identify the information required in order to assess the benefits and costs of warranties. To do this, extensive reference will be made to the working paper, "Evaluating the Benefits and Costs of DOD Warranties," by Professor Leroy Gill of the Air Force Institute of Technology. This chapter begins first by considering the nature of costs and benefits. Next the purposes of commercial and DOD warranties are contrasted, and the insurance and assurance aspects of warranties are separated. Then the impact of warranties on manufacturer incentives is considered. Finally, the methodology of evaluating the benefits and costs of DOD warranties is addressed.

The Nature of Costs and Benefits

Nature of Costs. Costs are the value of the relevant inputs associated with producing a given product or outcome. Relevant means that the costs are contingent upon the specific decision or choice being made. In this sense, the term cost differs from its standard usage. The relevant costs, used to decide between alternatives, are costs that lie in the future not in the past (42:33). Relevant costs do not include "sunk" cost and do include "opportunity" costs.

"Sunk" costs are past costs. They are costs that have been incurred as the result of a previous decision (36:20; 42:33). Sunk costs can not be retrieved, therefore they are not relevant because they are beyond the control of the current decision or choice being made. Relevant costs are avoidable costs. "Opportunity" costs are the value of the alternative given up as a result of the current decision (42:25; 44:49). For new items, opportunity costs are equal to their purchase price. For previously purchased items, their opportunity cost is equal to their current resale value.

Nature of Benefits. Benefits are the value of the output produced. In order to assess benefits it is necessary to identify and classify outputs. The categories for the outputs should be defined/described in accordance with the requirements of the decision. The characteristics of the categories include all relevant benefits in relation to the objective of the alternative (36:23). The benefits may be quantitative or qualitative. Ideally, they should be discretely identifiable and measurable.

Commercial Warranties and DOD Warranties

Commercial Warranties. In the private sector, competitive conditions encourage manufacturers to offer warranties (60:2). The warranties make a statement that the manufacturer will stand behind its product, and assume the risk in case the product fails to perform as promised. Many manufacturers offer warranties so that customers gain confidence that the product quality is equal to the advertised promises (62:3).

DOD Warranties. In DOD, warranties are desirable as an incentive to control Life Cycle Cost and as a method to obtain quality products (53:23; 64). The DOD recognizes that the cost of a system includes expenses of not only acquiring the system, but also, the expenses of operating and supporting the system. Part of the support cost includes equipment failure and the expense involved in repair/replacement (53:24). In order to motivate the manufacturer to consider the support cost, DOD warrants performance requirements (53:26). This is an attempt to improve product reliability, by providing economic sanctions (i.e., repair or replacement of the product by the manufacturer) if the product fails to perform as intended (16:3; 60:2). In addition, the improved reliability increases readiness by having more equipment available for use (43:8; 60:26; 73:2,3).

Warranties as Insurance and as Assurance

Both the commercial and DOD customer can view warranties from two perspectives (73:5). First, the warranty as insurance in that the customer does not have to pay for the repair/replacement of a failure during the period of the warranty (43:1; 60:3). Second, the warranty as assurance in that the customer is receiving a quality product (43:1; 60:3).

Warranty as Insurance. The insurance perspective can be referred to as the direct advantage of a warranty for the purchaser (60:3). If the product purchased does not perform as intended, the purchaser receives compensation from the seller. The attractiveness of warranties from this perspective can be explained by looking at the concepts of risk and insurance. With a warranty, the risk of "loss" is shifted from the buyer to the seller for a specified period of time.

Consider an example given by Dr. Gill in "Evaluating the Benefits and Costs of DOD Warranties," (43:2). If the annual probability to an individual of losing his/her home to a fire is 1 in 100,000 and the value of the home is $100,000, then the expected loss per year is $1 (43:2). However, in reality, the homeowner could lose as much as $100,000, so, for protection, the homeowner buys an annual fire insurance policy. The buyer pays a premium to cover the loss of his/her home in case a fire should destroy it during the year. The homeowner is shifting the risk of loss (replacing the home) to the insurance company.

On the other hand, the insurance company spreads the potential losses over a large number of insured homes, by pooling the risk or probability of a loss occurring. For the insurance company, by insuring a large number of homes, the probability that all the homes will burn down is minuscule. Therefore, by pooling risk, the insurance company has greatly diminished the probability of a catastrophic outcome (43:2).

For the DOD, the insurance advantages of a warranty are more likely achieved by "self-insuring", because of the large number of like items in DOD inventory for which risk of loss can be pooled (43:2).

Warranty as Assurance. A warranty implies the seller is producing a quality product, because non-quality products would have to be repaired/replaced under warranty claims. Implicitly it is reasoned, that warranty claims would cost the seller money in repairing and/or replacing the non-quality product and would affect the manufacturer's profit (43:2; 60:3). It is also reasoned, that with a warranty, the cost of warranty claims is more than the incremental cost associated with producing a product of the advertised quality (43:2,3).

Impact of Warranty on Manufacturer Incentives

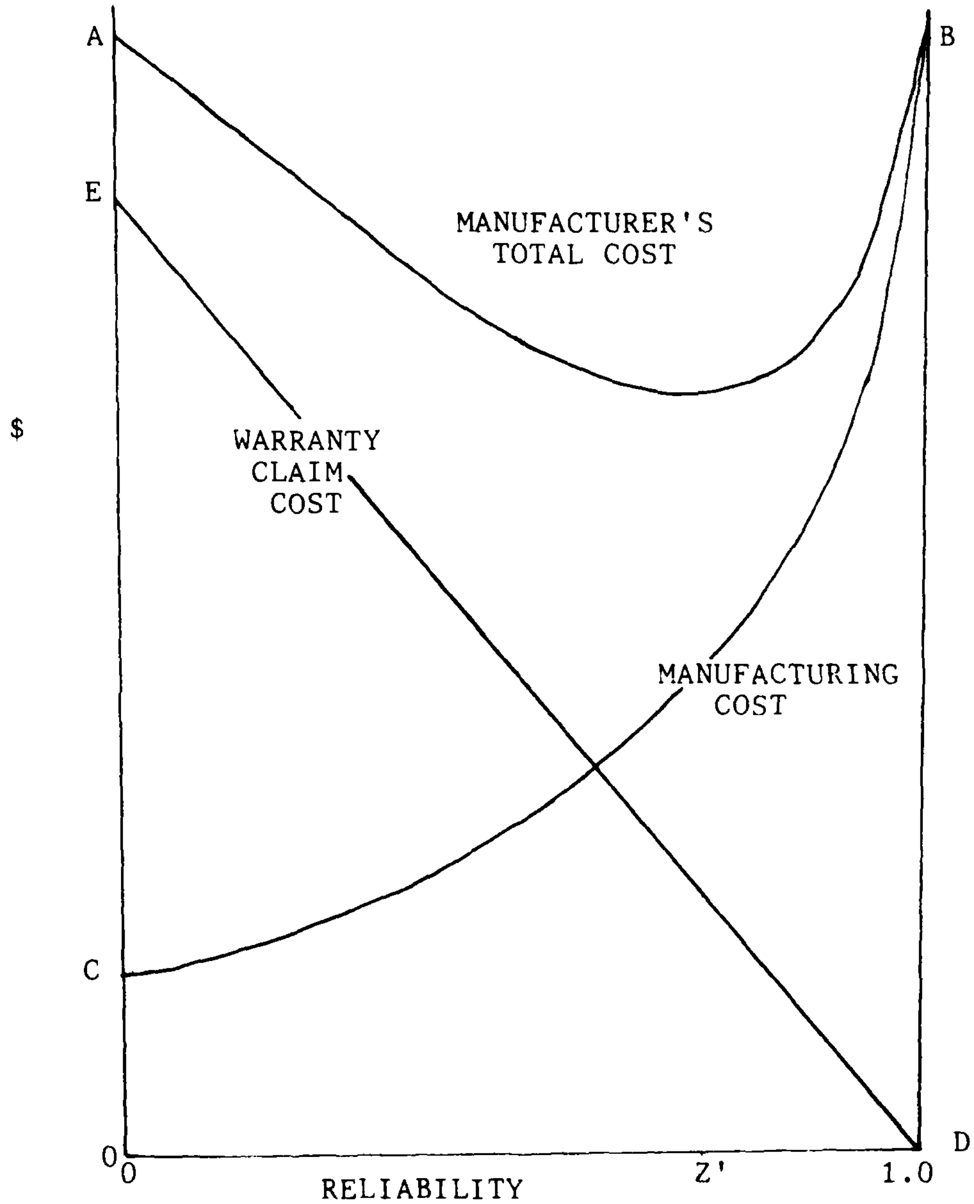
When a purchase is made without a warranty, there is no direct incentive for the manufacturer to make his product any more reliable than the market demands. This is because, greater reliability increases manufacturing costs and such increased costs will be avoided unless market conditions make it profitable for a manufacturer to build a more reliable product. Under a warranty, decreases in reliability of the product means increases in the number of warranty claims which affect the manufacturer's profit

(60:3). Alternatively, increases in reliability of the product means increases in manufacturing costs which also affects the manufacturer's profit (53:24). A model which shows the effect of the warranty on the manufacturer's total cost can be visualized in Figure 1 (43:5).

Figure 1 describes (for a fixed number of units produced) the standard case of the manufacturer's total cost when warranty claim cost are included (43:7). The convex curve assumption is used to illustrate the practical considerations that the observed percentage of reliable products will lie between zero and one (43:7); and that, as reliability is improved, the manufacturing costs increases at an increasing rate (43:7; 53:24). Another assumption is that the warranty requires the manufacturer to pay a fixed penalty cost per failure (43:3). The manufacturer's total cost is obtained by vertically adding the warranty claim cost and the manufacturing cost (43:4).

The warranty claim cost is equal to the fixed penalty cost per failure times the number of failures (43:4). For example in Figure 1, if all the products produced failed, the manufacturer's potential warranty claim cost would be equal to E. On the other hand, if there are no failures, the warranty claim cost would be equal to zero.

The manufacturing cost is a function of (1) the quantity of the products produced (for Figure 1 the quantity is fixed), and (2) the reliability of those products



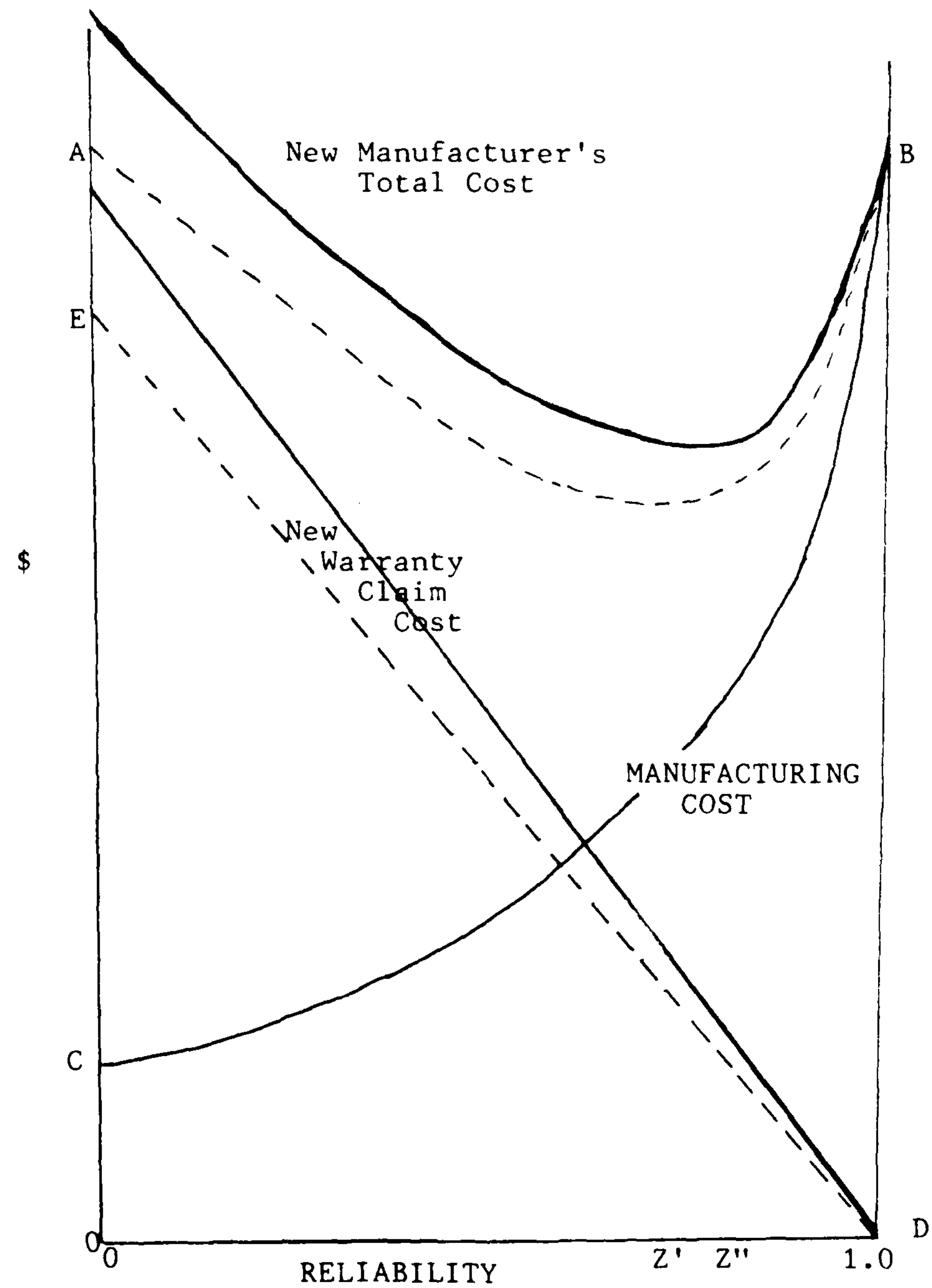
Standard Case of the Manufacturer's Total Cost

Figure 1 (43:5)

produced (43:4). If the given quantity of products in Figure 1 have a zero reliability, the manufacturing cost would be equal to C. However, if the products are 100 percent reliable, the manufacturing cost would be B.

The standard assumption is that the manufacturer is a profit maximizer. A corollary, is that the manufacturer will tend to reduce total cost, or be a cost minimizer for any given level of output. Therefore, in Figure 1 with the level of output (and revenue) fixed, the manufacturer will strive for the cost which corresponds to the minimum point on the total cost curve and is associated with the reliability of Z' (43:6).

The effect of an increase in warranty coverage is graphically shown in Figure 2. An increase in warranty coverage makes the cost of failures more expensive, thus increasing the fixed warranty cost per failure. The shift in the warranty claim cost slope, changes the manufacturer's total cost curve (43:9). The change is shown in Figure 2 where the solid lines are the new cost curves and the dashed lines are the cost curves from Figure 1. The minimum point on the total cost curve also shifts and the associated reliability increases. In Figure 2 the increased reliability is annotated as Z''. Therefore, increases in warranty cost per failure (or warranty claim penalties) motivates the manufacturer to produce units of higher reliability (43:7).



Note: Dashed Lines are Figure 1's costs

The Effect of an Increase in Warranty Coverage

Figure 2

In reality, profit maximizing solutions may be bounded so that the reliability can not fall below a given positive level due to political or market considerations; and also, reliability can not rise above a maximum level due to technological constraints (43:7). The effect of an increase in warranty coverage can also be shown mathematically. The interested reader is referred to Dr. Gill's paper, "Evaluating the Benefits and Costs of DOD Warranties" (43:15).

Using the simple models in Figures 1 and 2, it can be seen that the level of warranty coverage influences the manufacturer's total cost and can motivate the manufacturer to produce more reliable products. Warranties affect the manufacturer's total cost by influencing the warranty claim costs and the manufacturing costs (43:12). The manufacturer makes a trade-off between these two costs. For example, as warranty claim costs increases the manufacturing costs decreases and vice-a-versa (43:12). Analysis of the models shows that increasing the cost of failure to the manufacturer, the warranty claim cost, increases the total manufacturing cost and provides an incentive for the manufacturer to build a more reliable product (43:12).

Defining the Benefits and Costs of DOD Warranties

DOD warranties represent a trade-off between the benefits and the costs of improving reliability. These trade-offs can be evaluated using cost-benefit analysis. In order to make effective comparisons of alternatives, it is necessary to carefully separate costs from benefits (43:7). The following considerations should be made when defining the benefits and costs of DOD warranties.

Defining the Benefits of DOD Warranties. Before describing what the benefits are, let's look at what they are not. Benefits are not cost savings (43:7). For example, if, as a result of a warranty, there are reductions in certain costs, such as fewer repair parts purchased, these advantages are measured when comparing total costs of the different alternatives (43:8). The repair parts for the warranted system are reduced or eliminated in comparison to the cost of operating a non-warranted system. Therefore, the "cost-savings" of purchasing less repair parts should not be considered a "benefit" of the warranty.

DOD benefits relate to mission performance and are improvements in readiness as a result of having more reliable equipment available for use (43:8; 60:26; 73:2-3). Reliability estimates are important to DOD analyses of benefits (43:8). When comparing alternatives, considerations should be given to changes in reliability that are accomplished by warranties and other methods (i.e., increased preventive maintenance; extended development; intensive testing; design redundancy; etc.) (43:8; 73:4).

The benefits of a warranty are the value of the increased performance as result of a warranty when compared to the other alternatives. When evaluating warranty benefits, the important question concerns the change in reliability as a result of the change in warranty coverage (43:8).

Defining the Costs of DOD Warranties. The costs of warranties can be classified as explicit cost and implicit cost. The explicit cost of DOD warranties are the manufacturer's total cost for a given reliability level plus the manufacturer's profit. Because the manufacturer's profit is included in the cost of the DOD warranty, it might be possible for DOD to obtain improved warranty coverage at no additional cost, but instead, at a reduction of the manufacturer's profits (43:9; 77:387). What the DOD pays for the warranty will depend on the negotiating power of the DOD with the manufacturer (43:9). The DOD should not pay more for a change in reliability than the value of the benefit. Also, it should be recognized, the manufacturer's minimally acceptable increase in price, for a change in warranty coverage, is likely to be the change in the manufacturer's total cost; since any lesser price would reduce the manufacturer's profit from previous levels (43:10).

In order to negotiate intelligently for a warranty or a change in warranty coverage, it is important for DOD to estimate the increased product reliability, and also, the impact on the manufacturer's total cost (43:10).

For DOD to estimate the cost of a warranty or a change in warranty coverage for the manufacturer, several values need to be known. DOD needs to know the manufacturing cost of the product, the initial level of reliability, the change in reliability, and the penalty cost per warranty claim (43:10). Estimates of the manufacturing cost require detailed engineering and financial information (43:10). Estimates of the reliability and the warranty claim cost requires knowledge of the number of failures before and after the warranty, and also, an estimate of the contractor's cost to repair/replace the product in accordance with the warranty contract provision(s) (43:10).

Implicit costs to DOD are the costs necessary to enforce the warranty coverage. These implicit costs are costs internal to DOD that are necessary to enforce legal warranty claims (i.e., administrative costs) (43:10). Unless these costs and the actions they represent are identified and controlled, DOD may not be receiving full value of the warranty. For example, if one-half of the warranty claims are not filed or paid because of inadequate administrative costs or poor procedures, then the manufacturer's warranty claim cost is one-half what it should be (43:11). The result could be either the DOD doesn't have reliable products available for missions, or the manufacturer, in order to increase profits, could be producing products that are of lesser reliability than the warranted reliability level.

Implications for the Evaluation of the Benefits and Costs of DOD Warranties

From a theoretical viewpoint, there are several implications with regard to the evaluation of the benefits and costs of DOD warranties. First, for benefits, warranties increase reliability. In order to evaluate the benefits, one has to know or estimate the change in reliability which results from a warranty and the value of the changed reliability in an operational context to DOD (43:12).

Second, for costs, warranties increase the manufacture's total cost. In order for DOD to evaluate the costs one has to know as much as possible about (a) the actual cost (to the manufacturer) of a failure; (b) the number of failures which occur at a given level of warranty coverage; and (c) the manufacturer's cost of building reliability into the product (43:12,13).

With regard to the actual cost (to the manufacturer) of a failure, it is important to realize that the actual cost could differ from implied contractual cost because of the lack of adequate documentation or violation of warranty provisions. In addition, the manufacturer could decrease his actual cost for a failure by making slow or incorrect repairs and by requiring excessive documentation (43:13).

Finally, to evaluate the cost-effectiveness of warranties, the benefits and costs of DOD warranties must be compared to those of other alternatives (i.e., no warranty, increased maintenance, etc.). For DOD, the benefits of warranties are the value of increases in reliability, which increases the products availability for use, net any limitations on use of the product and any reduction in in availability (due to sending the product back to the contractor for repair/replacement) that is sometimes associated with warranties. The cost of warranties include not only the actual contract price, but also the internal cost of documenting and complying with the claim provisions (43:13). These costs are partially offset by lower operating and support costs due to fewer repairs and the costs absorbed by the contractor who repairs/replaces the failed units during the warranty period.

In order for warranties to assure that manufacturers deliver products that will work as advertised at the least cost for the government, reliability and cost information must be collected and used in evaluating the benefits and costs of DOD warranties.

In the next chapter the focus will be on jet engine warranties, particularly, the history of AF engine warranties, the acquisition of engines and warranties, and the selection of engines to be studied.

III. Air Force Jet Engine Background

This research is limited to a consideration of the information available for evaluating the costs and benefits jet engine warranties. In order to facilitate the discussion, this chapter provides a brief history of engine warranties in the Air Force. In addition, information on Air Force procedures pertaining to engines is given. Finally, the specific engines studied are identified.

Past History of Air Force Engine Warranties

Commercial airlines were the leaders in the area of aircraft engine warranties. Commercial airlines received extensive warranties from engine manufacturers for a number of years prior to the same type of warranties being applied to Department of Defense aircraft engines (34:8; 48:12; 82:9). The engine manufacturers were reluctant to provide other than limited warranties to the Air Force; because they considered it too risky with respect to the military aircraft operational and maintenance environment (34:10; 48:13,14; 82:11).

The only warranty provision that was widely used by the Air Force for engines was the Correction of Deficiencies (COD) clause, which required the contractor to correct any condition that was not in compliance with the contract (34:10; 82:13). The limitation for the Air Force was that the COD clause only covered direct or primary damage (damage suffered by a part due to it own failure) (82:13). In addition, it was difficult to prove that the contractor was at fault for the deficiency (34:10).

In 1972, a study was conducted for the Assistant Secretary of Defense for Installations and Logistics on "Methods of Acquiring and Maintaining Aircraft Engines." Among the conclusions resulting from the study were the following:

> The aircraft engine warranty has been successful in circumstances where the management, maintenance, and operation of the engine were highly controlled. The usual military environment does not permit such control (23:II-3).
>
> A warranty almost always reduces life cycle support costs by reason of the warranty (34:11).

The study recommended "against the use by DOD of aircraft engine warranties at this time," and that "continued research and analysis into specific application of warranties to military aircraft engines should be encouraged" (23:II-3).

The Air Force continued to assess the advantages of engine warranties in the commercial sector and their applicability to military aircraft engines (23:II-3; 34:11,12).

In 1978, General Alton D. Slay, then the Commander of Air Force Systems Command, directed procurement agencies to explore and implement useful commercial contracting practices which included warranties (48:2,15; 82:3). From this direction, the Deputy for Propulsion, Aeronautical Systems Division initiated a number of studies for engine warranty application (48;2,16). Out of the initial research, warranties for military engines were requested in Air Force engine proposals (23:II-3; 82:13).

By 1980 the Air Force had a few warranties on jet engines. Each of these warranties was unique and designed to meet the specific needs of the program and the individual engine (65). As time went on, the number of engine warranties being applied increased, in part due to Congressional action.

In 1982, Congressional action specifically addressed the warranty of the Air Force's alternate fighter engine with the 1983 Defense Appropriation Act, Section 797 of Public Law 97-377. Briefly, the act stated that no funds would be provided to purchase the alternate fighter engines unless a specific warranty was written in the contract (21; 23:II-4, II-6).

The evolution of engine warranties resulted in two documents, the Model Engine Warranty and the Joint Engine Warranty Development Guide. In 1981, the Model Engine Warranty was developed to reduce the effort required to create an engine warranty (82:19). The model, influenced by commercial and military warranties, provided a baseline that could be tailored to fit individual engine programs (65).

In October 1984 the Joint Engine Warranty Development Guide (for military aircraft turbine engines) was published. A Joint Logistics Commanders' ad hoc group with warranty expert representatives from the Air Force, the Army, and the Navy developed and co-authored the guide (80:36). Its purpose was to tie together the technical information needed by program managers, and to provide a framework for creating and applying engine warranties (80:36).

From this brief history of engine warranties, it can be seen that the use of Air Force engine warranties (other than COD) is relatively new. However, substantial interest and involvement have made engine warranties for the Air Force far more than exploratory and has increased their use on engine contracts.

Background Information on Acquisition of Air Force Engines and Warranties

To introduce the reader to specific Air Force processes that pertain to engines, this section will present some general background information. Specifically, information will be provided on the engine acquisition cycle, the timing of warranty application, and relevant organizational structure and process of obtaining an engine warranty.

Engine Acquisition Cycle. The engine acquisition process conforms to the phases or life cycle for Major Defense Systems Acquisition found in DOD directive 5000.1. The acquisition life cycle is essentially a logical flow of activity representing on orderly progression from an identification of a system need to final operational deployment (29). It can be described as a four phase process. Included in the acquisition cycle are the concept exploration phase, the demonstration and validation phase, the full scale development phase, and the production and deployment phase (29).

In the first phase, the concept exploration phase, the need for a new system is identified. Initial research is done to define the system that will best meet the need. This is followed by the definition of the base line requirements for such a system (29).

The acquisition process then moves into the demonstration and validation phase. Those systems that have met the base line requirements are further studied. Within this phase, system requirements are more closely identified and defined. This narrows the field to perhaps two or three contractors whose designs meet the specifications. Prototypes may be developed to demonstrate the validity of the particular design for meeting the governments's need. At the end of this phase, one design is selected for full scale development (29).

In the full scale development phase, the selected design is developed in even more detail than in the previous phases. Also, specifics for further system development and construction are worked out, and the production contracts are formalized. With the system in detailed form and the contract for production finalized, the system then moves into the final phase (29).

In the production and deployment phase, the new system goes into production and is distributed to the user. In addition, throughout the phase, follow-on production may be contracted and engineering improvements may continue during the production and use of the product (29).

In the Air Force, the Air Force Systems Command (AFSC) is responsible for the acquisition of major systems. Within AFSC are a number of product divisions. One of these divisions is Aeronautical Systems Division (ASD) which is located at Wright-Patterson Air Force Base, Ohio. ASD directs the design, development, and acquisition of major aerospace systems. These include manned bombers and fighters, trainers, transports, utility aircraft, unmanned vehicles, long- and short-range air-to-surface missiles, simulators, reconnaissance and electronic warfare equipment, and related equipment (10:61-63).

Within ASD, the Deputy for Propulsion organization is responsible for acquiring the aircraft engines, although the funds for the engines are provided by the aircraft system program office (SPO) (26). For example, the Deputy for B-1B provided the funds to the Deputy for Propulsion to acquire the F101-GE-102 engines used in the B-1B aircraft. The acquisition cycle for both the engines and the airframes

<table>
<tr><td>I
Concept
Exploration
Phase</td><td>II
Demonstration
and Validation
Phase</td><td>III
Full Scale
Development
Phase</td><td>IV
Production/
Deployment
Phase</td></tr>
<tr><td colspan="2">YZN, New Engines</td><td>YZS, Adv Tactical Fighter
YZA, Airlift/Trainer
YZF, Tactical
YZY, Strategic</td><td>PMRT
to ALC</td></tr>
</table>

Acquisition Phases and Responsible Propulsion Directorate

Figure 3

occurs simultaneously. The aircraft SPO establishes the delivery schedule for the engines which are provided to the airframe contractor as government furnished equipment (26).

The program management for an engine changes during the acquisition cycle. Illustrated in Figure 3 is a generic overview of the engine acquisition cycle and the responsible program manager; however, tracing the acquisition of a specific engine could result in a modification (combination/omission) of the acquisition phases (26).

During the early acquisition phases (I and II in Figure 3) the responsible program manager is in the New Engines SPO (YZN) under the Deputy for Propulsion. Sometime during the demonstration and validation phase (II in Figure 3) and through a portion of the production/deployment phase (IV in Figure 3), a program manager in a specific propulsion SPO is identified to continue the acquisition management. The specific propulsion SPO is usually identified by the type of aircraft for which the engine is being made. As an example, the program manager for the B-1B engines is in the Strategic Engines SPO. During the deployment phase (part of IV in Figure 3), management responsibility of the engine is transferred to an Air Logistics Center (ALC) through Program Management Responsibility Transfer (PMRT). However, the Deputy for Propulsion remains responsible for the Air Force's procurement of engines (26).

Applying Engine Warranties. Having looked at the engine acquisition cycle, the next question is when during the acquisition cycle can the engine warranty be applied. Simply, an engine warranty can be applied either early or late in the acquisition cycle (48:23). Each has its own advantages and drawbacks as explained below.

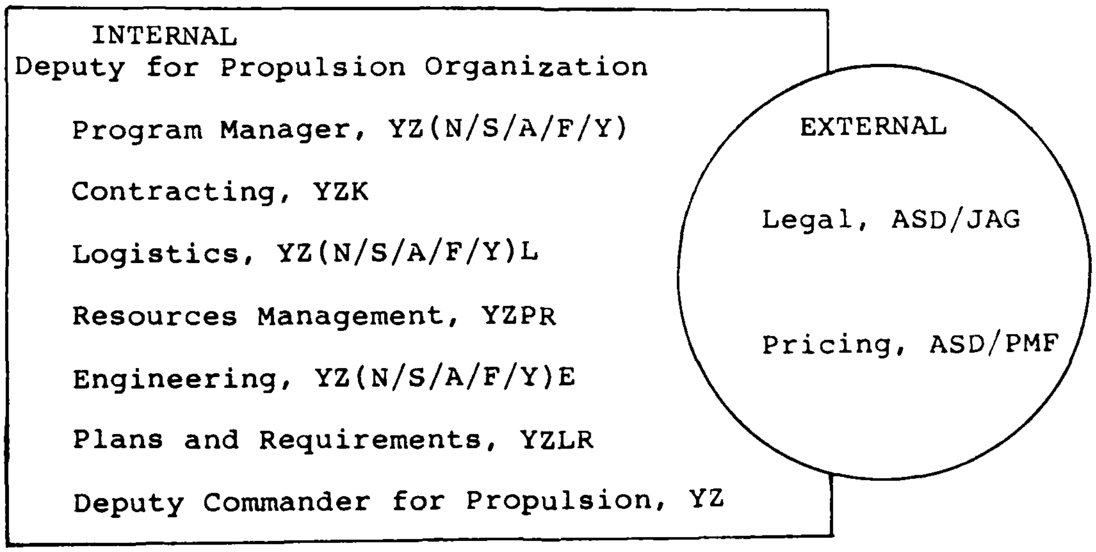
An early warranty application could occur during the end of the concept exploration phase in which several contractors may be bidding against each other (48:23; 82:20). Although the competition would be favorable for the government, the drawback would be that it is early in the program and the engine specifications are not well known (48:23 82:20,21). The result may make actual contract price negotiations between the Air Force and the contractor difficult (48:23).

A late warranty application could occur during the development and production phase. The main advantage may be that firm data on engine failures and reliability would be available (48:23). However, the drawback is that there may be only one contractor bidding which could result in the government not being able to receive the advantages of competition.

Ideally, warranties are developed after field failure data has been accumulated from operational tests conducted during the demonstration and validation phase; then, they are implemented during the full scale development or the production phase (82:21).

Obtaining an Engine Warranty. The next procedure to be examined is obtaining an engine warranty. Specifically, the individuals involved and the process of obtaining an engine warranty will now be discussed.

As shown in Figure 4, the sequence of events taken to obtain an engine warranty involves the interaction of



Functional Disciplines Involved to Obtain an Engine Warranty

Figure 4

individuals from several functional disciplines, both internal and external to the Deputy for Propulsion organization. The internal individuals include the Deputy Commander for Propulsion, the program manager, and personnel from contracting, logistics, plans and requirements, resources management, and engineering; the external individuals are personnel from legal and pricing (66).

Illustrated in Table I, are the steps in the process of obtaining a warranty and who is involved. As the illustration is a general overview, the timing and occurrence of each step is dependent on the engine program (66).

Steps 1 through 8 are performed prior to negotiations in order to establish the Air Force position of the value of a warranty in relationship to the systems Life Cycle Cost (LCC).

The program manager establishes the warranty objectives. Then the warranty clause is written. The responsible functional discipline for writing the warranty clause is dependent on the specific engine program. Typically, the responsibility has been from one of the following functions: plans and requirements, program manager, or contracting (66).

The warranty clause is reviewed by legal, contracting, and logistics to determine if it is both in compliance with the law and is enforceable. LCC estimates of the system are

TABLE I

OBTAINING AN ENGINE WARRANTY

STEPS	WHO DOES
1. Establish warranty objectives	Program Manager
2. Review and interpret warranty	Legal/Contracting/ Logistics
3. Obtain latest Life Cycle Cost (LCC) Data	Logistics
4. Obtain current warranty price data, including Government administration cost	Resources Management/ Contracting
5. Perform technical evaluation	Engineering
6. Calculate warranty benefits	Plans and Requirements
7. Perform LCC analysis	Plans and Requirements/ Resources Management
8. Issue Request for Proposal	Contracting
9. Begin negotiations	Contracting/Pricing
10. Conduct Risk Assessment	Engineering
11. Perform reliability/ sensitivity analysis	Plans and Requirements/ Engineering
12. Conclude Negotiations	Contracting
13. Perform cost-benefit analysis	Plans and Requirements
14. Make cost effectiveness determination	Program Manager/Deputy Commander for Propulsion
15. Place warranty on contract or initiate waiver request	Contracting

obtained for both with and without the warranty (steps 3 through 7).

During negotiations (steps 9 through 12) additional data that could change the LCC estimates are considered. The Air Force conducts a risk assessment and performs reliability/sensitivity analysis. The LCC analysis is updated.

After negotiations (steps 13 through 15) a cost-benefit analysis is completed and a cost effectiveness determination is made. Finally, if the warranty clause is determined to be cost effective it is put on contract. On the other hand, if the warranty clause is not determined to be cost effective a request for a warranty waiver is initiated.

Currently, there is no official definition for cost effectiveness criteria (9:31; 23:II-31-II-34). The criteria currently used by the Deputy for Propulsion organization to make the cost effectiveness decision for engine warranties is based on the contractor's profit margin allowed on the contract. The warranty is considered cost effective if the profit margin for the warranty is equal to or less than the profit margin allowed on other parts of the contract (66).

For example, assume (1) that the profit margin for the contract is 15%; and (2) that the government's costs minus benefits in the cost-benefit analysis is considered to be the contractor's warranty profit. Then, the warranty is considered cost effective if the estimated warranty profit to the contractor is less than or equal to 15% of the government's costs for the warranty.

The warranty clause put on contract not only specifies the warranted conditions, but could also request that the contractor is to provide cost and reliability data to the government. The cost and reliability requests are put on contract by using the contract data requirements list (CDRL) (66).

The preceding background information briefly introduced the reader to some of the procedures of acquiring engines and engine warranties. In addition, some differences that can occur were highlighted. For example, during the engine's acquisition cycle the program management changes and engine warranties can be applied at different times. Also, many individuals are involved with obtaining an engine warranty, and the timing and occurrence of the steps in the process can be engine program specific. The next section will identify the specific engines to be studied in this research.

Identifying the Specific Engines to be Studied

In order to determine which engines to study, a list of jet engines currently in the Air Force Inventory was compiled, see Table II. The list shows the model designation of the engine, the aircraft(s) using the engine, the manufacturer, and if there is/was an engine warranty.

TABLE II

JET ENGINES CURRENTLY IN THE AIR FORCE INVENTORY

Engine Model Designation	Aircraft Using Engine	Engine Manufacture	Warranty
F100-PW-100	F-15A/B/D; YF-15A	PW	YES
F100-PW-200	F-16A/B/C/D	PW	YES
F101-GE-102	B-1B	GE	YES
F108-CF-100	KC-135R	GE	YES
F109-100	T46A	GARRETT	YES
F100-PW-220	F-15C/D/E	PW	YES
PW 2037	Proposed C-17	PW	YES
F110-GE-100	F-16D/C	GE	YES
TF34-GE-100	A-10A/B	GE	YES
J85-GE-5	T-38A	GE	NO
J85-GE-5L	AT-38B; T-38A	GE	NO
J85-GE-13C/-13D	F-5B	GE	NO
J85-GE-17(POD)/-17A	C-123K; A/OA-37B	GE	NO
TF39-GE-1A/-1C	C-5A/B	GE	NO
J85-GE-21A/-21B	F-5E/F	GE	NO
J69-T-25/-25A	T-37B	TELEDYNE	NO
T76-G-10A/-418	OV-10A LEFT	GARRETT	NO
T76-G-10A/-419	OV-10A RIGHT	GARRETT	NO
J57-P-19W/-29WA	NB-52B; B-52D	PW	NO
J57-P-43WB	C/NC/NKC-135A; EC-135H; B-52G	PW	NO
J57-P-59W	C/EC/KC/NKC-135A; EC-135D/Q; EC-135G/L	PW	NO
J79-GE-15	F/RF-4C; F-4D	GE	NO
J79-GE-17	F-4E/G	GE	NO
J75-P-17	F-106A/B	PW	NO
J75-P-19W	F-105D/F	PW	NO

NOTE: PW = PRATT WHITNEY
GE = GENERAL ELECTRIC

Continued next page

TABLE II (Continued)

JET ENGINES CURRENTLY IN THE AIR FORCE INVENTORY

Engine Model Designation	Aircraft Using Engine	Engine Manufacture	Warranty
TF33-P-3	B-52H	PW	NO
TF33-P-5	C/EC/WC-135B; C-135C; RC-135M/S/W	PW	NO
TF33-P-7/-7A	C-141A/B; NC-141A	PW	NO
TF33-P-9	EC-135C/J; RC-135U/V	PW	NO
TF33-PW-100	E-3A	PW	NO
TF33-PW-102	C/EC/KC/NKC-135E; EC-135H/K/P; RC-135T	PW	NO
T33-PW-102A	C-18A	PW	NO
TF41-A-1A/-1B	A/AY-7D; A-7K	ALLISON	NO
TF30-P-3	F/EF-111A; F-111F	PW	NO
TF30-P-7	FB-111A	PW	NO
TF30-P-9	F-111D	PW	NO
TF30-P-100	F-111F	PW	NO
T56-A-7B	C-130B; C/EC/WC-130E	ALLISON	NO
T56-A-9B/-9C/-9D	AC/C/DC-130A; C-130D	ALLISON	NO
T56-A-15	MC-130E; HC-130N/P; AC/C/DC/EC/HC/WC-130H	ALLISON	NO
J33-A-35/35A	T-33A	ALLISON	NO
F103-GE-100	E-4A/B; KC-10A	ALLISON	NO
JT3D-3B	VC-137B/C	PW	NO
JT8D-9	C-9A; T-43A	PW	NO
J58	SR-71A	PW	NO
J60-P-3/-3A	CT/NT/T-39A; T-39B	PW	NO
J60-P-5A/-5B	TR-1A/B	PW	NO
PT6A-20	C-6A	PW	NO
PT6A-27	UV-18A	PW	NO

NOTE: PW = PRATT WHITNEY
GE = GENERAL ELECTRIC

The criteria used to select the engines for this research was that the engines have an expired warranty. This criteria was chosen in order to make sure all the costs would have been incurred for the assessment of the cost effectiveness.

The selection criteria narrowed the choices to some of the F100-PW-100 and F100-PW-200, and the TF34-GE-100 engines. The F100-PW-100 engines are used to power the twin engine McDonnell Douglas F-15 Eagle fighter aircraft, and the F100-PW-200 engines power the single engine General Dynamics F-16 aircraft; these engines were produced by Pratt and Whitney Group of United Technologies Corporation (51:885). The TF34-GE-100 engines are used to power the twin-engined Fairchild Republic A-10A Thunderbolt II; they were produced by General Electric Company Aircraft Engine Business Group (51:870).

From these engines, a judgmental selection was made based on how long the warranty has been in effect, the number of claims processed, and the limited time to conduct this research. The engines selected were the F100-PW-100 and the F100-PW-200 which are no longer under warranty; specifically, Lot IX engines. [A "Lot" is an annual purchase of engines.] Hereafter the F100-PW-100 and the F100-PW-200 will be simply refered to as the F100 engines.

Table III provides a description of the warranties used for the F100 engines.

TABLE III

F100 ENGINE WARRANTY DESCRIPTIONS

Supply Warranty

The contractor, Pratt and Whitney, warranted that they would repair or replace any part found to be defective in material or workmanship within 240 days of first installation in an aircraft when installed within one year after acceptance date.

High Pressure Turbine Warranty

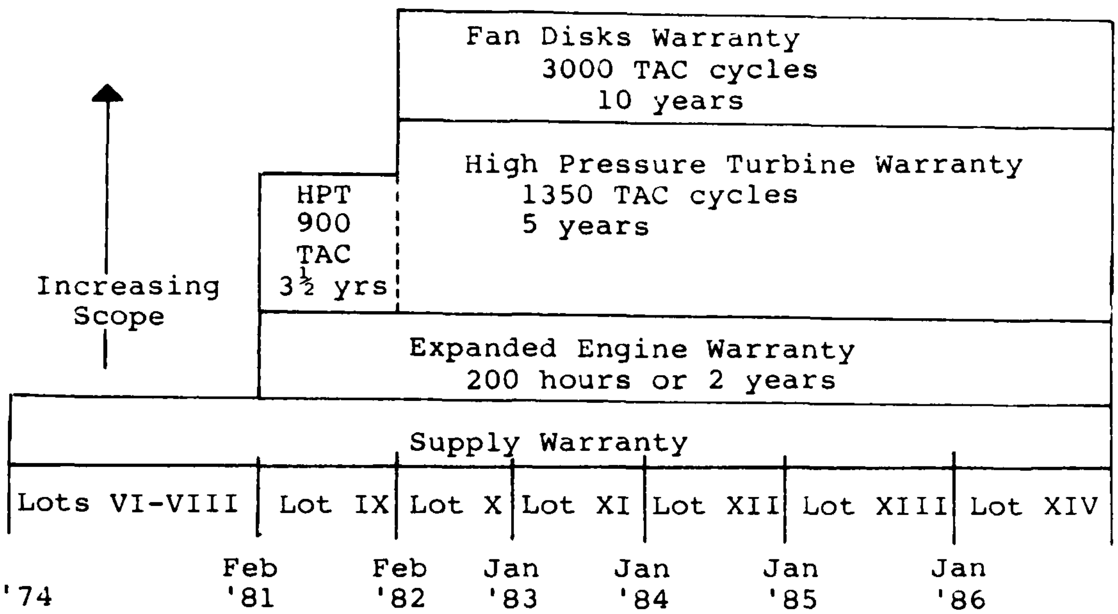
The contractor warranted that they would repair or replace high pressure turbines found to be unserviceable to the limits of the technical orders for durability reasons within 900 equivalent Tactical Air Command (TAC) cycles or 42 months from acceptance date whichever occurred first.

Expanded Engine Warranty

The contractor warranted that they would repair or replace any engine, module, or accessory found to be unserviceable to the limits of the technical orders within the first 200 hours total operating hours (TOT) or two years from acceptance date, whichever occurred first. Also, this warranty covered secondary damage to the warranted engine.

Fan Disk Warranty

The contractor warranted the fan disk against any disk failure caused by a manufacturing flaw for a period of 3000 equivalent TAC cycles or ten years after original acceptance date.



Growth of F100 Warranty Coverage

Figure 5 (Adapted from 40:2)

The warranty history of the F100 engines can be seen in Figure 5. As Figure 5 shows, the warranty coverage on the F100 engines has increased in scope with subsequent production Lots.

The F100 engines had been covered by the Supply Warranty clause since the beginning of its production Lots (81:17). This clause protects the government against defects in material and workmanship.

Additional coverage, the High Pressure Turbine Warranty, was offered to the government for Lot IX engines at no increase in the price. Even though there was no increase in the contract price, the government considered the additional pipeline costs in shipping and repair times which would result in meeting the warranty requirement, that all repairs were to be made at the contractor's (Pratt and Whitney) facilities rather than the government depot. A determination was made to accept the coverage in view of substantial positive benefits (81:17,18).

Both primary and secondary damage was covered; a "first" in military coverage for a fighter jet engine. This gave the military warranty coverage similar to the coverage that had been offered to the commercial aircraft industry for years (38).

The High Pressure Turbine Warranty was followed with the addition of the Expanded Engine Warranty. This Lot IX warranty was developed and applied due, in a large part, to the emphasis Headquarters Air Force Systems Command was placing on the desire for more meaningful warranties. Before this warranty was applied, the government was eight years and 1845 engines into the F100 program (38).

Beginning with Lot X F100 engines, the High Pressure Turbine Warranty was expanded to include coverage for 1350 Tactical Air Command (TAC) cycles [a cycle is a unit of measure for engines] or five years from the acceptance date. Also, beginning with the Lot X engines, all fan disks supplied in the engine and modules were warranted for a period of 3000 TAC cycles or ten years after the acceptance date (23:III-8).

In this chapter a brief history of Air Force engine warranties was given. Background information on selected Air Force procedures pertaining to engines and engine warranties was provided. Finally, a selection of the engines to be used in this study was made. The next chapter will discuss the feasibility of obtaining the information required for assessing the benefits and costs of jet engine warranties using the approach described in chapter two.

IV. Evaluating and Measuring Engine Warranty Costs and Benefits

The purpose of this chapter is to determine the feasibility of obtaining the information required for assessing the benefits and costs of jet engine warranties. In order to do this, the nature and availability of the information needed to analyze DOD warranties is described. Specifically, the information required to evaluate and measure warranty costs and benefits is discussed along with examples of data obtained from engine warranties. The first section considers the information required to evaluate warranty costs. Next, the problems involved in measuring warranty costs are considered and some of the problems found in obtaining these costs are discussed. Finally, the problems involved in evaluating and measuring warranty benefits are approached in the same manner.

Evaluating Warranty Costs

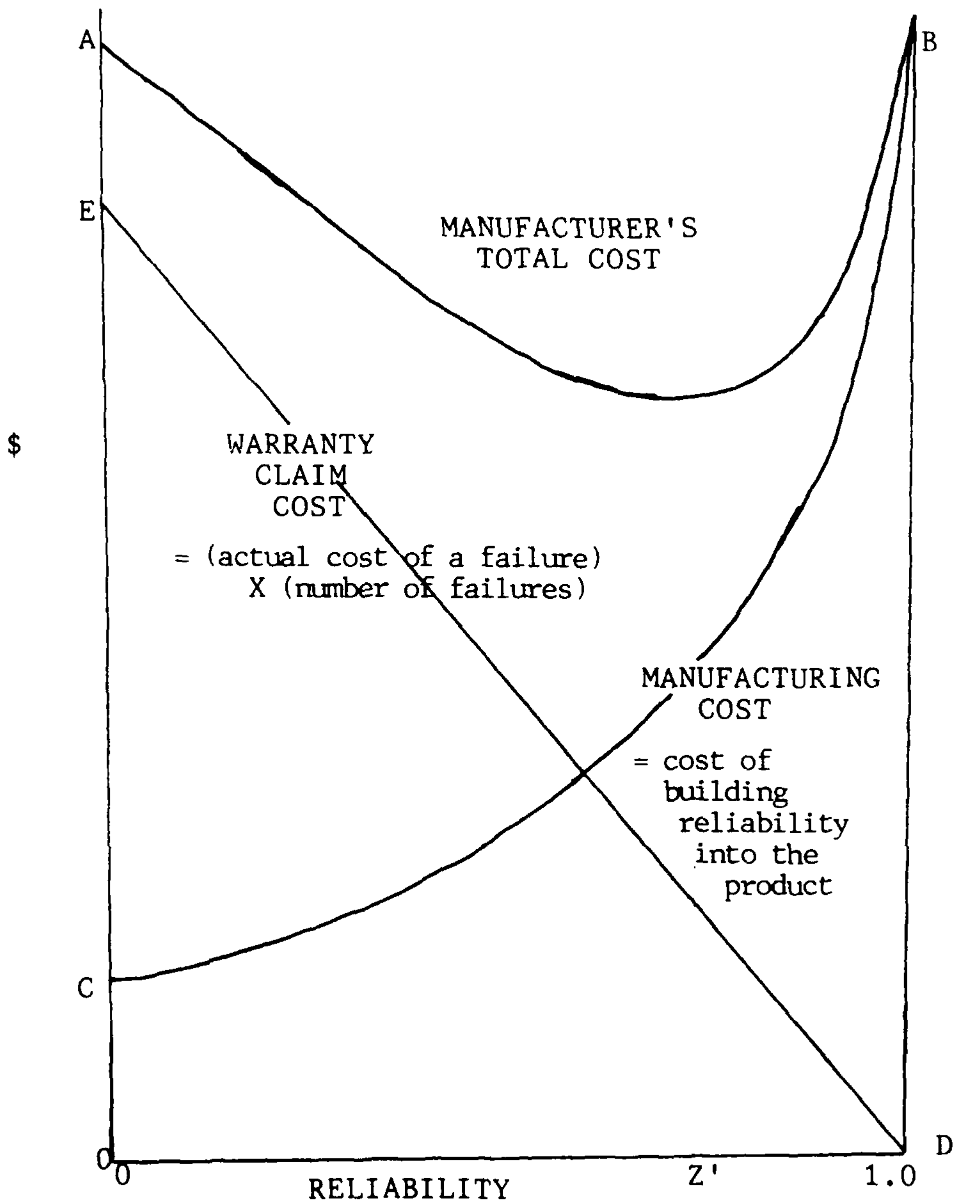
In chapter two the information required to evaluate the cost of DOD warranties was identified. The costs to DOD were classified as explicit and implicit. The explicit cost of warranties was defined as the manufacturer's total costs for a given reliability level plus the manufacturer's profit. The implicit cost of warranties was defined as DOD's costs necessary to enforce the warranty.

The model in chapter two, illustrated again in Figure 6, describes the manufacturer's total cost as a function of the manufacturing cost and the warranty claim cost. The manufacturer can make a trade-off between these two costs. In addition, the manufacturer, in order to maximize profit (when revenue is assumed to be fixed), strives for the cost which corresponds to the minimum point on the total cost curve.

As explained in chapter two, in order to make the best decisions regarding warranties, it is necessary know the costs to the manufacturer and the costs to DOD. With regard to the manufacturer, relevant costs are the actual cost (to the manufacturer) of a failure, the number of failures which occurred at a given level of warranty coverage, and the manufacturer's cost of building reliability into the product. From a DOD perspective, it is necessary to know the price paid for the warranty (the explicit cost) and also, the internal cost of documenting and complying with the warranty claim provisions (the implicit cost).

Interpretation of Terms. Before expounding on measuring the costs to the manufacturer and the costs to DOD, it will be useful to interpret the terms "failure" and "reliability" as used in the model (Figure 6).

Defining "Failure". "Failure" is a generic term used in the model to describe a condition that the manufacturer is responsible for correcting. When discussing



Standard Case of the Manufacturer's Total Cost

Figure 6 (43:5)

warranties, "failure" can take on a number of meanings. As an example, it could mean a complete breakdown in the operation of an item, or it could mean a partial breakdown of the item. For a partial breakdown, the item may still operate, but not at 100% capability.

Unless "failure" is explicitly defined, there could be problems in determining who is responsible for fixing the breakdown. For the user, any breakdown of the item should be fixed by the manufacturer. On the other hand, for the manufacturer, any correction would cost money and decrease profits. Therefore, the manufacturer may be reluctant to fix the item.

A warranty clause can alleviate the ambiguity of the term "failure" by describing the condition under which a claim can be made. Also, the warranty clause can make the responsibility for fixing the item legally binding. Engine warranty clauses provide an illustration of the diversity of the term "failure."

A jet engine is a complicated piece of hardware with 3500 plus parts and a great number of ways it could fail, or not function as specified. The engine "failures" that are warranted (to be corrected by the contractor), are explicitly described in the contracts between the Air Force and the contractor. Two definitions of warranted engine failures follow.

The first example is from the F100 Lot IX engine contract. One of the warranties in that contract was the Expanded Engine Warranty. A failure under the terms of this warranty was described as the condition when an engine, module, or specified component was not serviceable in accordance with procedures specified in applicable technical orders (4:Atch 8).

The second example is from the F101-GE-102 Lot II engine contract. One of the warranties in that contract was the Unscheduled Engine Removal and Selected Controls and Accessories (C&A) Removal Warranty. A failure under the terms of this warranty was described as the condition when the fleetwide unscheduled engine removal rate per 1000 engine flying hours was greater than specified. In addition, another type of failure occurred if the combined unscheduled removal rate of C&A exceeded specified parameters (5:11).

Defining "Reliability". "Reliability" is a generic term used in the model (Figure 6) to describe the quality of the product. It is defined in the Compendium of Authenticated Systems and Logistics Terms, Definitions and Acronyms, as "the probability that a system, subsystem, or equipment will perform a required function under specified conditions without a failure, for a specified period of time (59:576).

There are three variables in the term reliability: "specified conditions," "failures," and "time." These terms must be strictly defined when applying any reliability parameter to a warranty. When discussing warranties, "reliability" can take on different meanings. Therefore, it is important, when measuring the costs of warranties, that the term reliability is defined for the specific warranty being evaluated. Engine warranties can provide an illustration of the differences in meanings. Two examples are provided below.

The first example is from the F100-PW-220 engine contract. The Warranty Part 1 describes one engine performance parameter. The contractor warrants that the performance of each engine delivered, for the period specified, shall not be less than 98% of the intermediate thrust as set forth in specification and shall not exceed 105% of the intermediate specific fuel consumption as set forth in the specification (6:205).

The second example is from the F100 Lot IX engine contract. The Warranty of Supply describes the quality parameter of the product. The contractor warrants that at the time of delivery all supplies f rnished under this contract shall be free from defects in material and workmanship and shall conform with the purchase description and all other requirements of this contract (3:85).

From the interpretation of the terms "failure" and "reliability" used in the model (Figure 6), it can be seen that they can represent many different ideas. In addition, when they are used in discussing warranties, each term must be explicitly defined.

Measuring Warranty Costs

To measure warranty cost, DOD must obtain or estimate the costs to the manufacturer and the costs to DOD.

Manufacturer's Costs. For the manufacturer, three elements of information are required. One, the actual cost of a failure. Two, the number of failures. Three, the cost of building reliability into the product.

Actual Cost of a Failure. The first element of information to measure costs to the manufacturer is the actual cost of a failure.

What is Required. The cost of a failure depends on the contract warranty clause and what the contractor's obligations are. The contractor's obligations can include the costs to remedy or take corrective action when a warranted failure occurs. Costs are also incurred by providing a warranty on the item. The cost include the cost of preparing reports to be submitted to the government, and also, the cost of a program in order to administer the warranty claims (13:4-13; 46:117). An explanation of the manufacturer's remedy, report, and administration costs follows.

Remedies. The way in which the contractor will correct the failure is called the remedy and is specified in the contract. According to the Defense Federal Acquisition Regulation Supplement, there are three basic remedies the contractor can take (13:D-4). One, the contractor takes such action as repair, replace, and/or redesign at no additional cost to the government. Two, the contractor is responsible for reimbursing the government for actions taken to correct the failure. Three, the contractor provides an equitable adjustment, such as a reduction in contract price, in the event of a failure.

Engine warranties have been written in which the contractor was required to take corrective action of a failure. One example is in the F100 Lot IX High Pressure Turbine Warranty. In addition, engine warranties have been written in which the government would receive an equitable adjustment in the contract price when a failure was repaired by the government. One example is in the F101-GE-102 Lot II Warranty Part I.

Reports. The contractor is sometimes required to provide reports pertaining to the warranty corrections. These reports can be used by the government to implement certain warranted turnaround times, to maintain appropriate inventory and configuration control, and to assess the effectiveness of the warranty (13:4-13).

For engines, warranty reports required from the contractor are identified in the warranty clause of the contract. An example of one type of report is a monthly warranty performance report. With the report, the contractor provides data of the action taken under the warranty including the cost of the action. This type of report was required by the contractor for the F100 Lot IX Expanded Engine Warranty. The monthly report, Contractor Warranty Cost Report, included the item nomenclature, the serial or part number, the total operating time [the reliability measurement being warranted], the reported problem, the number of days to satisfy claim [turnaround time], and the costs incurred, both during the month and upto the reporting date.

Contractor Warranty Administration. A contractor's program to administer the warranty claims can involve office personnel, engineering and manufacturing functions, and also, establishing an area for working on failures and/or storing replacement parts for anticipated failures (46:117). An example of a program to administer engine warranty claims follows.

For one engine contractor, there is an organizational group which is responsible for the overall management, repair disposition, vendor direction, coordination with the Air Force, and reporting on the warranty program efforts. In addition, warranted item repair facilities are located at the contractor and some of its vendor plants (35:32).

Obtaining the Cost of a Failure. For DOD to obtain the manufacturer's cost of a failure, two possible scenario's exist with regard to timing. The first involves obtaining the information prior to the warranty in order to perform the cost-benefit analysis and pricing the warranty. The second scenario involves obtaining the information after the warranty expires in order to evaluate the warranty effectiveness.

Prior to the Warranty. Prior to the warranty, DOD estimates the manufacturer's cost of a failure based on technical analysis of projected failures and the contractor's remedy cost for those failures (7; 51:7-4,7-5; 66). Also, the manufacturer's cost could be provided by the contractor during its proposal submission (66; 69). To acquire a warranty with an item, the government obtains the contractor's proposal of the warranty price. Under the disclosure requirements of Public Law 87-653, Truth in Negotiations Act, the contractor is responsible for substantiating the proposal with current, accurate, and complete cost and pricing data (46:87; 67:41; 69). The proposal is subject to audit by the Defense Contractor Audit Agency. For some contractors, because warranties have only recently become mandatory, there is lack of a historical warranty data base to support the proposal (74). However, for engine contractors, this is not true (69). For example, one engine contractor maintains a warranty cost accumulation system that has been operational for over 25 years (59:31).

After the Warranty Expires. After the warranty expires, if there was a requirement in the contract for the contractor to submit information for the cost of a failure, then it could be used for evaluating the warranty.

This was the case for the F100 Lot IX Expanded Engine Warranty. The report titled, Contractor Warranty Cost Report, provided the cost incurred for the reporting period and total expenditures as of the reporting date. The report listed the warranty cost for the F100-PW-100 engines, that power the F-15 aircraft, separately from the warranty cost for the F100-PW-200 engines, that power the F-16 aircraft. In addition, the cost were divided into three categories: engine/module; components; and tooling. The total contractor's costs, shown in Table IV, was $4,914,000.

TABLE IV

Total Contractor Warranty Cost for F100 Engine Lot IX

(Adapted from 7)

Engine Type	F100-PW-100	F100-PW-200	Totals
Engine/Modules	723,000	---	723,000
Components	3,071,000	135,000	3,206,000
Tooling	985,000	---	985,000
Total	$4,779,000	$ 135,000	$4,914,000

Also, Table IV shows that the distribution of the cost was $4,779,000 for the F100-PW-100 engines and $135,000 for the F100-PW-200 engines.

After the warranty expires, if there was not a contract requirement for the contractor to submit information for the cost of a failure, it would be difficult to obtain the information.

One suggested method to obtain the data is to use Air Force maintenance records. To first, determine the failures of the units covered by the warranty. Secondly, to estimate the costs of the failure by using labor/material cost and/or the cost of replacement parts. Finally, use the estimates as the cost of the warranty claims in evaluating the warranty. Two problems occur with this method. The first problem, is that the maintenance data may not be accurate due to inherent errors in military data collection systems (13:4-4; 61; 79). One cause for the errors is that no entry or an incorrect entry is made when a failure occurs, because the maintenance worker, who is responsible for making the entry, has no vested interest in the accuracy or the usefulness of the data (61). The second problem with using the maintenance records is that the other contractor claim costs, such as preparing reports, administering the warranty, and operating repair facilities, are not considered. This would result in an underestimated warranty claim cost for the contractor.

Number of Failures. The second element of information required to measure the cost to the manufacturer, in order to evaluate a warranty, is the number of failures. As previously noted, a failure is a warranted condition that the contractor is required to remedy. Also, the term failure must be explicitly defined in the warranty clause.

What is Required. The number of failures is needed in order to evaluate the warranty cost. According to the 1986 Government Contract Costs Manual, the contractor and the government must have some idea of the number of failures in order to price a warranty (46:117). The difficulty in estimating the expected number of failures contributes to the risk of the warranty (13:3-14). For example, take the case of a new item being produced. The new item has no historical data to use for estimating the expected number of failures. The risk to the contractor, is the potential liability that may be incurred if the number of failures is underestimated. The risk to the government if the number of failures is overestimated, is the potential that the warranty claim cost (a function of the number of failures and the cost of the failures) will not assure a reliable product is delivered and/or that the government will pay too much for the warranty.

On the other hand, take the case of the item that is in production. The historical failure data on previous lots provide information to both the government and the contractor (13:3-14). This data can be used to better estimate the expected number of failures. Thus, reducing the risk to both parties.

Obtaining the Number of Failures.

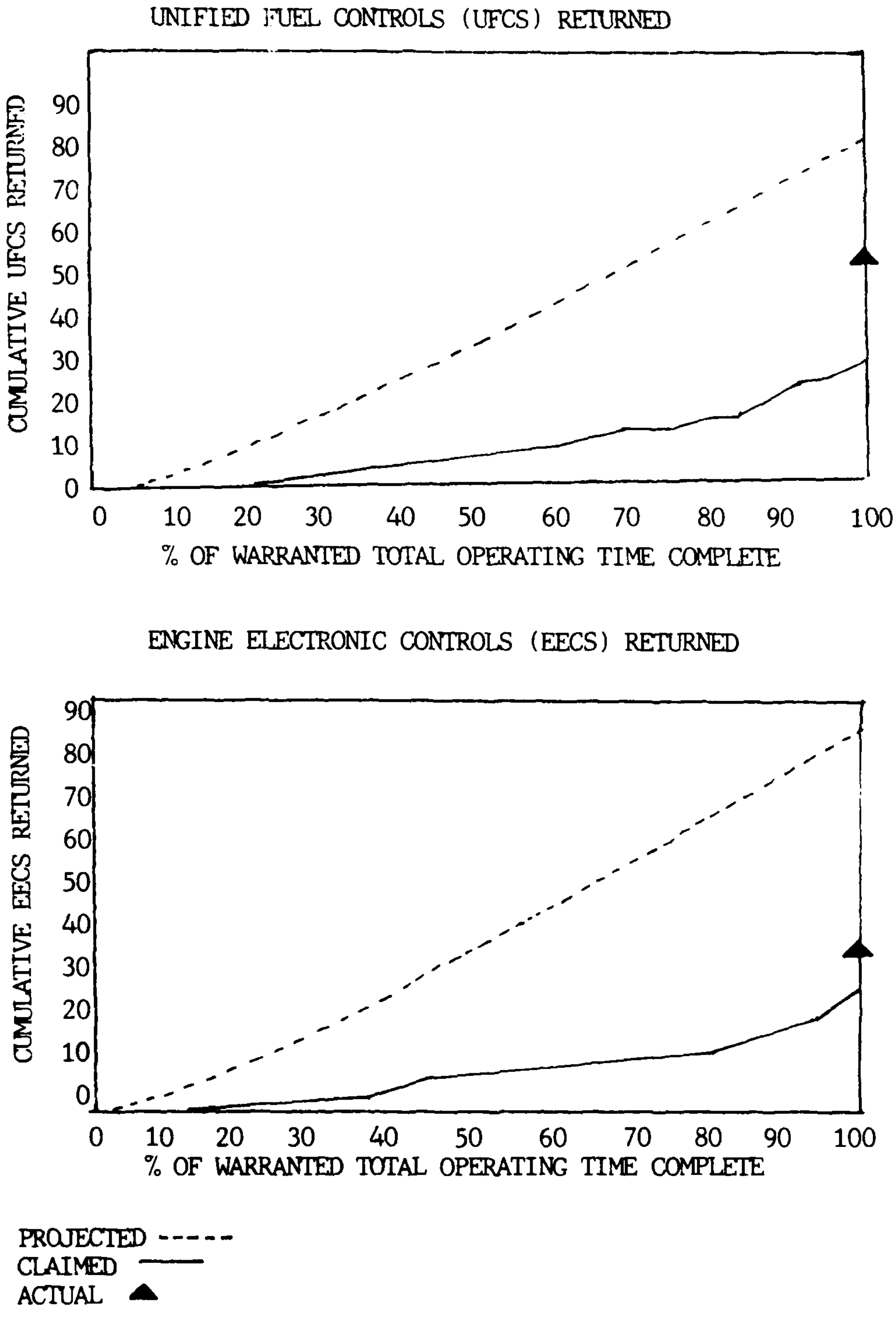
Prior to the Warranty. Prior to the warranty, the number of failures must be estimated. The estimates are based on historical failure data, the results of operational testing, and technical evaluations by an engineering specialist. If no historical failure data is available, data from a like system is used, with appropriate adjustments made for the differences (61; 69; 71).

For engines there is an enormous amount of historical data available in the maintenance record systems maintained by Headquarters Air Force Logistics Command (57). However, problems occur when a performance measurement, or parameter, being warranted is not captured in the maintenance records (20; 27). As an example, "mean time between failure" (MTBF) is a contractual measurement for reliability. However, there is no historical maintenance data on the MTBF of an item. The maintenance records have data for when the item was serviced. All engine service can be considered either preventive maintenance or corrective maintenance. Preventive maintenance is performed so that a failure will not occur, while corrective maintenance takes place after a failure has occurred (37:7). These entries can be used to obtain a "mean time between maintenance" (MTBM). Maintenance action on an item does not equate to a failure of the item, therefore, MTBM does not equal MTBF (20).

After the Warranty Expires. After the warranty expires, if there was a requirement in the contract for the contractor to submit information for the number of failures, then it could be used for evaluating the warranty.

This was the case for the F100 Lot IX Expanded Engine Warranty. A monthly report titled, Contractor Warranty Cost Report, accounted for the number of failures returned to and processed by the contractor. Two of the twenty-nine types of components covered under the Expanded Engine Warranty for the F100 Lot IX engines were the unified fuel controls (UFC) and the engine electronic controls (EEC). Figure 7 shows the projected number of failures and the number of claimed failures for these two types of components. In can be seen in Figure 7, that in both cases, the number of claimed failures were about 30 percent of the projected number of failures.

One reason for the discrepancy was that some of the failures under this warranty were not claimed, instead repairs were made by the Air Force which voided the warranty (23:IV-11; 39:17). The reason for the Air Force repairs was attributable to problems in warranty implementation, which included weak initial warranty claim procedures, inadequate field level training, and problems in screening procedures



Projected, Claimed, and Actual Failures

Figure 7

at the depot to prevent voiding warranties (23:IV-9, IV-10; 38; 55).

Warranted failures that should be corrected by the contractor but are corrected by the Air Force voids the warranty and, results in two conditions. The first condition is a decrease in the warranty claim cost (a function of the the number of failures and the cost of a failure) for the contractor. The decrease could be enough so that the warranty claim cost is not a factor in assuring a reliable product. Also, the contractor, by not paying for unclaimed failures, increases its profit.

The second condition of the voided warranty is the additional internal cost to DOD. When the repairs should be made by the contractor but are made by the Air Force, then the costs of the repairs are additionally incurred costs which could have been avoided. This condition is discussed in the section of DOD's implicit costs.

When determining the number of claims, in order to evaluate the warranty cost, the contractor's monthly report only provided a portion of the data required. It only provided information on the failures that were claimed by the Air Force.

Also shown in Figure 7 are triangles that represent the actual number of UFC and EEC failures that occurred during the warranted period, including both claimed failures and voided warranted failures. Only about 62 percent of the projected unified fuel control failures actually failed. Also, only about 37 percent of the projected engine electronic control failures actually failed (7; 39:14-16). The reasons for the difference between the Air Forces's projected number of failures and the actual number of failures included, the Air Force's inaccurate forecast of projected failures, and also, improvements in the production quality of the delivered engines (38).

After the warranty expires, if there was not a contract requirement for the contractor to provide information about the number of failures, or, as above, the report provided by the contractor is only for a portion of the warranted failures, a method, to obtain the number of failures, would be to use the data from Air Force maintenance records. However as previously discussed, to use this method, the warranted measurement parameter must be recorded in the data base. In addition, the results of using this method may not be adequate, because the maintenance data may not be completely accurate (13:4-4; 61; 79). As an example, expressed in a discussion with a specialist who was in the failure reporting process, some failures were exempt from being reported (79). These failures were considered random and of a known (acceptable) type. However, not reporting the failures leds to inaccuracies in the data base.

The Cost of Building Reliability into the Product. The third element of information required to measure cost to the manufacturer, in order to evaluate warranty costs, is the manufacturer's cost of building reliability into the product. As previously discussed, reliability is the quality of the product. Also, reliability must be explicitly defined in the warranty clause.

What is Required. The process of determining and designing a given reliability level into a product is the application of scientific and engineering efforts (17:6,192; 71). The process begins in the early phases of the products acquisition cycle. System specifications are the output of the scientific and engineering efforts (17:193). As the product enters the production phase, changes in reliability are accomplished by additional processes such as quality control, changes in the production techniques, and/or redesign of the product (17:282,284).

If the system specifications produce the required reliability level, the manufacturing cost to build reliability into a product could be associated only with the design and production costs. On the other hand, if a process is used to change the reliability level, the manufacturing cost includes the cost to the manufacturer of the process.

For engines, DOD sets the terms of the reliability requirement. During the early acquisition phases, engineering efforts integrate safety, reliability, producibility, cost, and etc. into the engine design (71).

The goal is to achieve an acceptable balance among operational, economic, and logistic factors (17:192). Once the baselined design is established, the design, materials, and manufacturing processes of the engines are constantly changed in an effort to increase reliability (37:6).

To increase reliability, one method is the Component Improvement Program (CIP). A function of the CIP is to generate Engineering Change Proposals (ECP's) (22:15). The purpose of these ECP's may be to correct problems (such as wear, failure, degradation of engine performance) that are detected once the system has been fielded (63; 71).

Another method of increasing reliability has been changing the manufacturing process. As an example, increases in technology have enhanced the bolting applications for engines. At one time bolt holes were made in two engine parts and then the parts were held together with bolts. The bolt holes were placed where stress on the engine which could led to failures. A new process, "inertia bonding" is now used to weld the engine parts together. This process decreased the probability for the type of failures caused by the earlier bolt holes, thus it increased reliability (63).

As explained in chapter two, the manufacturer can trade-off manufacturing cost and warranty claim cost. The manufacturing cost, the cost to the manufacturer of building a given reliability into the product, is needed in order to measure warranty costs. To determine the manufacturing costs detailed engineering and financial information with regard to the production process is required (43:10).

Obtaining the Cost of Building Reliability.

Prior to the Warranty. Prior to the warranty, information pertaining to the contractor's costs of production, is provided by the contractor and estimated by the government. This information is used to establish the basis for negotiation of contract prices (46:30; 69).

A contractor's proposal, describes the manner in which the product will be produced. In addition, to justify the price, the contractor intends to charge, a detailed estimate of proposed or anticipated costs are described. If the contractor has not produced similar products before, extensive technical estimates are used to develop the production costs. On the other hand, if the contractor has experience in making similar products, cost information is usually estimated using the contractor's accounting systems (46:84-88).

The government prepares independent cost estimates as a measure to compare the contractor's proposed prices (46:30). The government estimates are prepared using engineering analysis of the item to be procured and are supported with historical data on the cost of producing similar items (46:30).

For engines, historical cost and engineering data is available (66). The data is used by specialist in the Program Control, Engineering, and Logistics sections of the Deputy for Propulsion organization, and other offices to develop the government estimates for negotiations (15; 66; 69). During negotiations the estimates are used by contract negotiators in support of the contracting officer for determining what the contract price will be (15; 69). Although the data is used for technical evaluations, to determine estimates for production cost, a methodology of using the data to evaluate warranty cost does not presently exist (66; 69).

One reason for this, according to a contract price analyst who has experience with pricing engine warranties, is that the process to determine the cost of building reliability into an engine would involve a great amount of time and effort. It would include finding and collecting the documents relating to reliability and cost (i.e., contracts, technical engineering data, cost documents, ECP and CIP data, etc.), then determining the relationship of costs to the changes in reliability. This approach of collecting and formatting the data to use for evaluating warranty cost has not been considered because the time and effort to perform such an analysis may not be worth the benefits (69). Since the manufacture's cost of building reliability into the product influences the manufacturer's total cost, knowing this information would enhance the government's ability to determine the warranty price.

After the Warranty Expires. After the warranty expires, the type of data available to the government, is the result of the contract requirements. As an example, several cost reports were required from the contractor for the F100 Lot IX engines. One report, the Cost of Sales Report, was generated monthly by the contractor and provided actual manufacturing costs (22:1; 76). Other reports were the Cost Information Reports, generated annually, which provided quality control, indirect, and tooling costs in addition to the manufacturing costs (24).

Although the cost reports could be used to determine manufacturing costs, other costs that impact reliability (such as contractor's costs of a change in the production process and/or an ECP) would have to be obtained from other sources. In order to determine the cost to the contractor of building reliability into the engines, it would take an understanding of both the contractor's cost accounting system and all the processes that changed the engines reliability (57; 69; 71; 76).

A method suggested to obtain the manufacturer's cost of building reliability into the product was to require the data in a specified format to be provided by the contractor as a condition of the contract. According to a financial specialist in the Deputy for Propulsion organization, this method would require additional cost to the government and should be compared with the benefits of the data (76).

DOD's Costs. For DOD, there are two costs that must be obtained in order to measure the warranty cost, explicit cost and implicit cost.

Explicit Cost. As described in chapter two, the explicit cost for DOD is the price paid for the warranty. It is equal to the manufacturer's total cost plus the manufacturer's profit.

What is Required. It is necessary to know the warranty price in order to evaluate the cost effectiveness of a warranty. What DOD pays for the warranty will depend on the negotiating power of DOD with the manufacturer (43:9). Since the manufacturer's profit is included in the cost of the warranty, it might be possible for DOD to negotiate an increased warranty coverage at no additional cost, but instead, at a reduction in the manufacturer's profit.

Obtaining the Explicit Cost.

Prior to the Warranty. Prior the the warranty, there are at least three methods of estimating the explicit cost (23:3-1-3-10; 81:39-40). One, rule of thumb; two, cost estimating relationships; and three, the bottom-up approach. These methods provide an estimate of what DOD should pay for a warranty, however there are problems with the methods.

The first explicit cost estimating method, rule of thumb, is the development of a ratio of one cost to another. It is simple, quick, and generalized. However, it yields imprecise estimates and it's oversimplification may obscure relevant details that make its use inappropriate. An example of the rule of thumb method for an engine warranty is the F100 Lot IX Supply Warranty. The warranty cost was based on a percentage of the manufacturing costs (8).

The second method of estimating explicit cost is the cost estimating relationships (CER). The CER is a statistically developed parametric relationship of cost elements that drive the warranty cost. Although the estimate can provide a firm statistical basis for projections and predictions, it needs extensive data requirements and extensive development efforts. Presently, since there have only been a limited number of engine warranties, there is lack of an extensive data base in order to use this method for engine warranties (66).

The third explicit cost estimating method, the bottom-up approach, identifies all warranty costs elements required to estimate costs and summarizes them into a total cost. It requires a "build up" of costs that may include elements of costs based on historical data, rule of thumb, or cost estimating relationships. The bottom-up approach has distinct advantages in that it can provide a very accurate cost estimate. However, it can be time consuming, complex, and expensive to develop. In addition, because of the detail, the data needs to be current, accurate, and complete. An example of the bottom-up method for an engine warranty is the F100 Lot IX Expanded Engine Warranty. The warranty cost was based on estimates of incremental costs to the contractor for the warranty coverage (8). As an example, the increase in the contractor's cost of material and labor, in order to remedy failures projected to occur during the warranted period, was estimated. For some warranties this approach is not possible to use, however in this case, the engines had been in production for eight years and there was historical data to support the estimate.

After the Warranty Expires. After the warranty expires, the price paid for the warranty can sometimes be obtained as a line item on the contract or from the contracting files (58; 66). The price, the explicit cost of the warranty, should be the manufacturer's total cost plus the manufacturer's profit.

For the F100 Lot IX engine warranties, the price paid was documented in the contract files (28). Table V shows the prices paid for the three warranties. The Supply Warranty covered failures in material and workmanship; it was negotiated as a percentage of manufacturing cost and was priced at $6,073,229. By basing the price on a direct cost, the contractor's cost and the contractor's profit, if any, were hidden in the overall procurement costs.

TABLE V

Explicit Costs for F100 Lot IX Engine Warranties

Warranty	Explicit Cost		
	Price Govt. Paid	Contractor's Costs	Contractor's Profit
Supply	$ 6,073,229	?	?
High Pressure Turbine	$ -0-	?	?
Expanded Engine	$12,650,000	$4,914,000	$7,736,000

As shown in Table V, the High Pressure Turbine Warranty which covered failures of the high pressure turbines was offered to the government for no change in the contract price. When the contractor offered this warranty, it was a change to the existing Lot IX procurement contract. A government evaluation of the warranty was completed. The expected number of failures and the costs to repair the failures were considered in order to determine the value of the warranty. The value was estimated to fall between 2.5 and 7.4 million dollars (56: Tab D). However, the contractor was not required to provide warranty cost data, so the actual cost and profit to the contractor could not be obtained.

The Expanded Engine Warranty covered failures of the engines, modules, and accessories; it was negotiated for a price of $12,650,000, as shown in Table V. With this warranty, the contractor was required to provide cost data.

The data, a report titled Contractor Warranty Cost Report, showed that the contractor's warranty cost was $4,914,000. Subtracting the warranty cost from the price paid for the warranty, leaves the contractor's warranty profit. In this case, the profit was $7,736,000.

Implicit Costs. As described in chapter two, the implicit DOD cost of warranties are the internal costs of enforcing the warranty, the cost of documenting and complying with the claim provisions.

What is Required. Identification and measuring of the implicit costs are necessary in order to evaluate the cost-effectiveness of warranties. The Warranty Handbook divides implicit costs into direct costs and indirect costs, depending on the relationship of the cost with the warranty. Direct costs includes those costs for warranty development and administration, obtaining and providing special data, warranty training, warranty monitoring, and special transportation (13:3-14).

Indirect costs include those costs that increase spares requirements because of longer pipelines, and also, reduce self-sufficiency by having the contractor repair failures as opposed to enhancing organic repair capabilities (13:3-14).

The implicit costs are also known as the government administrative costs (81:26,27). For engine warranties, the implicit cost can include, but not be limited to, data management costs, contractor/Air Force interface costs, warranty administration training costs, and transportation costs (23:III-29; 57; 72; 81:27). These implicit costs are discussed below.

Data Management Costs. Data management costs includes the labor, material, and computer costs to document and support warranty claims. These costs may be incurred from the following activities:

(1) development and implementation of a manual and/or computer system to track warranted items;

(2) collecting information about a failure incident to determine and document the failures covered by the warranty; and

(3) preparing and processing forms in order to file the warranty claim.

Contractor/Air Force Interface Costs. The contractor/Air Force interface costs includes the labor and material costs for government personnel to monitor and manage the warranty. The functions under this cost may include the following:

(1) liaison between the program, support, user, and contractor activities;

(2) determining warranty compensation; and

(3) preparing and initiating an implementation plan.

Warranty Administration Training Costs. The warranty administration training costs includes the cost of training personnel to operate, maintain, and support the warranted items so as not to void the warranty. In addition, the cost of training personnel to initiate and process warranty claims may be included.

Transportation Costs. Transportation costs include the cost of packaging, handling, and shipping warranted items to and from the contractor.

From this brief discussion, it can be seen that there are numerous implicit costs that can be considered when evaluating warranties. In order to do the evaluation accurately, it is necessary to identify and collect those costs that could have an impact on the systems life cycle cost.

Obtaining the Implicit Costs.

Prior to the Warranty. Prior to the warranty, the implicit cost must be estimated. It is necessary to identify and determine the costs that could have an impact on the systems life cycle cost (13:7-7).

Presently there is disagreement about the significance of implicit costs to the warranty cost effectiveness decision. As an example, on one hand, a task force team, consisting of functional specialist from within the Aeronautical Systems Division (ASD) and the Air Force Acquisition Logistics Center, believed that government administrative cost may, generally, be insignificant (9:27). Although there was no data to support their claim, the believe was that the implicit cost would seldom drive the decision in the warranty cost effectiveness determination (9:27).

On the other hand, in the report, Cost Effectiveness Study USAF Jet Engine Warranty Programs: The Alternate Fighter Engine Warranty, administrative cost were not considered negligible (23:III-29). The report discussed several implicit cost considerations for the Alternate Fighter Engine Warranty (the F100-PW-220 and F110-GE-100 engines). The implicit costs included the transportation costs of shipping engines from operational bases to either contractor or government repair facilities, and also, the costs of filing the warranty claims. In addition, methods to estimate the costs were described. The conclusion was that the implicit cost could impact the life cycle cost of the engines (23:III-25-III-33).

Actual implicit costs data has not been collected and analyzed to validate either viewpoint. An effort was being conducted by an ASD organization to develop an approach for estimating the Government's costs (9:26; 72); but the effort has subsequently been canceled due to other organizational priorities (72). The Cost Analysis Office, Directorate of Aeronautical Systems Division (ASD) recommends, for ASD products being procured, an estimate for government administrative cost to be used when conducting a cost-benefit analysis (72). The estimate for contracts containing warranties, is a cost of $55,000 per operational base for each of the three years following deployment of the system. The estimate is based on experience with warranties on aircraft engines and the following criteria (9:26; 72):

(a) Contract quantity orders of 100-200 units.
(b) Supply/Maintenance guarantee followed by shop visit rate guarantee (most frequently used on engine contracts).
(c) Product deliveries 1-2 years after contract award.
(d) Payback beginning after fielding with major payback first 3 years after fielding.
(e) Warranty cost is a function of the number of engines on contract.
(f) Shop visit rate guarantee payback is based on the number of actual shop visits per 1000 engine operating hours calculated at 12 month intervals.

After the Warranty Expires. After the warranty expires, the implicit costs may not be easy to obtain because the costs are not tracked and collected (72).

For the F100 Lot IX engine warranties, the implicit costs have already been incurred. However, the costs have not been measured in order to evaluate the warranty. Three of the implicit costs for the F100 Lot IX warranties will be described. One implicit cost was the transportation cost of shipping warranted items between the operational base and the contractor's repair facilities. A second implicit cost was the cost of changes made to the USAF Material Deficiency Reporting and Investigating System to include the warranty claim procedures. A third implicit cost was the additional costs incurred by the Air Force when components and modules were misrouted to the depot where government repair voided the warranty coverage. These implicit costs will be examined separately.

Transportation. The contract for the F100 Lot IX warranties required the government to pay the transportation costs of any warranted item returned to or sent from the contractor's plant. These transportation costs would be difficult to measure because there is no existing data system that collects these costs (25:30; 66). A method to obtain the cost would be to identify the items shipped, determine the route and mode of shipping, and calculate the transportation cost. This method is similar to the approach used in the report, "Cost Effectiveness Study USAF Jet Engine Warranty Programs: The Alternate Fighter Engine Warranty," to estimate the shipping cost of a F100-PW-220 engine (23: III-25-III-27).

Warranty Claim Procedures. The claim procedures used for the F100 Lot IX warranties, in order to report a warranted failure, were implemented as a change to the established Technical Order (TO) 00-35D-54, USAF Material Deficiency Reporting and Investigating System (38). A brief discussion of the TO 00-35D-54 reporting procedure and the process used to claim a warranty failure follows.

Historically, prior to the utilization of warranties on engine contracts, the reporting procedures under TO 00-35D-54 were activated to report deficiencies such as design, maintenance, material, quality, and software. The purpose of reporting these deficiencies under TO 00-35D-54 has been to provide data from the using activity to the engine program manager. The data is used to determine the reason for the deficiency, discover if trends are occurring, and also, to initiate fixes for the deficiency (30:1-1; 79).

According to the TO 00-35D-54, deficiencies must be reported using either a Service Report (when the engine program management is with the Deputy for Propulsion organization) or a Material Deficiency Report (when the engine program management responsibility has been transferred to an Air Logistic Center). With the utilization of warranties on engine contracts, the TO 00-35D-54 reporting procedures were supplemented in order to be used to initiate warranty claims (38).

The process by which F100 Lot IX warranted failures were claimed is illustrated in Figure 8. The warranty claim process began with the using activity (A in Figure 8) discovering a deficient engine, module, or component. Next the using activity documented the deficiency on a Service Report (SR) or a Material Deficiency Report (MDR) and held the deficient item, called an exhibit, for disposition instructions. As shown in Figure 8, the SR or MDR was sent to the contact point (B in Figure 8). The contact point was the office which controlled and routed the SR's or MDR's to the warranty administrator.

The warranty administrator (C in Figure 8), with the engine manufacturer representative (D in Figure 8),

AD-A175 107 THE FEASIBILITY OF A COST-EFFECTIVENESS ASSESSMENT OF AIR FORCE JET ENGIN (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF SYST D A BIELLING 2/2

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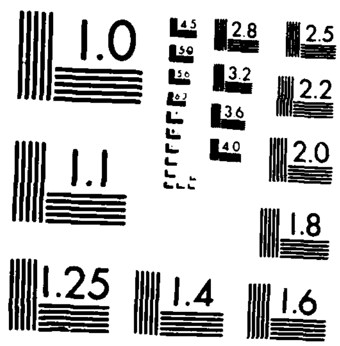

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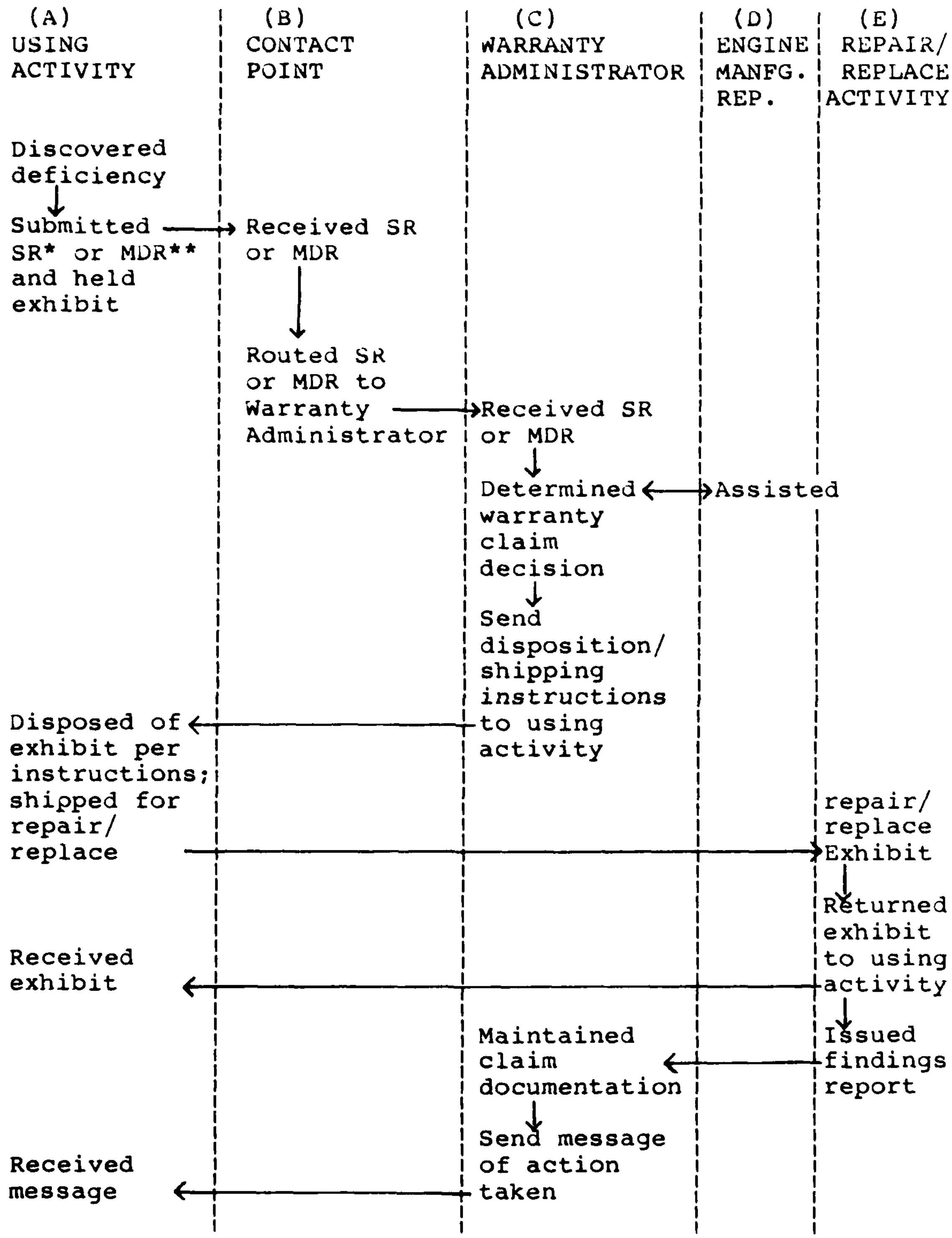

SR* = Service Report
MDR** = Material Deficiency Report

Warranty Claim Flow
Figure 8 (Adapted from 40:32)

determined the warranty claim decision (i.e., claim valid, who/where to make corrections in accordance with the contract, etc.). Then the administrator distributed exhibit disposition instructions to the using activity. The exhibit was shipped to the repair/replace activity (E in Figure 8) where appropriate action was taken. A repaired or replaced item was returned to the using activity (from E to A in Figure 8). A findings (or investigation) report was made of the action taken to complete the warranty claim documentation. In addition, the using activity was sent a message of the action taken.

For the F100 Lot IX warranties, the warranty claim procedures costs included the cost of supplementing the TO 00-35D-54 reporting procedures. One of the implicit costs was training cost to make sure the procedures were understood and properly implemented. Another implicit cost may have been cost for warranty administrators. With the additional type of warranties (the High Pressure Turbine and the Expanded Engine Warranties were first introduced with the F100 Lot IX engines) there was an increase in the type of claims, which meant additional workload in administering the warranties. These costs and others associated with the warranty claim procedures need to be identified and priced in order to measure the implicit cost for the F100 Lot IX warranties.

Voided Warranties. The contract for the F100 Lot IX engine warranties, required that all repairs were to be made at the contractor's facilities rather than the government depot. During the course of the warranty period some modules and components were sent to the depot where government repair voided the warranty coverage (55; 75). The voided warranties increased the implicit costs in that the government incurred unnecessary repair costs. A method to obtain the implicit cost of voided warranties would be to identify the items repaired and determine what costs were incurred. This method is similar to the approach used in an Air Force Audit Report to estimate the the voided warranty costs incurred by the government as of October 1984 for the F100 High Pressure Turbine Warranties (2:6). In the audit report it was stated, the warranty on 81 high pressure engine turbines had been voided and the government had incurred costs upto $2.5 million to inspect, service, or repair the items.

Another implicit cost, incurred for the F100 Lot IX engine warranties, was the additional pipeline in shipping and repair times of items sent to be repaired at the contractor's facilities instead of the government depot (81:17).

Although the implicit costs for the F100 Lot IX warranties have already been incurred, these costs would not be easy to obtain. Without complete knowledge of which implicit costs incurred and collection of those costs, it is not possible to measure the implicit cost for the F100 Lot IX warranties.

Evaluating Warranty Benefits

In chapter two the information required to evaluate the benefits of DOD warranties was identified. The benefit of warranties was defined as the value of the increased reliability as a result of a warranty. As explained in chapter two, in order to evaluate warranty benefits, one must know the change in reliability, before and after the warranty, and the value of the change in an operational context to DOD.

Measuring Warranty Benefits

To measure the warranty benefit, DOD must obtain or estimate the benefits that were/will be a result of the warranty.

What is Required. The DOD benefits associated with a warranty must be identified and defined. Benefits may be quantitative or qualitative. The quantitative benefits are normally stated in terms of controlling or improving equipment quality, availability, reliability, supportability, support or repair costs, and etc. The qualitative benefits are normally stated in terms of the quality of the products delivered, and the contractor's incentive provided by the warranty in order to increase the product's reliability (13:7-12; 31:7,30).

Quantitative Benefits. Quantitative benefits can be measurements of improved performance, reliability, and quality. The improvements can be quantified through the use of reliability and maintainability parameters such as Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR). In addition, quantitative benefits can be measured as reductions in life cycle costs. For example, increased reliability means less failures, which influences logistics and support elements associated with the failures. These elements include spares levels, maintenance manpower levels, and material costs for repair (13:7-12; 31:7).

Qualitative Benefits. Qualitative benefits are not measurable in quantitative terms, but instead are based on subjective assessments. Qualitative warranty benefits may include (13:7-12; 31:7):

(a) motivating the contractor to design the system to meet requirements at initial production release and to operate as intended in the field;

(b) early and rapid resolution of problem areas due to high visibility and management's attention;

(c) incentive for the contractor to introduce no-cost engineering change proposals in order to reduce the number of repairs during the warranty period; and

(d) more realistic estimates of field performance which permit improved accuracy in planning operation and support resources.

Obtaining the Warranty Benefits.

Prior to the Warranty. Prior to the warranty the benefits are estimated. The estimates can be based on engineering calculations of the number of failures that are predicted to occur during the warranty period (9:31).

For engines, the projected number of failures are determined by the technical evaluation of the engineering function. The benefits are the value of the material, labor, and services associated with taking corrective action for the projected failures (66).

After the Warranty Expires. After the warranty expires, the change in reliability before and after the warranty must be measured in order to evaluate the effectiveness of the warranty.

For the weapon systems that use the F100 engines, an essential performance reliability parameter is the unscheduled engine removal (UER). This parameter is a measurement of any inherent failure that resulted in an engine removal and is affected by the warranted parameter of engine failures within 200 hours of total operating time. This type of warranted parameter was used on the F100 Lot IX engines.

Shown in Table VI is the UER parameter of the F100 engines for Lot XIII (before the warranty) and Lot IX (after the warranty). It can be seen that the UER reliability increased for both the F100-PW-100 and F100-PW-200 engines

TABLE VI

UER/1000 Engine Flying Hours Reliability
at 200 Hours Total Operating Time

	F-15 (used two F100-PW-100 engines)	F-16 (used one F100-PW-200 engine)
Lot VIII (before the warranty)	2.1	4.4
Lot IX (after the warranty)	1.7	3.8

from Lot XIII to Lot IX. However, an engineer from the Deputy of Propulsion organization stated that the UER reliability increases are more likely due to the Component Improvement Program and normal maturity of the engine systems than to the warranty (71).

Some of the Component Improvement Program (CIP) initiatives implemented during the period of the F100 Lot IX warranty were:

(a) improved wear resistance of boost piston;

(b) incorporation of vane stage and boost stage improvements;

(c) increased 1st and 2nd turbine blade durability (22).

These and other reliability improvements could have changed the UER rate (71). Since reliability is not monitored by the impacting factors, the benefits attributable to the CIP's and the benefits attributable to the warranty are unclear. Without knowing and measuring the change in reliability resulting from the warranty, the benefits can not used to evaluate the warranty.

In this chapter results of the research have been reported. In the next chapter a summary, conclusions, and recommendations will be given.

V. Summary, Conclusions, and Recommendations

The purpose of this chapter is to present the summary, conclusions, and recommendations of this thesis effort. The summary will be an overview of what is needed in order to evaluate the costs and benefits of DOD warranties. Next the conclusions of chapter four will be discussed. Specifically, the discussion will center on some of the problems in obtaining the information required for assessing the benefits and costs of jet engine warranties using the methodology of chapter two. Finally the recommendations for future research will be outlined.

Summary

With the passage of Public Laws 98-212 and 98-525 requiring cost effective warranties, and also, the requirements of DOD guidance, the costs of the warranty must be compared to the benefits of the warranty to perform the cost-benefit analysis. A comparison of the alternatives (i.e., with a warranty and without a warranty) can be made to determine the warranty's cost effectiveness. A structure for evaluating the costs and benefits of a warranty is illustrated in Figure 9.

As shown in Figure 9, the costs to DOD of the warranty is the price of the warranty, plus the cost of enforcing the

DOD's Costs

Price of the Warranty **

Plus

Cost of Enforcing the Warranty

Minus

Reduction in Operating and Support Costs

** a function of:
Manufacturer's Total Cost and DOD's Negotiating Power
warranty claim cost
manufacturing cost

vs

DOD's Benefits

Increase in Availability

Minus

Reduction in Availability Due to Contractor's Repair/Replacement Actions

Minus

Limitations of Product Use to Preserve the Warranty

Evaluating DOD's Warranties:
a Cost and Benefit Structure

Figure 9

warranty, minus the reduction in operating and support costs. The price of the warranty is a function of the manufacturer's total cost (the manufacturer's warranty claim cost and the manufacturing cost) and DOD's ability to negotiate a fair profit with the contractor. The cost of enforcing the warranty is associated with DOD's implicit costs including the costs of administration, training, and transportation. The reduction in operating and support cost is due to fewer failures and the repairs cost that would have been associated with the failures had a warranty not been utilized. With a warranty, the contractor partially absorbs these repair costs.

The benefits to DOD, as shown in Figure 9, is the increase in product availability due to a higher product reliability, minus any reduction in availability due to sending the product back to the contractor for repair/replacement, minus any limitations on use of the product in order to preserve the warranty.

It is important to establish a structure for separating the costs and benefits in order to ensure that all costs and benefits are accounted for. In addition, it is suggested that all the costs for the warranty, whether cost additions or reductions, be compared to all benefits, whether benefit additions or reductions, to ensure that all costs and benefits are included in the analysis and are not double counted.

From this summary of evaluating the costs and benefits of a warranty, a framework can be established for discussing the information that is required to be obtained. The framework requires that the manufacturer's and DOD's costs, and also, DOD's benefits be obtained. Some of the problems found in obtaining this information for assessing jet engine warranties were analyzed in chapter four. The following conclusions are based on the analysis accomplished in chapter four.

Conclusions

The conclusions of chapter four can be separated into three sections. The first section is that of the manufacturer's total costs. This information, known or estimated, enhances DOD's negotiating power for the warranty price. The second section is DOD's costs which includes explicit cost (influenced by the manufacturer's total costs) and implicit costs. The third section is DOD's benefits which are attributable to the warranty. Table VII is a summary of some problems found during this research effort. Each problem will be discussed below.

Manufacturer's Total Costs. For DOD it is important to know the manufacturer's total cost of the warranty in order to determine the price of the warranty, DOD's explicit cost. The analysis in chapter four revealed that these costs are generally not available in the Air Force records. The

Table VII

Conclusions Summarized: Problems in Measuring Costs and Benefits of Jet Engine Warranties

<u>Manufacturer's Total Cost</u>

- Warranty Claim Cost
  - Manufacturer's Cost of a Failure
    - Difficult to measure unless data provided by contractor
    - Not all costs are traceable in AF records
  - Number of Failures
    - Difficult to estimate if contracted parameter does not equate to maintenance data
    - Failure data from contractor does not include all failures
- Manufacturing Costs
  - Engine manufacturing cost available, however not used to evaluate warranty costs

<u>DOD's Costs</u>

- Explicit Cost
  - Based on negotiations, sometimes documented price is not the same as the estimated manufacturer's total cost plus profit
- Implicit Costs
  - Disagreement about significance
  - Must know what the implicit cost are in order to measure

<u>DOD's Benefits</u>

- Change in Reliability
  - Difficult to determine the change in reliability attributable to the warranty

manufacturer's total cost is a function of the warranty claim costs and the manufacturing costs.

Warranty Claim Cost. The warranty claim cost is made up of the manufacturer's cost of a failure and the number of failures.

For the manufacturer's cost of a failure, Table VII shows two problems that were exposed in chapter four. The first is the difficulty in measuring the manufacturer's cost of a failure unless the data is provided by the contractor. This is accomplished, prior to the warranty, in the contractor's proposal; and after the warranty expires, in contractor provided reports, if the data was required in the terms of the contract. For the Air Force, these cost are important from the standpoint of providing information that can be used (a) for comparing contractor's cost with previous lots (or similar systems), (b) to support the price of the warranty, and also (c) to evaluate the warranty after it expires.

In Table VII, the second problem is that not all the contractor's cost are traceable in Air Force records. For engines, Air Force maintenance records are useful to estimate the cost to correct a failure. However, at least two problems occur when extensively using Air Force records to evaluate the contractor's cost of a warranty. One problem is that the maintenance data may not be accurate. Secondly, the estimate will only include the cost to repair/replace a failure and not consider the other contractor's claim costs (i.e., preparing reports, administration).

For the number of failures two problems were encountered in chapter four, as shown in Table VII. The first problem can occur prior to a warranty, when the data must be estimated. Air Force maintenance records provide historical failure data on engines. However, if the performance measurement, or parameter, being warranted is not captured in the maintenance records, estimating the expected number of failures is limited to operational testing and engineer's technical evaluations. The difficulty in estimating the expected number of failures contributes to the risk of the warranty which tends to increase the warranty price.

The second problem can occur after the warranty expires. If the contractor provided a report of failures claimed, the report may not include all the failures. This is especially true, if some of the failures were not claimed. Unclaimed failures can result in two conditions. One condition is that the warranty does not motivate the contractor and assure a reliable product, instead the warranty increases the contractor's profit. The second condition is that DOD incurs additional internal costs to correct the failure, costs that should be borne by the contractor.

Manufacturing Cost. Manufacturing cost is the costs of building reliability into the product. Knowing these costs, would enhance DOD's ability to determine the warranty price. The problem in this area, discussed in chapter four and shown in Table VII, is that, although the cost of building a product and the reliability level can be determined, these costs are not being used to evaluate engine warranty costs. The primary reason for this is that the data is not collected and formatted so that it can be utilized for warranty evaluations. A contract price analyst who has experience with pricing engine warranties, stated that, the time and effort necessary to gather and put the data into a useful format may outweigh any benefits (69).

DOD's Costs. DOD's costs include both *explicit cost* and implicit cost.

Explicit Cost. Explicit cost is the price paid for a warranty and is a function of the manufacturer's total cost and DOD's negotiating power. The problem in this area, shown in Table VII, is that the negotiated price (what the government paid for the warranty) is not always based on the manufacturer's cost plus its profit. Sometimes it is based on a percentage of a direct cost. In this case, DOD can not determine what the contractor's cost of the warranty is or the level of profit, if any, the contractor is receiving. Instead these costs are hidden in the overall procurement costs and it is difficult for DOD to determine if the warranty price is fair to both the contractor and DOD.

Implicit Costs. Implicit costs are DOD's internal costs of enforcing the warranty. In Table VII there are two problems in this area that were encountered in chapter four. The first problem was the disagreement about the significance of DOD's internal costs of a warranty to the cost-benefit analysis. Although, a standard rate is suggested for the administrative (implicit) cost of Aeronautical Systems Division products, actual implicit costs data has not been collected and analyzed to develop a comprehensive estimate. The second problem, which actuates the arguments regarding the significance of the implicit cost, is that, without knowledge of what implicit costs are incurred due to a warranty, the costs can not be collected and measured.

DOD's Benefits. DOD's benefits of a warranty are the value of the increased reliability as a result of a warranty. An increase in reliability means fewer failures and fewer failures means an increase in availability. Therefore, an increase in reliability has an impact on a systems availability. The problem, analyzed in chapter four and shown in Table VII, of measuring the change in reliability, is the difficulty in separating the benefits attributable to a warranty and the benefits attributable to other factors. Unless the benefits of warranties are identified, defined, and measured there will be complications in performing cost-benefit analyses and evaluating warranties.

Recommendations for Future Research

During the course of this thesis effort some areas for future research became evident. Included were the five topics which are discussed below.

First, since warranties on major weapon systems are for the most part mandatory, creating a data base of the manufacturer's costs would be beneficial for future warranty evaluations. In particular, the warranty claim cost and the cost of building reliability into the product could help DOD in future warranty negotiations. Research in this area could provide a structure of what data to collect and how to format it so that the data could be used for assessing warranty cost.

Second, an analysis of the relevant implicit costs should be conducted. The study should determine what cost categories, if any, contribute to DOD's cost of enforcing warranties. In addition, the analysis could validate that the government's administrative cost are either significant or they are not significant to the warranty cost effectiveness determination.

Third, a study of the relationship between warranties and other methods used to improve reliability (i.e., Component Improvement Program, or Engineering Change Proposals) should be made. The purpose would be to determine the benefits (change in reliability) attributable to each of the various methods. In addition, a study of the impact of each method on one another would be of value.

Fourth, now that warranties must be included in procurement contracts for weapon systems, there should be an examination of the impact of multiple warranties on a weapon system. Research in the this area could address how a warranty on an major subsystem (i.e., aircraft engines) and the warranty on the overall system (i.e., the aircraft itself) impact each other.

Fifth, because of the problems associated with warranting reliability parameters and keeping maintenance data as historical records, an examination of translating the maintenance data into reliability parameters would be useful. A possible starting point is with AFALC/ERRR, the Reliability and Maintainability Directorate of the Air Force Acquisition Logistics Center, who suggested that such an examination is needed (20).

Closing Comments

A cost-benefit analysis is conducted to determine whether use of a warranty would be cost effective. In addition, a cost-benefit analysis is required to be performed, and should be documented in the contract files. Today, there is not a standard procedure for these analyses. In some cases it is difficult to obtain the data required to perform a cost-benefit analysis and to evaluate a warranty. An example of such a case was illustrated in this research effort. Unless the data necessary is available and utilized to perform a cost-benefit analysis, there is no assurance the Air Force is purchasing cost effective warranties.

This thesis effort is useful in that a structure for warranty cost-benefit analysis is provided and several problem areas are identified. Future improvements will require data collected and formatted in a way that can be used to perform a cost-benefit analysis prior to applying the warranty and also to perform evaluations after the warranty expires.

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With the enactment of Public Laws (P.L. 98-212 and 98-525) warranties must be considered for DOD weapon systems. It is DOD's policy to only obtain cost effective warranties. To determine if a warranty is cost effective a cost-benefit analysis is required. There has been concern by Congress, the General Accounting Office, and the Air Force about the adequacy of the cost-benefit analyses. This thesis effort examined the nature and availability of information needed to conduct cost-benefit analysis of warranties.

A theoretical model of warranty relationships was described and used to identify the information required to assess the benefits and costs of warranties. In order to limit the scope of the research, only jet engine warranties were considered. This thesis effort is useful in that a structure for warranty cost-benefit analysis is provided. In addition, several problem areas involved in evaluating and measuring warranty costs and benefits are identified and discussed.

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