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THESIS

AN APPRAISAL OF COST-EFFECTIVENESS MODELS USED IN THE AIR FORCE AND NAVY AIRCRAFT ENGINE COMPONENT IMPROVEMENT PROGRAMS

by

James D. Davis

December 1991

Thesis Advisor: Alan W. McMasters

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This thesis examines the cost-effectiveness models used by the Air Force and Navy to assist with the decision-making process of their Component Improvement Programs (CIP). The focus is on the elements of the two models and the reasonableness of each model's results. A sensitivity analysis was performed on significant input parameters to determine what effect errors in these parameters would have on the predicted return on-investment (ROI) results. The author concluded that, although the models provide insight into the life cycle costs (LCC) of aircraft engines, they are extremely sesitive to errors in certain input variables and should not be relied upon for CIP budget justification.

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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

This thesis examines the cost-effectiveness models used by the Air Force and Navy to assist with the decision-making process of their Component Improvement Programs (CIP). The focus is on the elements of the two models and the reasonableness of each model's results. A sensitivity analysis was performed on significant input parameters to determine what effect errors in these parameters would have on the predicted return-on-investment (ROI) results. The author concluded that, although the models provide insight into the life-cycle costs (LCC) of aircraft engines, they are extremely sensitive to errors in certain input variables and should not be relied upon for CIP budget justification.

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I. INTRODUCTION

A. BACKGROUND

This thesis will examine whether the Air Force and Navy's cost analysis models for the Component Improvement Program (CIP) are accurate enough to provide sound support in the CIP decision making process.

The Navy is facing a situation in which no new tactical aircraft will be deployed before 2005. This factor, combined with Congressional pressure to sustain readiness while lowering costs, will place a severe strain on logistical support for our tactical aircraft. The Navy will be forced to extend aircraft beyond their planned operational life while, at the same time, trying to lower operating and support costs for these aircraft.

One method to lower readiness costs is through CIP. The Component Improvement Program is an expensive program which calls for significant investment with the expectation of lower operations and support costs. However, justifying CIP investment from an economic standpoint requires a cost analysis model which will accurately portray the return on investment (ROI). This return is based on the expected savings from reduced life-cycle costs.

The key question becomes: **Are we able to accurately determine the cost savings associated with CIP investment?** In order to correctly prioritize and justify Engineering Planning Documents (EPD) and Engineering Change Proposals (ECP) for life cycle cost improvements, a model must be developed which reliably portrays the relevant costs and savings expected as a consequence of the component improvement. The Air Force and Navy currently use computer-based models which perform cost-benefit calculations based on certain sets of inputs and assumptions.

This thesis is concerned with the validity of the assumptions, data inputs and formulas incorporated into these computer-based models and attempts to provide an objective viewpoint concerning these issues.

B. OBJECTIVES

The primary objectives of this thesis focus on three steps which are:

1. Conduct a literature review of logistics engineering concepts to determine reasonable procedures for calculating life cycle costs and ROI analysis.

2. Evaluate the Cost Analysis models used in the decision-making process of the Air Force and Navy for the Component Improvement Program (CIP).

3. Determine if the models in step 2 accurately reflect life cycle costs and return on investment for aircraft engine

component improvements based on the information obtained in step 1. If not, then suggest improvements which should be made in these models.

C. LIMITATIONS

The primary limitation to this study is the relative recent implementation of the current Navy and Air Force models. It is extremely important to validate the recommendations from the models with historical results. However, because the models have only recently been developed, there has not been sufficient time to obtain data for such a validation.

Another serious limitation has been the inconsistencies of information obtained from contractors and cognizant military commands. These were primarily related to the interpretations of data inputs and assumptions. These inconsistencies appear to also be due to the relative newness of the models.

D. METHODOLOGY

In order to objectively analyze the Air Force and Navy CIP cost analysis models, a sound basis must be established with regard to the reasonableness of various costing techniques. Acceptable methods for formulating a basis of current versus future costs need to be determined. The literature review of applicable logistic engineering concepts and their influence on life cycle cost models will provide that basis.

The Air Force and Navy CIP cost models will be then examined in an attempt to reveal the reasons for the assumptions and mathematical formulas. To accomplish this, the author obtained the computer coding for both models.

E. ORGANIZATION OF THE THESIS

Chapter II presents a framework for understanding the aircraft engine Component Improvement Program. The functions, objectives and evaluation criteria for CIP are all described in enough detail to provide the reader a basic knowledge of the program.

Chapter III describes the results of the literature review. As mentioned above, the intent is to establish an adequate background for understanding the costs associated with a system's life cycle and the effects which various factors such as reliability and maintainability play in a cost analysis model.

Chapter IV provides an evaluation of the Air Force model to determine the reasonableness of its variables and mathematical formulas. Chapter V provides a comparable evaluation of the Navy model.

Chapter VI contains a summary of the thesis, conclusions reached from the analyses, and recommendations for improvements.

II. BACKGROUND

A. WHAT IS CIP

It is common practice for aircraft gas turbine engines to be released into operation prior to solving all of their design inadequacies. The trade-off between Full Scale Development (FSD)[1] and future component improvements is made to ensure that an engine can enter operational service at a reasonable cost. Deficiencies which were not identified during the research and development (R&D) phase are corrected through continuing investments in design improvements of the in-service gas turbine engine. Initially these are related to safety; later they are related to reliability and maintainability. [Ref. 1:p. I-1]

Funding for CIP in the defense budget moved from the Aircraft Procurement Account to the Research, Development, Testing, and Evaluation (RDT&E) Account in fiscal year 1981. The funding transfer was directed by Congress and resulted from a General Accounting Office study on CIP. The study concluded that CIP was essential, but that the efforts primarily involved research and development. [Ref. 2:p. 2]

[1]Full scale development refers to the phase between validation and production. During FSD, work proceeds toward development of operational capability.

B. WHAT ARE THE OBJECTIVES OF CIP

The basic objectives of CIP are:

- Solve as quickly as possible any safety-of-flight problems identified to engine design inadequacies.
- Correct design inadequacies which create unsatisfactory engine performance.
- Reduce engine Life Cycle Cost (LCC) by improving reliability, maintainability and supportability.

[Ref. 3:p. 1]

These objectives are reached through coordination of engineering, manufacturing, testing, quality control, and management functions. The Component Improvement Program is not designed to address improvement of the engine performance; development of prototypes; or examination of additional applications. Furthermore, CIP does not address issues which are covered under the engine's warranty program. [Ref. 1:pp. I-2 to I-7]

Two of the three objectives of CIP, solving safety-of-flight and correction of unsatisfactory engine performance, are meant to address prevention of Class A accidents[2] and fleet-wide grounding of aircraft for serious problems. These problems are usually discovered early in an engine's operational life.

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[2]Class A mishaps are accidents which cause greater than 500 thousand dollars in damage, damage the aircraft beyond repair, or cause a serious casualty (fatal/permanently disabled).

The third objective, improving the logistics aspects of an aircraft engine, requires the CIP manager to consider the entire life-cycle of the engine and determine ways to lower operating and support costs. An improvement in the reliability and maintainability of the engine will potentially lower the labor and material costs associated with the operating and support costs.

Figure 1 on the following page provides a flowchart which outlines the evaluation process of initiating a design change. [Ref. 4:p. 96]

C. WHO IS RESPONSIBLE FOR CIP

The Department of Defense (DOD) is a key player in aircraft engine CIP, helping to identify design inadequacies and fund their correction. As previously mentioned, the Military CIP program falls under RDT&E in the defense budget with each service (Air Force, Navy, and Army) separately managing their cognizant engines. There is a Tri-Service Aircraft Engine Component Improvement Program which coordinates CIP efforts on engines which are shared by two or more of the services.

The tri-service agreement calls for selecting a lead service to coordinate all CIP efforts on the shared engine. The tri-service agreement also includes funding support from Foreign Military Sales (FMS) customers and, in cases where the engine has substantial commercial applications, the engine contractors.

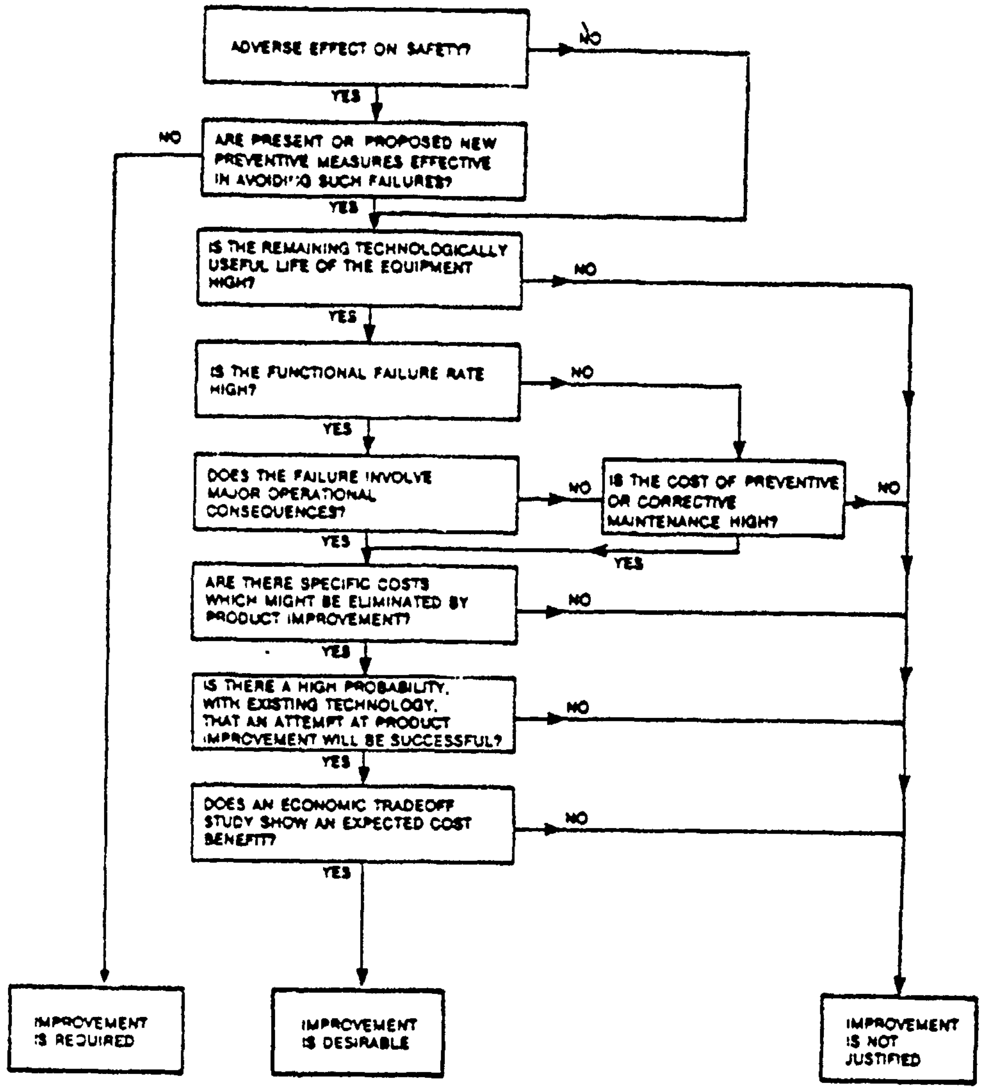

Figure 1 - Decision diagram for evaluating the necessity or desirability of initiating design changes

D. THE AIR FORCE COMPONENT IMPROVEMENT PROGRAM

The Air Force CIP effort is managed by the Air Force System Command (AFSC) through the Aeronautical Systems Division's (ASD) Directorate of Plans and Projects within the Propulsion System Program Office. The Aeronautical Systems Division is located at Wright-Patterson Air Force Base, Ohio.

The coordination of CIP for all Air Force engines includes (1) the preparation, combination and submission of budget requests for engine CIP, (2) policy review and guidance for engine managers, (3) the coordination of CIP funds to ensure all funds are forwarded to the appropriate organizations with respect to the Engine Advisory Group's (EAG) recommendations, (4) the management of all financial data on commitments, obligations, and expenditures for CIP funds, and (5) sponsorship of the EAG. [Ref. 5:p. 3]

The Engine Advisory Group is composed of members from ASD's Propulsion System Program Office and members of the Engineering Logistics and Material Management Offices. The EAG is responsible for reviewing and prioritizing all Air Force CIP funding. Each engine manager ranks his engine tasks and meets with the EAG in order to develop an overall plan for CIP funding. A cost-analysis model has been incorporated into the Air Force prioritization process in order to compare CIP tasks which are specifically designed to lower life cycle costs. This model will be discussed in Chapter IV.

E. THE NAVY COMPONENT IMPROVEMENT PROGRAM

The Navy's CIP effort is managed by the Naval Air Systems Command. The specific responsibilities are detailed to the Propulsion and Power Division (AIR-536) with assistance from the Maintenance Policy and Engineering Division (AIR-411). The precise duties are as follows:

(1) AIR-536

(a) Plan, budget, and allocated CIP funds.

(b) Implement, execute and manage the program.

(c) Coordinate CIP with the Air Force and Army to achieve the maximum benefits from CIP within funding constraints.

(d) Integrate Foreign Military Sales for CIP.

(e) Justify the level of funding that is required to incorporate modifications resulting from approved ECPs.

(2) AIR-411

(a) Assess the logistic support impact of proposed ECPs and make any required adjustments to the maintenance plan. [Ref. 3:p. 4]

The Navy's evaluation procedures for CIP proposals are designed to comply with the regulations set out in the Competition in Contracting Act (CICA) of 1984. Each proposal is subjected to a uniform evaluation which addresses the following questions [Ref. 2:pp. 4-11]:

a. What is the proposed program trying to do and why?

b. How will the objective be accomplished?

c. What are the alternate strategies or approaches to accomplish the objective?

d. What are the total resources required?

e. What are the benefits of the completed program output?

f. How will the program output be implemented?

g. What happens if the proposed program is not approved?

The results to these questions are formatted into a decision package which is prioritized through a ranking matrix. Three measures of system effectiveness are matched to three programs to create a critical ranking matrix. The measures of system effectiveness are: Operational dependability (Do), operational capability (Co), and operational availability (Ao).

Operational dependability is defined as the probability that the system, if available at the beginning of a mission, is able to successfully fulfill the mission. Operational capability is defined as the ability of the system to perform its intended mission. Deficiencies in operational capability usually involve the degradation of system effectiveness. Operational availability is the probability that the system, under normal conditions, is ready to perform its intended mission when called upon.

The programs matched to these operational factors are: problem solution programs which deal with actual fleet incidents; problem avoidance programs which deal with testing potential problems; and product improvement programs which address cost of ownership issues. The most critical situations are operational dependability deficiencies which show up through actual incidents (problem solution programs). [Ref. 6:pp. 3-19]

Table I shows the ranking matrix profile for the measures of effectiveness and the programs.

TABLE I

ENGINE CIP RANKING MATRIX

Critical Ranking Factors	Problem Solution Programs	Problem Avoidance Programs	Product Improvement Programs
Operational Dependability (Do)	1	2	NA
Operational Capability (Co)	2	3	NA
Operational Availability (Ao)	3	4	5

Those tasks which receive ranking factors of 1 and 2 are considered to be mandatory in terms of mission and objectives.

The tasks are then prioritized according to urgency with the ROI factor being used only in case of a tie. Tasks which receive factors of 3 or 4 are to be prioritized based on the equipment's position in the health of the fleet chart. Tasks which receive ranking factors of 5 are considered less critical and will only be accepted based on ROI. The task ranking will take into account the risk involved in successfully incorporating and implementing the task. The ROI model used for Navy CIP is discussed in Chapter V.

The health of the fleet parameters are ten bottom-line indicators which are derived from Navy 3-M data. These indicators act as flags for identifying maintenance related distress points. Each of the parameters are monitored through a color-coded chart. The chart indicates a range for red, yellow, and green. The colors represent unacceptable, marginal, and acceptable conditions, respectively. Table II on the following page shows the health of the fleet parameters and the range for each condition. [Ref. 7:p. 6-7]

TABLE II

HEALTH OF THE FLEET PARAMETERS

Parameter	Red	Yellow	Green
Engine Flight Hours (EFH) per Fail	20	20-30	30
EFH per Maint Action	10	10-20	20
Aborts per 1000 EFH	3	3-2.5	2.5
Failure Aborts per 1000 EFH	2.5	2.5-2	2
Engine Removal per 1000 EFH	4	4-2	2
Failure Engine Removal per 1000 EFH	2	2-1	1
Maint Man-Hours per EFH	1.5	1.5-1	1
Elapsed Maint Time per Maint Action	10	10-7.5	7.5
Not Mission Capable per EFH	4	4-2	2
Component Removal per 1000 EFH	10	10-7.5	7.5

III. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This chapter is divided into two sections. The first section is designed to explain some of the basic concepts of logistics engineering and cost analysis. The second section will review pertinent literature concerning the conceptual aspects for developing cost analysis models in general, and aircraft engine life cycle cost analysis models, in particular.

A. LOGISTICS ENGINEERING CONCEPTS

The field of logistics has experienced tremendous growth over the last few decades as industries and governments realize the advantages of managing the entire system/product life cycle. Costly errors can be made when a complex system is designed and developed without factoring in the long range support of the system. In order to understand some of the alternatives which engineers consider in system development it is necessary to be familiar with logistics terminology.

1. Cost Effectiveness (C-E)

C-E attempts to measure a system in terms of both mission fulfillment and life-cycle cost. There are trade-offs to be considered when developing any system. These trade-offs are between the life-cycle cost and the system effectiveness. [Ref. 8:p. 19]

2. Reliability

Reliability is a design characteristic of a system or component, and can be defined as the probability that the system or component will perform its intended function for a specified period in a specific environment. There are various measures used in measuring reliability. One of the most common measures is mean time between failure (MTBF). [Ref. 8:p. 12]

3. Reliability Prediction

Reliability prediction can be obtained by a variety of methods which are outlined as follows:

a. The prediction is based on a comparison with similar equipment. In this case, the MTBF is assumed to be equivalent to that of a piece of equipment which matches closely in terms of performance and complexity. Some extrapolation may be necessary in this procedure.

b. The prediction is based on an estimate of active element groups (AEG). This method breaks down the component to those parts which will be subjected to failure. The component MTBF is then determined with the assistance of a complexity chart.

c. The prediction is based upon a stress analysis. This method takes into account the interaction of various parts of a component in determining the MTBF.[Ref. 8:pp. 208-209]

4. Maintainability

Maintainability is also a design characteristic of the system or component and relates to the ability with which an item can be maintained. Maintainability involves measuring factors such as the time and costs associated with performing maintenance actions. Maintenance actions are either preventive actions or corrective actions. Preventive actions include inspections, monitoring, and any programmed item replacements.

The purpose of preventive maintenance is to keep a system within specified operating parameters. Preventive maintenance can be measured by the mean preventive maintenance time (Mpt). Corrective actions are performed to repair a failed system back to within specified operating parameters. Corrective maintenance can be measured by mean corrective maintenance time (Mct). [Ref. 8:p. 15]

5. Mean Time Between Maintenances (MTBM)

Mean Time Between Maintenances (MTBM) is the mean time between all maintenance actions. This takes into account both preventive and corrective maintenances. MTBM is significant in determining system availability. [Ref. 8:p. 46]

6. Life Cycle Costs (LCC)

Life Cycle Costs include the total costs of acquisition and ownership of a system over its entire life. Such costs include research and development, acquisition, operations and support, and disposal. [Ref. 8:p. 19] The Department of Defense requires careful analysis of life cycle costs for major acquisition programs.

7. Return on Investment (ROI)

Return on Investment (ROI) provides a means to judge various investment alternatives [Ref. 9:p. 776]. In the case of CIP, the return on investment is obtained in the operations and support cycle through the reduced costs resulting from increased reliability and maintainability of an engine. The investment refers to the cost involved with researching, procuring and installing the ECP.

8. Net Present Value (NPV)

Net Present Value (NPV) refers to the present value of all future cash inflows anticipated in a project or from an investment at a given discount rate [Ref. 9:p. 761]. A discount rate of 10 percent is specified by DOD. This rate is consistent with Circular No. A-94 of the Office of Management and Budget [Ref. 10:p. 4]. It is important to consider NPV when performing a LCC analysis since life cycle costs are usually spread over a long period of time and alternatives may have different lifetimes.

B. COST ANALYSIS MODELS

The development of a sound cost analysis model centers on the relative simplicity of the model and on how well it represents all relevant costs associated with the system.

Blanchard [Ref. 8:pp. 148-149] describes the following features which should be incorporated into any analytical model. These features are:

1. The model should represent the dynamics of the system being evaluated in a way that is simple enough to understand and manipulate, yet close enough to the operating reality to yield successful results.

2. The model should highlight those factors that are most relevant to the problem at hand, and suppress (with discretion) those that are not as important.

3. The model should be comprehensive by including all relevant factors and reliable in terms of repeatability of results.

4. Model design should be simple enough to allow for timely implementation in problem solving. Unless the tool can be utilized in a timely and efficient manner by the analyst or the manager, it is of little value. If the model is large and highly complex, it may be appropriate to develop a series of models where the output of one can be tied to the input of another. Also, it may be desirable to evaluate a specific element of the system independently from other elements.

5. Model design should incorporate provisions for easy modification and/or expansion to permit the evaluation of additional factors as required. Successful model development often includes a series of trials before the overall objective is met. Initial attempts may suggest information gaps which are not immediately apparent and consequently may suggest beneficial changes.

The objective of these five guidelines is to develop a balanced model which is powerful enough to provide significant decision-making support, yet be reasonable enough to design and employ. Turban [Ref. 11:p. 36] notes that:

> The characteristics of simplification and representation are difficult to achieve simultaneously in practice (they contradict each other).

Both Turban [Ref. 11:p. 42] and Blanchard [Ref. 8:p. 150] emphasize that modeling is as much an art as it is a science.

As the model is developed, the analyst must periodically evaluate the model. In addressing a model's competence, Blanchard [Ref. 8:p. 150] offers four questions which the analyst should ask about the model. These questions are:

1. Can the model describe known facts and situations sufficiently well?

2. When major input parameters are varied, do the results remain consistent and are they realistic?

3. Relative to system application, is the model sensitive to changes in operational requirements, production / construction, and logistic support?

4. Can cause-and-effect relationships be established?

Relative to question number 3, Turban [Ref. 11:p. 56] states:

> Sensitivity analysis is conducted in order to gain better understanding of the model and the world it purports to describe. It checks relationships such as: Effect of uncertainty in estimating external variables; effects of interactions among variables; and robustness of decisions.

Department of Defense acquisition management policies and procedures agree with the need for sensitivity analysis in support of establishing cost and operational effectiveness analyses. As noted in DOD Instruction 5000.2 [Ref. 12: p.4-E-5]:

Sensitivity analyses should be conducted as appropriate to highlight the magnitude of effects resulting from realistic possible changes or uncertainties regarding items such as:

(a) The threat,
(b) Key performance criteria, or
(c) Other baseline parameters that may change during the acquisition process or the fielding of the resulting system.

Blanchard [Ref. 8:pp. 440-442] discusses developing a sound analytical model based on some general rules which require accuracy, simplicity, and validity. Each of these factors present risks and limitations to the user. Common sense and good judgement must always be applied when examining the parameters and results of any model.

Finally, Isaacson suggests eight primary "rules of thumb" for a LCC analysis model. These are [Ref. 13:pp. 344-345]:

a. Results are as accurate as the input data,
b. Results are only an estimate,
c. Accuracy of the estimate is hard to measure,
d. Field data is limited for support analysis,
e. LCC analysis should be used for comparative purposes and not as an absolute measure,
f. Understand the sensitivity of the LCC analysis, especially when using the results for budgetary purposes,
g. LCC results from different models for the same system under the same operating and support conditions will rarely be equivalent,
h. Always apply common sense when interpreting LCC results.

C. AIRCRAFT ENGINE LIFE CYCLE COST ANALYSIS

Aircraft engine LCC analysis is a complex process which requires the analyst to make difficult predictions concerning an assortment of future costs. These future costs fall into a variety of budget accounts which must all be incorporated into the engine's total life-cycle cost. Davidson and Griffiths [Ref. 14] state:

> The Life Cycle Cost (LCC) for jet engines includes the cost of design and development, test and evaluation, production, operation and support, and where applicable, disposal. Although only a small portion of the total LCC is incurred prior to production, the decisions made up to that point determine most of the engine LCC. It is during this early design phase that there is insufficient operational information on the new engine to permit prediction of costs incurred during the operation and support phase of LCC. Estimation of LCC is further hindered by the absence of knowledge about techniques which could be used during engine design.

Nelson [Ref. 15:pp. 2-5] agrees with the requirement to incorporate all phases in the evaluation of the life-cycle process and expounds further of the difficulties in trying to obtain the relevant data which is needed. He contends:

> The life-cycle cost of an aircraft turbine engine is the sum of all elements of acquisition and ownership costs. To enable effective trade-off decisions, detailed definitions of those elements are necessary, particularly in terms of what belongs under acquisition cost and what belongs under ownership cost...(1) engine acquisition costs, comprising the RDT&E and procurement portions of the acquisition phase involving design, development, test, manufacture, and delivery to the field; (2) engine ownership costs, comprising operating and support maintenance cost for all base and depot activities; and (3) weapon-system-related costs for fuel and for attrition due to accidents and catastrophic failures...Researchers attempting a life-cycle study of a weapon system constantly run up against the same obstacle: obtaining all the relevant data required. The problem is much like trying to put together a jigsaw puzzle when some of the pieces are missing and other pieces seem to have wandered in from another similar puzzle.

The efforts to reduce life-cycle costs through CIP has some advantages and disadvantages when compared to new engine acquisition. Certainly CIP provides more operational information on the aircraft engine. However, this advantage is mitigated by the decrease in the potential of life cycle cost savings. Minnick [Ref. 16:p. 353] maintains:

> 95 percent of the total life-cycle cost of the system over its entire life cycle is committed by the end of the development phase.

While Minnick was not referring specifically to aircraft engines, the point is clear that the ability to influence life-cycle cost savings is greatest during the early stages of a system's life. Thus we may see a continuing trade-off between acquisition LCC analysis, which offers greater cost savings opportunities but is severely limited in the availability of data, and CIP LCC analysis.

IV. THE AIR FORCE MODEL

A. BACKGROUND OF THE AIR FORCE MODEL

The Aeronautical Systems Division uses a computer-based cost-effectiveness model called, the "Cost Effectiveness Analysis Model (CEAMOD)", to evaluate the ECPs produced from the CIP process. The model was originally developed by Pratt & Whitney for a mainframe computer and has been recently adapted by General Electric for a microcomputer using LOTUS 123 software.

The emphasis of CEAMOD is to project the savings which would be achieved from an ECP's implementation and to use this data to prioritize it in a list of proposed ECPs. The projected savings are determined from the costs difference between implementing the proposed configuration and sustaining the current configuration. Ideally, the costs of implementing the ECP would be outweighed by the resultant operations and support savings.

B. FORMAT OF CEAMOD

The model's structure is simple and consists of three primary sections. These sections are comprised of the model's assumptions, data inputs, and results summary. The assumption section is made up of 13 factors which deal primarily with when the proposed engine change will occur. The input section accepts the value of the input parameters provided by the operator and are used to compile the LCC costs for the current and proposed engine configurations.

A major portion of the input section identifies the scheduled and unscheduled work which is expected to be performed on the component. The terms "work" and "maintenance" are interchangeable in the description of the input parameters. Maintenance actions include inspection, monitoring, servicing, and repair. The results summary section performs the LCC calculations and shows the predicted net dollar savings from incorporating the ECP.

C. DESCRIPTION OF INPUT PARAMETERS 1.0 THROUGH 21.0

The input section contains 53 elements which are subdivided into two key sections. Section one contains 21 elements which deal mainly with general input data elements while section two provides the data element comparison between the current configuration and the proposed configuration. The impact each of the elements has on the model are described below. [Ref. 17]

1.0 Incorporation style offers three options for the operator in determining when a model change will be integrated into the fleet. These options are:

1 = Attrition

2 = First Opportunity

3 = Forced Retrofit

The "Attrition" style assumes a modification will occur only when the current component fails. "First Opportunity" replacement assumes the modifications will occur during both scheduled and unscheduled maintenance. "Forced Retrofit" allows the modifications to occur at a specific rate set by the operator.

The method chosen for incorporating the modification is important to the model's results since it determines the rate that the modification will be employed and consequently determines how quickly the modification costs can begin to be recouped through lower operating and support costs.

It may appear to be advantageous to choose the forced retrofit style in order to maximize the benefits of the modification. However, the real world has limitations which may not allow the "Forced Retrofit" style. One of these limitations would be a depot's inability to handle the increased workload of a forced retrofit.

2.0 Delta Production Cost is the difference between the old and new hardware production costs. This factor only involves engines still under production. The delta production cost is provided by the contractor and is incorporated directly into the results summary section.

3.0 Kit Hardware Cost ($) per engine is the purchase cost of the component modification kit. This cost is usually provided by the contractor.

4.0 Kit Labor Man-hours is broken into two sections to account for organizational and intermediate (O & I) level labor hours and depot labor hours. The contractor determines these values through logistics support analysis. For example, General Electric's Aircraft Engine Division maintains a detailed record of all service maintenance performed on General Electric aircraft engines. This data is compiled by their field representatives and is centrally managed at headquarters. The maintenance records are time accurate to 0.01 hours [Ref. 18].

5.0 Labor Cost per Man-hour is determined by Air Force Logistics Command (AFLC) from labor cost data supplied by their Air Logistic Centers (ALC). The rates set by the Air Force for 1991 are $34.55 for O&I and $50.52 for depot.

6.0 Tech Pubs Cost incorporates any technical publication costs associated with the proposed engine change. This input data is supplied by the contractor and is usually a minor cost. The cost determination is generally based on a page count. Tech Pubs Cost is incorporated directly into the results summary section.

7.0 TCTO Cost could be considered a subset of the Tech Pubs Cost. It refers to a time compliance technical order cost which is issued for important changes. These changes usually provide information on field procedures which must be followed in accomplishing forced retrofits or first opportunity changes.

8.0 New Part Number Intro Cost includes the cost of introducing a new part into the Air Force supply system. This cost is determined by AFLC.

9.0 Annual Part Number Maintenance Cost covers the annual cost of maintaining a part in the Air Force supply system. This cost is also set by AFLC and is periodically updated as required.

10.0 Tooling and Support Equipment Cost includes any special tooling or support equipment which would be required to carry out the component modification. This would include the cost to modify tools to comply with the engine change requirement. The contractor supplies this cost estimate.

11.0 Test fuel - $/Gal refers to the cost per gallon of fuel used in testing the engine.

12.0 Test fuel - Gal/Hr comes directly from the standard history file on the engine and is multiplied by the price per gallon in order to obtain the fuel cost for engine testing.

13.0 Spare Parts Factor is calculated by the contractor through an operations and support costs model. This factor is used in determining the spare parts requirements for the component for the engine's remaining life cycle.

14.0 Year Field Modification Starts is the year that modifications will begin on engines which have already been produced. The purpose of this input is to recognize that the initial supply of the improved components will go into engines currently on the production line and that field modifications could be delayed until there were sufficient improved components available.

15.0 % Sch Events Being Modified allows the operator to adjust the number of scheduled maintenance actions which will incorporate the modification. The only restriction to the percentage value is that it must be greater than or equal to the estimated percentage of scheduled scrapped units. This prevents a unit which is beyond economic repair from being replaced by an unmodified component.

16.0 % Unsch Events Being Modified allows the operator to adjust the number of unscheduled events which will receive the modification. The only restriction to the percentage value is that it must be greater than or equal to the expected percentage value of unscheduled scrapped units. This prevents a unit which is beyond economic repair from being replaced by an unmodified component.

17.0 Failure Rate Allowing Modification is the rate at which unscheduled opportunities occur which allow the modification. If the incorporation can occur at any maintenance level, then this rate is equal to the failure rate (see item 22.0).

18.0 Year Production Starts is used for in-production engines and has no impact on kit modifications.

19.0 Fiscal Year Dollars allows the dollar values to be measured in constant dollar terms.

20.0 TAC/EFH Ratio is the ratio of total accumulated cycles (TAC) to engine flight (EFH) hours. An engine cycle is a measurement of the variation in thrust which an engine endures during operation. The formula used to measure engine cycles places the greatest emphasis on extreme variations in engine thrust and the least emphasis on constant cruise conditions. An engine will normally accumulate multiple cycles per sortie. The TAC/EFH ratio is provided by the standard history file of the engine.

21.0 TOT/EFH Ratio also comes from the standard history file and is a ratio of total engine hours to engine flight hours. Total engine hours include such time as engine test time and runway taxi time.

D. DESCRIPTION OF INPUT PARAMETERS 22.0 THROUGH 53.0

Input parameters 22.0 through 53.0 are in a two-column format and require information about the current and proposed engine component designs. Elements 25.0 through 37.0 account for any variations in labor and material costs which might result from scheduled inspections, removals, and repairs between the current design and proposed design. Elements 38.0 through 49.0 account for any variations in labor and material costs which might result from unscheduled inspections, removals, and repairs between the current and proposed design.

22.0 Unscheduled Failure Rate/1000 EFH provides the current component's MTBF and the proposed component's predicted MTBF. The current MTBF rate is available from the maintenance data which is maintained by both the contractor and the Air Force. The proposed MTBF rate is provided by the contractor's engineering division.

As discussed in Chapter III, there are various methods of predicting reliability. However, there is no exact method of obtaining the proposed MTBF rate and it often requires a combination of extrapolating data from a baseline engine and/or applying an engineering judgement to predict the failure rate on a proposed design.

The difference between the MTBF of the current and the proposed components can have a major effect on the predicted life-cycle cost savings. A sensitivity analysis of critical input elements, such as MTBF, is presented later in this chapter to demonstrate their effects on life-cycle costs.

23.0 Scheduled Maintenance Interval (TAC's) provides the schedule of times during which an engine is expected to be available for component modification.

24.0 Calculated Rate/1000 EFH is not actually an input element. It is derived by taking the TAC's and divided by (Sch Maint Inv/1000). The "Calculated Rate/1000 EFH" represents a scheduled maintenance rate for the engine. An increase to the scheduled maintenance interval (input 23.0), lowers the calculated rate factor (input 24.0). The model's

LCC formulas use the calculated rate factor in calculating the scheduled maintenance costs.

25.0 **Scheduled Man-Hours to inspect, O Level** refers to the number of manhours at the organizational level which are required to accomplish any scheduled inspections on the component being modified.

26.0 **Scheduled % Removed at O&I level** is the percentage of total units for which scheduled removal is required and performed at the O&I level. The remaining percentage of removals which must be accomplished are performed at the depot level.

27.0 **Scheduled Man-Hours to Remove and Replace (O level)** is the number of man-hours to perform any scheduled maintenance at the O level to remove and replace the component being modified.

28.0 **Scheduled Man-Hours at I level** provides the number of man-hours expended to accomplish any scheduled maintenance at the I level on the component being modified.

29.0 **Scheduled % O&I Requiring Repair** provides the percentage of total units which require repair at the O&I level during any scheduled maintenance.

30.0 **Scheduled Repair Cost (O&I level)** provides the total cost to repair one unit at O&I levels.

31.0 **Scheduled % Returned to Depot** is the percentage of components which require scheduled maintenance that cannot be performed at the O&I level. Scheduled maintenance includes inspections, monitoring, servicing and repair.

32.0 **Scheduled Man-Hours Depot** accounts for the total number of scheduled mainten... .e man-hours required for the component at the depot.

33.0 **Scheduled % at Depot Requiring Repair** refers to the percentage of total components requiring scheduled repair at the depot level. The scheduled repair category is a subset of scheduled maintenance.

34.0 **Scheduled Material Cost (Depot)** is the total material cost resulting from scheduled work to repair one unit at the depot level.

35.0 **Scheduled % scrap** represents the percentage of total units, identified during scheduled maintenance, which must be scrapped. Basically, those are the units identified during scheduled maintenance as beyond economic repair.

36.0 **Hardware Cost to Scrap** represents the replacement cost of the scrapped unit. The assumption is that it is scrapped, a new unit must be purchased as a replacement. Hardware Cost to Scrap is not related to disposal costs.

37.0 **Scheduled Test Time** is the number of hours of engine test time required for each unit undergoing scheduled maintenance at the depot level.

38.0 **Unscheduled Man-Hours to inspect, O Level** refers to the number of man-hours at the organizational level which are required to accomplish any unscheduled inspections on the component being modified.

39.0 Unscheduled % Removed at O&I level is the percentage of total components for which unscheduled removal is required and performed at the O&I levels. The rest of the unscheduled removals are performed at the depot level.

40.0 Unscheduled Man-Hours to Remove and Replace (O level) is the number of man-hours required to remove and replace the component at the O level in order to perform unscheduled maintenance.

41.0 Unscheduled Man-Hours at I level provides the number of man-hours expended at the I level on the component in order to accomplish unscheduled maintenance.

42.0 Unscheduled % O&I Requiring Repair provides the percentage of total units which were found to require repair at the O&I level during unscheduled maintenance.

43.0 Unscheduled Material Cost (O&I level) provides the total cost of material to repair one unit at O&I levels.

44.0 Unscheduled % Returned to Depot is the value of the percentage of components which are beyond the repair capabilities of the O&I level and must be returned to the depot for unscheduled maintenance.

45.0 Unscheduled Man-Hours Depot accounts for the total number of manhours required to perform unscheduled maintenance on the component at the depot.

46.0 Unscheduled % at Depot Requiring Repair refers to the percentage of total components requiring unscheduled repair at the depot level.

47.0 Unscheduled Material Cost (Depot) is the total material cost resulting from unscheduled maintenance to repair one unit at the depot level.

48.0 Unscheduled % scrap represents the percentage of total components which are identified as beyond economic repair during unscheduled maintenance.

49.0 Hardware Cost to Scrap represents the replacement cost of the component. The assumption is that if a component is scrapped, a new component must be purchased as a replacement. Hardware Cost to Scrap is not related to disposal costs.

50.0 Unscheduled Test Time is the total hours engine test time required for each component undergoing unscheduled maintenance at the depot level.

51.0 Secondary Damage Cost covers the estimated material costs to other components due to the failure of the part being modified. It is assumed that most of the labor involved to repair and replace the failed unit would cover any labor cost for secondary damages. If this is not the case, then all related costs for repairing the secondary damages are included in this input.

52.0 Incidental Costs is a collective element which accounts for any miscellaneous material costs per unscheduled event that are not covered by any other input element.

53.0 Number of Part Numbers reflects the total number of part numbers related to the modification. A proposed configuration change which reduces the number of parts in the component will offer lower costs in part number maintenance costs.

E. DISCUSSION OF THE RESULTS SUMMARY SECTION

The model's result summary section performs the final cost calculations and produces a summary which displays the costs and savings (negative costs) from implementing the engine change proposal. The costs and savings are broken down into eight categories which are:

Production Engine Costs are taken directly from the input section and represent the difference in price between the old and new production hardware costs. This category could represent a savings if the new production engine costs are less than the old production engine costs. The production engine costs will only be a factor with engines still under production.

Total Production Engine Costs equal E(N-O) where:

E = Number of New Production Engines

N = New Production Engine Costs

O = Old Production Engine Costs

Operational Engine Modification Costs are equal to the kit purchase costs plus the kit installation costs (when the kit costs do not replace maintenance costs). If the kit costs replace maintenance costs then those maintenance costs (sum of unscheduled and scheduled maintenance costs and hardware scrapping costs) are subtracted from the engine modification costs. These maintenance costs refer to specific maintenance which is replaced by the modification installation.

For example, if a modification is performed on a component which was to undergo scheduled or unscheduled maintenance, then the elimination of these maintenance costs offset the kit installation costs. Operational engine modification costs account for the costs (or savings) which will occur from implementing the component modification.

Total Operational Engine Modification Costs equal

(K+I) - (S+U+H) where:

K = Kit Purchase Costs.

I = Kit Installation Costs.

S = Scheduled Maintenance Costs (replaced by kit installation costs) incurred during the installation period.

U = Unscheduled Maintenance Costs (replaced by kit installation costs) incurred during the installation period.

H = Hardware Scrapping Costs (replaced by kit installation costs).

If the kit installation costs do not replace maintenance costs, then the total operational engine modification costs are equal to K+I.

Follow-on Maintenance Material Costs are equal to the difference between the follow-on maintenance material costs for the proposed component and those for the current component over the remaining life cycle. Both scheduled and unscheduled maintenance actions are included. The calculations rely on the input section to determine the aggregate number of maintenance hours which will be required and how much material will be needed. Differences in maintenance action requirements and material costs between the current and proposed designs will account for the savings or costs identified under this category.

Total Follow-on Maintenance Material Costs equal

(M + R) - C where:

M = Material Costs (Sked and Unsked for Proposed Change).

R = Material and Hardware Scrapping Costs (which are replaced by kit installation costs).

C = Material Costs (Sked and Unsked for Current Configuration).

Follow-on Maintenance Labor Costs follow the same logic as follow-on maintenance material costs and are equal to the difference between the follow-on maintenance labor costs for the current component and those of the proposed component over the remaining life cycle. Both scheduled and unscheduled maintenance actions are included.

Total Follow-on Labor Costs equal $L_1 - L$ where:

L_1 = Labor Costs for Proposed Change.

L = Labor Costs for Current Configuration.

Publication Costs are taken directly from input element 6.0 in the input section. There are no model calculations required for Publication Costs.

Tooling/Support Equipment Costs are taken directly from input element 10.0 in the input section. There are no model calculations required for Tooling/Support Equipment Costs.

Part Number Costs account for the fixed cost of introducing a new part into the supply system. These costs also consider the life-cycle costs of part number maintenance in the supply system.

Total Part Number Costs equal: $P_1 - P$ where:

P_1 = Costs to introduce and maintain the new part numbers in the supply system.

P = Costs which will be saved from eliminating any obsolete part numbers as a result of the modification.

Fuel Cost factors in any LCC fuel consumption savings or costs which are attributable to the proposed engine change.

Total Fuel Costs equal: $F_1 - F$ where:

F_1 = Total Fuel Costs with proposed modification.

F = Total Fuel Costs with current configuration.

The total expected life cycle costs associated with the ECP can be expressed as:

$$T = E(N-O) + (K+I) - (S+U+H) + (M+R) - C + (L_1-L) + B + R + (P_1-P) + (F_1-F),$$ where:

B = Publication Costs,

R = Tooling and Support Costs.

F. SENSITIVITY ANALYSIS OF SIGNIFICANT INPUT PARAMETERS

Certain input parameters exert notable influence on the model. Input parameters which vary significantly between the current and proposed designs are especially critical in determining the results of the model.

A sensitivity analysis was conducted by the author using data from an actual ECP which had been approved by the Air Force for implementation. The input parameters which offered significant differences between the current and proposed configurations were:

1. Unscheduled Failure Rate/1000 EFH.
2. Scheduled Maintenance Costs.

The sensitivity analysis attempted to determine the impact which these parameters had on the net dollar savings predicted by the model. The selection of this particular ECP was merely for convenience.

Successive iterations of the model were run while changing the proposed configuration's input parameters in 10 percent increments toward the current configuration's input parameter values. The logic behind this effort was to show what would happen if the ECP failed to some extent to meet its predicted level of increased reliability and maintainability.

The sensitivity analysis varied the following proposed design input parameters: unscheduled failure rate; scheduled maintenance interval (TAC's); calculated rate/1000 EFH; scheduled man-hours to inspect, O level; scheduled % removed, O&I level; scheduled man-hours to repair/replace, O level; scheduled man-hours, I level; scheduled % O&I requiring repair; scheduled material cost, O & I level; scheduled % returned to depot; scheduled man-hours, depot; scheduled % depot requiring repair; scheduled material cost, depot; scheduled % scrapped; hardware cost to scrap. These parameters were varied as a group in order to show the aggregate effects of which reliability and maintainability have on the engine's life-cycle costs. Figure 2 on the following page shows the results of the analysis. While such an analysis does not provide the specific effects of each of these input parameter, it does offer the opportunity to observe the overall effects that reliability and maintainability improvements have on the model's results.

Appendix A presents the original input parameters and the results for each iteration of the sensitivity analysis.

The author is unsure of the exact mathematical equation which ties these factors together. The assumption above was a linear connection. Further research is necessary to fully understand how this relationship was determined by the model developers. The overall conclusion is that the model's user must understand which particular input parameters are driving the model's results and be sure to concentrate on the accuracy of these input parameters.

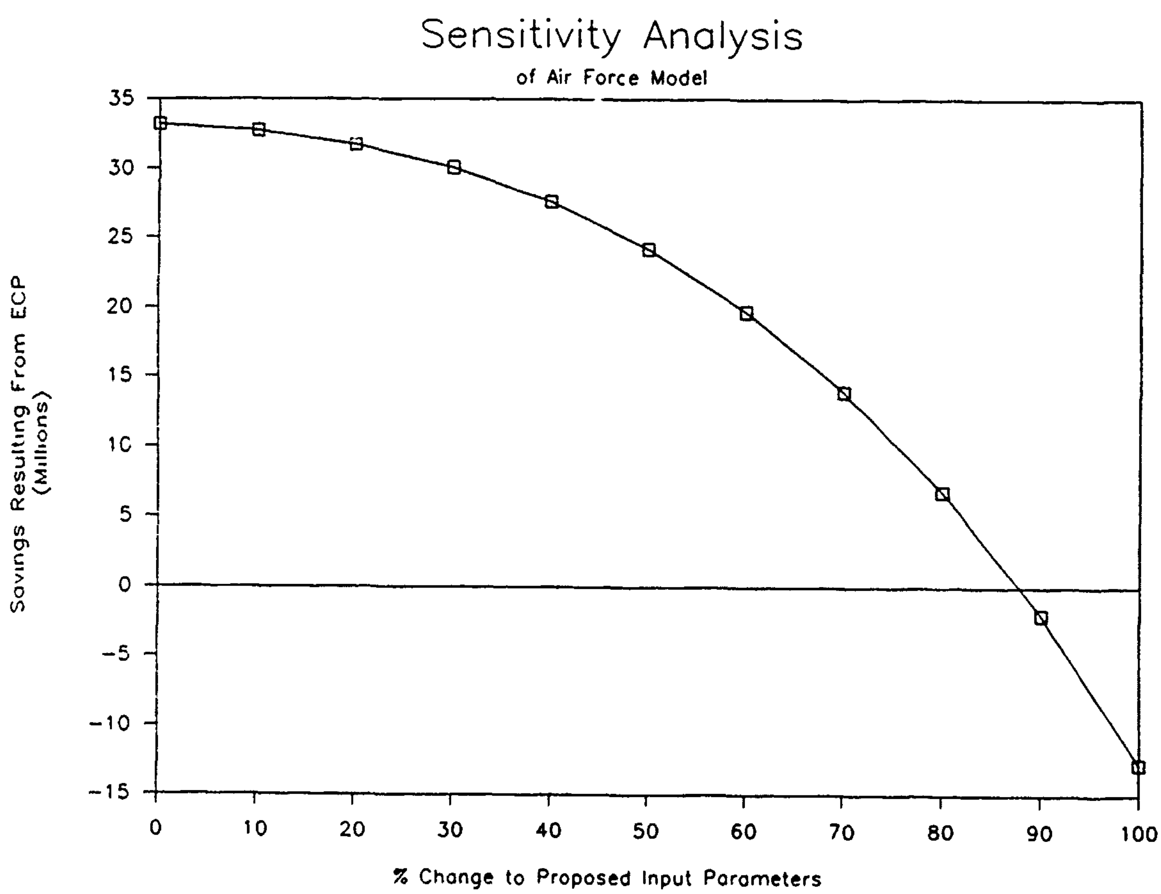

Figure 2 - Graph of the results to the Air Force model sensitivity analysis

V. THE NAVY MODEL

A. BACKGROUND OF THE NAVY MODEL

The Navy cost analysis model was developed by NAVAIR in 1985. It provides a return-on-investment analysis which is used to support the CIP decision-making process. The ROI model is designed to run on a microcomputer using the DBASE programming language.

As should be expected, the Navy model and Air Force model are similar in some respects and quite different in other regards. The intent of both models is to determine what operating and support cost savings, if any, will result from the implementation of an ECP. However, there are two important differences between the two models. The first difference is that the Navy model includes both the investment of CIP funds to develop an ECP and the procurement funds required to implement the ECP. The Air Force model includes only the procurement funds which are used to implement an ECP.

The second important difference deals with how benefits are measured. The Air Force model uses a net present value approach in predicting the dollar savings for an ECP. The Navy model does not use net present value. Instead, the Navy model shows the unadjusted dollar savings and how long it will take to recoup the investment. Fortunately, It would be fairly simple to alter the models in order to provide both options. A summary of these differences as well as other differences between the models is presented at the end of this chapter.

B. FORMAT OF THE NAVY'S ROI MODEL

The ROI model encompasses five essential steps. These steps are [Ref. 19]:

1. Determine the basic operation and cost data for the engine and weapon system.

2. Determine the expected fleet operation costs for the current system.

3. Determine the expected fleet operation costs for the system after the modification is performed.

4. Determine the expected costs associated with the development, production and installation of the engine ECP.

5. Process the above inputs in the ROI model to determine the length of time it will take to payback the investment.

The model accepts a series of input data elements which are used to compute the costs and savings for the component improvement. The data elements are separated into four segments. These segments are basic data elements, operational data before the design change, operational data after the design change, and investment costs data. The input data and investment cost data are used to compute the expected in-service cost per flight hour (before and after the design change) and the return on investment.

The model subdivides engine service costs into five categories which are: inspections, planned or end-of-life replacements, unscheduled replacements, aircraft/personnel loss, and fuel consumption.

C. DISCUSSION OF THE BASIC DATA PARAMETERS

The basic data elements refer to the essential costs associated with the engine and the aircraft. The input elements for this section are broken down into four sections. The first section covers nine elements and encompasses general assumptions about the engine and the aircraft. The second section covers the operational data for the current component (before fix). The third section covers operational data for the proposed component (after fix). The fourth section covers the investment costs data and includes eleven sub-categories to cover costs related to the development and implementation of the ECP.

The first, second and fourth sections will be discussed in detail. A discussion of the third section (after fix) has been omitted since the item descriptions correlate directly with those of the second section (before fix). [Ref. 19]

0.1 Engine Flight Hours per Year includes the anticipated total flight hours on the engine for which the component change is being proposed. This input element allows the operator to account for anticipated expanding or declining flight hours through the use of a customized schedule.

0.2 Expected Remaining Life of Engine refers to the number of years which the engine is expected to remain in operational service. There are usually three phases which an engine will go through. These phases are: introduction, maturity, and phase-out.

0.3 Total Expected EFH Remaining in the life of the engine. The number of EFH remaining relates to the phase which the engine is in when the component improvement is examined.

0.4 Cost of Weapon System is the cost of the fully equipped aircraft. The price of the weapon system is based on the current purchase price. If this information is unavailable, then the last known purchase price is used and adjusted to current year dollars.

0.5 Amortization Period for Weapon System is the planned period of use of the system. A twenty-year period is usually assumed.

0.6 Cost of Not-Mission-Capable (NMC) Hour is the cost of the weapon system (0.4) divided by the amortization period (0.5). The logic for measuring this cost centers on the operational availability of the system. The model attempts to measure the cost incurred for not having the aircraft mission capable. For example, if a 10 million dollar aircraft had an amortization period of twenty years (175,320 hours), then the cost per NMC hour would be 10 million divided by 175,320 or 57 dollars.

The weakness in trying to measure this cost lies in the fact that while the subject engine component may have caused the NMC condition, other maintenance is also performed during the aircraft downtime. It would be rather difficult to track and apportion the NMC cost to the myriad of work which will be performed during the aircraft down-time.

0.7 Cost Per MMH is the cost per maintenance man-hour which is supplied by NAVAIR's Visibility and Management of Operating and Support Cost Management Information System (VAMOSC).

0.8 Cost of Fuel (per Gallon) is self-explanatory and is used for cases where the ECP is expected to result in a change in fuel efficiency.

0.9 Cost of Personnel Loss (Training Cost) incorporates the average cost to train the aircraft crew members. This value is taken from OPNAVINST 3750.6. The purpose of the category is to consider the cost incurred from component failure which results in fatal mishaps. The Air Force model does not consider the cost of personnel loss.

1.1 Inspection Frequency (before fix) refers to the scheduled maintenance plan. The frequency is determined by the maintenance plan for the particular engine.

1.2 Not-Mission Capable (NMC) Time per Inspection (before fix) is the calendar hours which are required to return the system to service after the inspection has begun. The engine maintenance plan provides this information.

1.3 Maintenance Man-hours per Inspection (before fix) is the maintenance manhours required to perform the scheduled inspection. This information is available in the engine's maintenance plan.

1.4 End-of-Life Replacement Frequency (before fix) incorporates the rate at which components are replaced based on EFH. The replacement is a preventive measure which is established by either NAVAIR or the manufacturer. This input is important for those component changes which alter the replacement frequency. A component which requires replacement less frequently will normally incur lower operating and support costs.

1.5 Not-Mission Capable (NMC) Time per Replacement (before fix) is similar to item 1.2 only this time with regards to the replacement factor.

1.6 Maintenance Man-hours per Replacement (before fix) is similar to item 1.3 only this time with regards to the replacement factor.

1.7 Cost of Replacement (before fix) is the cost to restore the removed item to a usable condition.

1.8 Maintenance Action Frequency (before fix) refers to corrective maintenance actions. This frequency is equivalent to MTBF.

1.9 Not-Mission Capable Time per Maintenance Action (before fix) is the number of hours that an aircraft is down due to an unscheduled maintenance action.

1.10 Maintenance Man-hours per Maintenance Action (before fix) is similar to item 1.3 and refers to unscheduled maintenance actions.

1.11 Cost per Maintenance Action (before fix) is the cost to return the part to usable service. This cost will be the replacement cost if the unit is beyond economic repair.

1.12 Aircraft Loss Frequency (before fix) attempts to encompass a ratio of aircraft losses to the number of flight hours. The losses refer to those which are attributable to the subject component. This frequency is not easy to measure and can best be described as an attempt to incorporate the cost of losing the entire system due to the unscheduled failure of the component. While this factor is not presently included in the Air Force model, it is being considered as an addition.

1.13 Personnel Loss Frequency is similar to item 1.12 and attempts to incorporate the cost of component failure which results in the loss of aircrew members.

1.14 Number of Gallons of Fuel per Engine Flight Hour (before fix) is self explanatory. This category is available to cover those cases where the proposed fix is predicted to alter the fuel consumption rate of the aircraft.

2.1 through 2.14 Expected Operational Data After the Fix correspond directly with the "before fix" data elements. For simplicity, the model could have been arranged like the Air Force model which has a two-column input format.

3.1 Investment Costs of ECP are a summation of eleven cost categories and their cost elements. The costs for each element are arrived at through contractor estimates, historical data, and NAVAIR's VAMOSC-AIR management information system. The author has omitted a specific breakdown of each cost element. The eleven cost categories and their cost elements are:

1. Engineering Investigation
   - Program Management
   - Engineering & Support
   - Computer & Data Analysis
   - Travel & Subsistence
   - Other EPD costs
2. Development of ECP
   - Program Management
   - Engineering
   - Component & Prototype Testing
   - Prototype Tooling/Fixtures/Equip
3. Engine Production
   - Tooling and Test Equipment
   - Cost Differential New Engines

- Quantity of New Engines
- TAAF (Test Analyze & Fix Program)

4. ECP Kit or Materials for Modification
   - Tooling and Test
   - Unit Production Cost
   - Quantity

5. Documentation
   - Maintenance Manuals/Tapes
   - Maintenance Plans
   - Integrated Logistics Support (New P/Ns)

6. Installation of Kits or Mod Materials
   - Tools & Equipment
   - Man-hours

7. Training
   - Operators
   - Maintenance Personnel

8. Spares (One year Initial Provision)
   - Unit Cost
   - Quantity

9. Scrappage
   - Obsolete Units on Engines
   - Obsolete Units in Supply
   - Cost of Obsolete Units

10. Downtime
    - Aircraft Downtime for Mod
    - Number of Aircraft

11. <u>Testing</u>

- Spin Tests
- Engine Tests

D. DISCUSSION OF THE EXPECTED COST SECTIONS

The expected cost section shows the calculations of costs incurred both before and after the fix. The calculations are broken down for inspections, end-of-life replacements, unscheduled replacements, aircraft/personnel loss, and fuel consumption. The formulas for each section are as follows [Ref. 19:pp. 48-56]

Total Inspection costs equals I(MC+EJ) where:

I = Inspection frequency

M = MMH per Inspections

C = Cost per MMH

E = Elapsed Maintenance Time (EMT)[3] per Inspection

J = Cost per NMC Hour

Total Replacement costs equals R(AC+P+BJ) where:

R = End-of-Life Replacement frequency

A = MMH per Replacement

C = Cost per MMH

P = Cost of Replacement Materials/Parts

[3]EMT is equal to the total maintenance time required to return the aircraft to mission-capable status. EMT is usually equivalent to NMC.

B = EMT per Replacement

J = Cost per NMC Hour

Total Maintenance Costs equal F(CD+N+GJ) where:

F = Maintenance action frequency

C = Cost per MMH

D = MMH per MA

N = Cost of Materials/Parts

G = NMC per MA

J = Cost per NMC Hour

Total Cost of Weapon System & Personnel Loss equals H(K+LU) where:

H = Aircraft loss frequency

K = Cost of Weapon System

L = Personnel loss frequency

U = Cost of personnel

Total Cost of Specific Fuel Consumption equals g*f where:

g = specific fuel consumption

f = fuel cost per gallon

The total expected costs per flight hour can be shown as:

$$T = I(MC+EJ) + R(AC+P+BJ) + F(CD+N+GJ) + H(K+LU) + gf$$

E. DISCUSSION OF THE RETURN ON INVESTMENT SECTION

The return on investment section provides a series of measurements of effectiveness. These measurements include:

1) Return - This is the net savings of implementing the proposed change after the investment cost is subtracted out.

2) Ratio: Benefit/Investment - This is the savings from the implementation divided by the investment cost.

3) Return on Investment Ratio - This is the return divided by the investment. If the projected savings from the proposed ECP is 3 million dollars and the investment cost of the proposed ECP is 2 million dollars then the ROI ratio is 1.50.

4) Flight Hours to Return Investment - This is the investment costs divided by the savings per flight hour. This measure indicates how many engine flight hours it will take before operating and support cost savings will equal the investment cost of the ECP.

F. SENSITIVITY ANALYSIS OF SIGNIFICANT INPUT PARAMETERS

A sensitivity analysis was performed on the Navy model in order to examine the influence that certain input elements have on the model's results. As was the case in the Air Force model, those input elements which show large differences between the current and proposed design are especially critical to the results.

The sensitivity analysis was performed on the example ECP provided in the program user's guide. The input parameters for this ECP which offered significant differences between the current and proposed configurations were:

1. Unscheduled Maintenance Action Frequency.
2. Scheduled End-of-Life Replacement Frequency.

The sensitivity analysis attempted to determine the impact which these parameters had on the model's results. The selection of this ECP was purely for convenience.

As with the Air Force model, successive iterations of the model were run while changing the proposed configuration's input parameters in 10 percent increments toward the current configuration's parameter values. The sensitivity analysis varied the following proposed input parameters: scheduled end-of-life replacement frequency per EFH and unscheduled maintenance action frequency rate.

Appendix B presents the original input parameters and the results for each of the sensitivity analyses. Figure 3 on the following page shows the results of the analysis. The results showed that the input parameters had a significant effect on the model's results. The author suggests a similar situation to that of the Air Force model where there is a connection between the component's reliability and the costs associated with scheduled and unscheduled maintenance.

As with the Air Force model, the overall conclusion is that the model's user must understand which particular input parameters are driving the model's results and be sure to concentrate on the accuracy of these input parameters.

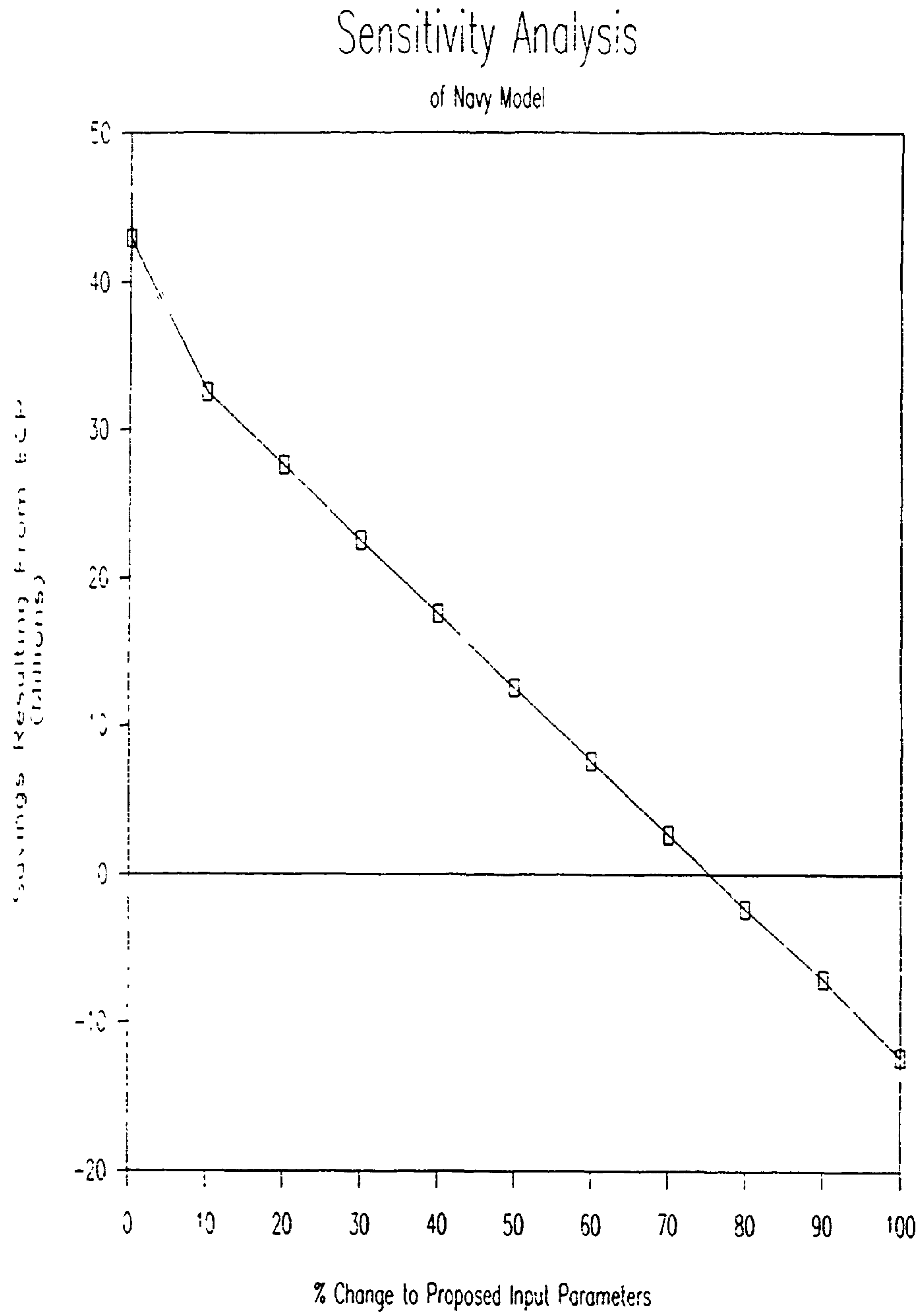

Figure 3 - Graph of the results to the Navy model sensitivity analysis

G. DIFFERENCES BETWEEN THE AIR FORCE AND NAVY MODEL

Both models attempt to measure the change in LCC which would result from implementing ECPs. The model developers approached this task in similar fashion. Nevertheless, there are significant differences between the models. The author has identified four particular areas of difference which are:

Model Utilization - The Navy model is intended to examine the entire CIP process and assist NAVAIR with the selection of ECP development plans. This approach requires much more forecasting to be done concerning the various costs.

The Air Force model is intended for use after the ECP has been developed. The focus of this model is to assist in the efficient allocation of ECP implementation funds. Since the Air Force model is run at a later point than the Navy model, the predicted costs estimates should be more fully developed.

Costs Concerns - Four costs which the Navy model examines which are not part of the Air Force are: NMC costs; aircraft loss costs; personnel loss costs; and scrappage costs. As discussed earlier, the author feels that while NMC costs can be significant, they are simply too difficult to measure. The author is of the same opinion for aircraft and personnel loss costs. The Navy needs to make much more progress in its abilities to measure operating and support costs before it can approach the tougher subjects of aircraft and personnel loss costs.

The author strongly agrees with the inclusion of scrappage costs in the Navy model. The scrappage costs fall under the investment cost category and include the cost of obsolescence of the replaced components on the aircraft engines and in the supply system.

Costs which could be significant that show up in the Air Force model are secondary damage costs. These costs cover damages to other engine components caused by the failure of the subject component. The relevance of this element certainly depends on the specific component, but this input parameter should be available for consideration in the models.

Input Parameter Format - The Air Force model goes into much more detail concerning the operating and support costs. The Air Force model devotes a great deal of effort in trying to break costs down as far as possible. This is shown in their effort to identify both the level of work required (O, I or D) and the type of work required (inspection, maintenance, repair/replace).

The Navy model is much simpler than the Air Force model in this area. It breaks maintenance costs down into inspections (which include all scheduled maintenance actions), and unscheduled maintenance.

Measurements of Effectiveness - The Air Force model is more concerned with the long-term return of the ECP investment. All savings are calculated in terms of their net present value. The savings are then added together and an aggregate savings is shown in the results summary section.

The Navy model's presentation of the results does not consider NPV and simply centers on the time it will take to recoup the investment. Both models could be easily modified to supply the same information.

VI. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. Summary

The question addressed in this thesis is whether it is possible to accurately estimate the LCC savings for any specific CIP efforts? A secondary concern has been the comparison of the CIP cost-effectiveness models used by the Air Force and Navy. In addition, are they good enough to justify budget proposals to Congress?

To answer these questions the author first set out to establish the framework of CIP. It became apparent that CIP can achieve tremendous savings in aircraft engine operating and support costs. However, it was also obvious that CIP requires significant initial investments in order to design and implement an engine component change.

In Chapter III, the author expounded on some basic principles which should be considered when altering a system's design in order to improve LCC. The advantages and limitations of modeling an LCC analysis were discussed as well as some basic background terminology which is used in describing these models.

Chapters IV and V specifically discussed the CIP cost-effectiveness models used by the Air Force and Navy, respectively. This included a discussion of the models' input parameters and how they calculated their results.

A sensitivity analysis was performed on both models to determine how responsive the models were to errors in the proposed unscheduled and scheduled maintenance parameters.

Finally, the author made a direct comparison of the two models. This comparison focused on: Model utilization; cost concerns; input parameter format; and measurements of effectiveness.

B. CONCLUSIONS

The benefits of CIP are without question. Unfortunately, in order to rely on the models to justify CIP budget proposals, we must be able to validate the results of the models and prove with a significant level of certainty, their accuracy. In the author's opinion, the lack of validation of the Air Force and Navy models and their sensitivity to input parameter errors prohibit them from being the primary basis for CIP budgeting. This lack of validation is partly due to the fact that the models have only recently been implemented and partly due to the lack of resources available to perform a validation of the models. Obviously, it would be extremely risky to justify the Navy's CIP budget on the results of models which have not been validated.

C. Recommendations

It is recommended that NAVAIR continue to use their current ROI model to initially evaluate CIP proposals. In addition, NAVAIR should consider developing a second ROI model which does not include investment costs. This model would be run after the development of the ECP but before its implementation. This step would provide NAVAIR the opportunity to update the LCC input data and determine if the ECP implementation is still cost-effective. If the ECP does not look to be cost-effective, it should be cancelled prior to its implementation phase.

Both the Air Force and Navy models provide a framework which can be used in developing a model which could be used for budget justification. However, before this can occur the services should closely examine their methods for determining life-cycle costs and work closely in developing an accurate means to measure and collect the relevant LCC data which would be required for any model.

As just mentioned, there is the need to evaluate the methods for determining life-cycle costs of aircraft engines. One area which could be of significant interest would be the validation of operating and support costs. These costs play a significant role in both the Air Force and Navy models and are, at the same time, the hardest factors to precisely quantify.

APPENDIX A
AIR FORCE MODEL SENSITIVITY ANALYSIS

Appendix A shows the original and altered input parameters for the ECP. The input parameters were altered in 10 percent increments and are highlighted in the initial table for ease of identification. The results summary section for each set of variations is presented immediately following each iteration of the input parameters.

ORIGINAL ASSUMPTIONS FOR THE ECP INPUT PARAMETERS

1.0	Incorporation style (1,2, or 3)	2	
	1= Attrition		
	2= 1st Opportunity		
	3= Forced		
	Does Kit Cost Replace Maint Cost?	Yes	
	Pct of Sch Events Requiring Maint	100%	
2.0	Delta Production Cost	$0	
3.0	Kit Hardware Cost - $ per engine	$11,722	
4.0	Kit labor manhours:		
	4.1 O&I	14.00	
	4.2 Depot	0.00	
5.0	Labor cost per manhour:		
	5.1 O&I	$34.55	
	5.2 Depot	$50.52	
6.0	Tech pubs cost - total $	$0	
7.0	TCTO Cost - total $	$0	
8.0	New P/N intro cost - $/ P/N	$1,630	
9.0	Annual P/N maint cost	$268	
10.0	Tooling & SE - Total cost	$0.00	
11.0	Test Fuel - $/Gal	$1.18	
12.0	Test Fuel - Gal/Hr	890.80	
13.0	Spare Parts Factor	0.500	
14.0	Year Field modification starts	1992	
15.0	% Sch events being modified	100%	
16.0	% Unsch events being modified	100%	
17.0	Failure rate allowing mod	0.29194	
18.0	Year Production starts	1992	
	Engine Attrition Rate (Engs/EFH)	0.00002	
	Average EFH per Eng Per Year	198.32	
19.0	Fiscal Year dollars	1991	
20.0	TAC/EFH Ratio	3.60	
21.0	TOT/EFH Ratio	1.60	
		Current	**Proposed**
22.0	**Unsch fail rate/1000 EFH**	**0.291940**	**0.021020**
23.0	**Sch maint interval (TAC's)**	**1080**	**3240**
24.0	**Calculated rate/1000 EFH**	**3.333**	**1.111**
25.0	**Sch MHrs to inspect, O level**	**0.0**	**0.0**
26.0	**Sch % rmvd, O&I level**	**48%**	**1%**
27.0	**Sch MHrs to R/R, O level**	**5.00**	**2.80**
28.0	**Sch MHrs, I level**	**45.00**	**0.00**
29.0	**Sch % O&I req repair**	**80%**	**0%**
30.0	**Sch material cost O&I**	**$0.00**	**$0.00**
31.0	**Sch % ret to Depot**	**100%**	**0%**
32.0	**Sch MHrs, Depot**	**24**	**2.60**
33.0	**Sch % Depot req repair**	**48%**	**0%**
34.0	**Sch material cost, Depot**	**$11**	**$11**
35.0	**Sch % scrap**	**11.30%**	**3.00%**

36.0	**Hardware cost to scrap**	**$12,565.00**	**$42.00**
37.0	**Sch test time**	**0.00**	**0.00**
38.0	Unsch MHrs to inspect, O level	0.0	0.0
39.0	Unsch % rmvd, O&I level	50%	50%
40.0	Unsch MHrs to R/R, O level	2.80	2.80
41.0	Unsch MHrs, I level	9.00	9.00
42.0	Unsch % O&I req repair	80%	80%
43.0	Unsch material cost O&I	$0	$0
44.0	Unsch % ret to Depot	10%	10%
45.0	Unsch MHrs, Depot	2.00	2.00
46.0	Unsch % Depot req repair	50%	50%
47.0	Unsch material cost, Depot	$11	$11
48.0	Unsch % scrap	5%	5%
49.0	Hardware cost to scrap	$2,527.90	$2,527.90
50.0	Unsch test time	0.00	0.00
51.0	Secondary damage cost	$0.00	$0.00
52.0	Incidental costs	$0.00	$0.00
53.0	Number of P/N's	3	3

ORIGINAL RESULTS SUMMARY SECTION

	Cost $(000)	Savings $(000)
1) Production Engine Cost		
2) Operational Engine Mod Cost	13,834.6	
3) Follow-on Maint Matl Cost		18,941.6
4) Follow-on Maint Labor Cost		28,140.3
5) Publications Cost	0.0	
6) Support Equip Cost	0.0	
7) Part Number Cost	6.5	
8) Fuel Cost		
Totals	13,841.1	47,081.9
Net Delta Dollar Impact $(000)		33,240.9

ITERATION 1 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 10%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.048112
23.0	Sch maint interval (TAC's)	1080	3024
24.0	Calculated rate/1000 EFH	3.333	1.333
26.0	Sch % rmvd, O&I level	48%	5.7%
27.0	Sch MHrs to R/R, O level	5.00	3.02
28.0	Sch MHrs, I level	45.00	4.50
29.0	Sch % O&I req repair	80%	8%
31.0	Sch % ret to Depot	100%	10%
32.0	Sch MHrs, Depot	24	4.74
33.0	Sch % Depot req repair	48%	4.8%
35.0	Sch % scrap	11.30%	3.83%
36.0	Hardware cost to scrap	$12,565.00	$1294.30

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		18,671.2
4)	Follow-on Maint Labor Cost		27,919.0
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	46,590.2
Net Delta Dollar Impact $(000)			32,749.1

ITERATION 2 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 20%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.075204
23.0	Sch maint interval (TAC's)	1080	2808
24.0	Calculated rate/1000 EFH	3.333	1.555
26.0	Sch % rmvd, O&I level	48%	10.4%
27.0	Sch MHrs to R/R, O level	5.00	3.24
28.0	Sch MHrs, I level	45.00	9.00
29.0	Sch % O&I req repair	80%	16%
31.0	Sch % ret to Depot	100%	20%
32.0	Sch MHrs, Depot	24	6.88
33.0	Sch % Depot req repair	48%	9.6%
35.0	Sch % scrap	11.30%	4.66%
36.0	Hardware cost to scrap	$12,565.00	$2,546.60

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		18,188.5
4)	Follow-on Maint Labor Cost		27,405.9
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	45,594.4
Net Delta Dollar Impact $(000)			31,753.4

ITERATION 3 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 30%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.102296
23.0	Sch maint interval (TAC's)	1080	2592
24.0	Calculated rate/1000 EFH	3.333	1.778
26.0	Sch % rmvd, O&I level	48%	15.1%
27.0	Sch MHrs to R/R, O level	5.00	3.48
28.0	Sch MHrs, I level	45.00	13.50
29.0	Sch % O&I req repair	80%	24%
31.0	Sch % ret to Depot	100%	30%
32.0	Sch MHrs, Depot	24	9.02
33.0	Sch % Depot req repair	48%	14.4%
35.0	Sch % scrap	11.30%	5.49%
36.0	Hardware cost to scrap	$12,565.00	$3,798.90

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		17,438.7
4)	Follow-on Maint Labor Cost		26,503.2
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	43,941.9
Net Delta Dollar Impact $(000)			30,100.9

ITERATION 4 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 40%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.129388
23.0	Sch maint interval (TAC's)	1080	2376
24.0	Calculated rate/1000 EFH	3.333	2.000
26.0	Sch % rmvd, O&I level	48%	19.8%
27.0	Sch MHrs to R/R, O level	5.00	3.68
28.0	Sch MHrs, I level	45.00	18.00
29.0	Sch % O&I req repair	80%	32%
31.0	Sch % ret to Depot	100%	40%
32.0	Sch MHrs, Depot	24	11.16
33.0	Sch % Depot req repair	48%	19.2%
35.0	Sch % scrap	11.30%	6.32%
36.0	Hardware cost to scrap	$12,565.00	$5,051.20

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		16,368.3
4)	Follow-on Maint Labor Cost		25,117.3
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	41,485.6

Net Delta Dollar Impact $(000) 27,644.6

ITERATION 5 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 50%

	Current	Proposed
22.0 Unsch fail rate/1000 EFH	0.291940	0.156480
23.0 Sch maint interval (TAC's)	1080	2160
24.0 Calculated rate/1000 EFH	3.333	2.222
26.0 Sch % rmvd, O&I level	48%	24.5%
27.0 Sch MHrs to R/R, O level	5.00	3.90
28.0 Sch MHrs, I level	45.00	22.50
29.0 Sch % O&I req repair	80%	40%
31.0 Sch % ret to Depot	100%	50%
32.0 Sch MHrs, Depot	24	13.30
33.0 Sch % Depot req repair	48%	24%
35.0 Sch % scrap	11.30%	7.15%
36.0 Hardware cost to scrap	$12,565.00	$6,303.50

RESULTS SUMMARY SECTION

	Cost $(000)	Savings $(000)
1) Production Engine Cost		
2) Operational Engine Mod Cost	13,834.6	
3) Follow-on Maint Matl Cost		14,922.7
4) Follow-on Maint Labor Cost		23,149.3
5) Publications Cost	0.0	
6) Support Equip Cost	0.0	
7) Part Number Cost	6.5	
8) Fuel Cost		
Totals	13,841.1	38,072.0
Net Delta Dollar Impact $(000)		24,231.0

ITERATION 6 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 60%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.183572
23.0	Sch maint interval (TAC's)	1080	1944
24.0	Calculated rate/1000 EFH	3.333	2.444
26.0	Sch % rmvd, O&I level	48%	29.2%
27.0	Sch MHrs to R/R, O level	5.00	4.12
28.0	Sch MHrs, I level	45.00	27.00
29.0	Sch % O&I req repair	80%	48%
31.0	Sch % ret to Depot	100%	60%
32.0	Sch MHrs, Depot	24	15.44
33.0	Sch % Depot req repair	48%	28.8%
35.0	Sch % scrap	11.30%	7.98%
36.0	Hardware cost to scrap	$12,565.00	$7,555.80

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		13,077.7
4)	Follow-on Maint Labor Cost		20,503.0
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	33,580.7
Net Delta Dollar Impact $(000)			19,739.7

ITERATION 7 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 70%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.210664
23.0	Sch maint interval (TAC's)	1080	1728
24.0	Calculated rate/1000 EFH	3.333	2.666
26.0	Sch % rmvd, O&I level	48%	33.9%
27.0	Sch MHrs to R/R, O level	5.00	4.34
28.0	Sch MHrs, I level	45.00	31.50
29.0	Sch % O&I req repair	80%	56%
31.0	Sch % ret to Depot	100%	70%
32.0	Sch MHrs, Depot	24	17.58
33.0	Sch % Depot req repair	48%	33.6%
35.0	Sch % scrap	11.30%	8.81%
36.0	Hardware cost to scrap	$12,565.00	$8,808.10

RESULTS SUMMARY SECTION

	Cost $(000)	Savings $(000)
1) Production Engine Cost		
2) Operational Engine Mod Cost	13,834.6	
3) Follow-on Maint Matl Cost		10,726.6
4) Follow-on Maint Labor Cost		17,081.6
5) Publications Cost	0.0	
6) Support Equip Cost	0.0	
7) Part Number Cost	6.5	
8) Fuel Cost		
Totals	13,841.1	27,808.2
Net Delta Dollar Impact $(000)		13,967.2

ITERATION 8 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 80%

	Current	Proposed
22.0 Unsch fail rate/1000 EFH	0.291940	0.237756
23.0 Sch maint interval (TAC's)	1080	1512
24.0 Calculated rate/1000 EFH	3.333	2.889
26.0 Sch % rmvd, O&I level	48%	38.6%
27.0 Sch MHrs to R/R, O level	5.00	4.56
28.0 Sch MHrs, I level	45.00	36.00
29.0 Sch % O&I req repair	80%	64%
31.0 Sch % ret to Depot	100%	80%
32.0 Sch MHrs, Depot	24	19.72
33.0 Sch % Depot req repair	48%	38.4%
35.0 Sch % scrap	11.30%	9.64%
36.0 Hardware cost to scrap	$12,565.00	$10,060.40

RESULTS SUMMARY SECTION

	Cost $(000)	Savings $(000)
1) Production Engine Cost		
2) Operational Engine Mod Cost	13,834.6	
3) Follow-on Maint Matl Cost		7,880.0
4) Follow-on Maint Labor Cost		12,783.7
5) Publications Cost	0.0	
6) Support Equip Cost	0.0	
7) Part Number Cost	6.5	
8) Fuel Cost		
Totals	13,841.1	20,663.7
Net Delta Dollar Impact $(000)		6,822.6

ITERATION 9 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 90%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.264848
23.0	Sch maint interval (TAC's)	1080	1296
24.0	Calculated rate/1000 EFH	3.333	3.111
26.0	Sch % rmvd, O&I level	48%	43.3%
27.0	Sch MHrs to R/R, O level	5.00	4.78
28.0	Sch MHrs, I level	45.00	40.50
29.0	Sch % O&I req repair	80%	72%
31.0	Sch % ret to Depot	100%	90%
32.0	Sch MHrs, Depot	24	21.86
33.0	Sch % Depot req repair	48%	43.2%
35.0	Sch % scrap	11.30%	10.47%
36.0	Hardware cost to scrap	$12,565.00	$11,312.70

RESULTS SUMMARY SECTION

		Cost $(000)	Savings $(000)
1)	Production Engine Cost		
2)	Operational Engine Mod Cost	13,834.6	
3)	Follow-on Maint Matl Cost		4,353.1
4)	Follow-on Maint Labor Cost		7,521.3
5)	Publications Cost	0.0	
6)	Support Equip Cost	0.0	
7)	Part Number Cost	6.5	
8)	Fuel Cost		
Totals		13,841.1	11,874.4

Net Delta Dollar Impact $(000) 1,966.7

(This impact results in a net cost of $1,966,700)

ITERATION 10 PROPOSED UNSCHED AND SCHED MAINT PARAMETERS DECREASED 100%

		Current	Proposed
22.0	Unsch fail rate/1000 EFH	0.291940	0.291940
23.0	Sch maint interval (TAC's)	1080	1080
24.0	Calculated rate/1000 EFH	3.333	3.333
26.0	Sch % rmvd, O&I level	48%	48%
27.0	Sch MHrs to R/R, O level	5.00	5.00
28.0	Sch MHrs, I level	45.00	45.00
29.0	Sch % O&I req repair	80%	80%
31.0	Sch % ret to Depot	100%	100%
32.0	Sch MHrs, Depot	24	24
33.0	Sch % Depot req repair	48%	48%
35.0	Sch % scrap	11.30%	11.30%
36.0	Hardware cost to scrap	$12,565.00	$12,565.00

RESULTS SUMMARY SECTION

	Cost $(000)	Savings $(000)
1) Production Engine Cost		
2) Operational Engine Mod Cost	13,834.6	
3) Follow-on Maint Matl Cost		99.9
4) Follow-on Maint Labor Cost		1,013.4
5) Publications Cost	0.0	
6) Support Equip Cost	0.0	
7) Part Number Cost	6.5	
8) Fuel Cost		
Totals	13,841.1	1,113.4
Net Delta Dollar Impact $(000)	12,727.7	

(This impact results in a net cost of $12,727,700)

APPENDIX B

NAVY ROI MODEL SENSITIVITY ANALYSIS

Appendix B shows the original and altered input parameters for the ECP. The input parameters were altered in 10 percent increments and are highlighted in the initial table for ease of identification. The return-on-investment section for each set of variations is presented immediately following each iteration of the input parameters.

ORIGINAL BASIC INPUT ASSUMPTIONS FOR THE ECP

[0.0 Cost and Other Basic Data]

0.1	Engine Flight Hours per Year	W	(see sched)
0.2	Expected Remaining Life of Engine	Z	13
0.3	Total Expected EFH remaining	X	0
0.4	Cost of Weapon System	K	$42775000
0.5	Amortization Period for Weapon System	Y	175320
0.6	Cost per NMC Hour (J=K/Y)	J	$244
0.7	Cost per MMH (O&I level)	C	$31
0.8	Cost of Fuel (per Gallon)	f	$0
0.9	Cost of Personnel Loss (Train Costs)	U	$330000

[1.0 Operational Data]

Engine Inspections

1.1	Inspection Frequency (Insp per EFH)	I	0.00
1.2	NMC (EMT) per Inspection	E	0.00
1.3	MMH per Inspection	M	0.00

Scheduled Maintenance

1.4	End-of-Life Replace Freq. (per FH)	R	.00136
1.5	NMC (EMT) per Replace	B	12.0
1.6	MMH per Replacement	A	42.0
1.7	Cost of Replacement (material/parts depot labor, test, fuel, et al)	P	$36496

Unscheduled Maintenance

1.8	Maint Action Freq (MAs per EFH)	F	.000465
1.9	NMC per MA (EMT + other downtime)	G	14.0
1.10	MMH per MA	D	42.0
1.11	Cost per MA (materials/parts, depot labor, test, fuel, et al)	N	$48171

Equipment Losses

1.12	Aircraft Loss Frequency	H	0.0000000
1.13	Personnel Loss Frequency	L	0.0000000

Specific Fuel Consumption

1.14	Number of Gallon of Fuel per EFH	g	0

[2.0 Expected Operational Data After the Fix]

Engine Inspections

2.1	Inspection Frequency after Fix	I'	0.000000
2.2	NMC (EMT) per Inspection	E'	0.0
2.3	MMH per Inspection	M'	0.0

Scheduled Maintenance

2.4	**End-of-Life Replace Freq.**	**R′**	**.000614**
2.5	NMC (EMT) per Replacement	B′	12.0
2.6	MMH per Replacement	A′	42.0
2.7	Cost of Replacement (materials/parts depot labor, test, fuel, et al)	P′	$36496

Unscheduled Maintenance

2.8	**Maintenance Action Freq After Fix**	**F′**	**.000266**
2.9	NMC per MA	G′	14.0
2.10	MMH per MA	D′	42.0
2.11	Cost per MA (materials/parts,	N′	$48171

Equipment Losses

2.12	Aircraft Loss Freq After Fix	H′	0.000000
2.13	Personnel Loss Freq After Fix	L′	0.000000

Specific Fuel Consumption

2.14	Number of Gallon of Fuel per EFH	g′	0

[3.0 Investment Cost Data]

3.1	Investment Costs of ECP	Q	$22175168
3.2	One-half of Installation Period (years)		1.5

Return on Investment

[1.0 Investment Costs]

	Total Investment Costs	Q	$22175168

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T′	$39.07
	Cost Reduction per EFH (T-T′) =	S	$40.90
	Cost Reduction for Tot Period (T-T′)(W)Z	V	$43008283

3.0	Return	(V-Q)	$20833115
4.0	Ratio: Benefit/Investment	V/Q	1.94
5.0	Return on Investment	(V-Q)/Q	0.94
6.0	Flight Hours to Return Investment	Q/S	542093

Years to Return Investment	(Q/S)/W	2.76
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		4.26

FLIGHT HOUR SCHEDULE

Number of Years in Schedule: 13
First Year: 1988

Year	FLT. HRS.	CUM. HRS.
1988	207,000	207,000
1989	194,400	401,400
1990	185,400	586,800
1991	174,060	760,860
1992	157,320	918,180
1993	133,740	1,051,920
1994	105,660	1,157,580
1995	75,060	1,232,640
1996	48,240	1,280,880
1997	33,660	1,314,540
1998	23,760	1,338,300
1999	12,960	1,351,260
2000	4,320	1,355,580

ITERATION 1 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 10%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.000689
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000286

[2.0 Benefit = In-Service Cost Reduction]

2.1 Expected Cost per EFH without Fix	T	$79.98
2.2 Expected Cost per EFH with Fix	T'	$48.99
Cost Reduction per EFH (T-T') =	S	$30.99
Cost Reduction for Tot Period (T-T')(W)Z	V	$32578956
3.0 Return	(V-Q)	$10403788
4.0 Ratio: Benefit/Investment	V/Q	1.47
5.0 Return on Investment	(V-Q)/Q	047
6.0 Flight Hours to Return Investment	Q/S	715631
Years to Return Investment	(Q/S)/W	3.74
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		5.24

ITERATION 2 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 20%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.000763
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000306

[2.0 Benefit = In-Service Cost Reduction]

2.1 Expected Cost per EFH without Fix	T	$79.98
2.2 Expected Cost per EFH with Fix	T'	$53.71
Cost Reduction per EFH (T-T') =	S	$26.27
Cost Reduction for Tot Period (T-T')(W)Z	V	$27616634
3.0 Return	(V-Q)	$5441466
4.0 Ratio: Benefit/Investment	V/Q	1.25
5.0 Return on Investment	(V-Q)/Q	0.25
6.0 Flight Hours to Return Investment	Q/S	844220
Years to Return Investment	(Q/S)/W	4.53
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		6.03

ITERATION 3 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 30%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.000838
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000326

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$58.48
Cost	Reduction per EFH (T-T') =	S	$21.50
Cost	Reduction for Tot Period (T-T')(W)Z	V	$22601630

3.0	Return	(V-Q)	$426462
4.0	Ratio: Benefit/Investment	V/Q	1.02
5.0	Return on Investment	(V-Q)/Q	0.02
6.0	Flight Hours to Return Investment	Q/S	1031541

Years to Return Investment	(Q/S)/W	5.85
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		7.35

ITERATION 4 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 40%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.000912
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000346

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$63.20
Cost	Reduction per EFH (T-T') =	S	$16.77
Cost	Reduction for Tot Period (T T')(W)Z	V	$17639308

3.0	Return	(V-Q)	$(4535859)
4.0	Ratio: Benefit/Investment	V/Q	0.80
5.0	Return on Investment	(V-Q)/Q	(.20)
6.0	Flight Hours to Return Investment	Q/S	1321737

Years to Return Investment	(Q/S)/W	10.30
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		11.80

ITERATION 5 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 50%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.000987
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000366

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$67.97
Cost	Reduction per EFH (T-T') =	S	$12.00
Cost	Reduction for Tot Period (T-T')(W)Z	V	$12624304
3.0	Return	(V-Q)	$(9550863)
4.0	Ratio: Benefit/Investment	V/Q	0.57
5.0	Return on Investment	(V-Q)/Q	(0.43)
6.0	Flight Hours to Return Investment	Q/S	1846797

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

******* indicates "Beyond remaining life of engine"**

ITERATION 6 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 60%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.001062
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000385

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$72.69
Cost	Reduction per EFH (T-T') =	S	$7.28
Cost	Reduction for Tot Period (T-T')(W)Z	V	$7662495
3.0	Return	(V-Q)	$(14512672)
4.0	Ratio: Benefit/Investment	V/Q	0.35
5.0	Return on Investment	(V-Q)/Q	(0.65)
6.0	Flight Hours to Return Investment	Q/S	3042680

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

ITERATION 7 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 70%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.001136
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000405

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$77.41
Cost	Reduction per EFH (T-T') =	S	$2.56
Cost	Reduction for Tot Period (T-T')(W)Z	V	$2700173
3.0	Return	(V-Q)	($19474994)
4.0	Ratio: Benefit/Investment	V/Q	0.12
5.0	Return on Investment	(V-Q)/Q	(0.88)
6.0	Flight Hours to Return Investment	Q/S	8634457

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

ITERATION 8 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 80%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.001211
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000425

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$82.18
Cost	Reduction per EFH (T-T') =	S	($2.2)
Cost	Reduction for Tot Period (T-T')(W)Z	V	($2314830)
3.0	Return	(V-Q)	($24489998)
4.0	Ratio: Benefit/Investment	V/Q	(0.10)
5.0	Return on Investment	(V-Q)/Q	(1.10)
6.0	Flight Hours to Return Investment	Q/S	(10071807)

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

ITERATION 9 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 90%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.001285
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000445

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$86.64
Cost	Reduction per EFH (T-T') =	S	($6.67)
Cost	Reduction for Tot Period (T-T')(W)Z	V	($7011180)
3.0	Return	(V-Q)	(29186348)
4.0	Ratio: Benefit/Investment	V/Q	(0.32)
5.0	Return on Investment	(V-Q)/Q	(1.32)
6.0	Flight Hours to Return Investment	Q/S	(3325335)

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

ITERATION 10 PROPOSED END-OF-LIFE REPLACE FREQ AND UNSKED MAINT ACTION FREQ DECREASE 100%

	Scheduled Maintenance		
2.4	End-of-Life Replace Freq.	R'	.001360
	Unscheduled Maintenance		
2.7	Unsked Maint Action Freq.	F'	.000465

[2.0 Benefit = In-Service Cost Reduction]

2.1	Expected Cost per EFH without Fix	T	$79.98
2.2	Expected Cost per EFH with Fix	T'	$91.67
Cost	Reduction per EFH (T-T') =	S	($11.69)
Cost	Reduction for Tot Period (T-T')(W)Z	V	($12292156)
3.0	Return	(V-Q)	($34467324)
4.0	Ratio: Benefit/Investment	V/Q	(0.55)
5.0	Return on Investment	(V-Q)/Q	(1.55)
6.0	Flight Hours to Return Investment	Q/S	(1896699)

Years to Return Investment	(Q/S)/W	*****
One-half Installation period (years)		1.50 years
Total Calander Time to Return Investment		*****

(***** - Beyond Schedule Years)

LIST OF REFERENCES

1. Nelson, J. R., Harmon, B. R., and Tyson, K. W., "Policy Options for the Aircraft Turbine Engine Component Improvement Program", Institute for Defense Analyses, Alexandria, VA, May 1987.

2. "Acquisition Plan AP No. A42-48-0-50 Rev B for Aircraft Engine Component Improvement Program", Naval Air Systems Command, Washington, D.C., August 1987.

3. "Policy Guidelines and Responsibilities for the Administration of the Aircraft Engine Component Improvement Program", NAVAIR Instruction 5200.35, Naval Air Systems Command, Washington, D.C., 25 January 1982.

4. "Military Standard 2173(AS) Reliability-Centered Maintenance Requirements for Naval Aircraft, Weapon Systems and Support Equipment", Department of Defense, Washington, D.C., August 1981.

5. "Program Management Plan for the Engine Component Improvement Program", Air Force Systems Command, United States Air Force, Acquisition Support Division, Wright Patters;on Air Force Base, OH, 10 March 1989.

6. "Component Improvement Program Technical Evaluation Plan", Naval Air Systems Command, Washington, D.C., 21 June 1988.

7. "Engine Component Improvement Feedback Report (ECIFR)"; Naval Air Systems Command, Washington, D.C., March 1989.

8. Blanchard, Benjamin S., Logistics Engineering and Manangement, 3rd edition, Prentice-Hall, Englewood Cliffs, New Jersey, 1986.

9. Davidson, Sidney, Stickney, Clyde P., and Weil, Roman L., Financial Accounting: An Introduction to Concepts, Methods, and Uses, 5th edition, Dryden Press, Chicago, 1988.

10. Office of Management and Budget, Circular No. A-94, Washington, D.C., 1972.

11. Turban, Efraim, Decision Support and Expert Systems: Management Support Systems, 2nd edition, Macmillian Publishing Company, New York, 1990.

12. Department of Defense; DOD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures", 1 January 1991.

13. Isaacson, Donald, "Life Cycle Cost Analysis, in the Reliability, Maintainability, and Supportability Guidebook", Society of Automotive Engineers, Inc., Warrendale, PA, 1990.

14. Davidson, George H., Capt, USAF and Griffiths, Raymond E., Capt, USAF, "An Identification and Characterization of Cost Models/Techniques Used by Air Force Logistics Command to Estimate Jet Engine Operation and Support Costs"; Air Force Institute of Technology, Wright Patterson Air Force Base, OH; June 1977.

15. Nelson, J.R., "An Approach To The Life-Cycle Analysis Of Aircraft Turbine Engines, in the Application of Design to Cost and Life Cycle Cost to Aircraft Engines", AGARD Series No. 107, May 1980.

16. Minnick, Arthur E., "Life Cycle Cost Management, in the Reliability, Maintainability, and Supportability Guidebook", Society of Automotive Engineers, Inc., Warrendale, PA, 1990.

17. Francke, K. P., "User's Manual, Cost Effectiveness Analysis Model for Program Task Plan and Engineering Change Proposals", United Technologies Corp, West Palm Beach, FL, March 1989.

18. Telephone Conversation between John Blakley, Aircraft Engine Group, General Electric Company and the author on November 7, 1991.

19. "AIR-536 Return-on-Investment Analysis Program User's Guide", Naval Air Systems Command, Washington, D.C., September 1989.

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