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THESIS

EVALUATION OF THE COST EFFECTIVENESS ANALYSIS MODEL BEING DEVELOPED FOR THE COMPONENT IMPROVEMENT PROGRAMS OF THE AIR FORCE AND THE NAVY

by

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Evaluation of the Cost Effectiveness Model Being Developed for the Component Improvement Programs of the Air Force and the Navy

by

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ABSTRACT

This thesis examines the Cost Effectiveness Analysis (CEA) model used by the Air Force to assist with the decision making process of their Component Improvement Program (CIP). The emphasis was on studying the model for its use in the Naval Component Improvement Program. With an example provided by General Electric, a sensitivity analysis was performed to determine the cost drivers of the model. For the example, the major cost drivers were found to be the Incorporation Style, Kit Hardware Cost, and the Spare Parts Factor. Next a simple simulation was conducted to determine how random component failures affect the life cycle cost variability of the CEA model. The author concluded that additional simulation studies should be conducted for other causes of variation. A detailed analysis of the model formulas and assumptions are needed as part of a users' manual.

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I. INTRODUCTION

A. BACKGROUND

A main objective of CIP is to reduce the cost of ownership of an aircraft engine currently in use by the military forces. Any CIP proposal needs justification. A contractor may formulate the justification to increase flight safety, increase mission effectiveness, or to decrease aircraft or engine operating costs. In the latter case, a contractor could use a justification method that compares an old engine component to a new component. This could come in the form of increased mean time between failures, less preventative or scheduled maintenance, or the component may be cheaper to repair.

One type of justification method currently in use is the Cost Effectiveness Analysis (CEA) Model of the Air Force. It compares the Life Cycle Costs between an existing component and an Engineering Change Proposal (ECP). Hopefully, investment of Component Improvement Program (CIP) dollars in Engineering Change Proposals (ECP) or Power Plant Changes (PPC) are justified because of future dollar savings. Future dollar savings are usually expressed in net present value terms and an estimate is made of the calendar time or flight hours to achieve the Return of Investment. This model is now beginning to be used by the contractors of the Air Force, with the Navy discussing its merit for their Justification process for ECP's. This thesis will continue the evaluation of the structure of the CEA model begun by Davis. [Ref. 1]

B. OBJECTIVES

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

1. Conduct a literature review of Life Cycle Cost Models to determine what elements in a model should be considered for evaluation.

2. Determine if the CEA model accurately reflects the life cycle costs for aircraft engine component improvements based on the information obtained from the literature review and the evaluation. If not, then suggestions will be made for improvements to the model.

3. Identify the cost drivers in the CEA Model.

C. METHODOLOGY

The methodology for conducting this research involved a thorough review of current literature, instructions, reference materials and guidance dealing with Life Cycle Cost models.

Secondly, a sensitivity analysis on the structure of the Cost Effectiveness Analysis model will be performed to determine what costs drive the model. Additionally, these cost drivers will be verified against the model description to validate their relevance in life cycle costing.

Finally, simulations of component failures will be performed on the model by randomly generating these failures and incorporating them into the model, thus determining what effect reliability has on the model.

D. ORGANIZATION OF THE THESIS

Chapter II describes the format of the Cost Effectiveness Analysis Model and defines the input elements.

Chapter III briefly describes typical elements of life cycle cost, and life cycle costing models, explains the sensitivity analysis performed to determine the cost drivers of the CEA model and details the simulation process used to evaluate the effect reliability plays in the model.

Chapter IV contains a summary of the thesis, conclusions obtained from the analysis, and recommendations for improvements.

II THE CEA MODEL

A. BACKGROUND OF THE MODEL

The Cost Effectiveness Analysis Model (CEAMOD) was originally a spread sheet based model developed by Pratt & Whitney from an initial structure proposed by Larry Briskin of the Air Force. P&W developed a mainframe computer spread sheet using DYNAPLAN. The model has recently been adapted by General Electric for a microcomputer using LOTUS 123 software.

The main purpose of CEAMOD is to project the savings which would be achieved from implementing an ECP. The military services can use that information to prioritize a list of proposed ECP's. The projected savings are determined from the cost differences between implementing the proposed configuration and sustaining the current configuration. Ideally, the costs of implementing the ECP should be outweighed by the resultant operations and support savings [Ref. 2:p. I-1].

B. FORMAT OF THE MODEL

The model's structure is comprised of three primary sections which contain the assumptions, data inputs, and the results summary. The assumption section is made up of 13 elements which propose how and when the proposed modification will take place. The data input section consists of current and proposed parameter values, provided by the operator, which are used to calculate the life cycle cost differences between the current and proposed configurations. These parameters address the overall operational and support costs that are to be expected in any decision involving an engine change proposal. Finally, the results summary consists of a summary page and pages detailing the calculations performed to predict the net annual dollar savings from incorporating the ECP. A typical example using CEAMOD, is illustrated in Appendix A.

C. DESCRIPTION OF INPUT PARAMETERS 1.0 THROUGH 21.0

The input section contains 53 elements which are subdivided into two sections. Section one contains 21 elements which are general data elements while section two provides the data elements to be used to show the comparison between the current configuration and the proposed configuration. The role of each of the elements in the model are described below for the first 21 elements.
[Ref. 3]

1.0 Incorporation style selects the method of incorporating the modification into the existing fleet.

- Attrition incorporates the modification only during a "failure" of the engine or old component.
- First Opportunity incorporates the modification during an engine unscheduled or scheduled event, whichever occurs first.

- Forced Retrofit allows the modification to occur at a specific rate set by the user.

2.0 **Delta Production Cost** is the difference between the production cost of an engine incorporating the modification and one that does not contain the modification. 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.

3.0 **Kit Hardware Cost** is the purchase price per engine of the component modification kit. This cost is provided by the contractor.

4.0 **Kit Labor Man-hours** is the expected time in hours to install a modification kit and is usually broken into two values; one for organizational and intermediate (O&I) level labor hours and the other for depot labor hours.

5.0 **Labor Cost per Man-hour** is determined from labor cost data maintained by the military organization that is considering the ECP.

6.0 **Tech Pubs Cost** incorporates any technical publication costs associated with the proposed component change. This input is supplied by the contractor.

7.0 **TCTO Cost** is a time compliance technical order cost. A TCTO is issued for important changes when urgency is an issue. The associated costs usually coincide with forced retrofits or first opportunity changes.

8.0 New Part Number Intro Cost is the cost of introducing a new part number into the military supply system. An ECP may result in several new parts.

9.0 Part Number Maintenance Cost covers the annual cost of maintaining a part in the military supply system.

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 the current tooling and support equipment to comply with the engine change requirement.

11.0 Test Fuel- $/Gal is the cost per gallon of fuel to test the engine after the modification has been installed.

12.0 Test Fuel- Gal/Hr comes from the standard history file and is the number of gallons required to test the engine following modification.

13.0 Spare Parts Factor is an estimate, as a percentage of total installed/modified engines, of the spare engines or spare modules which will also require the proposed modification.

14.0 Year Field Modification Starts is the year that modifications will begin on engines which have already been produced. Usually, the initial supply of the improved components will go into engines currently on the production line. Following that, field modifications will begin. These field modifications cannot begin until there are sufficient improved components available beyond the needs of engine production.

15.0 % Scheduled Events Being Modified allows only a percentage of those scheduled events when a engine is eligible to receive the modification to actually receive the modification. The remaining events for that year for other engines receive no modifications.

16.0 % Unscheduled Events Being Modified allows only a percentage of those unscheduled events when an engine is eligible to receive the modification to actually receive the modification. The remaining events for that year for other engines receive no modifications.

17.0 Failure Rate Allowing Modification is the rate at which unscheduled opportunities occur due to an engine failure which would allow the modification to be installed.

18.0 Year Production Starts is when production of engines incorporating the modification starts.

19.0 Fiscal Year Dollars is the baseline year from which net present value will be calculated.

20.0 TAC/EFH Ratio is the number of engine cycles expected per flight hours (EFH). 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 can be obtained from the engine standard history file by averaging the total accumulated cycles (TAC) over a given number of EFH.

21.0 TOT/EFH Ratio also comes from the engine standard history file and is the average of total engine operating hours per engine flight hour. Total engine hours include test time and runway taxi time.

D. DESCRIPTION OF INPUT PARAMETERS 22.0 THROUGH 53.0

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

22.0 Unscheduled Failure Rate/1000 EFH is the failure rate which represents how often the component being modified is expected to fail per EFH. This rate drives the component's unscheduled events and associated costs.

23.0 Scheduled Maintenance Intervals (TAC's) represents the scheduled time interval, measured in engine cycles, between inspections of the engine to check for possible problems. A scheduled maintenance may be an opportunity to install the proposed modification. This interval drives the scheduled events and the associated costs.

24.0 Calculated Rate/1000 EFH is not an input element. It is derived by taking the element no. 22 value and dividing it by element no. 20. The "Calculated Rate/1000 EFH" represents a scheduled maintenance rate factor for the engine based on EFH. The model's Life Cycle Cost formulas use this rate factor in calculating the expected EFH between scheduled maintenance actions.

25.0 Scheduled Hours to Inspect, O Level is the number of man-hours necessary at the O level to accomplish any scheduled inspection on the part to be modified.

26.0 Scheduled % Removed at O&I Level is the percentage of the total units requiring scheduled work that are removed at the O or I levels. If this percentage is not 100%, the remaining units would, by necessity, be removed at a depot or not removed at all.

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 required 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 are expected to require repair at the O&I levels during any scheduled maintenance.

30.0 **Scheduled Repair Cost O&I Level** provides the cost to repair one unit at either the O and I level.

31.0 **Scheduled % Returned to Depot** is the percentage of components which require repair during scheduled maintenance that cannot be performed at the O&I level.

32.0 **Scheduled Man-hours Depot** accounts for the total number of scheduled maintenance man-hours required to repair 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.

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** is the percentage of total units, identified during scheduled maintenance, which must be scrapped (beyond economic repair).

36.0 **Hardware Cost to Scrap** represents the replacement cost of a component which is scrapped during scheduled maintenance. The assumption is that if a component is scrapped, then a new unit must be bought to replace the old one.

37.0 Scheduled Engine 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 O level which are required to accomplish any unscheduled inspections on the component being considered for modification.

39.0 Unscheduled % Removed at O&I level is the percentage of total components for which unscheduled removal is able to be 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 Level 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 to repair one unit at the O or I level.

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 man-hours 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 maintenance 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 expected to be identified as beyond economical repair during unscheduled maintenance.

49.0 Hardware Cost to Scrap represents the replacement cost of the component associated with unscheduled failures. It has the same value as element no. 36 except in unusual cases.

50.0 Unscheduled Test Time is the total engine test time required for each component requiring repair during unscheduled maintenance.

51.0 Secondary Damage Cost covers the estimated material costs to other components due to the failure of the component being proposed for modification.

52.0 Incidental Costs represent 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 is the total number of part numbers that will be required in inventory in support of the new modification.

Although these definitions seem general in nature and somewhat redundant at times, according to Christian [Ref. 4], they allow the user to interpret the information to suit a particular situation and also allow for general bookkeeping costs that do not have a unique input element.

E. THE RESULTS SUMMARY SECTION

The model's result summary section performs the final cost calculations and produces a summary which displays the cost and savings 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 represents the difference in price between a new engine incorporating the modification and one not incorporating the modification. The production engine cost will only be a factor only if there are engines still in production.

Operational Engine Modification Costs are the total of kit purchase costs plus the kit installation costs over the engine's life cycle. If the kit costs replace any maintenance costs then those maintenance costs (unscheduled, scheduled, and hardware scrapping costs) are subtracted from the engine modification costs. These engine modification costs account for the costs, or savings, which are expected to occur from implementing the modification.

Follow-on Maintenance Material Costs are equal to the difference between the follow-on material costs for the proposed component and those for the current component over the remaining life cycle. Both expected scheduled and unscheduled maintenance actions are included.

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

Publication Costs are taken directly from the input section (element 6.0).

Tooling/Support Equipment Costs are also taken directly from the input section(element 10.0),

Part Number Costs account for the cost of introducing and maintaining a new part number in the supply system as a consequence of the proposed component modification.

Fuel Cost factors in any life cycle fuel consumption savings or costs which are attributable to the ECP.

III. MODEL ANALYSIS

A. INTRODUCTION

Chapter II provided a brief description of the model and the input data required. This chapter will first discuss life cycle costing, general modeling concepts and areas of evaluation. Next, the GE CEA model will be analyzed in two of these evaluation areas.

B. LIFE CYCLE COST

All systems and equipment pass through four major phases between the time of their creation to the time of their disposal. Dhillon [Ref. 5:p. 87] states that the four major phases of the life cycle are:

1. **The Concept and Definition Phase** - During the concept and definition phase a need for a product is established and the product's basic characteristics are defined. This activity results in documentation which states the requirements and how they can be met.

2. **The Acquisition Phase** - The activities of the acquisition phase are directed toward product acquisition and installation, and toward planning for the eventual support of the system or equipment chosen during the first phase.

3. The Operation and Maintenance Phase - The operation and maintenance phase, sometimes called the in-service phase, focuses on the maintenance and support of the system or the equipment during the entire operational life. This phase ensures that the capability requirements previously stated have been met, and will continue to be met, within the cost restraints.

4. The Disposal Phase - The disposal phase is the final phase and consolidates all tasks required to remove the system or equipment, plus all its required supporting material.

DOD Manual 5000.2-M states that cost and operational effectiveness analyses are essential elements of the decision making process for all acquisition programs. Life cycle cost estimating is part of the procurement *process.* Its purpose is to consider the overall total costs associated with each alternative form of the product. The comparison of the life cycle costs of alternatives requires some sort of common analytical, conceptual, or heuristic model be used.

C. LIFE CYCLE COST MODELS

To understand the full impact that the life cycle cost of a system or piece of equipment exerts on an organization, a life cycle cost model must be utilized to identify all facets of any future acquisition. There are a wide variety of life cycle cost models available in published literature [Ref. 6:p. 737-742]. They include both general and specific models.

There is no single life cycle cost model which has been accepted as a standard model within DOD. There could be several reasons for not having a standard model; e.g., nature of the problem, many different types of equipment, devices or systems, or the inclination of the user. Nevertheless, irrespective of the types of models used for life cycle cost analyses, they all must be visible, transparent, and effective in representing systems, subsystems, or devices [Ref. 7].

One may describe life cycle cost models as predictive in nature and characterized by an underlying stochastic process involving many parameters. Two important examples of such parameters are maintainability and reliability. In addition, costs and other parameters may not be independent variables [Ref. 8:p. 535-549].

1. Elements Associated with Life Cycle Cost Analysis

According to Dhillon [Ref. 9:p. 33] a life cycle cost analysis includes several activities. Some of those are:

A. Identifying cost drivers;

B. Establishing an accounting breakdown structure;

C. Developing for every component in the life cycle cost breakdown structure the cost estimating relationship;

D. Defining an item or product's life cycle;

E. Defining activities that generate a product's ownership costs;

F. Establishing constant dollar cost profiles;
G. Performing sensitivity analyses;
H. Determine cost and effect relationships; and
I. Developing escalated and discounted life cycle costs.

2. Areas for Evaluation of the Life Cycle Model

All phases of the life cycle model have to be evaluated periodically to keep it current to meet the needs of the user. The model user should perform the evaluation task. There are several areas about which questions should be asked to determine adequacy of the life cycle costing model. Some of these areas are as follows [Ref. 10]:

A. Construction of the cost model;
B. Identification of cost drivers;
C. Accuracy of cost estimating data base;
D. Soundness of cost estimating methods used;
E. Validation of cost estimates by an independent appraisal;
F. Management review of the top ten cost drivers for economy;
G. Compatibility of reliability with the life cycle cost requirements;
H. Adequate consideration of inflation and discounting factors;
I. Performance of trade-off studies;

J. Coordination of the life cycle cost and design to cost work;

K. Awareness of the buyer concerning top ten cost drivers; and

L. Suggestions by the model user for reducing such costs.

Since the cost drivers of the CEA model have never been studied, and the military places great emphasis on reliability when improving any component, the following sections will evaluate these two areas of the CEA model.

D. COST DRIVERS

Cost drivers in a life cycle cost model are the elements that dominate the costs in the model. When changed in magnitude,these cost drivers exert the largest percentage changes on the total life cycle cost. Each system or piece of equipment has unique cost drivers which depend on the system or piece of equipment being considered. For example, cost drivers may be the cost of spares, transportation costs, failure rates, or the costs of installation.

To help begin the study of the cost drivers in the model, an example is useful. Appendix A contains an example provided by GE [Ref. 11] of an ECP life cycle cost comparison for discussions at users group meetings. It will be used for all evaluations in this thesis.

Each of the first 18 input elements (See Chapter II) in the example was doubled, one at a time, to determine what effect that particular element had on the expected life cycle costs of the example ECP. The baseline costs were for the First Opportunity Incorporation Style. They were derived from the original data, including input changes, that came with the CEA model. Their values are: Current Configuration $29144.3; Proposed Configuration $22052.9; Savings $7091.31. The results are shown in Table I.

The Data column in the Table I illustrates both the original input data values provided in the GE example and the corresponding changes that were made to each data element for this study. The next three columns of the table show the life cycle costs as the current configuration costs, the proposed configuration costs, and the resulting savings or losses. The percent change column compares the change that each particular data element exerted caused in the proposed costs with the original proposed cost that was used as the baseline cost. Those showing a minus sign reflect the percentage of the proposed costs below the baseline proposed costs.

TABLE I: COST DRIVER ANALYSIS

Input Elem.	Data	Current $(000's)	Proposed $(000,s)	Savings $(000,s)	% CHANGE
1.00	1	29144.30	27506.50	1637.71	**25**
	2 BASE	29144.3	22052.9	7091.31	0
	3	29144.30	28290.50	853.73	**28**
2.00	10000-20000	29144.30	22382.90	6761.30	01
3.00	15000-30000	29144.30	30752.90	-1608.60	**39**
4.10	2-4	29144.30	22090.40	7053.80	00
4.20	20-40	29144.30	22555.20	6589.03	02
5.10	32.32-64.64	29144.30	24792.90	7707.60	12
5.20	43.30-86.60	29144.30	23900.00	6914.40	08
6.00	500-1000	29144.30	22053.40	7090.81	00
7.00	1500-3000	29144.30	22054.40	7089.80	00
8.00	1524-3048	29144.30	22059.00	7085.20	00
9.00	250-500	29144.30	22089.90	7080.30	00
10.00	500-1000	29144.30	22053.40	7090.80	00
11.00	.61-1.22	29144.30	22380.80	7170.60	01
12.00	150-300	29144.30	22380.80	7170.60	01
13.00	0-1	29144.30	31818.40	-2674.10	**44**
14.00	1991-1993	29144.30	24111.50	5032.70	09
15.00	1-2	29144.30	20890.40	8253.86	-05
16.00	1-2	29144.30	21749.70	7394.56	-01
17.00	0.10.2	29144.30	21774.10	7370.20	-01
18.00	1991-1993	29144.30	22512.30	6631.90	02

The results of this evaluation identified the Incorporation Style (element 1.00), Kit Hardware Cost (element 3.00), and the Spare Part Factor (element 13.00) as the principal cost drivers for this particular example. These drivers are highlighted in the table. The details associated with these cost drivers are explained below.

1. Incorporation Style

Incorporation Style (element 1.00) is the method by which the modification will be incorporated into the existing fleet. The methods include by Attrition, which is modifying a component only during a failure; First Opportunity, which is modifying during any scheduled or unscheduled maintenance; or by Forced Retrofit, which allows for a specific modification rate to be set by the operator which is independent of any scheduled or unscheduled maintenance.

Each incorporation style has its own unique costs which are derived by taking the number of engines entered in the attrition and forced removal columns of the standard history section of the model. These are then added to the number of kits installed at production, to give the total number of kits installed in the proposed configuration section.

First Opportunity was the style originally used in the example, and according to Stephanie McDonald of U.S. Air Force ECP Department, this is the Incorporation Style used ninety-nine percent of the time because of its low cost and timing of the modification installation. Table I shows that Attrition and Forced Retrofit increased the life cycle cost of the ECP by 25 and 28 percent respectively over the First Opportunity case which served as the baseline.

2. Kit Hardware Cost

Kit Hardware Cost (element 3.00) is the cost of all material and hardware required for an ECP modification. Table I shows that doubling this cost resulted in a 39 percent increase in the proposed ECP costs over those of the baseline. It also shows that there was no savings.

The user must carefully consider the impact of this cost because its value may not be known with any certainty initially. An investigation into how much the kit cost could change before it is uneconomical to incorporate the modification should be made. In particular, in safety of flight issues, the user of the model may discover that the trade-off between safety and the kit cost could become enormous. Figure 1 illustrates how the Kit Hardware Cost affects the savings.

As Figure 1 shows, the savings in life cycle costs are strictly a linear function of Kit Cost, decreasing as the cost of the kit increases. In this case, the modification will become uneconomical to install when the price per kit approaches $27,000 for the example data. The user of the model must be aware that since this is a linear function and a major cost driver, no matter what the reason is that an ECP should be incorporated, $27,000 is the maximum that kit hardware cost can be while still showing a savings in this example.

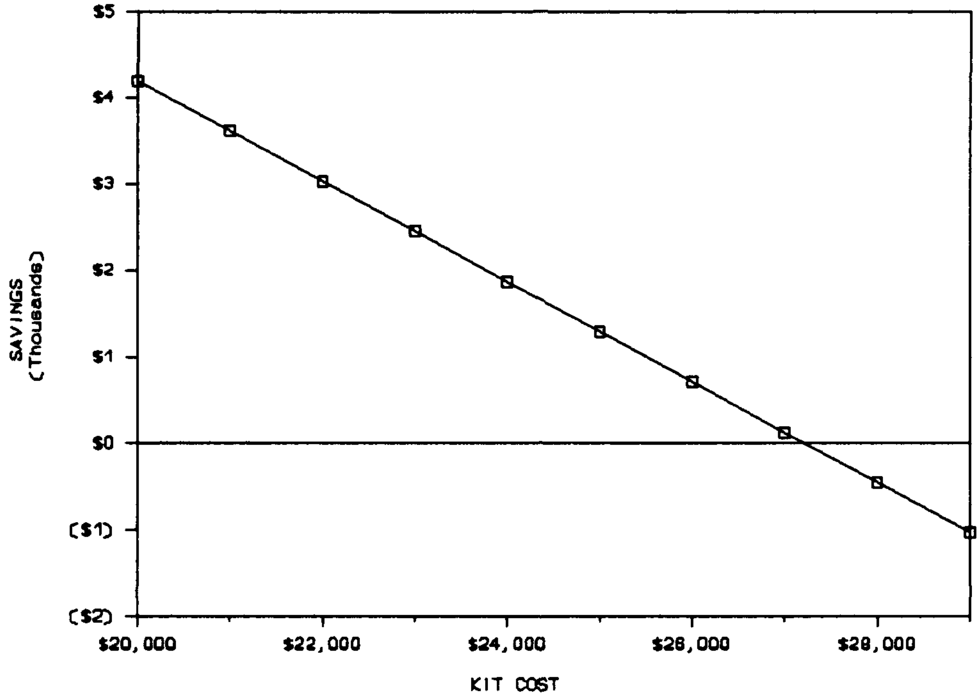

Figure 1

3. Spare Parts Factor

The last cost driver that is highlighted in Table I is the Spare Part Factor (element 13.00). The Pratt and Whitney representative defines this as the "percentage of total installed engines" that are assumed to be spare engines or modules sitting on the shelf at a warehouse that need to have the ECP upgrade. Kits are also needed for these engines and modules.

To evaluate the impact of this element, the author entered values for the spare parts factor ranging from 0.008 to 0.9. The model calculates the number of kits expected to be installed on spare engines and modules/components (column CO in the example), by multiplying the spare parts factor by the number of kits installed for a given year (column CL) on engines in use plus the number of engines modified at production (column CC) for that year. How the spare parts factor affects the savings is represented in Figure 2 below.

As Figure 2 indicates, the spare parts factor also reduces the savings but in a piece-wise linear fashion. A dramatic decrease in the savings from the spare parts factor occurs as the factor increases from 0.1 to 0.9. The reason for this piece-wise decrease in savings can be attributed to the rounding rule used to determine integer number of spares needed in any given year. In the example used, all fractional values were rounded down.

It must be noted that this spare cost factor does not take into account the spare required if a component which has a kit already installed fails.

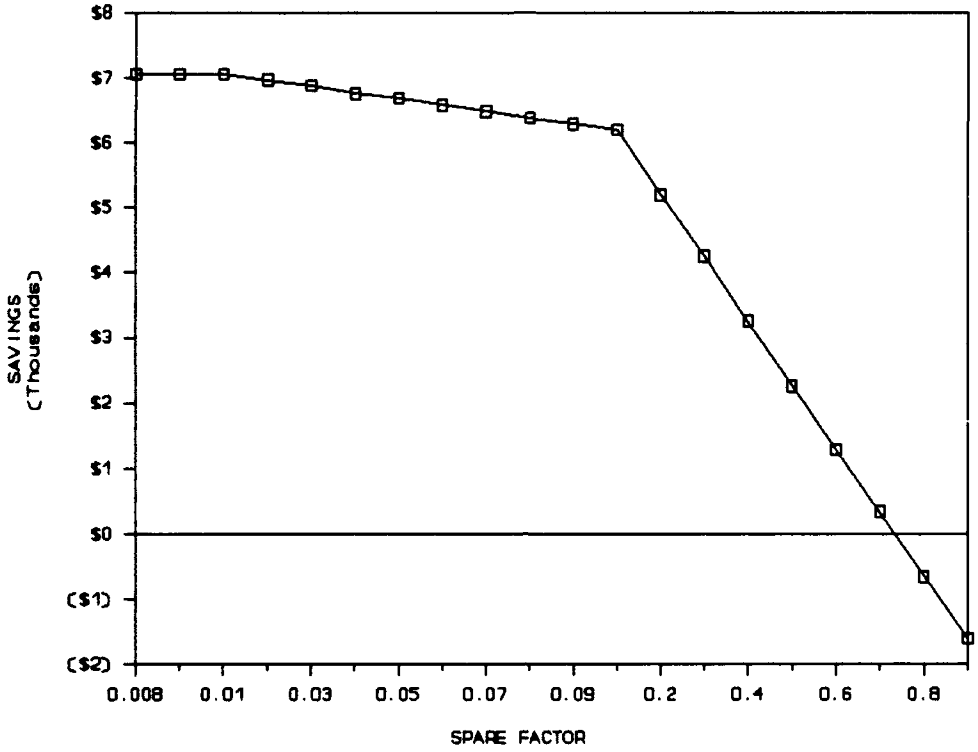

Figure 2

4. Section Summary

This section has examined the three major cost drivers for GE's example. The highlighted percentages from Table I identified these costs drivers as the Incorporation Style, Kit Cost, and the Spare Parts Factor. All of these elements increased the proposed baseline cost from twenty-five to forty-four percent. Increases in the other data elements in the model did not exert anywhere near as much influence as the three previously mentioned. It also appears from this sensitivity analysis that no matter what example is used, these three elements can be expected to exert the greatest amount of influence on any life cycle cost calculations.

E. RELIABILITY

The second area of the CEA model to be evaluated was the reliability of the component requiring the ECP and what effect it has on the final life cycle cost.

1. Introduction

Reliability may be described as "quality in the time dimension". [Ref. 12:p. 4] It is classically defined as the probability that an item will perform satisfactorily for a specified period of time under a stated set of use conditions. From a functional point of view, in order for an item to be reliable, it must do more than meet an initial factory performance or quality specification--it must also operate satisfactorily for an acceptable period of time in the field application for which it is intended. [Ref. 13:p. 9-1]

The classical definition of reliability, stated above, stresses four elements, namely: probability, performance requirements, time and use conditions. Probability is that quantitative term which expresses the likelihood of an event's occurrence (or non-occurrence) as a value between zero and one. Performance requirements are those criteria which clearly define or describe what is considered to be satisfactory operation. Time is the measure of that period over which one can expect satisfactory performance. Use conditions are the environmental conditions under which one expects an item to function adequately.

Determining reliability, therefore, involves the understanding of several concepts which relate to these four definitional elements. Among such concepts is that a failure rate can vary as a function of age. A failure rate is a measure of the number of malfunctions occurring per unit of time. In order to explain the variation in failure rate, separate consideration is typically given to three discrete periods when viewing the failure characteristics of a product or item over its life span (and then considering a large sample from its population). Anderson [Ref. 12] describes these periods as:

> a) Infant Mortality Period
>
> Initially, the item population exhibits a high failure rate. This failure rate decreases rapidly during this first period (often called the "infant mortality", "burn-in", or debugging period), and stabilizes at an approximate value when the weak units have died out. It may be caused by a number of things: gross built-in flaws due to faulty workmanship, transportation damage or installation errors. This initial failure rate is unusually pronounced in new equipment.
>
> b) Useful Life Period
>
> The item population, after having been burned-in, reaches its lowest failure rate level, which is normally characterized by a relatively constant failure rate, accompanied by negligible or very gradual changes due to wear. This second period is called the useful life period, and is characterized mainly by the occurrence of stress related failures. The exponential failure distribution is widely used as a mathematical model to approximate times between failure during this time period.

This period varies among hardware types, is the interval usually given most weight in design reliability action, and is the most significant period for reliability prediction and assessment activities.

c) Wearout Period

The third and final life period occurs when the item population reaches the point where the failure rate starts to increase noticeably. This point is identified as the end of useful life or the start of wearout. Beyond this point on the time axis, the failure rate increases rapidly. When the hardware failure rate becomes unacceptably high, replacement schedules (of critical short-life components) are based on the recognition of this failure rate.

Optimizing reliability involves the consideration of all three of these life periods. Early failures must be eliminated by systematic procedures of controlled screening and burn-in tests. Stress related failures must be minimized by providing design margin. Wearout must be eliminated by timely preventative replacement of short-life component parts. Thus, all major factors which influence (and degrade) a system's operational reliability must be addressed during design to optimize and control system reliability. [Ref. 14:p. 7]

In order to introduce several additional concepts, the author will focus now on the useful life period. The CEA model considers only the useful life period. During this time period, reliability is described by means of the single parameter exponential distribution:

$$R(t)=e^{-\lambda t}$$

where:

$R(t)$	is the probability that the item will operate without failure for the time period, t (usually expressed in hours), under stated operating conditions;
e	is the base of the natural logarithms, equal to 2.7182......;
λ	is the item failure rate (usually expressed in failures per hour), and is a constant for any given set of stress, temperature, and quality level conditions. It is determined for parts and components from large scale data collection and/or test programs.

When appropriate, the values of λ and t are inserted into the above expression to obtain the probability of success (i.e., reliability) is obtained for that time period.

As will be shown latter, the reciprocal of the failure rate is the mean time between failures (MTBF); i.e.,

$$MTBF = 1/\lambda.$$

The MTBF is primarily a figure of merit by which one hardware item can be compared to another.

2. Exponential Failure Model

The exponential failure model can be derived from the basic notions of probability. [Ref. 13] When a fixed number, N_o, of components are repeatedly tested, there will be, after a time t, N_s components which survive the test and N_f components which fail. The reliability or probability of survival, is at any time t during the test:

$$R(t)=\frac{N_s}{N_o}=\frac{N_s}{N_s+N_f}.$$

Since $N_s = N_o - N_f$, reliability can be written:

$$R(t)=\frac{N_o-N_f}{N_o}=1-\frac{N_f}{N_o}=1-F(t);$$

and

$$\frac{dR}{dt}=-\frac{1}{N_o}\frac{dN_f}{dt}=-f(t);$$

where f(t) = the failure density function; i.e., the probability that a failure will occur in the next time increment, dt.

The hazard rate z(t) is defined as the ratio of the fractional failure rate to the fractional surviving quantity. [Ref. 15:p. 345] Analytically, z(t) can be written as

$$z(t)=\frac{f(t)}{1-\int_{o}^{t}f(u)\,du}.$$

For the exponential distribution

$f(t) = \lambda e^{-\lambda t}$

and,therefore, it can be shown that

$z(t) = \lambda$.

In general, it can be assumed that the hazard rate of components and systems remains constant over practical intervals of time; i.e., is independent of the accumulated life of a system up to that point in time. Thus, λ represents the expected number of random failures per unit of operating time of a system or, in other words, the failure rate. When a constant failure rate is assumed:

$$R(t)=\int_0^t [1-F(u)]\,du=e^{-\lambda t}$$

gives the function based on the exponential distribution function commonly used in reliability prediction.

Also, the mean time to failure can be determined, when a constant failure rate is assumed, by:

$$MTBF=\int_0^\infty \lambda t e^{-\lambda t}dt=\frac{1}{\lambda}.$$

The above expressions for R(t) and MTBF are the basic mathematical relationships used in reliability prediction.

The assumption of a constant failure rate for complex systems is judged applicable because of the many forces that can act independently upon the item and cause failure. As stated previously, the stress/strength relationship and varying environmental conditions effectively result in such "random" failures.

3. Reliability Analysis

Before a reliability analysis on the CEA model can be conducted, it is necessary to first explain how failures are represented in the model. There are two types; the failures of the component being improved and the aggregate engine failure. For the first type, failure rates are provided by the contractor as element 22.0 in the input data. The units are given as failures per 1000 flight hours. The model then multiplies the total expected programmed engine flight hours per year by this failure rate and places this total in column BD, of the GE example, for the current configuration unscheduled maintenance, and column CH for the proposed configuration unscheduled maintenance. The values in these columns thus represent the expected number of failures of the component in each year. Similarly, the engine expected aggregate failure rate is entered as element 17.0. It, too, is multiplied by the total programmed flight hours to get aggregate engine failures per year.

F. SIMULATION

The CEA model is only an expected value cost model and thus does not consider the variability in life cycle cost and savings. An understanding of that variability can help decision makers make more careful decisions on ECP's.

This section describes a very simple simulation model which assumes the component is the only item failing based on the exponential distribution. The purpose is to begin to understand the impact improved reliability has on life cycle cost. The component failure rates for the example were 0.02 per 1000 hours and 0.002 per 1000 hours for the current and proposed configurations, respectively.

Fifty system lifetime simulations, covering twenty years, were conducted and the component failures for each year were incorporated into the appropriate columns of the model. At the end of each simulation the Current Costs, Proposed Costs, and resulting Savings were recorded. The results of these fifty simulations are illustrated in Figure 3.

The top curve represents the simulated life cycle costs for the current configuration of the component, the middle curve represents the simulated life cycle costs for the proposed configuration, and the lower curve represents the savings from the ECP. For the proposed configurations the costs show very little variability throughout the simulations, ranging from $21,900 to $23,000. The current configuration showed much more variable costs, ranging from $27,500 to $31,000. The savings ranged from $5000 to $8500. The variability of the life cycle costs is reduced as a consequence of having fewer failures per year due to a lower failure rate.

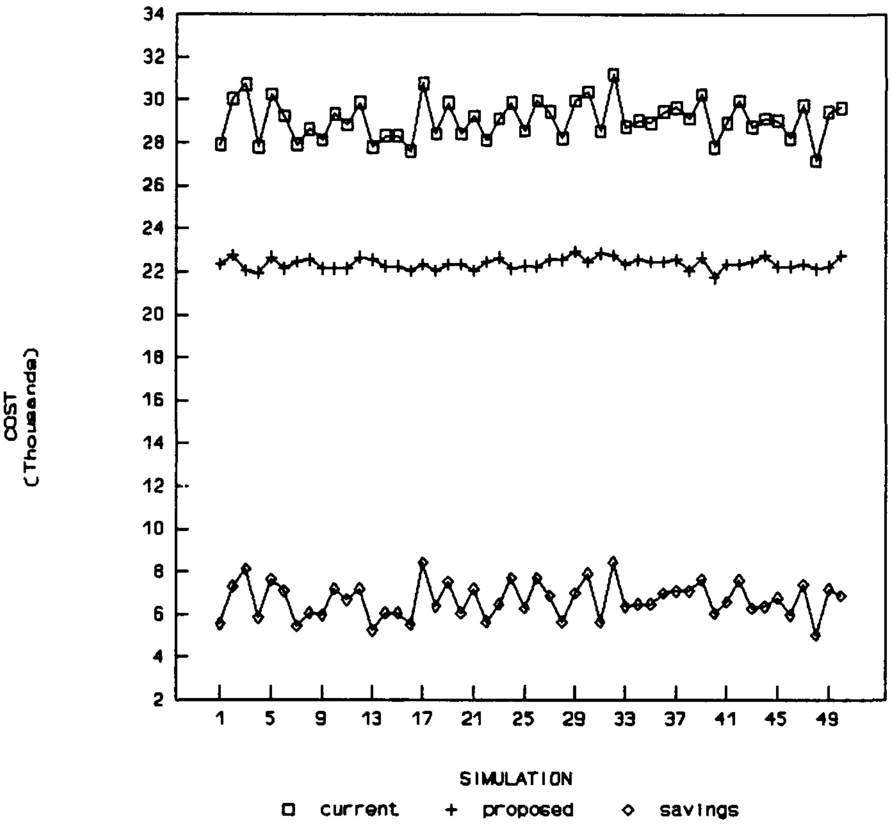

Figure 3

1. Section Summary

This section of the chapter evaluated how component reliability affects the CEA model. First, reliability was defined and the change in failure rates over the life of a component were explained. Next, the exponential distribution model's use in determining the failure rate of a component was discussed. Finally, a simulation analysis of the CEA model using the GE example was performed. This resulted in the variability of the life cycle costs of a component being reduced as the reliability of that component was improved.

IV. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

The main objective of this thesis was to determine if the CEA model actually reflects the life cycle costs for aircraft engine component improvements. A secondary consideration was to discover the cost drivers in the model by a sensitivity analysis. In addition, simulations were ran on an example provided by General Electric's Aircraft Engines Division to determine how reliability improvement of a component affects the variability of the model's life cycle cost calculations.

To accomplish these objectives, the author first had to determine if the CEA model calculates true life cycle cost. Chapter II specifically discussed the format of the CEA Model which included the definition of all input elements. Chapter III addressed the four phases of a life cycle that are required for an effective life cycle cost model and presented some areas that should be evaluated to determine if the model is achieving the objective for which it was designed. It became evident that the model does not calculate all of the life cycle costs, both before and after an ECP is installed on a component. It only considers those life cycle cost elements affected by the installation of the ECP.

A simple sensitivity analysis was then performed on the CEA model to determine which input elements were the cost drivers in the particular example provided by GE. Those found to be major drivers were then examined more carefully to determine how the savings were related to changes in their values.

Finally, fifty simulations were conducted on the model to study the variability of the life cycle cost savings as the reliability of a component is improved through a ECP.

B. CONCLUSIONS

The CEA Model does not incorporate all four phases of a component's life cycle cost. As stated earlier, it only calculates the costs before and after an ECP is installed.

The cost drivers for the GE example used with the CEA model were Incorporation Style, Kit Hardware Cost, and the Spare Parts Factor. Any ECP installed will require the input of the Incorporation Style and Kit Hardware Cost. Although the Spare Parts Factor proved to be a cost driver from the analysis, the true impact of its use in the model may be questionable. In all the examples provided by GE, illustrating various uses of the model, the Spare Parts Factor has always been zero. By the definition of this term , this means that there are no extra kits required because there are no spare engines or components that are on the shelf or in a warehouse that need modified. It is also important to note that the Spare Parts Factor does not address the question of using the inventory of spare modified components to replace those which fail. In fact, the hardware costs to scrap suggest that unexpected failures will result in high future costs to replace any failed components since no more modified components are available as spares in the inventory. However, even if there are spare modified spare components on the shelf, as reflected by a non-zero Spare Parts Factor, these are not used in the model to replace failed modified components.

This CEA Model does provide the basic information needed for the Useful Life and Disposal Phase part of an effective life cycle cost model. This information alone is not enough for justifying the expense of an ECP. What is needed is a model which incorporates all four phases to provide the user with some idea what all the costs of any ECP entails. At, the last CEA Users Group meeting, on 28 April 1992, the Air Force asked that the development costs be added to the model.

C. RECOMMENDATIONS

It is recommended that further evaluations be conducted on the CEA Model. At this point in time, there are still too many questions regarding the details of formulas used in this model for calculating life cycle costs. The definitions of the input elements need to be more specifically defined to make them mean the same for all situations. The elements that are redundant need to be removed and replaced with ones that can give more pertinent information about the ECP being contemplated.

In addition, the model should be programmed in a different computer language. The Lotus 1-2-3 spreadsheet style currently in use is too long and makes it difficult to track how one input element affects the entire outcome. At the recent Users Group meeting the decision was made to convert to EXCEL because the Air Force has converted from LOTUS to EXCEL in the Aeronautical Systems Division. This probably will not help much with model understanding. Professor McMasters, at the Naval Postgraduate School, is developing a FORTRAN program for the purpose of understanding the input/output interactions.

Finally, there is a strong possibility that the CEA model will be the model required by all the military services to justify the funding of ECP's but, until the Concept & Define and the Acquisition Phase costs are included in the model, no accurate trade offs can be made between these costs and the savings in "useful life" costs expected from the ECP.

APPENDIX A

COST EFFECTIVENESS ANALYSIS EXAMPLE

Appendix A is an example component modification provided by the General Electric Aircraft Engines Corporation.

General Electric Aircraft Engines

**** COST EFFECTIVENESS ANALYSIS ****

27-Apr-92

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA AIRCRAFT MODEL: F16
TASK/ECP: Sample Model

This is a sample spreadsheet prepared by GE Aircraft Engines for the April 1992 CEA User's Group.

The input parameters for this spreadsheet are the same as the ones used in the spreadsheet during the USN Briefing on 25/26-Feb-1992.

SUMMARY - Delta between current and proposed configurations.
All values are shown as Fiscal Year 1991 (SELL PRICE).

	F16	
	Cost $(000)	Savings $(000)
1) Production Engine Cost	$330.0	
2) Operational Engine Modification Cost	$9,176.0	
3) Follow-on Maintenance Material Cost		$15,305.1
4) Follow-on Maintenance Labor Cost		$852.5
5) Publications Cost	$2.0	
6) Tooling & SE - Total cost	$0.5	
7) Part Number Cost	$18.1	
8) Operational Fuel Cost		
Totals	$9,526.6	$16,157.6
Net Delta Dollar Impact $(000)		$6,631.0

ASSUMPTIONS

a) Incorporation in Production engines will begin:	MAY	1991
b) Number of engines produced with this change is		33
c) Number of spare units incorporating this change is		0
d) Modification of operational engines can begin in	AUG	1991
e) Incorporation of this change in operational engines will be accomplished by --->	1st Opportun. at O & I Level	
f) Total kits installed out of total engines not modified in production is	576 of	617
g) Total engines lost to attrition is		59
h) Total engines retired unmodified is		0
i) Estimated yearly EFH in future	240 EFH per year	

```
                    General Electric Aircraft Engines

      TITLE: GEAE Master With PW Sample Inputs                  27-Apr-92
      ENGINE MODEL: F110-GE-CEA                                    Page 1
      TASK/ECP: Sample Model             AIRCRAFT MODEL:  F16
      ******************       INPUT SHEET       ************************
 1.0  Incorporation style: (1,2, or 3)  >>            2  |
      1 = Attrition                     |                |
      2 = 1st Opportunity               |                |
      3 = Forced                        |                |
                                        |                |
      Does Kit Cost Replace Maint Cost? >>NO             |
      Pct of Sch Events Requiring Maint >>            0% |
 2.0  Delta Production Cost             >>       $10,000 |
 3.0    Kit hardware cost - $ per engine >>      $15,000 |
 4.0  Kit labor manhours:               |                |
      4.1 O&I                           >>          2.00 |
      4.2 Depot                         >>         20.00 |
 5.0  Labor cost per manhour:           |                |
      5.1 O&I                           >>        $32.32 |
      5.2 Depot                         >>        $43.30 |
 6.0  Tech pubs cost - total $          >>          $500 |
 7.0  TCTO Cost - total $               >>        $1,500 |
 8.0  New P/N intro cost - $/ P/N       >>        $1,524 |
 9.0  Annual P/N maint cost             >>          $250 |
10.0  Tooling & SE - Total cost         >>       $500.00 |
11.0  Test fuel - $/Gal                 >>         $0.61 |
12.0  Test fuel - Gal/Hr                >>        150.00 |
13.0  Spare parts factor                >>         0.000 |   1st month =
14.0  Year field modification starts    >>          1991 >>            8
15.0  % Sch events being modified       >>          100% |
16.0  % Unsch events being modified     >>          100% |
17.0  Failure rate allowing modification >>         0.02 |   1st month =
18.0  Year production starts            >>          1991 >>            5
      Engine Attrition Rate (Engs/EFH)  >>       0.00002 |
      Average EFH Per Eng Per Year      >>           240 |
19.0  Fiscal year dollars               >>          1991 >>(SELL PRICE)
20.0  TAC/EFH Ratio                     >>          3.00 |
21.0  TOT/EFH Ratio                     >>          1.50 |
                                         CURRENT DESIGN     PROPOSED EC
22.0  Unsch fail rate/1000 EFH          >>     0.020000 >>     0.002000
23.0  Sch maint interval (TAC's)        >>         3000 >>         4000
24.0  Calculated rate/1000 EFH          |         1.000 |         0.750
25.0  Sch MHrs to inspect, O level      >>          0.0 >>          0.0
26.0  Sch % rmvd, O&I level             >>         100% >>         100%
27.0    Sch MHrs to R/R, O level        >>        10.00 >>        10.00
28.0    Sch MHrs, I level               >>        25.00 >>        25.00
29.0    Sch % O&I req repair            >>         100% >>         100%
30.0    Sch material cost O&I           >>      $500.00 >>      $500.00
31.0  Sch % ret to Depot                >>         100% >>         100%
32.0    Sch MHrs, Depot                 >>        10.00 >>        10.00
33.0    Sch % Depot req repair          >>          10% >>           1%
34.0    Sch material cost, Depot        >>      $25,000 >>      $20,000
35.0  Sch % scrap                       >>        5.00% >>        0.50%
36.0    Hardware cost to scrap          >>   $62,500.00 >>   $50,000.00
37.0  Sch test time                     >>         1.50 >>         1.50

38.0  Unsch MHrs to inspect, O level    >>          0.0 >>          0.0
39.0  Unsch % rmvd O&I level            >>         100% >>         100%
40.0    Unsch MHrs to R/R, O level      >>        10.00 >>        10.00
41.0    Unsch MHrs, I level             >>        25.00 >>        25.00
42.0    Unsch % O&I req repair          >>         100% >>         100%
43.0    Unsch material cost, O&I        >>         $500 >>         $500
44.0  Unsch % ret to Depot              >>         100% >>         100%
45.0    Unsch MHrs, Depot               >>        10.00 >>        10.00
46.0    Unsch % Depot Req Repair        >>        2.50% >>        0.25%
47.0    Unsch material cost, Depot      >>       $1,250 >>       $1,000
48.0  Unsch % scrap                     >>        1.00% >>        0.10%
49.0    Hardware cost to scrap          >>   $62,500.00 >>    $5,000.00
50.0  Unsch test time                   >>         1.50 >>         1.50
51.0  Secondary damage cost             >>  $100,000.00 >>  $100,000.00
52.0  Incidental costs                  >>        $0.00 >>        $0.00
53.0  Number of P/N's                   >>            4 >>            4
      *****************        OPTIONS        ************************
54.0  Operational Fuel - $/Gal          |         $0.61 >>        $0.61
55.0  Operational Fuel - Gal/Hr         |        150.00 >>       150.00
```

General Electric Aircraft Engines

```
***********************  INTERIM CALCULATIONS   ************************
TITLE: GEAE Master With PW Sample Inputs                       4/27/92
ENGINE MODEL: F110-GE-CEA
TASK/ECP: Sample Model
                                                CURRENT        PROPOSED
NAME/CONTENTS/FORMULA (BASED ON INPUT REGION)---------------------------
A    OPERATIONAL FUEL COST PER HOUR                91.5            91.5
      54.0 * 55.0
<<<  SCHEDULED COST PER EVENT  >>>
B    O&I MANHOURS                                    35              35
      25.0 + 26.0 * (27.0 + 28.0)
C    O&I MATERIAL REPAIR COST                       500             500
      29.0 * 30.0
D    DEPOT MAN HOURS                                 10              10
      31.0 * 32.0
E    DEPOT MATERIAL REPAIR COST                    2500             200
      33.0 * 34.0
F    DEPOT SCRAP COST                              3125             250
      35.0 * 36.0
<<<  UNSCHEDULED COST PER EVENT  >>>
G    O&I MANHOURS                                    35              35
      38.0 + (39.0 * (40.0 + 41.0))
H    O&I MATERIAL REPAIR COST                       500             500
      42.0 * 43.0
J    DEPOT MAN HOURS                                 10              10
      44.0 * 45.0
K    DEPOT MATERIAL REPAIR COST                   31.25             2.5
      46.0 * 47.0
L    DEPOT SCRAP COST                               625               5
      48.0 * 49.0
M    MATERIAL SECONDARY DAMAGE                   100000          100000
      51.0
N    MATERIAL INCIDENTAL COST                         0               0
      52.0
P    SCHEDULED TEST COST (MATERIAL COST/EVENT)   267.15          267.15
      37.0 * (A + 2 * 5.2)
R    TEST COST/UNSCHEDULED EVENT                 267.15          267.15
      50.0 * (A + 2 * 5.2)
******* ASD FACTORS FOR EVALUATION:  USED IN REFERENCED COLUMNS *******
<<< SCHEDULED EVENTS >>>                CURRENT COLUMN  PROPOSED COLUMN
U    O&I LABOR COST PER EVENT            1131.2  BS      1131.2  DA, DE
      B * 5.1
V    DEPOT LABOR COST PER EVENT             433  BS         433  DA, DE
      D * 5.2
W    MATERIAL COST PER EVENT            6392.15  BT     1217.15  DB, DF
      C + E + F + P
<<< UNSCHEDULED EVENTS >>>
X    O&I LABOR COST PER EVENT            1131.2  BQ      1131.2  CY, DC
      G * 5.1
Y    DEPOT LABOR COST PER EVENT             433  BQ         433  CY, DC
      J * 5.2
Z    MATERIAL COST PER EVENT            101423.  BR     100774.  CZ, DD
      H + K + L + M + N + R
```

```
                         General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA                                                4/27/92
TASK/ECP: Sample Model
AIRCRAFT MODEL:        F16                                       TAC/EFH=      3
                                                                 TOT/EFH=    1.5
                 STANDARD HISTORY FILE                     Fuel Use/Hour =   150

Calr  Mod in  Mod in     Eng     Eng                 Avg      Cum     Cum Annual
Year    Prod   Field   Del'd     Cum    Annual       EFH      Eng   Whole    Eng
        # No    # No  per yr  w/Attr       EFH  /Eng/Yr     Attr Eng Attr   Lost

 (L)     (M)     (N)     (O)     (P)       (Q)      (R)      (S)     (T)     (U)


1985       0       0       0       0         0     0.00     0.00       0       0
1986       0       0     100     100    24,000   240.00     0.48       0       0
1987       0       0     125     225    54,000   240.00     1.56       1       1
1988       0       0     125     349    83,760   240.00     3.24       3       2
1989       0       0     150     497   119,280   240.00     5.62       5       2
1990       0       0     100     595   142,800   240.00     8.48       8       3
1991       8       5      50     642   154,080   240.00    11.56      11       3
1992      12      12       0     639   153,360   240.00    14.63      14       3
1993      12      12       0     636   152,640   240.00    17.68      17       3
1994      12      12       0     633   151,920   240.00    20.72      20       3
1995      12      12       0     630   151,200   240.00    23.74      23       3
1996      12      12       0     627   150,480   240.00    26.75      26       3
1997      12      12       0     624   149,760   240.00    29.75      29       3
1998      12      12       0     621   149,040   240.00    32.73      32       3
1999      12      12       0     618   148,320   240.00    35.69      35       3
2000      12      12       0     615   147,600   240.00    38.64      38       3
2001      12      12       0     612   146,880   240.00    41.58      41       3
2002      12      12       0     609   146,160   240.00    44.51      44       3
2003      12      12       0     606   145,440   240.00    47.41      47       3
2004      12      12       0     603   144,720   240.00    50.31      50       3
2005      12      12       0     600   144,000   240.00    53.19      53       3
2006      12      12     -91     506   121,440   240.00    55.62      55       2
2007      12      12    -114     390    93,600   240.00    57.49      57       2
2008      12      12    -114     274    65,760   240.00    58.80      58       1
2009      12      12    -137     136    32,640   240.00    59.46      59       1
2010      12      12     -91      44    10,560   240.00    59.67      59       0
2011      12      12     -44       0         0     0.00   —59.67      59       0
2012      12      12       0       0         0     0.00    59.67      59       0
2013      12      12       0       0         0     0.00    59.67      59       0
2014      12      12       0       0         0     0.00    59.67      59       0
2015      12      12       0       0         0     0.00    59.67      59       0
2016      12      12       0       0         0     0.00    59.67      59       0
2017      12      12       0       0         0     0.00    59.67      59       0

TOTAL ENG. DELIVERED =       650         2,983,440           0.00002              59

Incorporation in Production engines will begin:   1991 MAY
Number of engines produced with this change is      33
engines not modified in production is              617
```

General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA
TASK/ECP: Sample Model
AIRCRAFT MODEL: F16

CURRENT CONFIGURATION
1991 (SELL PRICE)

Line No	Cal Year	Avg No Unmod Eng	Avg No mod Eng	ANNUAL EFH Unmod (000'S)	ANNUAL EFH Mod (000'S)	UNSCH EVTS Unmod	UNSCH EVTS Mod	SCH EVTS Unmod	SCH EVTS Mod	No Kits Inst	Inst Kit Cost (000'S)	Mod Labor Cost (000'S)	No Spares Inst	Spares Kit Cost (000'S)	Spares Labor Cost (000'S)
(AX)	(AY)	(AZ)	(BA)	(BB)	(BC)	(BD)	(BE)	(BF)	(BG)	(BH)	(BI)	(BJ)	(BK)	(BL)	(BM)
												930.64	0.000	15000	930.64
1	1985	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
2	1986	50	0	12.0	0	0	0	0	0	0	0	0	0	0	0
3	1987	162	0	38.9	0	0	0	0	0	0	0	0	0	0	0
4	1988	287	0	68.9	0	1	0	0	0	0	0	0	0	0	0
5	1989	423	0	101.5	0	1	0	69	0	0	0	0	0	0	0
6	1990	546	0	131.0	0	2	0	102	0	0	0	0	0	0	0
7	1991	618	0	148.3	0	3	0	131	0	0	0	0	0	0	0
8	1992	640	0	153.6	0	3	0	148	0	0	0	0	0	0	0
9	1993	637	0	152.9	0	3	0	154	0	0	0	0	0	0	0
10	1994	634	0	152.2	0	3	0	153	0	0	0	0	0	0	0
11	1995	631	0	151.4	0	3	0	152	0	0	0	0	0	0	0
12	1996	628	0	150.7	0	3	0	151	0	0	0	0	0	0	0
13	1997	625	0	150.0	0	3	0	151	0	0	0	0	0	0	0
14	1998	622	0	149.3	0	3	0	150	0	0	0	0	0	0	0
15	1999	619	0	148.6	0	3	0	149	0	0	0	0	0	0	0
16	2000	616	0	147.8	0	3	0	149	0	0	0	0	0	0	0
17	2001	613	0	147.1	0	3	0	148	0	0	0	0	0	0	0
18	2002	610	0	146.4	0	3	0	147	0	0	0	0	0	0	0
19	2003	607	0	145.7	0	3	0	146	0	0	0	0	0	0	0
20	2004	604	0	145.0	0	2	0	146	0	0	0	0	0	0	0
21	2005	601	0	144.2	0	3	0	145	0	0	0	0	0	0	0
22	2006	553	0	132.7	0	3	0	144	0	0	0	0	0	0	0
23	2007	448	0	107.5	0	3	0	133	0	0	0	0	0	0	0
24	2008	332	0	79.7	0	2	0	108	0	0	0	0	0	0	0
25	2009	205	0	49.2	0	2	0	80	0	0	0	0	0	0	0
26	2010	90	0	21.6	0	1	0	49	0	0	0	0	0	0	0
27	2011	22	0	0.0	0	0	0	0	0	0	0	0	0	0	0
28	2012	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
29	2013	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
30	2014	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
31	2015	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
32	2016	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
33	2017	0	0	0.0	0	0	0	0	0	0	0	0	0	0	0
TOTALS				2976.24		59		2905							

General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA
TASK/ECP: Sample Model
AIRCRAFT MODEL: F16

4/27/92

CURRENT CONFIGURATION
1991 (SELL PRICE)

One-Time Costs (000'S)	PART NT COST		UNMODIFIED COSTS				MODIFIED COSTS				Total Cost Current Config (000'S)	Oper Fuel Gal/Yr (000'S)	Oper Fuel Cost ($000'S)	Total Cost Curr Config With Fuel ($000'S)
			UNSCHED		SCHED		UNSCHED		SCHED					
	Unmod (000'S)	Mod (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)				
(BN)	(BO)	(BP)	(BQ)	(BR)	(BS)	(BT)	(BU)	(BV)	(BW)	(BX)	(BY)	(BZ)	(CA)	(CB)
			1564	101423	1564	6392								
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	1	0	0	0	0	0	0	0	0	0	1.000	N/A	N/A	1.000
0	1	0	0	0	0	0	0	0	0	0	1.000	N/A	N/A	1.000
0	1	0	1.5642	101.423	0	0	0	0	0	0	103.988	N/A	N/A	103.988
0	1	0	1.5642	101.423	107.929	441.058	0	0	0	0	652.976	N/A	N/A	652.976
0	1	0	3.1284	202.846	159.548	651.999	0	0	0	0	1018.523	N/A	N/A	1018.523
0	1	0	4.6926	304.270	204.910	837.371	0	0	0	0	1352.245	N/A	N/A	1352.245
0	1	0	4.6926	304.270	231.501	946.038	0	0	0	0	1487.503	N/A	N/A	1487.503
0	1	0	4.6926	304.270	240.886	984.391	0	0	0	0	1535.241	N/A	N/A	1535.241
0	1	0	4.6926	304.270	239.322	977.998	0	0	0	0	1527.284	N/A	N/A	1527.284
0	1	0	4.6926	304.270	237.758	971.606	0	0	0	0	1519.328	N/A	N/A	1519.328
0	1	0	4.6926	304.270	236.194	965.214	0	0	0	0	1511.372	N/A	N/A	1511.372
0	1	0	4.6926	304.270	236.194	965.214	0	0	0	0	1511.372	N/A	N/A	1511.372
0	1	0	4.6926	304.270	234.63	958.822	0	0	0	0	1503.415	N/A	N/A	1503.415
0	1	0	4.6926	304.270	233.065	952.430	0	0	0	0	1495.459	N/A	N/A	1495.459
0	1	0	4.6926	304.270	233.065	952.430	0	0	0	0	1495.459	N/A	N/A	1495.459
0	1	0	4.6926	304.270	231.501	946.038	0	0	0	0	1487.503	N/A	N/A	1487.503
0	1	0	4.6926	304.270	229.937	939.646	0	0	0	0	1479.546	N/A	N/A	1479.546
0	1	0	4.6926	304.270	228.373	933.253	0	0	0	0	1471.590	N/A	N/A	1471.590
0	1	0	3.1284	202.846	228.373	933.253	0	0	0	0	1368.602	N/A	N/A	1368.602
0	1	0	4.6926	304.270	226.809	926.861	0	0	0	0	1463.634	N/A	N/A	1463.634
0	1	0	4.6926	304.270	225.244	920.469	0	0	0	0	1455.677	N/A	N/A	1455.677
0	1	0	4.6926	304.270	208.038	850.155	0	0	0	0	1368.157	N/A	N/A	1368.157
0	1	0	3.1284	202.846	168.933	690.352	0	0	0	0	1066.261	N/A	N/A	1066.261
0	1	0	3.1284	202.846	125.136	511.372	0	0	0	0	843.483	N/A	N/A	843.483
0	1	0	1.5642	101.423	76.6458	313.215	0	0	0	0	493.849	N/A	N/A	493.849
0	1	0	0	0	0	0	0	0	0	0	1.000	N/A	N/A	1.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
	26		92.2878	5983.98	4544.00	18569.1					$29,215		$0	$29,215

* Tooling, TCTO's, Part Entry Cost,
Support Equipment, Tech. Pubs.

General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA
TASK/ECP: Sample Model
AIRCRAFT MODEL: F16

4/27/92

PROPOSED CONFIGURATION
1991 (SELL PRICE)

Line No	Cal Year	Engs Mod At Prod (Yearly)	Avg No Unmod Eng	Avg No Mod Eng	ANNUAL EFH		UNSCH EVTS		SCH EVTS		No Kits Inst	Inst Kit Cost (000'S)	Mod Lab Cost (000'S)	No Spares Inst	Spares Kit Cost (000'S)	Spares Lab Cost (000'S)
					Unmod (000'S)	Mod (000'S)	Unmod	Mod	Unmod	Mod						
(CD)	(CE)	(CF)	(CG)	(CH)	(CI)	(CJ)	(CK)	(CL)	(CM)	(CN)	(CO)	(CP)	(CQ)	(CR)	(CS)	(CT)
													930.64	0.000	15000	930.64
1	1985	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
2	1986	0	50	0	12	0.0	0	0	0	0	0	0	0	0	0	0
3	1987	0	162	0	38.88	0.0	0	0	0	0	0	0	0	0	0	0
4	1988	0	287	0	68.88	0.0	1	0	0	0	0	0	0	0	0	0
5	1989	0	423	0	101.52	0.0	1	0	69	0	0	0	0	0	0	0
6	1990	0	546	0	131.04	0.0	2	0	102	0	0	0	0	0	0	0
7	1991	33	574	44	137.76	10.6	3	0	131	0	56	840	52.1158	0	0	0
8	1992	0	481	159	115.44	38.2	2	0	138	7.92	140	2100	130.289	0	0	0
9	1993	0	349	288	83.76	69.1	3	0	115	28.62	118	1770	109.815	0	0	0
10	1994	0	245	389	58.8	93.4	1	0	84	51.84	85	1275	79.1044	0	0	0
11	1995	0	169	462	40.56	110.9	1	0	59	70.02	60	900	55.8384	0	0	0
12	1996	0	115	513	27.6	123.1	1	0	41	83.16	42	630	39.0868	0	0	0
13	1997	0	77	548	18.48	131.5	1	0	28	92.34	29	435	26.9885	0	0	0
14	1998	0	50	572	12	137.3	0	1	18	98.64	18	270	16.7515	0	0	0
15	1999	0	32	587	7.68	140.9	0	0	12	102.9	12	180	11.1676	0	0	0
16	2000	0	19	597	4.56	143.3	1	0	8	105.6	9	135	8.37576	0	0	0
17	2001	0	9	604	2.16	145.0	0	0	5	107.4	5	75	4.6532	0	0	0
18	2002	0	2	608	0.48	145.9	0	1	2	108.7	2	30	1.86128	0	0	0
19	2003	0	0	607	0	145.7	0	0	0	109.4	0	0	0	0	0	0
20	2004	0	0	604	0	145.0	0	0	0	109.2	0	0	0	0	0	0
21	2005	0	0	601	0	144.2	0	1	0	108.7	0	0	0	0	0	0
22	2006	0	0	553	0	132.7	0	0	0	108.1	0	0	0	0	0	0
23	2007	0	0	448	0	107.5	0	0	0	99.54	0	0	0	0	0	0
24	2008	0	0	332	0	79.7	0	0	0	80.64	0	0	0	0	0	0
25	2009	0	0	205	0	49.2	0	1	0	59.76	0	0	0	0	0	0
26	2010	0	0	90	0	21.6	0	0	0	36.9	0	0	0	0	0	0
27	2011	0	0	22	0	0.0	0	0	0	16.2	0	0	0	0	0	0
28	2012	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
29	2013	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
30	2014	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
31	2015	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
32	2016	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
33	2017	0	0	0	0	0.0	0	0	0	0	0	0	0	0	0	0
TOTALS		33			861.6	2114.64	17	4	812	1585	576	8640	536.048	0	0	0
					TOTALS	2976.24		21		2397						

576 Total Kits

General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA
TASK/ECP: Sample Model
AIRCRAFT MODEL: F16

4/27/92

PROPOSED CONFIGURATION
1991 (SELL PRICE)

One-Time Costs (000'S)	Delta Prod Cost (000'S)	PART MT COST		------ UNMODIFIED COSTS -------				------- MODIFIED COSTS-------				Total Cost Proposed Config (000'S)	Oper Fuel Gal/[illegible] (000'S)	Oper Fuel Cost ($000'S)	Total Cost Prop Config With Fuel ($000'S)
				...UNSCHED.....		....SCHED......		...UNSCHED.....		....SCHED....					
		Unmod (000'S)	Mod (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)	Labor (000'S)	Mat (000'S)				
(CU)	(CV)	(CW)	(CX)	(CY)	(CZ)	(DA)	(DB)	(DC)	(DD)	(DE)	(DF)	(DG)	(DH)	(DI)	(DJ)
				1564	100775	1564	1217	1564	100775	1564	1217				
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	1	0	0	0	0	0	0	0	0	0	1.000	N/A	N/A	1.000
0	0	1	0	0	0	0	0	0	0	0	0	1.000	N/A	N/A	1.000
0	0	1	0	1.5642	101.423	0	0	0	0	0	0	103.988	N/A	N/A	103.988
0	0	1	0	1.5642	101.423	107.929	441.058	0	0	0	0	652.976	N/A	N/A	652.976
0	0	1	0	3.1284	202.846	159.548	651.999	0	0	0	0	1018.523	N/A	N/A	1018.523
8.596	330	1	1	4.6926	304.270	204.910	837.371	0	0	0	0	2583.956	N/A	N/A	2583.956
0	0	1	1	3.1284	202.846	215.859	882.116	0	0	12.3884	9.63982	3558.269	N/A	N/A	3558.269
0	0	1	1	4.6926	304.270	179.883	735.097	0	0	44.7674	34.8348	3185.361	N/A	N/A	3185.361
0	0	1	1	1.5642	101.423	131.392	536.940	0	0	81.0881	63.0970	2271.611	N/A	N/A	2271.611
0	0	1	1	1.5642	101.423	92.2878	377.136	0	0	109.525	85.2248	1725.001	N/A	N/A	1725.001
0	0	1	1	1.5642	101.423	64.1322	262.078	0	0	130.078	101.218	1331.582	N/A	N/A	1331.582
0	0	1	1	1.5642	101.423	43.7976	178.980	0	0	144.438	112.391	1046.584	N/A	N/A	1046.584
0	0	1	1	0	0	28.1556	115.058	1.5642	100.774	154.292	120.059	808.657	N/A	N/A	808.657
0	0	1	1	0	0	18.7704	76.7058	0	0	161.050	125.317	575.012	N/A	N/A	575.012
0	0	1	1	1.5642	101.423	12.5136	51.1372	0	0	165.273	128.604	605.892	N/A	N/A	605.892
0	0	1	1	0	0	7.821	31.9607	0	0	168.088	130.794	420.319	N/A	N/A	420.319
0	0	1	1	0	0	3.1284	12.7843	1.5642	100.774	170.059	132.328	454.501	N/A	N/A	454.501
0	0	0	1	0	0	0	0	0	0	171.186	133.204	305.391	N/A	N/A	305.391
0	0	0	1	0	0	0	0	0	0	170.904	132.985	304.890	N/A	N/A	304.890
0	0	0	1	0	0	0	0	1.5642	100.774	170.059	132.328	405.727	N/A	N/A	405.727
0	0	0	1	0	0	0	0	0	0	169.215	131.671	301.886	N/A	N/A	301.886
0	0	0	1	0	0	0	0	0	0	155.700	121.155	277.856	N/A	N/A	277.856
0	0	0	1	0	0	0	0	0	0	126.137	98.1509	225.288	N/A	N/A	225.288
0	0	0	1	0	0	0	0	1.5642	100.774	93.4765	72.7368	269.552	N/A	N/A	269.552
0	0	0	1	0	0	0	0	0	0	57.7189	44.9128	103.632	N/A	N/A	103.632
0	0	0	1	0	0	0	0	0	0	25.3400	19.7178	46.058	N/A	N/A	46.058
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
0	0	0	0	0	0	0	0	0	0	0	0	0.000	N/A	N/A	0.000
8.596	330	17	21	26.5914	1724.19	1270.13	5190.42	6.2568	403.098	2480.78	1930.37	$22,585		$0	$22,585
			38		1750.78		6460.55		409.355		4411.16				

* Tooling, TCTO's, Part Entry Cost,
Support Equipment, Tech. Pubs.

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                   General Electric Aircraft Engines

TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA                              4/27/92
TASK/ECP: Sample Model
AIRCRAFT MODEL:     F16                         1991 (SELL PRICE)

              COMPARISON OF CURRENT & PROPOSED COSTS

Line  Cal |..EXPENDITURES ..| CASHFLOW  CASHFLOW
  No Year | Current Proposed|   Yearly       Cum           IRR
          | (000'S)  (000'S)|  (000'S)   (000'S)

(DL) (DM)     (DN)      (DO)      (DP)      (DQ)          (DR)


   1 1985      0.0       0.0       0.0       0.0
   2 1986      1.0       1.0       0.0       0.0
   3 1987      1.0       1.0       0.0       0.0
   4 1988    104.0     104.0       0.0       0.0
   5 1989    653.0     653.0       0.0       0.0
   6 1990  1,018.5   1,018.5       0.0       0.0
   7 1991  1,352.2   2,584.0 (1,231.7) (1,231.7)
   8 1992  1,487.5   3,558.3 (2,070.8) (3,302.5)
   9 1993  1,535.2   3,185.4 (1,650.1) (4,952.6)
  10 1994  1,527.3   2,271.6   (744.3) (5,696.9)
  11 1995  1,519.3   1,725.0   (205.7) (5,902.6)
  12 1996  1,511.4   1,331.6     179.8 (5,722.8)
  13 1997  1,511.4   1,046.6     464.8 (5,258.0)
  14 1998  1,503.4     808.7     694.8 (4,563.3)
  15 1999  1,495.5     575.0     920.4 (3,642.8)
  16 2000  1,495.5     605.9     889.6 (2,753.2)
  17 2001  1,487.5     420.3   1,067.2 (1,686.1)
  18 2002  1,479.5     454.5   1,025.0   (661.0)
  19 2003  1,471.6     305.4   1,166.2     505.2           0.0
  20 2004  1,368.6     304.9   1,063.7   1,568.9           0.0
  21 2005  1,463.6     405.7   1,057.9   2,626.8           0.0
  22 2006  1,455.7     301.9   1,153.8   3,780.6           0.1
  23 2007  1,368.2     277.9   1,090.3   4,870.9           0.1
  24 2008  1,066.3     225.3     841.0   5,711.9           0.1
  25 2009    843.5     269.6     573.9   6,285.8           0.1
  26 2010    493.8     103.6     390.2   6,676.0           0.1
  27 2011      1.0      46.1    (45.1)   6,631.0           0.1
  28 2012      0.0       0.0       0.0   6,631.0           0.1
  29 2013      0.0       0.0       0.0   6,631.0           0.1
  30 2014      0.0       0.0       0.0   6,631.0           0.1
  31 2015      0.0       0.0       0.0   6,631.0           0.1
  32 2016      0.0       0.0       0.0   6,631.0           0.1
  33 2017      0.0       0.0       0.0   6,631.0           0.1
TOTALS     $29,215   $22,585   6,631.0

NPV AT      CURENT  PROPOSED   CASH FL
 0.1 2017    12260     13234      -974
0.07 2017    15100     14879       221
0.05 2017    17608     16213      1395
0.03 2017    20803     17797      3006
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General Electric Aircraft Engines

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TITLE: GEAE Master With PW Sample Inputs
ENGINE MODEL: F110-GE-CEA                                                                                   4/27/92
TASK/ECP: Sample Model
AIRCRAFT MODEL:        F16

   NPV @   NPV @   NPV @   NPV @           NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @   NPV @
     10%      7%      5%      3%             10%      7%      5%      3%     10%      7%      5%      3%     10%      7%      5%      3%
                                     IRR
   <---- C A S H   F L O W ---->           <---- C A S H   F L O W ----> <---- C U R R E N T   ----> <---- P R O P O S E D ---->

    (DS)    (DT)    (DU)    (DV)    (DW)    (DX)    (DY)    (DZ)    (EA)    (EB)    (EC)    (ED)    (EE)    (EF)    (EG)    (EH)    (EI)


      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA
      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA
      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA      NA
 -841.27 -939.66 -1013.3 -1094.3      NA      NA      NA      NA      NA 2,323.0 2,530.6 2,683.6 2,850.0 3,164.3 3,470.2 3,697.0 3,944.4
 -925.40 -1005.4 -1063.9 -1127.1      NA      NA      NA      NA      NA 2,451.3 2,603.7 2,713.8 2,831.5 3,376.7 3,609.2 3,777.8 3,958.7
 -1017.9 -1075.8 -1117.1 -1161.0      NA      NA      NA      NA      NA 2,043.5 2,133.0 2,196.5 2,263.5 3,061.4 3,208.8 3,313.7 3,424.5
 -1119.7 -1151.1 -1173.0 -1195.8     0.1 -973.89 220.674 1394.95 3005.80 1,229.3 1,263.8 1,287.9 1,312.9 2,349.1 2,414.9 2,460.9 2,508.7
 -2831.1 -2959.8 -3051.3 -3147.7     0.1 -973.89 220.674 1394.95 3005.80 2,458.7 2,563.0 2,637.1 2,715.0 5,289.8 5,522.8 5,688.4 5,862.7
 -4070.8 -4306.8 -4476.7 -4657.8     0.1 -973.89 220.674 1394.95 3005.80 3,612.1 3,816.2 3,963.3 4,119.9 7,683.0 8,123.0 8,440.0 8,777.8
 -4579.2 -4874.6 -5089.1 -5319.1     0.1 -973.89 220.674 1394.95 3005.80 4,655.3 4,981.4 5,219.8 5,476.9 9,234.5 9,856.0 ***************
 -4706.9 -5021.2 -5250.2 -5496.5     0.1 -973.89 220.674 1394.95 3005.80 5,598.6 6,064.7 6,410.2 6,787.5 *******************************
 -4605.4 -4901.4 -5116.0 -5345.9     0.1 -973.89 220.674 1394.95 3005.80 6,451.8 7,071.7 7,538.0 8,053.2 *******************************
 -4366.9 -4612.0 -4785.7 -4968.0     0.1 -973.89 220.674 1394.95 3005.80 7,227.3 8,013.0 8,612.1 9,282.1 *******************************
 -4042.8 -4207.6 -4315.5 -4419.6     0.1 -973.89 220.674 1394.95 3005.80 7,928.7 8,888.0 9,629.7 ***************************************
 -3652.5 -3707.0 -3722.2 -3714.1     0.1 -973.89 220.674 1394.95 3005.80 8,562.9 9,701.4 ***********************************************
 -3309.5 -3254.8 -3176.0 -3052.2     0.1 -973.89 220.674 1394.95 3005.80 9,139.5 *******************************************************
 -2935.4 -2747.8 -2552.1 -2281.3     0.1 -973.89 220.674 1394.95 3005.80 9,660.8 *******************************************************
 -2608.8 -2292.6 -1981.3 -1562.3     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -2271.0 -1808.7 -1362.8 -768.23     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1990.9 -1396.2 -825.63 -64.997     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1737.7 -1012.7 -316.76 614.032     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1486.6 -621.95 211.799 1333.03     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1270.9 -276.79 687.494 1992.68     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1119.6 -27.979 1036.93 2486.66     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -1025.8 130.717 1264.06 2813.97     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -967.80 231.556 1411.12 3030.02     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
 -973.89 220.674 1394.95 3005.80     0.1 -973.89 220.674 1394.95 3005.80 ***************************************************************
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LIST OF REFERENCES

1. Davis, J. D., "An Appraisal of Cost-Effectiveness Models used in the Air Force and Navy Aircraft Engine Component Improvement Programs", M.S. Thesis, Naval Postgraduate School, Monterey, CA, December, 1991.

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

3. 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.

4. Telephone Conversation between Bob Christian, Pratt and Whitney and the author on May 19, 1992.

5. Dhillon, B. S., and Reiche, H., Reliability and Maintainability Management, Van Nostrand Reinhold Company, New York, 1985.

6. Dhillon, B. S., Life Cycle Cost: A Survey, Microelectronics and Reliability: An International Journal, Vol.20, 1980.

7. Dhillon, B. S., Reliability Engineering in Systems Design and Operation, Van Nostrand Reinhold Company, New York, 1983.

8. Gupta, Y. P., Life Cycle Cost Models in Electronics Systems Effectiveness and Life Cycle Costing, Springer-Verlag, Berlin, 1983.

9. Dhillon, B. S., Life Cycle Costing, Gordon and Breach Science Publishers, New York, 1989.

10. Robert-Seldon, M., Life Cycle Costing: A Better Method of Government Procurement, Westview Press, Boulder, CO, 1979.

11. Bales, P. R., "GEAE Cost Effectiveness Analysis Model", General Electric Aeronautical Systems Division, Dayton, OH, February 1992.

12. Anderson, R. T., Reliability Design Handbook, ITT Research Institute, Chicago, IL, March, 1976.

13. Bazovsky, I., Reliability Theory and Practice, Prentice-Hall, Englewood Cliffs, NJ, 1961.

14. Selby, J. and Miller, S., "Reliability Planning and Management", Symposium for Reliability and Maintainability Technology for Mechanical Systems, Washington D. C., April, 1972.

15. Military Standard 781B, Reliability Tests: Exponential Distribution, 1967.

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