UNCLASSIFIED

AD NUMBER

AD881694

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution: No Foreign without approval of Commandant, Air Force Inst. of Tech., Attn: Dean, School of Engineering. Wright-Patterson AFB, Ohio 45433.

AUTHORITY

AFIT ltr, 31 Jul 1980

THIS PAGE IS UNCLASSIFIED

AD881694

AD No. ____
DDC FILE COPY

AIR FORCE INSTITUTE OF TECHNOLOGY

AIR UNIVERSITY
UNITED STATES AIR FORCE

SCHOOL OF ENGINEERING

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

80

AN ANALYSIS OF FACTORS

INFLUENCING SPARE ENGINE MANAGEMENT

THESIS

GSM/SM/70-10 Ted L. Kehl
Capt. USAF

AN ANALYSIS OF FACTORS

INFLUENCING SPARE ENGINE MANAGEMENT

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
Requirements for the Degree of

Master of Science

by

Ted L. Kehl, B.S.E.E.
Captain USAF

Graduate Systems Management

November 1970

Preface

Preparing this thesis has been a valuable learning experience for me as a student and Air Force officer. The insights I have gained into the complexities and uncertainties of the spare engine program have further convinced me of the challenges facing managers committed to improving Air Force efficiency.

The general philosophy of this paper is directed toward stressing the value to managers of clearly understanding the reasons for, and the consequences of, the techniques and methods used in the engine management system. I strongly believe every manager should understand and question the logic, rationale, and advantages behind any approach used to determine spare engine requirements.

I extend my grateful thanks to Major Ronald J. Quayle, Assistant Professor of Operations Research, Air Force Institute of Technology for agreeing to advise and review this thesis.

I also note with appreciation the willingness of engine management personnel at Wright-Patterson Air Force Base to supply the information and ideas that made this paper possible. In particular I am grateful to Captain John M. Pearson, Mr. Tom Brennan, and Mr. Leo Watkins of the Propulsion Office of Headquarters Air Force Logistics Command for their valuable assistance in suggesting topics and supplying information.

I must acknowledge my gratitude to my wife, Judy, for her understanding, her encouragement, and her efforts in editing and typing this thesis.

Ted L. Kehl

Contents

Contents

List of Figures

List of Tables

Abstract

This report deals with the problems and complexities faced by the Air Force in attempting to determine "proper" spare engine levels. Spare engine levels are examined as a function of both requirement factors and management decisions concerning the methods and techniques to be used for dealing with the requirement factors.

Systems theory is introduced to present a conceptual framework for better understanding the viewpoints and priorities possessed by the organizations involved with engine management. The concept of a system objective is considered as compared to the particular command interests of an organization such as Air Force Logistics Command or Air Force Systems Command.

Analytical techniques including marginal analysis, discounting, tradeoff analysis, and sensitivity analysis are discussed in terms of their possible application to engine management policy and procedure.

The factors affecting spare engine requirements are reviewed with respect to their impact on spare engine levels. Considerable attention is focused on the consequence of the marked difference in how engine stock safety quantities are determined for base stock as compared to depot stock.

Engine pipeline standards are discussed with reference to potential tradeoffs between pipeline lengths and the number of spare engines required. Additional pipeline discussion includes examining the concept of average time requirements, and considerations in developing standards including the identification of a resource baseline.

AN ANALYSIS OF FACTORS INFLUENCING SPARE ENGINE MANAGEMENT

I. Introduction

The United States Air Force requires a wide variety of aircraft engines ranging in capability and cost from the J-69 ($17,000) for the Q-2 drone to the J-93 ($1,000,000) used for the B-70. Table I shows the unit cost for a number of engines and indicates there is a marked difference in the unit cost between various aircraft engines. The high dollar cost of major new aircraft engines such as the TF-39 for the C-5A requires that the engine management system be as efficient as possible if excess procurements are to be avoided while still meeting performance objectives and hopefully, staying within budget constraints.

Table I
Approximate Unit Cost for Selected Aircraft Engines

Engine	Aircraft	Approx. Unit Cost
J-69	Q-2 drone	$ 17,000
J-47	B-47	48,000
J-57	F-100,101,102	270,000
TF-39	C-5A	700-800,000
J-93	XB-70	1,000,000

(From Ref 17:3, 3:105, 3:I-8)

Selective Management

The recognized need to carefully control the inventory levels of high dollar value items is known in the Air Force as "selective management." This philosophy designates certain items that are to be precisely controlled to insure their inventory level is "kept at the lowest possible level that is consistent with computed peacetime requirements and projected wartime needs" (Ref 1:1-1).

Aircraft spare engines were one of the first items to be affected by the selective management approach due to their cost and the relative difficulty of determining what is the lowest possible inventory capable of supporting requirements. Consequently, the Air Force has tried to develop and update policy and techniques for evaluating its methods used for determining spare engine requirements. Official Air Force spare engine policy and guidance is contained in Air Force Manual 400-1, Selective Management of Propulsion Units. However, determining spare engine levels still presents formidable problems in many areas of concern from repair times to how to allocate funds as budget constraints become tighter and more restrictive.

The General Problem

Engine inventory managers are continually faced with determining proper spare engine levels and how available spares should be distributed to the system of base users and depot support activities. The previously noted high cost of engines results in budget constraints limiting the number of spare engines that can be procured in attempting to insure the availability of spare engines to meet demand requirements.

Current methods of determining spare engine levels are a mixture of historical precedent, the results of numerous studies, and of the perceptions, viewpoints, and values of the people and organizations that collectively comprise the spare engine system. While such a mixture may not be theoretically ideal, it is probably a typical growth pattern for a complex activity such as engine management and is made to work by the knowledge and dedication of engine management personnel.

However, during the last 10 years, the Department of Defense (DOD) and the Air Force have emphasized the necessity of determining and using objective, analytical techniques in the decision making process whenever possible. The goal of these efforts is simply to have better methods for determining more optimal allocations of the limited resources available to the services.

Thus, the difficult problem faced by engine managers is how do you implement the selective management philosophy. That is, how does one determine requirements, what is the "proper" level for spare stock, and how does one "precisely control" the engine inventory and the engine management system.

<u>The Problem as Presented</u>

Conversations of faculty members from the School of Engineering and the School of Systems and Logistics of the Air Force Institute of Technology, with personnel from the C-5A program office, Aeronautical Systems Division, Air Force Systems Command, and personnel from Air Force Logistics Command resulted in the suggestion that the question of decision rules for determining spare engine levels could possibly be a student thesis topic of some use to the Air Force.

This rather broad topic was accepted by the writer who previously had no experience with aircraft engine management. Further study and numerous conversations resulted in the topic being reduced to problems associated with the present method of calculating spare engine levels particularly in the area of determining so called standards for repair cycle times, commonly called pipeline times.

Objectives of the Study

One purpose of this study is to examine the general approach, philosophy, and consistency of the present method for determining spare engine levels. A second purpose is to develop a conceptual framework for the reader that will allow him to better understand the complexities and interfaces, in the engine system as well as provide a better basis for understanding the conflicts and variety of opinions held by those affected by engine management decisions. A third purpose is to introduce certain analytical techniques that might be valuable for determining, evaluating, comparing and understanding the decision factors and criteria associated with spare engine management.

The study's purpose is not to produce the "answer" for engine management problems but is more oriented toward helping the manager appreciate the importance of understanding questions and criticism about decision criteria and techniques for procuring weapon systems. Such questions and criticism were raised in a recent student paper by Major Charles Albo. Major Albo extended his criticism of weapon system decision making to the point of inditing several current practices. His inditement:

"includes both the Department of Defense and the Air Force whose regulations explicitly define responsibility and procedures, but make no mention of any philosophy or criteria for decisions. It includes published articles in periodicals that extol the virtues of the new weapons but not why these are the virtues that are really needed. It also includes the managers, themselves, who fail to publicly justify the decision process" (Ref 2:2).

Major Albo's point is well taken that the decision criteria, philosophy, and process must be carefully examined, understood and constantly reviewed to have any hope of producing better decisions resulting in more efficient Air Force operations.

In trying to meet these purposes, this study includes sections discussing engine management and systems theory, analytical techniques available and their use, and the factors that determine spare engine levels, including a separate section on the engine pipeline.

Methodology

The first step in the study was to become acquainted with the spare engine management system. This was accomplished by informal interviews with Wright-Patterson Air Force Base personnel from both Air Force Systems Command (AFSC) and Air Force Logistics Command (AFLC). Many of these same contacts also supplied written material ranging from applicable Air Force regulations to minutes of various working groups. From these sources, potential problem areas worthy of investigation were slowly developed and insights gained into the maze of relationships present in the engine management program.

One of the first contacts, Captain John Muckstadt of the School of Systems and Logistics faculty, suggested that the writer help in his investigation of an analytical model developed by the RAND Corporation called Multi-Echelon Technique for Recoverable Item

Control, (METRIC), for its feasibility in determining engine stock levels (Ref 16). Considerable time was spent in examining literature on the model and developing an elementary understanding of the mathematical process.

Although the METRIC concept did not become the basis for this study, it provided a useful contribution. METRIC emphasizes that decision parameters such as expected demand rates are much more likely to be probabilistic in nature than deterministic. Thus, a probability distribution probably better expresses the uncertainty present in complex activities such as engine management than does a point estimate. This problem of point estimates of uncertainty will be further pursued later in the study.

Past studies of engine activities were particularly useful in helping the writer to appreciate the effort and time that has been put forth in attempting to develop a workable engine management system, and also pointed out the usual incremental nature of change in such activities. These past investigations by both Air Force and civilian agencies have resulted in many new ideas or techniques that have increased general understanding and helped improve the efficiency of spare engine operations.

One of the most recent efforts, A Study of the Air Force Jet Engine Maintenance Program, was completed in May, 1970 by the ARINC Research Corporation and was particularly useful in preparing this report. The ARINC study's purpose was to examine "all aspects of the Engine Maintenance Program from the procurement stage through and including base maintenance concept and depot maintenance overhaul" (Ref 2:A-2). As might be expected, reaction to this study ranged from "nothing we didn't already know," to "some ideas appear to have great merit."

Such comments stress the importance of trying to appreciate and understand the variety of viewpoints of people within the engine management system. The writer must honestly note, this study was strongly influenced by the viewpoints of those people presenting problems and supplying information. The final step in the methodology was to analyze the problems and information in the context of management concepts and analytical techniques that the writer has been exposed to by the Department of Systems Management, School of Engineering, Air Force Institute of Technology.

The Dilemma of Determining Proper Spare Engine Procurement Levels

As noted the Air Force objective in selective management is to provide necessary capability with a minimum number of spares. While this objective is sound and probably widely supported, the real challenge is precisely determining requirements, and carefully measuring and evaluating subsequent performance. It seems likely to expect disagreement among users, logistics managers, and other interested parties when trying to determine "proper" spare engine levels due to possible differences in organizational interests, in assumptions, and in decision criteria.

However, all parties recognize that every spare engine system will have an excess of spares at that point in its life cycle when the aircraft it supports are phased out of the inventory or lose their mission requirement. Obviously, it is highly desirable to have this inevitable excess point occur as late as possible and not occur as the result of ineffective management. Table II is a listing of some engine systems presently in the excess spares category primarily due to a reduction or phase out of mission requirements.

Table II
Spare Engine Levels For Selected Aircraft Past Their Peak Support Point

Aircraft	Engine	Installed Engines	Spares	Spares Percentage
T-33	J33-A-35	690	460	67%
F-101	J57-13/53	270	140	52%
F-100	J57-P-21	780	460	59%
F-102	J57-P-23	620	190	31%
B-66	J-71-A-13	180	130	72%

(Ref 3:107)

Of prime concern must be the factors that influence the possibility of excess spares during the build up and maximum demand periods for an engine system. One difficulty is simply that engines are long lead items typically requiring about 3 years from the initial estimate of need until delivery of the engine. Although the actual contractual phase for additional engines may only be about 2 years, this time period is still long enough to possibly have significant changes in the parameter values of the factors used to determine spare engine levels.

The following list suggests some reasons why spare engine levels may become improper at any phase of the engine life cycle.

1. Inability to precisely forecast requirements
2. Changes in aircraft inventories and wartime planning factors
3. Overstatement of the flying hour program
4. Design changes and modifications
5. Changing technology
6. Reduction in stockage objectives and retention levels
7. Increase in the service life of engines
8. Greater base self-sufficiency in repairing engines

9. Past emphasis on customer support with less heed to avoiding overprocurement
10. Reduction in the flying hour program

(Ref 17:14)

The list can be summarized by two general thoughts. First, procurement levels are a function of objectives that can and do change. Second, the factors or numbers used in rigorous mathematical computations of required engines are not single valued, but in reality are some measure of a probability distribution associated with that factor. For instance, if the forecast monthly flying hour program is 2000 hours, it is important to know the range associated with that estimate. Figure 1 is useful in exploring this concept further.

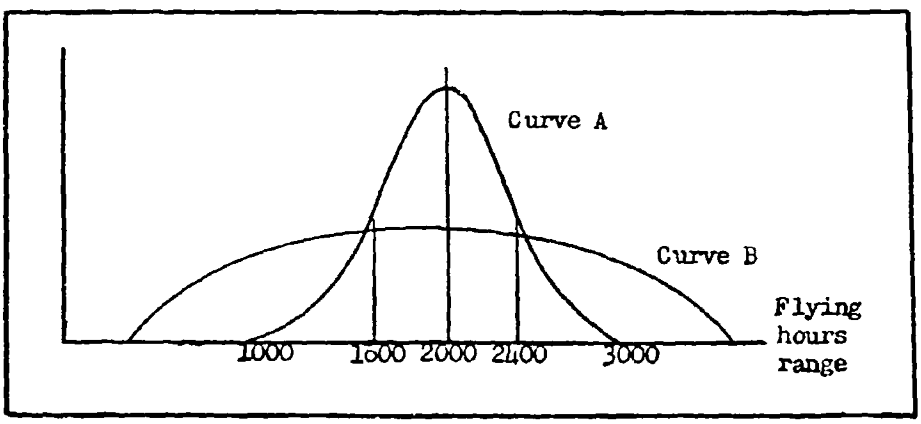

Fig. 1. Possible Probability Distribution

A probability distribution is usually described in terms of a measure of central tendency called the mean or average value, and a measure of the distribution spread called the variance. Of more use for computations is the square root of the variance which is called the standard deviation. For continuous distributions such as those shown in Figure 1, the probability of occurrence of a particular point outcome along the abscissa is meaningless. What is important is the probability of being within a particular interval of the possible abscissa values.

In Figure 1, curve A has been drawn as a normal distribution with a mean of 2000 hours and a standard deviation of about 400 hours. The normal distribution has the characteristic that its inflection points occur at plus and minus one standard deviation from the mean. Also, the area between plus and minus one standard deviation of the mean is approximately equal to 67% of the total area under the curve which is equal to one for all probability distributions. Thus, for curve A there is a 67% probability that the actual flying hours will be between plus or minus one standard deviation from the mean. For curve A, this translates to a 67% probability of being between 1600 and 2400 hours.

Curve B also has a mean of 2000 hours but has a larger standard deviation than curve A. Examination of curve B roughly indicates that only about 1/3 of its area is between 1600 and 2400 hours or that there is only a 33% chance that the actual flying hours will be in this range.

If the two curves reflected estimates for a flying hour program, there is more uncertainty associated with curve B. However, in calculating spare engine requirements, the same number of 2,000 hours would be used as the point estimate of the average or mean value for distributions with significantly different characteristics. The manager must decide if these relative differences in uncertainty will be ignored or accounted for by some acceptable technique such as an appropriate probability calculation.

Indicators of Possible Excess Engine Procurement

The question of whether, in general, the present Air Force method for determining spare engine levels produces excess procurements is controversial and difficult to determine. However, there are certain indicators that the present method tends to produce some excess procurements.

The first indicator is the result of past studies, particularly in the area of transportation methods and times, which have clearly shown overall cost could be reduced by tradeoffs between the number of engines procured and pipeline times.

A second indicator is that the present method treats all engine systems equally. That is, the same method is applied to determine the required number of spares regardless of engine unit cost or aircraft mission. In fact, the present method does not foster tradeoff analysis, but rather concentrates on the quantity of spare engines as the prime consideration for meeting performance objectives. In doing this, the present technique tends to be conservative and allows for many contingencies.

In the ARINC report, several factors were noted which its authors felt indicated excess spare engine levels.

> "A comparison of airline and Air Force spare-engine/installed-engine ratios showed the following: United Air Lines had an overall ratio of 13 percent, i.e., 150 spares for 1172 installed engines, as of January 1970, while the Air Force had an overall spares ratio of 32 percent for propulsion engines as of 30 September 1969.
>
> There are many differences between Air Force and airline operations, and direct comparisons can be misleading. These differences, all of which have an impact on spares requirements, include single-engine fighter vs. multi-engine transport, different structural and thermal stress environments, different size of fleets, and different maintenance approaches. Some of these differences are in areas in which the Air Force has management latitude; however, some are completely dictated by mission requirements. For a more direct comparison, certain differences can be minimized by examining one engine type used in applications

and operated in environments quite similar to those of the airlines. The TF-33 model engines are used in the B52H, C-135, C-141, EC-135, and B-57 aircraft. The TF-33 models are very much like models of the JT3D used by United Air Lines in the DC-8-50/61l freighter aircraft. The respective ratios were as follows: UAL's spares ratio on the JT3D-1/3/3B was 12 percent as of January 1970, while the spares ratio on the TF-33 models for slightly over 2,000 installed was 24 percent as of September 1969. In the case of the C-141/TF33-P-7 fleet, which is about the same size as the total UAL fleet (noted previously as having a spares ratio of 12 percent), the spare-engine ratio was 30 percent.

In some instances noted during the ARINC Research survey a number of spare engines were unserviceable because of parts supply problems (i.e., the engines were in an ENORS status) without identifiable impact on mission support. A specific case was the Air Training Command's J85-5 engine for the T-38A. For several months in 1969 the ENORS rate was very high, reaching 60 percent at one time, largely because of turbine-wheel problems experienced in the engine. The non-availability of the engines did not, according to ATC personnel, prevent the command from flying its full student-training mission. As of September 1969, the ratio of spare engines to installed engines in the T38A was about 21 percent.

A third factor in the conclusion that the Air Force has excessive spares was the information obtained in interviews with depot supply and transportation personnel. Many of these personnel indicated that there were normally two reparable engines for every serviceable engine in storage at the depot" (Ref 3:66).

It must be noted that evaluations made with the benefit of hindsight are much more easily made than original decisions made in the face of uncertainty. Also, it is generally easier to criticize present methods than propose logical, supportable alternatives. Thus, the remaining pages of this study are approached with the hope that the ideas and concepts developed in subsequent chapters on system considerations, analytical techniques, the factors used in spare engine calculations and the engine pipelines may be useful to those faced with making decisions that determine the efficiency of the Air Force spare engine program.

II. Spare Engine Management and Systems Theory

Air Force engine management activities are impressive in terms of the number of organizations involved and the size of the engine inventory being managed. The subset of engine management dealing just with jet engines has responsibility for 40,000 engines that cost some 7 billion dollars and requires about 450 million dollars worth of spare parts yearly (Ref 3:23). This 7 billion dollars of just jet engine assets can be better appreciated by comparing it to the 7.4 billion dollars of assets possessed by the International Business Machines Corporation which ranked fourth in assets in Fortune magazine's 1970 listing of the 500 largest industrial corporations (Ref 10:184).

This rather gigantic engine operation requires the talents and efforts of many people from a variety of Air Force organizations. These organizations have varying views of their particular role and relative importance in the total engine management system. But what is a system? One possible definition is "an array or configuration of components which functions according to a set plan to achieve specific and predetermined objectives" (Ref 7).

From a system standpoint, one might ask if the engine management system has a plan and specific objectives that bind the many organizational elements together and give a sense of overall purpose and direction. In this chapter several thoughts will be discussed suggesting the engine management system may be faced with organizational conflicts due to the inability or difficulty for many organizations to be very concerned with or aware of, the viewpoints and problems of other participating organizations. Even more difficult for component organizations is the problem of recognizing and understanding the big picture or the systems view. But this view is necessary to understand such concepts as tradeoff analysis that attempts to reduce overall system cost or increase overall system performance.

Organizational Responsibility

The responsibilities of each organization are generally defined in Air Force Manual (AFM) 400-1, Selective Management of Propulsion Units. The ARINC report summarized the responsibilities of each major organizational element as follows:

> "Headquarters USAF provides the policy guidelines for the management of jet engines and promulgates basic Air Force planning. It establishes priorities and allocates funds to the various commands on the basis of the appropriations received and the priorities established. Headquarters USAF also monitors the jet-engine management program and provides management by exception when the need arises.
>
> The Air Force Systems Command (AFSC) and its prime engineering division, the Aeronautical Systems Division(ASD), are responsible for the design, development, and acquisition of new and modified jet engines. ASD provides the design-engineering and procurement functions for Air Force gas-turbine engines. These functions are discharged through either (1) a System Program Office (SPO) established to manage-by-exception new weapon systems development or (2) the Director of Propulsion and Power Subsystems Engineering (ASNJ).
>
> The Air Force Logistics Command (AFLC) is responsible for providing logistics support and services for Air Force organizations, systems, and commands. AFLC discharges this responsibility by establishing policy and procedures at the headquarters level and promulgating these through the seven Air Materiel Areas (AMA) established to provide support by function or geographical location, or both. Logistics support and services for jet engines are provided by two Air Materiel Areas - Oklahoma City Air Materiel Area (OCAMA) and San Antonio Air Materiel Area (SAAMA). These two AMAs are responsible for support management of assigned engines.
>
> The major commands (Air Training Command, Air Defense Command, Military Airlift Command, Tactical Air Command, etc.) are the users of the engines. They use them in those aircraft assigned to accomplish the command mission. The commands are responsible for the day-to-day operation and maintenance of the engines. Reporting of engine status and maintenance actions is the responsibility of the various

> operating bases of the major commands.
>
> Superimposed on the normal line organization for engine management are two other management groups--the Air Force Engine Logistics Planning Board and the Aerospace Engine Life Committee. These groups were established by AFM 400-1. The Air Force Engine Logistics Planning Board acts in an advisory capacity on matters related to determining spare-engine requirements. It provides engine-logistics planning guidance to the Air Force for use in developing logistics plans and in effectively managing resources. The Aerospace Engine Life Committee (AELC) is a decision-making group that establishes engine-life expectancies, dependability indices, base-maintenance return rates, maximum operating times, and removal rates per inspection cycle as applicable. These groups meet periodically to discuss problems, suggest methods for improvement, and exchange ideas for more efficient management of the Air Force engine program. Each of these groups is made up of representatives from Headquarters USAF, AFLC, the major commands, and the Air National Guard" (Ref 3:124).

This system of management activities applicable to aircraft engines, is shown in Figure 2.

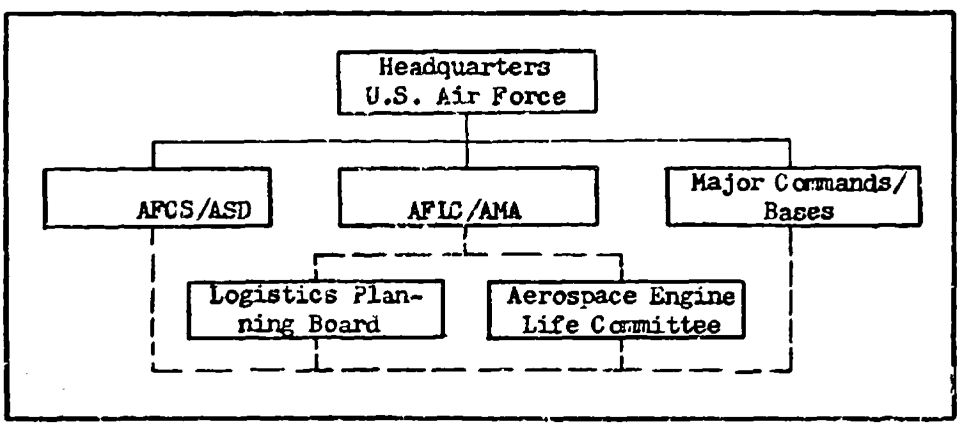

Figure 2. The Engine Management System

The intriguing question of how these various managerial elements interrelate in attempting to support a common objective is the major reason for introducing systems concepts and theory. The framework of a systems view of any rather complex activity is essentially a recognition of the need to identify and focus on the interactions and interdependencies of component elements to insure the actions of the elements are truly beneficial to the system under study. Thus, one may well suspect that AFLC engine managers will probably be very interested in finding ways to reduce the number of spare engines while base maintenance personnel (the users) may be far more interested in insuring a good supply of spares reflecting the difference of viewpoints and interests of the organizations they represent.

The following comments from a Base Maintenance Pipeline Cycle Meeting illustrates this potential difference of viewpoints.

> "A major point of discussion was the amount of non-work time that should or would be included in the standard.
> PACAF recommendations included a shop "backlog" quantity in the "Receiving Transportation to start Build up" and "Removal to start work" segments. This "backlog quantity" is said to be necessary to allow scheduling of work in the engine shop and for leveling out of peak workloads.
> SAC's recommended standards for "In Build Up" and "In Work" take into consideration "Non-work days."
> The AFLC position is that non-work days cannot be allowed in the standard for any engine presently being procured or critical. Some leniency can and should be allowed on engines that are past their peak requirement. However, the holding of a raw serviceable engine for a period of time without accomplishing "Build-Up" would indicate that the activity does not require the engine and, therefore, the base level is too high" (Ref 11:7).

Such a conflict of goals or objectives is always a possibility for systems encompassing a number of elements that may have strong parochial interests. One reason for such conflicts is the reality that most of the system's elements have their own internal goals and also their own criteria for determining and evaluating performance. The PACAF requests for additional pipeline time (resulting in more spares) to help even out workload is an excellent example of how the element's internal interests may not support the system's objective of determining and maintaining the minimum number of spares while still meeting performance requirements.

Functional Organization's Potential Problems

The engine system elements are basically organized along functional lines (logistics, procurement, maintenance), which tends to require special effort to insure smooth coordination and good interfacing between elements as proper integration often does not naturally occur. The engine management system like any complex organizational system should recognize and attempt to avoid the following "functional" organization potential problems.

1. There may be no one except very top management who is entirely responsible for the system's activities.
2. The total perspective of the entire system is often lost or never developed by the functional elements.
3. The functional element can become jealous of its prerogative and be more concerned with insuring or extending its influences than contributing to the overall objective.

The system's approach strongly supports the concept that someone should have total responsibility, accountability, and authority for developing and controlling the plans, policies, and procedures necessary to meet quality, quantity, cost, and time objectives. Furthermore, a clear system perspective is a proper basis for technical innovation and sound managerial actions necessary to insure that changing requirements are continually identified and properly incorporated into system objectives; to insure timely adaptation of new techniques and processes; and to insure effective coordination of the highly differentiated organizational activities.

However, the ARINC study concludes that: "Currently, no central authority within the Air Staff has the responsibility for establishing Air Force policy for propulsion systems management" (Ref 3:125).

Systems theory tends to support ARINC's recommendation that centralizing certain engine management functions within the Air Staff is advisable to effectively integrate the various engine activities and determine the responsibilities of each organizational element.

> The ARINC report suggests the main function of this group should be "the establishment of management policies for propulsion systems and would devote its efforts to analyzing existing management procedures and devising better means for propulsion-system management. The central organization would be responsible for all logistic elements of propulsion-system management and would assess the impact of changes among elements by conducting trade-off studies. It would have at its disposal all the necessary data and information for such studies. With these functions in a central organization, the Air Staff would have an agency that could manage by action rather than by reaction" (Ref 3:125).

Conflicts Among Organizations

There is evidence that the lack of consistent and timely direction from Air Force Headquarters does confuse the issue of who has responsibility for what in engine management. The following thoughts came from a recent AFSC/AFLC AD HOC Working Group trying to resolve the difference of opinion between the two commands for funding and managing retrofit of certain engine Engineering Change Proposals.

> "Headquarters USAF has been inconsistent in assignment of new and Improved Operational Capacity retrofit requirements to AFSC and AFLC" (Ref 15:14).

> "Headquarters USAF has, in some instances, issued program guidance to AFSC that conflicts with joint AFSC/AFLC operating procedures and policy expressed in AFSCR 57-2/AFLC 57-24. The net result of this conflict is to render ineffective any joint AFSC/AFLC agreement on retrofit management responsibility" (Ref 15:24).

> "There is a definite lack of implementing guidance and policy in the establishment of specific requirements for logistics support in new systems and equipment" (Ref 15:6).

These interesting comments rather vividly express the realization that engine logistic support and services (AFLC responsibility) are not independent of engine design and development (AFSC responsibility). Such recognition should result in the Air Force emphasizing system considerations (rather than general command functional interests) in determining management and funding responsibilities.

Overall long term system cost should be the basis for determining when, where and by whom funds should be spent for effective improvements in reliability, maintainability and overall logistics. This systems approach suggests that the present policy of separate funding for procurement (system program funds), updating change funds, and component improvement (CIP) funds may be dysfunctional to reducing costs in the long run.

Project ABLE

The need to carefully determine and evaluate logistics tradeoffs from an overall system standpoint is the basis of a proposal developed by the Operations Analysis Office, Headquarters, Air Force Logistics Command.

> Their proposal called ABLE, Acquisition Based on Consideration of Logistic Effects, is "directed towards creating tools which measure the logistic consequences of reliability and maintainability, and applying them so as to make new weapon systems better - sooner. The tools consist of formulae for total Logistic Effects (LE), comprising inventory spares, repairs, other logistic costs, system availability and system dependability. The formulae are used initially by bidders to project Target Logistic Effects (TLE), which the government used in the source selection process and then again in an incentive structure. The latter would provide for a bonus or penalty based on the winning bidder's TLE and his Measured Logistic Effects (MLE), which are based on a predetermined test program. Throughout the life cycle of each new weapon system, the LE formulae can be used in making tradeoff decisions, measuring progress, and forecasting

future effects" (Ref 13:1).

ABLE clearly recognizes that the type and quality of decisions made during the design and development stages may well dictate the cost and even effectiveness of future support operations. ABLE's approach of developing quantitative means of measuring tradeoffs supports the idea that overall system performance is likely only to be optimal if development, acquisition, and operating costs are all considered as early as feasible. Thus, it is important not to entirely segment new systems into performance areas and support areas, and then attempt to optimize each segment at the expense of the other.

Summary

Systems theory is helpful in providing a conceptual base for better understanding the reasons for potential conflicts between functional organizations. A systems view tends to help the manager recognize the value of alternatives and tradeoffs based on the explicit consideration of system effects as well as subsystem or organizational benefits and disadvantages. Systems theory supports the need for overall objectives and a sound interface plan that helps bind component elements into a fully integrated system.

Close cooperation and well developed interfaces are necessary between commands such as AFSC and AFLC if the Air Force is to have an engine management system that recognizes and focuses on questions of system cost and system effectiveness as part of the decision making process. The type and level of logistics support eventually required by an engine system will be strongly influenced by the criteria used for making decisions during engine design and development.

III. Analytical Techniques

The Air Force as part of the Department of Defense will undoubtably continue to face tight budget constraints while necessary weapon systems will increase in cost and complexity. In such a situation the need for skilled management to plan, organize, direct and control the allocation and use of available resources is paramount. Various analytical techniques are one type of management tool available in the effort to increase military economic efficiency or the measure of the capabilities possessed against the resources required.

Cost-Effectiveness

Terms such as systems analysis, cost-effectiveness, and optimization are commonly used in discussions about efficiency but, unfortunately, they can be somewhat misunderstood. Cost-effectiveness is believed by some to involve maximizing effectiveness while minimizing cost. Careful consideration of the concept leads to the recognition that such an idea is impossible, as cost can be minimized only relative to a given effectiveness criteria, or effectiveness can be maximized only relative to given cost criteria.

The maximize effectiveness/minimize cost fallacy is illustrated by the impossible situation of always having available spare engines (maximize effectiveness) while at the same time reducing the number of spares to zero (minimize cost). Obviously what the manager can and should do is attempt to reduce system costs to a minimum while maintaining the required degree of capability, or maximize capability when given a set budget constraint. Thus, the engine manager who is given a performance objective of satisfying demand 90% of the time should also have the objective of minimizing cost while maintaining the required capability. If the performance objective is dropped to 80% satisfaction of demand, the system minimum cost should then be lower than in the case of a higher performance objective.

Optimization

The situation where the manager determines the best set of parameters (the specific value selected from a range of values) that come closest to satisfying objectives is the goal of optimization. It is quite common for the optimization process to involve an objective requiring a parameter set that minimizes overall system cost for a given performance level.

System cost is used to stress the fact that for a given performance level, tradeoffs with different costs exist among such factors as the length and cost of the engine pipeline, the engine unit cost, and the quantity of spare engines required. Such an approach was the basis for a number of past tradeoff studies primarily concerned with transportation times and costs, and the required number of spare engines.

Objectives and Constraints

Optimization is relative to the objective chosen and the existing constraints on the possible range for decision parameters. The previous statement should be carefully considered as it suggests there is probably not such a thing as "the answer" applicable to all situations but rather the optimal parameter values change as objectives or constraints change. It is reasonable to expect different parameter sets if the objective changes from 90% to 70% demand satisfaction or if a constraint such as the minimum possible transportation time or cost changes.

The manager must be keenly aware of and understand the importance of the impact of objectives and constraints on the options available to him. Part of his responsibility should include identifying and expressing in specific terms the effect on parameters when constraints are loosened or objectives changed. If the engine manager has determined that 100 spares are required and Air Force Headquarters states only 85 engines can be funded, the manager should be able to identify the effect this constraint has on his capability of meeting objectives.

However, the manager clearly must accept the proposition that identification of constraints will not necessarily remove them and, that in fact, part of his job is living with constraints. General James Ferguson, when commander of Air Force System Command, forcefully expressed this idea in a letter to his major System Program Directors.

> "I <u>know</u> that there are many constraints and directions over <u>which this</u> Command does not have control, but which have had serious and far reaching effects upon our management of these programs. I am sure that we will continue to encounter such constraints. Our work can and must include all possible constructive efforts to relieve all constraints which impede good <u>management, and it is not management under ideal circumstances; it is management in our world as we have to accept it.</u> Our task is to achieve, and maintain the best possible program management, changing the constraints when we can, and changing our management approach as we must, to fit the circumstances of the time, the characteristics of the programs, and the capabilities of the people we have" (Ref 7:1).

The use of analytical techniques is one management approach widely accepted in attempting to determine and evaluate potential tradeoffs based on explicit consideration of the entire range of parameter possibilities, such as reduced engine procurement costs against the increased costs of a shortened pipeline time. While such an approach may be difficult in real situations, the benefits can be great when honest attempts are made to determine the comparable worth of a dollar spent for one system component versus the same dollar being spent on another system component.

Marginal Analysis

The technique of marginal analysis is basically an attempt to see if a proposed action will add sufficiently to the benefits of the system to make the action worth the cost.

W. J. Baumol states there are two fundamental rules governing marginal analysis.

1. Optimal activity level: The scale of an activity should if possible be expanded so long as its marginal net yield (taking into account both benefits and cost) is a positive value; and the activity should, therefore, be carried to a point where this marginal net yield is zero.
2. Relative activity levels: For optimal results activities should, wherever possible, be carried to levels where they all yield the same marginal returns per unit of effort (cost)" (Ref 4:22-23).

The first rule suggests that the returns from an activity may not be constant at all activity levels. In the case of spare engines this translates to the consideration that an increase from 60 spares to 80 spares may not have the same marginal value that an increase from 40 to 60 spares would have for the same system although the cost of 20 engines for either case may be the same. However, the first rule also states the second set of 20 engines should be procured if the marginal net yield or increase in performance capability compared against the cost is positive.

Reality, however, is the acceptance of military budget constraints and the recognition that funds are limited. But limited funds is the basis of rule two which is simply stating funds should be allocated to the activity yielding the largest marginal return.

Consider the situation where a budget constraint is given at the Congressional or DOD level below the combined requests of all the services. The question now is how to allocate the funds among the various programs. An approach that is simple is just to cut all requests by the same percentage until the budget level is obtained. In essence this implies all programs are of equal marginal value at the proposed funding level in contributing to overall military capability. While this is possible, it is also highly unlikely. In reality there may well be a preference for strategic forces against tactical, or sea based against land based, or tactical against airlift.

Marginal analysis may suggest the need to increase one procurement while drastically cutting another rather than cutting all, as the opportunity to benefit always exists if resources can be reallocated from an activity with a smaller marginal return to one with a larger marginal return.

Marginal Analysis and Safety Quantities

A portion of the present process for determining spare engine requirements involves the use of a safety table based on a Poisson distribution governing demand for spares. The mean of this distribution is the number calculated as the average requirement per unit time for spare engines for the base considered. Since the calculated value is an average requirement, management has the option of adjusting this figure to either increase or decrease the expected ability to support demand in any particular situation.

By AFM 400-1, the average requirement is used as a basis for determining a quantity of spares reflecting the 90% cumulative probability point in a Poisson distribution. This quantity is normally thought of as giving a 90% confidence level of meeting all peacetime or wartime demand. This is not actually true since the engine quantity identified only gives a 90% confidence level if the actual average requirement turns out to be the calculated value and the engine demand is Poisson in nature.

However, after recognizing these limitations, the manager should still understand the consequence or meaning of the method required by AFM 400-1. Inherent in this method is a value judgment (or decision) that the marginal worth of all aircraft spare engines is equal at the 90% expected demand satisfaction point, i.e., it is equally desirable to have spare capability at 90% for all engine systems and at all times in the life cycle.

Marginal analysis techniques offers the potential for considering the possibility that perhaps strategic bombers ought to be maintained at 90% even if jet trainer spares are funded at only a 70% expected demand capability. That is, the real consideration exists that the use of various levels in the safety table for different types of spares such as for bombers, airlift, training, air defense, or tactical use may be one approach in attempting to reduce spares while allocating funds to the spares that will increase overall Air Force capability the most.

The difficulties associated with efforts to determine the comparative worth of various spare engine types are obviously greater than accepting a set percentage approach for all spare engines. But such difficulties should not be the basis for avoiding attempts to make spare calculations more credible and logical. The Operations Analysis Office at AFLC Headquarters reports "the percentage approach makes everyone uneasy about possible errors. In addition, the arguments for selecting one percentage may not convince someone who believes it should be a different percentage" (Ref 3:67). The percentage approach in the quote was not concerning the safety table percentage but was concerning the unofficial Air Force objective of trying to reach about 20% spares to installed engines by the end of aircraft production. However, the thought is appropriate that careful and logical consideration of desirable capabilities for each spare engine system could well result in significantly different values than would result from a common percentage approach.

Such analysis could also evaluate the possibility of using different safety levels at various stages in engine system life cycle. For instance, if the peak requirement for spare engines is expected to last only a relatively short time, it may be possible to drop the safety requirement to a lower level during the peak requirement.

In any case, the goal or objective of considering a range of alternatives and recognizing the advantages, costs, and penalities of each is a step in developing a more rational and sound approach to decision making.

Discounting

Another analytical tool is the concept of discounting or the time value of money. In essence the concept involves determining the effect of allocating resources (money in this case) at different time periods where the discount rate represents the opportunity cost associated with an expenditure now rather than some time in the future. Discounting suggests that a dollar spent today, a dollar spent 2 years from now, and a dollar spent 6 years from now are not the same amounts but rather must be translated into their equivalent current or present value to be comparable. Inflation is an additional factor beyond discounting which also effects the time value of money, but it is not considered here.

Discounting projected expenditures to present value is now required in the Defense Department as part of the economic analysis techniques incorporated in DOD Directive 7041.3, Economic Analysis of Proposed Department of Defense Investments. The reason for using discounting or the present value method is that it "provides a common denominator to a decision equation. Dollars spent over the entire life of a weapons system or on a special project can be compared on a more rational basis" (Ref 8:61).

For instance, if a choice were available between alternatives of spending one million dollars now or 250,000 dollars now and the same amount for the next 3 years, the second choice should be made, if all other factors are equal, since the second choice would have a lower present value.

The discount factor is the fraction $1/(1+i)^n$ where i is the discount rate and n is the number of years hence. It can be used to calculate the time value of money by considering that an expenditure today, x, is equivalent to an expenditure of $(1+i)x$ one year from now since the x amount can be invested to grow to (1+i)x in a year, or in other words, an expenditure of x a year from now has a present value of x/(1+i). At present 10% is a common discount rate used in the Department of Defense.

In general, since the discount concept favors delayed expenditures over present expenditures of equal amounts, discounting can be a crucial consideration in determining more optimal decisions. As the unit price of engines continues to increase, alternate ways of satisfying requirements may become more attractive.

Sensitivity Analysis

The last analytical tool to be discussed is perhaps the most useful for developing a sound conceptual framework for making and understanding the effects of decisions. Sensitivity analysis is based on a recognition that optimal decisions are not absolute, but rather are a function of the assumptions, parameter values (such as probability), constraints, objectives, and techniques used in the analysis. Variance in these factors often explain why people working with the same data and the same problem can arrive at remarkably different conclusions.

The purpose of performing a sensitivity analysis is to clearly indicate over what range of values the decision is still correct, and to help better realize the impact each decision factor has on the solution outcome. In essence, sensitivity studies give the manager a method for evaluating the consequence of changing parameters he can control or influence.

Spare engine requirements are influenced by many factors such as engine time between overhaul, flying hours, the pipeline length, safety factors, and the objectives set for meeting spare engine demands. Sensitivity analysis implies the manager ought to be aware of how these factors impact spare calculations, and be prepared to make tradeoffs between the factors if a different set of values can meet objectives more efficiently.

Some sample sensitivity calculations will be presented after discussing the requirement factors more extensively in the next chapter.

IV. Factors Determining Spare Engine Requirements

Spare engine calculations are influenced by numerous factors including aircraft flying hours projections, transportation and repair times, the time between required engine overhauls, and contingency and safety requirements. The basic spare engine performance objectives are determined by value judgments of what Air Force capabilities are necessary in the overall United States defense posture as constrained by the defense budget approved by Congress.

Once the desired capability has been determined, the actual spare engine calculations for each engine type are quite well defined. Spare levels are computed to provide engines to fill the individual base requirement, the depot major overhaul requirement and contingency requirements.

The base stock requirements consist of engines to meet three requirements; ARBUT quantity, base repair cycle quantity, and safety factor quantity.

Automatic Resupply and Buildup Time (ARBUT)

ARBUT is the time required for an engine to be issued from depot stock, transported to the base, built-up, tested, and become base stock. The ARBUT segment of the engine flow cycle is shown in Fig. 5, Chapter V, page 45. The ARBUT quantity insures engines are available during the delay from the time a base notifies a depot that an engine has been removed for depot overhaul until the depot replacement engine reaches the base.

The ARBUT quantity (AQ) is determined by the following method:

AQ = engine removals for depot overhaul per day (ERDO) times
the ARBUT per engine

where

ERDO = command flying hours for 30 days divided by 30 and by the command engine overhaul removal interval (OHRI)

For instance, given the following conditions:

ARBUT = 15 days/engine (a common value)
Command engine flying hours (30 day period) = 6000 hours
Command OHRI = 1000 hours

then

ERDO = 6000/1000/30 = .2 engine removals/day

and

AQ = .2 (15) = 3 engines

Three spare engines are necessary then to fill the ARBUT "pipeline" in steady state conditions to allow a flow of spare engines without a delay for the pipeline time.

Base Repair Cycle

The base repair cycle determines the quantity necessary to cover the time period for base removal and repair. If the base repair cycle averages 10 days and one engine per day is removed for base maintenance, 10 spare engines are required to fill the base repair pipeline.

The total expected average spares required at the base is the sum of the ARBUT and base repair cycle quantities which would be 10 plus 3 or 13 engines in the examples used. However, the average requirement is modified by an additional consideration.

Safety Factor

The safety factor quantity exists to insure a 90% confidence level of satisfying expected demand in case removals for base maintenance and major overhaul exceed the expected average. This safety factor is an addition to the sum of the ARBUT and base repair cycle quantities based on an expected Poisson distribution for spare engine demand. The safety factor is determined by the use of a safety level table published in Air Force Manual 400-1. The table shows the number of engines required to satisfy 90% of the expected demand for average base requirements from zero to 50 engines.

The required values are found by determining the quantity necessary to first reach a 90% cumulative probability in a Poisson distribution with a mean value equal to the calculated average base requirement. The information in Table III can be used to illustrate

Table III
Poisson Distribution Function Cumulative Values

y \ x	20	21	22	23	24	25	26	27	28	29	30	31
20	.559	.664	.721	.787	.843	.888	.922	.948	.966	.978	.987	.992
25	.185	.247	.318	.394	.473	.553	.629	.700	.763	.818	.863	.900

(From Ref 14:397)

how safety level table values are determined. The x values from 20 to 31 represent possible spare engine levels at the base while the y values of 20 and 25 represent two possible average base spare requirements (the ARBUT and base repair cycle sum). The values in the table indicate the cumulative probability of satisfying expected demand for the various x and y combinations. Expected demand and actual demand only match if the actual demand is Poisson in nature and has an average value identical to the calculated average.

If a base had 20 spares, it could expect to satisfy 56% of demand for the 20 engines average case and only 18.5% of demand for the 25 engine case. If the base had 26 engines, it could expect to satisfy 92.2% of the 20 case demand and 62.9% of the 25 case demand. Note that for an average requirement of 20 engines, the $\underline{x}$ of 26 is the first value where 90% expected demand has been reached, as an $\underline{x}$ of 25 only has an expected value of 88.8%. The Safety Level Table in AFM 400-1 indicates that 26 engines are required if the calculated ARBUT and base repair cycle total is 20 engines. For the 25 average requirement case, Table III indicates the first $\underline{x}$ value reaching 90% is 31 matching the Safety Level Table number.

In both examples the safety factor resulted in an additional five engines being required above the calculated average requirement in order to reach the objective of satisfying 90% of the expected demand. It is very important to note that the safety level quantity is a function of the calculated requirement and a management decision desiring certain capabilities. If the same calculated base requirements are used but the confidence level is set at 75%, the required engines drop to 23 and 28 engines instead of 26 and 31 engines.

<u>Data Considerations</u>

The safety level approach is based on the ARBUT and base repair cycle sum representing the average or mean requirement for the two factors. The safety factor then added to the mean expected demand has the purpose of satisfying 90% of the possible instantaneous (daily) demand associated with a Poisson distribution having for its mean the sum of the two factors.

If the data used in calculating the sum does not truly represent the best estimated mean or average spare requirement, the safety factor loses some of its validity. This is particularly true if the ARBUT and base repair cycle times are conservative and tend to have built in allowances for cases exceeding the expected average requirement. (This potential problem is more extensively discussed in the Pipeline chapter).

Spare calculations are quite easily accomplished given the necessary data. The real problem is determining if the data does indeed represent the information required in the mathematical calculations so that the resultant figures are reliable indicators of true requirements. A great deal of emphasis should be placed on fully understanding the assumptions, possible errors, and timeliness of the techniques used to gather and process data rather than on the mechanics of the calculations.

Careful consideration should be given to the time measure used (hours, days, months) to insure the data is consistent, comparable, and sensitive to trends and changes in the quantities being measured.

Depot Spares

In addition to base spare requirements, AFM 400-1 provides for spare stock at the depot level to fill the major overhaul repair cycle pipeline (overhaul repair cycle quantity) and to insure that serviceable engines are available for issue to support base stock when the depot repair cycle exceeds the average and to handle unprogrammed contingency requirements (depot stock quantity).

Overhaul Repair Cycle Quantity

Overhaul repair cycle quantity (ORCQ) is determined from the following equation:

ORCQ = engine removals for overhauls per day times the overhaul cycle time per engine

where the removals for overhaul are the sum of the individual command removal figures. (The same figures used in the ARBUT calculations).

Depot Stock Quantity

This quantity is determined by multiplying engine removals for overhauls per day for an Air Materiel Area times the constant figure of 15 days per engine. The depot stock quantity is designed to provide the depot stock with the same type of factor that the safety table computation provides for base stock.

Recently, the CONUS standards for the depot overhaul pipeline time were increased from about 25 to 35 days to about 40 to 50 days. Both the depot overhaul repair cycle quantity and the depot stock quantity are determined by multiplying their respective standard by the daily engine removals for depot overhaul. Before the standard change, the depot stock quantity of 15 days increased the overhaul repair cycle quantity by about 50% since the average time for the overhaul cycle was about 25 to 35 days. With the new depot pipeline time of about 40 to 50 days, the depot stock quantity increases this average requirement by about 33% since the quantity of depot stock is the same for either case.

Thus, with a constant standard of 15 days, the depot stock quantity is not sensitive to the average depot requirement. The depot stock quantity varies only as a function of the engine removal rate rather than being a function of the expected average quantity of engines in the overhaul repair cycle.

Depot Stock Versus Safety Table Calculation

It is interesting to compare the depot stock quantity 33% increase in the overhaul cycle quantity with the general effect of the safety table calculations on the base stock requirements. The Poisson distribution characteristics are such that for any average or mean value less than about 6, the 90% calculation will result in more than a 50% increase in the mean to provide the safety quantity. For means between about 6 and 9 the safety level increase is approximately 50%. For any mean greater than 9 the safety level factor continually decreases as a percentage of the mean requirement. At a mean of 15 the safety factor is 5 or 33% of the mean while at means of 20, 30, 40, and 50 the percentages are 30, 23, 20, and 18.

Obviously, the safety table calculation is significantly different in its effect than the depot stock quantity calculation. Recalling that since normal overhaul cycle time is 40 to 50 days, any command engine removal for overhaul per day quantity that is greater than about .4 will result in an overhaul quantity of at least 18 engines. This result means the depot stock determined by a removal rate greater than .4 will be larger than a similar quantity determined by the use of a Poisson distribution at the 90% confidence level. Table IV indicates the difference between these two approaches for command overhaul removals per day from .1 to 1.1 and for an average overhaul cycle pipeline time of 45 days.

The difference between these two approaches becomes more meaningful when it is recalled engines have recently varied in cost from about 17,000 to 1 million dollars. For the TF-39 (C-5A engine costing about 750,000 dollars) a reduction of 7 engines involves saving some 5.25 million do.

Table IV
Comparison of Depot Stock Requirement
Against Safety Table Requirement

	Command Engine Removals for Overhaul per Day										
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0	1.1
ORCQ	4.5	9.0	13.5	18.0	22.5	27.0	31.5	36.0	40.5	45.0	48.5
DSQ	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5
SLQ	2.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	8.0	8.0	9.0
DIFF	-2.0	-1.0	0.0	1.0	2.0	2.0	3.5	4.0	5.5	7.0	7.5
CUM	.83	.87	.90	.94	.95	.98	.99	.99	.99	.99	.99

ORCQ = Over. . l Repair Cycle Quantity (45 times removal rate)
DSQ = Depot Stock Quantity (15 times removal rate)
SLQ = Safety Level Quantity for ORCQ average requirement
DIFF = DSQ minus SLQ
CUM = Cumulative Poisson probability for a distribution with a mean equal to ORCQ and with the DSQ added as the protective quantity

This marked variance in calculated requirements from these two techniques is an excellent example of how management decision (what approach to use) strongly influences calculated values. Consequently, one must question the basis for using an arbitrary time of 15 days for the depot stock quanti.y calculation rather than using a Poisson distribution of probabilities as is done for determining the safety quantity for base stock.

It seems reasonable that the assumptions of a Poisson distribution should apply to the overhaul pipeline segment if they apply to the ARBUT and base repair cycle portions of the overall engine pipeline. Furthermore, the safety table method appears to more closely match expected possibilities over a wide spectrum of values than an arbitrary selection of a time period of 15 days as is now done at least for the portion of the depot stock quantity designed to support the depot cycle repair time. The depot stock quantity portion for unprogrammed contingency requirements cannot really be determined by any information in AFM 400-1. It would be very difficult to evaluate either method as far as contingency requirements are concerned without a very clear definition of the scope of these requirements.

The Role of Protective Factors

The base safety level quantity and the depot safety level quantity are both protective factors but aimed at different segments of the engine pipeline. However, either factor could support the objective of the other one as long as both factors were not simultaneously needed. The safety level factor covers engine removals for base maintenance, the base repair pipeline, the ARBUT pipeline and engine removals for overhaul. The depot stock quantity also provides for engine removals for overhaul as well as the depot repair pipeline. It seems highly unlikely that all these factors would start exceeding their expected values at the same time. Since the total depot stock quantity is the sum of requirements necessary to support the various commands, it is also possible for one command's share to support another command in the safety factor area and the removals for overhaul providing again that all factors do not simultaneously go out of balance. Thus, it appears the present method of determining spares is quite conservative providing the data used for calculation is reliable and valid.

Flying Hours

The calculations previously considered all involved the command estimated flying hours for each engine type. The Air Force projects its flying-hour program both for war and peace conditions, but by AFM 400-1 only the greater of the two conditions is used in spare engine calculations to insure the availability of War Reserve Materiel as part of base stock. In reality both base and depot stock are affected by the flying hour figure as it is required in both sets of calculations.

While it seems appropriate to use the larger of the peace/war figures in the spares calculation, it should also be noted the pipeline time in the same set of calculations is based on a one-shift, 40 hour week. If engines are required to support an actual war/emergency situation, it seems highly unlikely that a 40 hour week would be worked in engine maintenance support. It would appear that an extended work week and even an extended two shift operation would be more likely. It is recognized that trained people are not readily available but a 60 hour work week (50% increase) could be instigated immediately in a crisis situation for an extended time period without any particular difficulty.

The possibility of using multi-shift operations for support also is a possible alternative for better dealing with the flying hour's peak phenomenon. In a gross general sense, the Air Force expects the typical flying hour program to first reach a peak about four years after the aircraft's introduction into the inventory with some 85 to 90 percent of the total flying hours remaining after this peak year. The aircraft fleet then continues flying at this peak for a number of years with an eventual rapid reduction in flying hours as the particular aircraft is removed from the inventory (Ref 3:71).

The ARINC report presents data of trends of total annual flying hours for selected bombers, tankers, cargo aircraft, fighters, interceptors, and trainers that suggest the general flying-hour program model is not the one just discussed, but rather more closely resembles Fig. 3. If this model is generally correct, it would be wise to very carefully evaluate a number of alternatives other than only buying additional engines to provide for the peak flying hours in the "other aircraft" case. These alternatives could involve tradeoffs in pipeline times, times between overhauls, and safety level quantity.

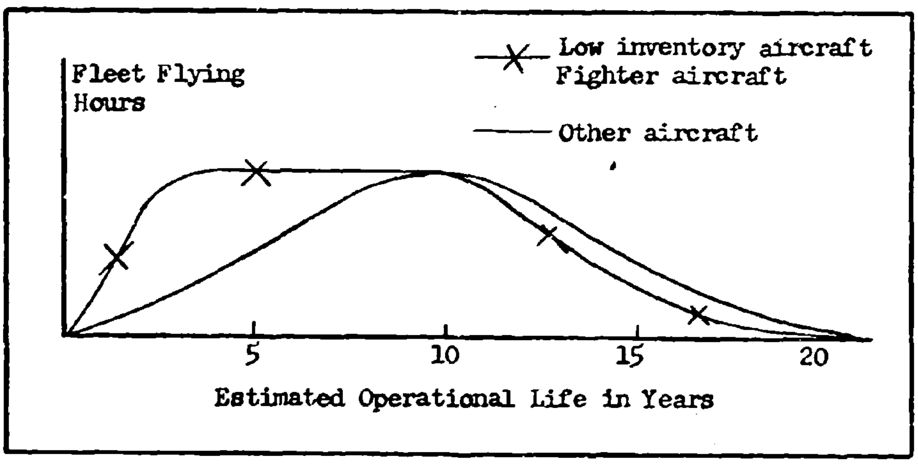

Fig. 3. Fleet Flying Hour Distribution (From Ref 3:80)

Scheduled Removals

A major factor affecting spare calculations is the scheduled engine removals for base maintenance and depot overhaul. Generally, the maximum time between overhauls start at a relatively low and conservative value and then increases in various increments as the major component problems are identified and engine improvement changes incorporated. For instance, the TF-39 (for the C-5A) planned time between overhauls (TBO) is 1000 cumulative engine hours at initial operational capability (IOC), 2,500 hours at 75,000 cumulative hours or two years after IOC (whichever is later) and 5,000 hours at 2 million cumulative hours or four years (whichever is later).

This increasing TBO generally plots as shown in Fig. 4 where the increase time occurs over about 7 years. The importance of this trend for spare calculations is that the increasing time between scheduled removals reduces required spares and tends to offset some of the effects of the increase in the flying hours. Thus, it appears highly desirable to incorporate improvements as early as feasible in an engine system. The previous discussion on AFSC/AFLC responsibilities from a system cost standpoint is applicable to this objective of rapidly increasing TBO to derive maximum benefit as a factor in reducing spare engine requirements.

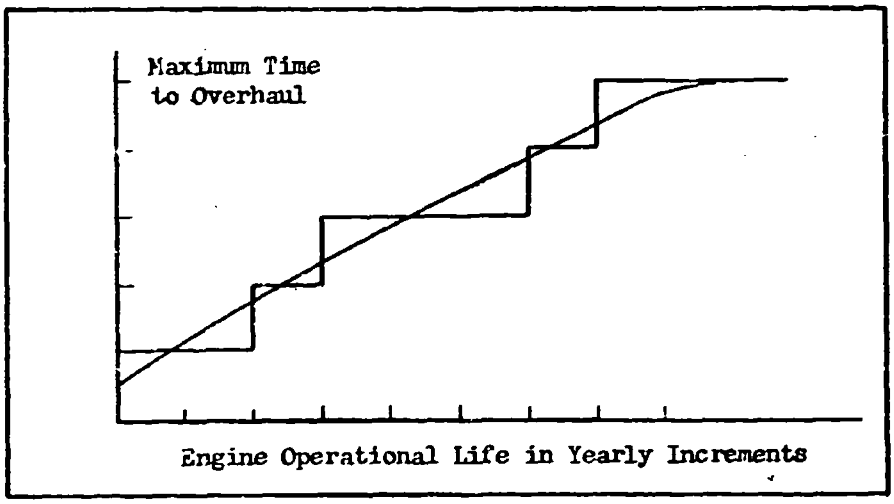

Fig. 4. Trend of Increasing Time to Overhaul Over Engine Life. (From Ref 3:93)

The present DOD policy of once again favoring prototype development should also improve capability in developing sound TBO policy as actual flying time in the real aircraft environment should help identify component improvements before production runs occur.

V. The Engine Pipeline

The existence of the pipeline or the line of movement an engine encounters from removal until once again being available for issue as a serviceable spare is the fundamental reason spare engines must be procured. Engines are recoverable items meaning that an engine removed from an aircraft will undergo a certain cycle of events and then become available as a serviceable spare. If this time from removal to availability could be made to approach zero the spares requirement would also approach zero, a theoretically ideal situation.

However, specific amounts of time are obviously required to remove, inspect, repair and transport engines. These times combine to form the pipeline time indicating the expected number of days before an engine entering the pipeline emerges from the piepline as a useful spare. The typical engine flow cycle is shown in Fig. 5.

Pipeline Times and Spare Engine Requirements

The pipeline time affects average spare requirements in a linear relation to its length. If the time is cut in half the average number of spares required to fill the pipeline is cut in half. If five engines per day enter a pipeline and the length of the pipeline is 30 days, 150 engines are required to fill the pipeline, while if the pipeline length is 20 days, only 100 engines are required. Since the the average quantity is augmented by a safety quantity, the linear relationship does not hold for the actual spares required.

The more pipeline segments are compressed, the smaller the number of spare engines needed to fill them and fewer extra engines

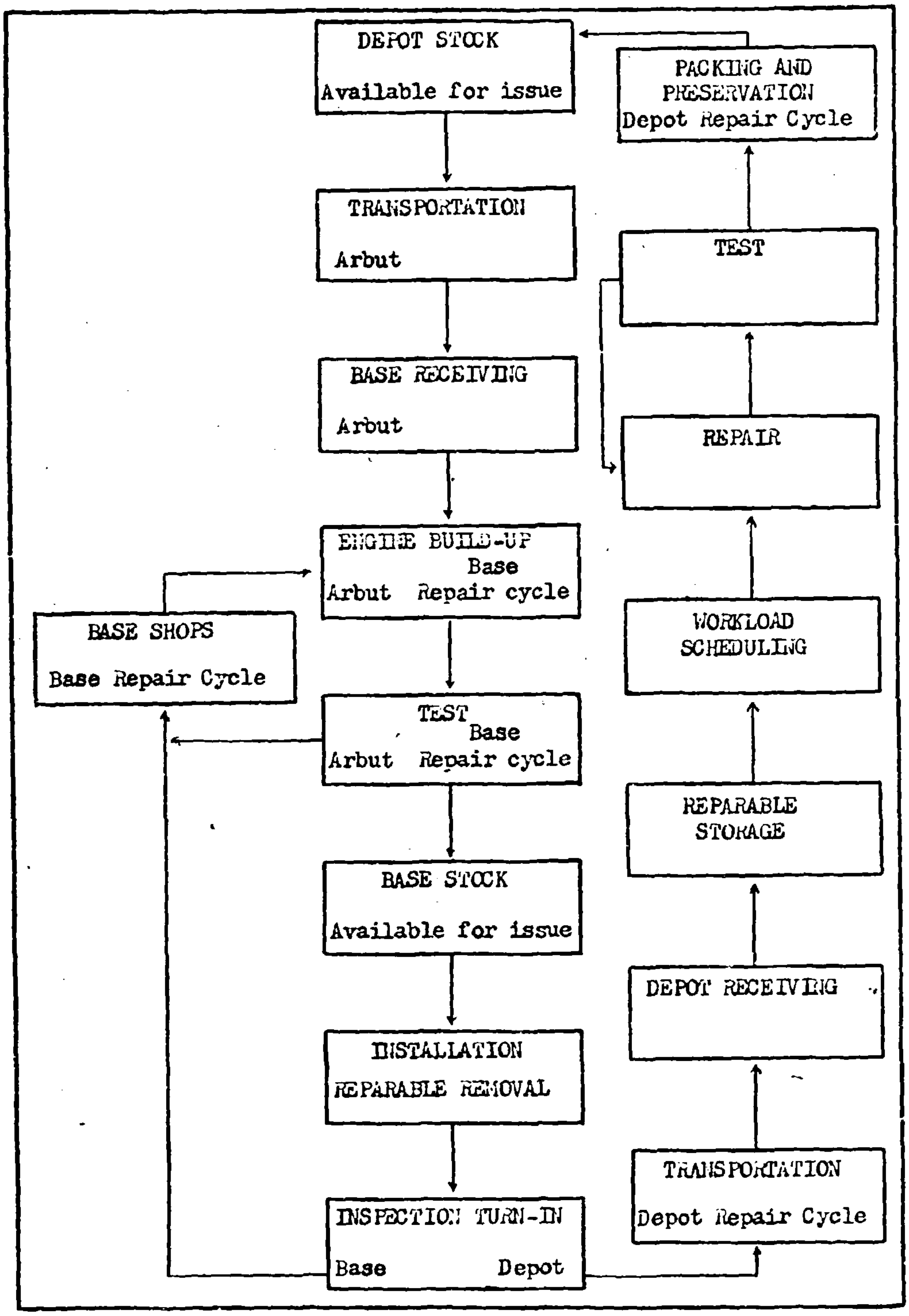

Fig. 5. Engine Flow Cycle

are required as the same engine may be used more frequently to satisfy demand.

In the 1950's a number of studies based on cost considerations indicated many pipeline segments could be reduced by better management and production techniques. In 1951, an Air Force Engine Study Group, under the chairmanship of a consultant, Dr. Edmund Learned of Harvard University, made a detailed analysis of aircraft engine requirements determination methods. Implementation of the Group's recommendations resulted in reducing stock levels and the time allowed to process engines through transportation and repair cycles. The total pipeline standard for CONUS was reduced from 6 months to 4 1/2 months; the 8 months overseas pipeline was reduced to 7 months.

In 1952, the San Antonio AMA made an extensive study to determine the economic practicability of airlifting aircraft engines and kindred cargo required in everyday operations of the Air Force. In 1954, following additional studies on the advantages of the use of overseas airlift and expedited surface transportation in the CONUS as means of further reducing pipeline times, the CONUS pipeline time was reduced to about 3 1/2 months, and the overseas pipeline was reduced drastically to about 4 months (Ref 17:6).

In recognizing the impact of pipeline times on spare engine requirements, Air Force policy has been to publish major pipeline segment time standards in Air Force Manual 400-1. These times are determined by the Engine Logistics Planning Board which must:

"1. Evaluate and establish pipeline standards for new engines prior to procurement.
2. Evaluate and approve changes in pipeline standards for in-production engines and in-service engines not yet past their peak requirement" (Ref 1:7-3).

The relevent question of how the standards are determined is a difficult consideration at best. In the November 1969 meeting of the Air Force Logistics Planning Board the standards were described as having been selected as "reasonable goals" (Ref 3:94). The objectives of a base maintenance pipeline cycle meeting in April, 1970 were to: "Identify appropriate pipeline segments and establish standards, and to discuss pipeline management reports" (Ref 11:1).

"Reasonable goals" are not perhaps the best criteria for improving efficiency and are not very satisfying as a basis for approaching optimal decisions. The pipeline cycle meeting's objectives indicate a recognition of the real need for management to carefully understand and control pipeline standards and reports if the objectives of minimizing cost for a set performance capability is to be reached.

<u>Concept of a Standard Against an Average Requirement</u>

Within the pipeline time standards are a number of interesting considerations. The pipeline times by AFM 400-1 "establish time standards in terms of average elapsed calendar days for each segment of engine pipelines." This average or mean indicates that the expected length of various pipeline segments is actually distributed over a range of values with the standard being a point estimate of some central tendency of the distribution. Thus, at any one time one would expect to find times on both sides of this mean figure.

However, often the concept of a standard implies poor performance when the standard is not met and good performance when the time required is less than the standard. This concept is reflected in inspections and local evaluations that rate performance by comparing it to published standards. Such actions can be misleading if the time period abd amount of data examined is not appropriate to the distribution governing the expected time for the pipeline segment. For example, if an inspection team examined the status of a certain engine type in some segment of the pipeline it should expect to find times on both sides of the standard if the standard is a mean of a distribution. However, generally in the Air Force, standards imply minimum performance and the inspection team would very likely be unhappy about any times exceeding the standard. This type of response leads to those, whose performance is being judged, wanting standards to include many factors for contingency, such as possible manpower or parts shortages so that the standards would generally make allowances for all foreseeable problems. But this concept of maximum allowed time is not compatable with the mean of a statistical distribution as the standards are suppose to represent.

A second major consideration is the effect on field people of reducing pipeline times. While a reduction in pipeline time reduces the number of required spares, an increase in the times does the opposite. Thus, one must ponder the motivation of the user commands for desiring to reduce pipeline times when the net effect is to reduce the number of spares deemed necessary and available to support their operations. This paradox is an example of the possible need for managers to better understand and utilize the systems theory discussed earlier; where in this case the interests of the user command may well conflict with the overall Air Force objectives.

These two considerations together then result in the difficult question of how objective user command representatives really can be in reducing standards that then reduce their spare engine support and from their viewpoint increase their chances of not meeting acceptable performance levels. The past difficulties associated with determining "reasonable goals" may be more apparent when the viewpoints and interests of the various representatives to the Engine Logistics Planning Board are better understood.

The purpose of the standards needs to be continually explained and the ground rules used in establishing them should be clearly communicated to all concerned with pipeline segment times. Such actions should help all concerned to be better motivated toward developing and accepting standards supporting a more efficient engine operation.

Developing Pipeline Standards

In general standards should have a number of characteristics including being consistent, clear, well communicated, accepted, attainable, and have a definite purpose. Therefore, the manager must openly attempt to fully understand the forces present in the work environment if the standards developed are to be as factual as possible and contribute to the organization's objectives. Pipeline standards can possibly be better understood by the following discussion.

The Learning Phenomenon

In developing time standards for pipeline segments, the engine manager should be aware of the implications of the learning phenomenon on potential standards. It is widely recognized that repetitive performance of a task results in improved efficiency particularly during the first few repetitions.

"It would seem reasonable to believe, particularly in cases of simple manual labor, that after a given number of repetitions of a task, learning would cease and peak level of efficiency would be reached. In the learning theory, however, it is held that the proportional amount of learning (or percentage of increase in efficiency of performance) is constant for proportional numbers of repetitions. This means, of course, that learning is a continuous process and that no limit to learning is reached regardless of the number of repetitions. At first glance, this concept appears to be impossible; however, the key to rationality of the theory is the term proportional repetitions. For example, if a worker engaged in a repetitious task improves his efficiency by one percent each time he quadruples his performance, it can be proven mathematically that to reduce the time to perform the task to 90 percent of the original time would require approximately 1,000,000 repetitions! Reduction to 80 percent would require approximately 1,100,000,000,000 repetitions!" (Ref 5:1).

Learning curve theory has found application in the airframe business and has been supported by aircraft engine production data. The learning phenomenon appears most useful in situations where:

1. There is a high degree of direct labor.
2. The product is complex and handled in relatively small quantities.
3. The product changes frequently due to technical changes, offering increased opportunities for learning to occur" (Ref 5:4).

Generally, the engine repair flow cycle possesses these characteristics and one should expect that learning considerations could be of some use in understanding and developing pipeline standards. The learning process suggests the manager should expect and look for continuing improved pipeline performance times particularly during the initial buildup time period. This means the setting of standards for new engine systems should probably be aimed at the time period shortly before peak engine requirements and not at the time initial operational capability begins, since the learning phenomenon should be acting in a way that supports a reduction in the pipeline segment times.

Of course, the most useful information would be to actually measure and determine the appropriate learning curve associated with pipeline segments in order to better predict the learning that should be expected by management. Numerous articles describing learning theory aspects are available and the AFIT thesis listed as source 5 in the bibliography is an excellent source for more specific data.

Pipeline Tradeoff Information

In previous sections the concept of system cost or performance was discussed with the goal of stressing the importance of recognizing tradeoffs and evaluating alternative choices for hopefully finding more optimal solutions to the problems at hand. These ideas can possibly be very useful in setting and evaluating pipeline time standards as was done in the 1950's with the extensive reviews of transportation times and costs versus the length of the pipeline and the required number of spare engines.

Recently, a good deal of emphasis has been placed on clearly identifying pertinent segments of the pipeline. After such identification, the problem of determining and evaluating potential standards must be faced, but on what basis can the engine manager agree or disagree with proposed standards? Indeed, one can even go further and suggest the people making evaluations and accepting standards should be able to categorically state both the costs and constraints that make any other values of the time segments undesirable. For example, the in-work (depot repair) standard for the TF-39 for the C-5A is, by AFM 400-1, 25 days. In evaluating this standard, cost figures should be available that allows the decision maker to see what additional requirements are necessary to reduce this time to 24 or less days so he can compare the increased costs against the reduced cost of spare engines to support a shortened pipeline. Obviously, information should be determined for ranges both above and below proposed or accepted standards.

This approach is aimed at forcing responsible personnel to rather critically determine what they are doing and why it is the best way of doing the task. In essence, the goal of such a program is to improve efficiency by carefully considering the cost tradeoffs between manpower, specialized equipment, increased training, and additional supplies against the pipeline time saved. The additional pipeline costs can then be compared to the savings in engine procurement costs which is a function of the particular engine being considered.

Critical Path Method

The idea of knowing the cost of tradeoffs has made such management tools as the Critical Path Method (CPM) very useful in certain circumstances. CPM has been widely used in the construction industry to identify the pacing path of tasks as well as the penalty costs for shortening tasks on the path. For example, a typical event on a critical path may normally require 10 days to complete. Along with this information, CPM techniques allows one to determine the penalty (or additional) cost of shortening this time period and the minimum time for the task. For example, the 10 day task may require 5 days to complete no matter how many resources are committed to the task due to some constraint such as say concrete curing time. If the task can be shortened from 10 days to 5 days or anything between for a penalty cost of 45 dollars, the decision maker can compare the increased cost against potential benefits. Thus, if the contractor were behind schedule and he stood to contractually lose 100 dollars a day for failing to meet his deadlines, it would be to his advantage to expediate the 10 day task to 5 days. This general CPM idea of committing resources where they will do the most good is another example of the marginal return techniques discussed previously.

The engine manager could well use information identifying absolute constraints and additional costs for accelerating times associated with the pipeline. With such information the decision maker has a basis for optimal decisions instead of decisions based on group consensus, of reasonable goals, dominant personalities, or just historical experience. In the example cited of the TF-39 engine, "such information" would hopefully not result in the concern expressed by a number of people that the present standard for the TF-39 is in essence, a directive, not a decision based, as much as possible on specific information supporting the decision.

A Resource Baseline

Currently, the "Propulsion Unit Pipeline Analysis" report indicates a significant variance for a number of actual in-work times for the same engine both within a command and between commands. These variances are good indicators that procedures, management control, personnel training, manpower levels, and facilities are not equal throughout the Air Force engine system. One objective of the process of identifying constraints and costs associated with the pipeline should be to determine why these differences exist and in the words of General Ryan insure there is "an interchange of ideas, so that improved procedures can be shared throughout the Air Force."

In determining standards it is important to know the resource baseline necessary to employ the standards and to involve the people living with the standards as much as possible. One possible approach to carrying out this formidable task would be to have each command and depot identify the costs and constraints associated with each engine system it possesses that is not past the peak demand point and with all new engine systems it stands to receive.

This action alone would tend to force the commands such as ATC to explain why one base "required an average of 13.4 base-maintenance in-work days to process 157 J85 engines while two others required averages of 4.7 and 4.6 days for 129 and 138 engines, respectively" (Ref 2:98).

The individual command and depot analyses on costs and constraints could then be collected by AFLC which would allow them to compare the various command and depot data to determine pipeline tradeoffs against additional engine costs.

VI. Tradeoff Calculations

It has been noted several times that many tradeoffs exist in the factors determining spare engine requirements. In this section a number of hypothethical examples will be presented to illustrate the use of analytical techniques in making such tradeoffs.

Suppose it has been determined that for a new engine with a unit cost of $400,000 it would be possible to eliminate 10 spare engines by shortening the pipeline time. However, this shortened pipeline is expected to cost an additional $800,000 per year (increased labor and transportation costs) for the 5 years the 10 engines would be used to support peak demand. Since either alternative involves 4 million dollars to do the same job, is there any difference between the two choices? The answer is yes if the concept of discounting or present value is applied. Assume today is program year zero and the 10 engines must be paid for 3 years from now, while the increased pipeline costs occur from year 4 through year 8 and the discount rate is 10%. Table V indicates the present value of buying the 10 engines is about 3 million while the other alternative's present value costs are only about 2.28 million. So for the given conditions and with all other factors equal, the shortened pipeline is a better method of meeting requirements than buying an additional 10 engines.

However, the sensitivity concept can now be used to consider the range of values where the chosen decision remains preferred. Factors which could change are the chosen discount rate, the engine unit cost, or the cost of shortening the pipeline.

If the same choices were to be considered but the total cost of

Table V
Present Value Comparison of Alternatives

Program Year	0	1	2	3	4	5	6	7	8	9	Total
10% discount factor	1	.909	.826	.751	.683	.621	.564	.513	.467	.424	
A's yearly costs				4.00							4.00
A's yearly present value costs				3.00							3.00
B's yearly costs					.8	.8	.8	.8	.8		4.00
B's yearly present value costs					.546	.497	.451	.410	.374		2.28

A = alternative of buying 10 engines
B = alternative of shortening pipeline
Costs are in millions of dollars

the engines to be procured was only 3 million dollars, the present value for the engines would be about 2.25 million or approximately the same cost as decreasing the pipeline time. Therefore, the range for total engine cost where shortening the pipeline is the best decision is for any engine cost above about 3 million dollars.

Another case would be the original value for the cost of the engines and the increased pipeline costs but the concern that the yearly costs for shortening the pipeline could run as high as 1 million dollars per year. The present value for the shortened pipeline costs would then be 2.85 million which is still below the present value cost of purchasing more engines. Here, any cost for the shortened pipeline time that is less than about 1.5 million per year results in the shortened pipeline being the best decision.

Another possibility would be a concern that the increased pipeline costs may last longer than 5 years. If the costs lasted 7 years instead of 5, their present value costs would be 2.92 million while at 8 years they would be 3.2 million. Thus, the shortened pipeline is still the proper decision as long as the increased pipeline costs are expected to last less than 8 years.

One might also be interested in how sensitive the decision outcome is to the chosen discount rate of 10%. Discounting would always favor the pipeline shortening alternative regardless of the chosen discount rate for the parameters used in the original example since both alternatives involved equal costs with the shortened pipeline costs all occuring after the engine procurement costs. Table VI shows the yearly discount values for discount rates of 6, 10, and 15%.

Table VI
Yearly Adjustment Factors for Selected Discount Rates

Discount Rate	Years Hence										
	0	1	2	3	4	5	6	7	8	9	10
6%	1	.943	.890	.840	.792	.747	.705	.665	.627	.592	.558
10%	1	.909	.826	.751	.683	.621	.564	.513	.467	.424	.386
15%	1	.870	.756	.658	.572	.497	.432	.376	.327	.284	.247

Changing the discount factor does markedly affect the range where the shortened pipeline is the better decision. Table VII indicates that for the 6% rate the yearly costs must not exceed .95 million against 1.05 million for 10% and 1.55 million for 15% if the shortened pipeline choice is to remain the better course of action. Thus, the discount rate also affects the range where a particular alternative is the proper choice.

Table VII
Present Value Comparison with Different Discount Rates

Discount Rate	6%	10%	15%
Present Value Cost of A	3.36	3.00	2.73
Present Value Cost of B	2.83	2.28	1.76
Max. Yearly Cost if B is to be chosen	.95	1.05	1.55

A = alternative of buying 10 engines
B = alternative of shortening pipeline
Costs are in millions of dollars

It is important to realize what has been accomplished by the previous series of calculations. Initially two alternatives were proposed that appeared to both have the same cost and be of equal effectiveness. However, by applying discounting, the two alternatives were shown to have different present value costs making one alternative more attractive. Thus, the choice of a decision rule, which in this case was whether or not to use discounting, determined which approach was preferred.

The sensitivity analysis provided the decision maker with more information as it determined the variation range for a parameter while all other factors were constant in which the proposed alternative remained the better choice. The manager was provided with objective information telling him how far engine costs could vary or how far yearly costs could increase before he should change his decision, and was given this information for a variety of discount rates.

Previously, it was suggested that Poisson safety level calculations could possibly be varied as one method of avoiding peak demand build-ups or as a means of discriminating between desired support levels for aircraft with different missions. Table VIII illustrates the changes in safety level quantity for a variety of average spare engine requirements.

Table VIII
Additional Engines Required for Various Confidence Levels
Using a Poisson Distribution

Confidence Level	65%	70%	75%	80%	85%	90%	95%
Average Requirement							
5	1	1	1	2	2	3	4
10	1	2	2	3	3	4	5
15	1	2	2	3	4	5	7
20	1	2	3	4	5	6	8
25	2	2	3	4	5	6	8

The data in Table VIII can be used to better appreciate the cost of objectives or constraints. That is, the manager can see the additional engines required as the confidence level constraint is varied. For instance, an 80% level requires from 1 to 2 engines less than does the 90% level. This means the price for expecting to satisfy 90% instead of 80% of the potential demand associated with a particular average requirement is one to two times the engine unit cost. Depending on the engine this price could be from about 50,000 to 1.5 million dollars.

One advantage of the general approach discussed in this chapter is that it fosters a decision making philosophy that requires a clear statement of objectives and evaluation criteria. Such a philosophy should help any manager privately and publicly state and justify his decision making techniques.

VII. Summary and Conclusions

The aircraft engine system is a large and complex operation involving a variety of Air Force organizations, personnel and includes assets costing billions of dollars. Official Air Force policy and guidance for managing engine activities is contained in Air Force Manual 400-1, Selective Management of Propulsion Units. However, engine managers have been, and will always probably be, forced to face the fundamental problem of determining how to insure engine inventory levels are kept as low as possible while still satisfying engine availability requirements.

The problem becomes more critical as engine unit costs increase and approach figures such as 3/4 of a million dollars as is the case for the TF-39 engine for the C-5A aircraft. The trend of increasing engine costs favors careful economic analysis to determine what alternatives best provide methods for avoiding excess procurements and for delaying the inevitable excess engine point to as late as possible in the engine life cycle.

Spare engine calculations are based on information that is generally probabilistic in nature requiring the numbers used to be based on some central tendency of the distribution associated with the particular factor. This uncertainty is increased by the need to project requirements three years or so into the future to allow for the necessary lead time to procure engines.

A complicating factor for management is the variety of views and objectives possessed by the many organizations associated with spare engine operations. Since users tend to look at potential problems differently than AFLC or Air Staff people, it is necessary to have overall system objectives that are carefully formulated, clearly communicated, and widely accepted. Furthermore, close integration of efforts is paramount in developing an efficient team that is aware of the need to understand and utilize a total perspective of the engine system.

For instance, the type and quality of decisions made during the design, development, and acquisition stages may well dictate the cost and even effectiveness of the following logistic support actions. Therefore, careful analysis should be given to potential tradeoffs between development, acquisition, and operating costs in determining when, how, and where dollars should be spent. Project ABLE is a proposal directed toward this general area of potential tradeoffs.

There are a number of analytical tools that can be helpful in formulating and evaluating alternatives. These tools, when properly used, can help the manager rationally choose a course of action by providing information on the specific advantages, disadvantages, and implications of the available alternatives. Managers committed to understanding the logic behind, and the consequences of, techniques and methods used in engine management decisions, should find analytical tools valuable both as a source of information and as an aid to a better conceptual viewpoint. However, analysis only contributes to the decision making process and is not an end in itself.

Cost effectiveness and optimization have the objective of satisfying performance requirements while minimizing the associated system cost. These processes are not designed to buy "cheap" weapons or put costs before performance. Rather, they recognize that comparisons among alternatives are much more meaningful when both benefits and costs are fully examined and compared.

Marginal analysis results from evaluating the relative worth of various activities. While difficult to procedurally do, marginal analysis is inherent in decisions ranging from grocery shopping, to buying weapon systems, to the decision to use a 90% confidence factor for all engine types and for all time in the life cycle.

Discounting to present value is a technique providing a common denominator to alternatives involving dollars spent over a period of years. Discounting suggests that dollars spent today are not directly comparable to dollars spent in the future until the time value of money has been accounted for. Discounting fosters a belief in the need to propose and evaluate other methods of meeting spare engine requirements than just buying more engines, since increasing engine costs make delayed expenditures for shortened pipeline times or increased engine overhaul times more attractive.

Sensitivity analysis is based on the reality that there is not an absolute answer applicable to all situations. Rather the best decision is a function of the assumptions, parameter values, objectives, constraints and methods present in the decision situation. The sensitivity technique is used to indicate over what range of values a particular alternative is the better choice and indicate the impact each variable has on the solution outcome.

Spare engines must be procured to provide for requirements at both the base and depot levels. The base stock consists of spare engines to meet the automatic resupply and buildup time (ARBUT), the base repair cycle quantity, and a safety level quantity. Depot spares consist of engines to provide for the depot overhaul repair cycle and a safety level quantity.

The safety quantity is determined differently for the base stock than for the depot stock. The base safety quantity is determined by the use of a Poisson distribution with a mean equal to the sum of the ARBUT and base repair cycle quantities. The depot stock quantity or safety quantity is determined by using a constant figure of 15 days times the engine removals for overhaul per day. This results in the depot overhaul repair cycle requirement being increased by about 33% to provide the depot safety stock quantity.

Flying hours are a prime factor influencing spare engine levels and a strongly peaked program can be a prime cause of excess engines with the current method of calculation.

The time between overhaul (TBO) for an engine normally increases as the engine system matures due to component improvements. This tends to offset the increased flying hour requirements if the increasing TBO occurs early enough. Consequently, it is desirable to incorporate component-type improvements as early as feasible.

The engine pipeline is another factor affecting spare engine levels. A real difficulty for the engine management system is determining appropriate pipeline times. These times, called standards, are supposed to reflect average figures which is not the typical Air Force concept of a standard.

In developing these standards, factors such as a baseline of men, materials, and equipment should be noted; learning should be considered to the extent that pipeline times should not be locked in concrete, but generally should be oriented toward peak demand times; and the standards should be set only after considering tradeoffs between pipeline time and costs, and the required engines and their costs as pipeline times change.

Recommendations

Safety Level Quantities. It is difficult to justify the different ways of determining safety quantities for base and depot stock. The use of a Poisson distribution for both cases appears to be much more theoretically justified since it is sensitive to the average requirement and is not an arbitrary rule. As was shown in Table IV, the Poisson technique does not provide as many extra engines for a large range of removal rates as does the depot stock method.

If one accepts using the Poisson distribution, thorough consideration should be given to the decision of what is the appropriate cumulative probability to be used in spare engine calculations. There is nothing magical about the 90% confidence level as indicated by the data in Table VIII. In fact, one possibility is to use more than one level with the level being determined by the type of aircraft mission or by the life cycle phase or some other criteria while recalling the safety quantity's purpose is to provide for contingencies and instantaneous increases above the average requirement.

It should also be noted the safety quantities are figured for each base and for each depot and cover all segments of the factors influencing requirements. It seems highly unlikely that all the factors such as repair cycle times, flying hours and removal rates would exceed their expected values at the same time.

The Engine Pipeline. The use of the word standard for pipeline times may be a poor choice of words. Standards normally connote minimum acceptable performance in the Air Force, not an average performance or requirement. It may be wise to use the term average time or mean time as a method of reducing confusion.

Uniform pipeline times for an engine system are only meaningful if a common resource baseline exists at all affected bases. That baseline must include the number of manhours per week worked by the organization as well as the type of equipment provided and the skills level of assigned personnel. The wide variety of actual pipeline times for the same engine system reported by different commands is a strong indicator that present pipeline times are not a realistic reflection of actual conditions.

Future pipeline times should not only be based on the expected time to repair and transport engines, but should also consider shortened pipeline times if this will reduce the required number of engines enough to offset the increased pipeline costs. This type of trade-off is a function of engine unit cost and is an area where discounting and sensitivity analysis increases the manager's awareness of the implications and desirability of each alternative.

Finally, in suggesting pipeline times, managers should be prepared to categorically state both the costs and constraints that make any other time segment undesirable as well as give specific reasons for their recommendations.

<u>Engine Overhaul Times</u>. An impressive number of people clearly recognize the need to incorporate the logistic factors of maintainability and reliability into new engines as soon as possible. The efforts being expended to more clearly determine how to closely integrate AFSC and AFLC requirements and procedures could be of

immense value if it results in reducing the logistic net support costs without degrading performance capabilities.

Management Activities. The engine management system can benefit by insuring all personnel are oriented toward understanding the reasons for, and the consequences of, the techniques and methods used in determining spare engine levels.

The present methods concentrate on extra engines to meet increasing flying hour requirements rather than fostering tradeoff considerations. They partly do this by treating all engine systems alike and ignoring the great variance in unit costs of different engines as well as mission requirements. Attempts to treat too many items with standard methods and processes can easily result in a very rigid system that is not flexible to changing requirements and conditions such as tighter budget constraints or changing technology.

Managers who strive to develop and evaluate alternatives and tradeoffs among the factors influencing spare engine inventory effectiveness and cost, are probably more likely to make better decisions that will eventually result in a more efficient spare engine management system.

Bibliography

1. AFM 400-1. Selective Management of Propulsion Units. Washington: Department of the Air Force, 5 January 1970.

2. Albo, Charles W. A Partial Analysis of the Weapons Systems Design Philosophy. Unpublished paper. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, 2 June 1970.

3. ARINC Research Corporation. A Study of the Air Force Jet Engine Maintenance Program. Annapolis, Maryland. Publication 930-01-1-1054, May 30, 1970.

4. Baumol, William J. Economic Theory and Operations Analysis (Second Edition). Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.

5. Brewer, Glenn M. The Learning Curve in the Airframe Industry. Unpublished thesis. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, August 1965.

6. Cavender, Lt. Raymond E. and Irving Katz. Project ABLE - Applied to Aircraft Engine Development and Procurement. Wright-Patterson Air Force Base, Ohio: Operations Analysis Office, Headquarters Air Force Logistics Command, January 1970.

7. Class notes: SM 6.40, Systems Management; Department of Systems Management, School of Engineering, Air Force Institute of Technology, Spring 1970.

8. "Economic Analysis Goes Down Chain of Command." Armed Forces Management. (May 1969).

9. Ferguson, General James, USAF. "Program Management." Andrews Air Force Base, Washington, D. C. 24 January 1970. (Typewritten).

10. "The Fortune Directory of the 500 Largest Industrial Corporations." Fortune, Vol. LXXXI, No. 5. (May 1970).

11. Headquarters, AFLC, (MCNP). Minutes of Base Maintenance Pipeline Cycle Meeting. Tinker Air Force Base, Oklahoma: Oklahoma City Air Materiel Area. 28, 29 April, 1970.

12. Headquarters, AFLC (MMP). Minutes of Pipeline Analysis Report Working Group (AF Engine Logistics Planning Board Subcommittee). Lockbourne Air Force Base, Ohio. 21-23 July, 1970.

13. Katz, Irving. Project ABLE (Acquisition Based on Consideration of Logistics Effects). Operations Analysis Report No. 8. Wright-Patterson Air Force Base, Ohio: Operations Analysis Office, Headquarters Air Force Logistics Command, May 1969.

14. Miller, Irwin and John E. Freund. Probability and Statistics for Engineers. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1965.

15. Report of AFSC/AFLC AD HOC Working Group for Management of Engineering Changes During Acquisition, January 1970.

16. Sherbrook, Craig C. Metric: A Multi-Echelon Technique for Recoverable Item Control. Santa Monica, Calif.: The Rand Corporation, Nov. 1966.

17. Van Berkum, Maj. Jacob J. and Maj. Edward F. Fisher. The Economics of Extended Versus Expedited Pipelines for Excess Aircraft Engines. Unpublished thesis. Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology, August 1964.

Vita

Ted Leo Kehl was born on 22 December 1943 in Salt Lake City, Utah. He graduated from Highland High School in 1962, obtained a Bachelor of Science Degree in Electrical Engineering from the University of Utah in 1966, and was commissioned in the United States Air Force upon graduation. He served as a Wing Engineering Officer and Launch Controller with the Advanced Ballistic Re-entry Systems program at Vandenberg Air Force Base, California, where he also attended the University of Southern California's graduate program in Aerospace Operations Management.

Permanent Address: 1274 Stringham Ave.
Salt Lake City, Utah 84106

This thesis was typed by Mrs. Judy Kehl.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Air Force Institute of Technology (AFIT-EN) Wright-Patterson AFB, Ohio 45433	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

AN ANALYSIS OF FACTORS INFLUENCING SPARE ENGINE MANAGEMENT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
AFIT Thesis

5. AUTHOR(S) (First name, middle initial, last name)
Ted L. Kehl
Capt. USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1970	78	17

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) GSM/SM/70-10
b. PROJECT NO. N/A	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Dean of Engineering, Air Force Institute of Technology (AFIT-EN), Wright-Patterson AFB, Ohio 45433.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT This report deals with the problems and complexities faced by the Air Force in attempting to determine "proper" spare engine levels. Spare engine levels are examined as a function of both requirement factors and management decisions concerning the methods and techniques to be used for dealing with the requirement factors.

Systems theory is introduced to present a conceptual framework for better understanding the viewpoints and priorities possessed by the organizations involved with engine management. The concept of a system objective is considered as compared to the particular command interests of an organization such as Air Force Logistics Command or Air Force Systems Command.

Analytical techniques including marginal analysis, discounting, tradeoff analysis, and sensitivity analysis are discussed in terms of their possible application to engine management policy and procedure.

The factors affecting spare engine requirements are reviewed with respect to their impact on spare engine levels. Considerable attention is focused on the consequence of the marked difference in how engine stock safety quantities are determined for base stock as compared to depot stock.

Engine pipeline standards are discussed with reference to potential tradeoffs between pipeline lengths and the number of spare engines required. Additional pipeline discussion includes examining the concept of average time requirements, and considerations in developing standards including the identification of a resource baseline.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
aircraft engines						
engine management system						
pipeline times						

Unclassified
Security Classification

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY (ATC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: NR 31 July 1980

SUBJECT: AFIT Masters Thesis GSM/SM/70-10

TO: LDE

The master thesis GSM/SM/70-10 entitled "An Analysis of Factors Influencing Sparc Engine Management" by Captain Ted L. Kehl is unclassified and is authorized for unlimited distribution.

Lynn Wolaver
LYNN E. WOLAVER
Dean for Research and
Professional Development

1 Atch
Thesis

1st Ind (PA) 31 July 1980

TO: LDE

Above subject report is approved for public release IAW AFR 190-17.

Fredric C. Lynch
FREDRIC C. LYNCH, Major, USAF
Director of Public Affairs

1 Atch
Thesis