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AN ANALYSIS OF AIR FORCE MANAGEMENT
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SYSTEMS (TEMS).

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Turbine Engine Monitoring Systems (TEMS) are engine health monitoring and diagnostic tools being developed and tested for use on Air Force engines in order to improve and reduce the cost of engine maintenance and management and to aid in the implementation of On Condition Maintenance. Previous researchers have described the major features of TEMS, analyzed the results of development and test efforts, and identified problems which must be overcome. This study examines the problem of fragmentation which exists in the Air Force management of TEMS development and testing. The authors describe and analyze the overall Air Force management of TEMS. Management problems were identified and classified into three major areas: structure and role problems, information flow and integration problems, and leadership and command problems. Four alternative management concepts were analyzed. Based on this analysis, the authors recommend that the management structure be modified, and a TEMS Task Force be established to more effectively utilize TEMS for Air Force engine maintenance and management.

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AN ANALYSIS OF AIR FORCE MANAGEMENT OF TURBINE ENGINE MONITORING SYSTEMS (TEMS)

A Thesis

Presented to the Faculty of the School of Systems and Logistics

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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Chapter 1

INTRODUCTION

OVERVIEW OF THE PROBLEM AREA

Today, the D024 Propulsion Unit Logistics System is the sole management system used by the U.S. Air Force to manage its entire inventory of aircraft engines. The D024 System, however, has two major problem areas: responsiveness and cost.

In December of 1973, the Air Force Inspector General (IG) stated in his report on engine management that the D024 System was not responsive to Air Force needs. Several limitations and deficiencies of the D024 System were noted in this report (31:1-49). The advent of new modular propulsion systems for the F-15/F-16 and A-10 aircraft has further emphasized the need for a more responsive engine management system because these systems require considerably more expensive components and maintenance than previous engines. Perhaps more noticeable than responsiveness is cost. Management of aircraft engines under the D024 System is costing one billion dollars per year (14:10).

In an attempt to reduce the cost of engine management and to provide a more responsive management system, the Secretary of the Air Force has directed the Air Force to implement a relatively new maintenance concept termed Reliability Centered Maintenance (RCM) (3:3). This concept allows maintenance to be accomplished when needed rather than being based solely on maximum operating times as was previously done. To determine when maintenance is needed, engine health data must be collected and analyzed on a frequent basis. Required maintenance can then be performed on "sick" parts while "healthy" parts are left untreated. Engine health data can be collected manually by aircrew observation of cockpit instruments or automatically by use of on-board "black boxes". Some examples of data collected include: time at temperature, engine run time, low cycle fatigue, oil pressure, vibration, fuel flow, and engine pressure ratio.

In order to operate under the RCM concept, it is imperative that engine health data be fully integrated into the engine management system. Presently, however, the D024 System is unable to collect or report engine health information, and, therefore, cannot provide suitable management under the RCM concept.

Air Force Logistics Command (AFLC) has proposed a new system called Comprehensive Engine Management System (CEMS) which will supplement the D024 System. CEMS is intended to provide less costly and more responsive engine management by providing a management information system which is compatible with the RCM concept. CEMS is designed to provide engine managers with information which can be transformed into more timely maintenance and management actions at less total cost (3:1). Expected areas for management improvement under CEMS are increased readiness posture, increased surge capacity, improved forecasting and budgeting, reduced spare engine and parts requirements, reduced base maintenance requirements, reduced depot maintenance requirements, and reduced transportation costs (4:1).

CEMS is currently in the project phase which will include four phased increments.

> Increment I of CEMS is a life limit management of critical parts on three selected engines; the F100, TF34 and the TF41. Increment II of CEMS is for similar life limit management on five other major engine inventories; the TF39, the TF33, and TF40, and J85 and the J60. Increment III of CEMS is for the engine status, the actuarial analysis and the logistics assessment of the repair and supply process for all engines. Increment IV of CEMS is for the engine diagnostic or engine health monitoring using the Turbine Engine Monitoring System (TEMS). Increment IV analysis will take data from all previous increments and evaluate it [sic] for any trends which show a given engine is being degraded or failing [3:2].

Turbine Engine Monitoring Systems (TEMS) will become an integral part of CEMS in Increment IV. Currently, a profusion of TEMS using a variety of techniques and approaches to gathering data are in various stages of development, test, and operation. An extensive study by Degrande and Eickmann concluded that TEMS is feasible and necessary to meet future Air Force needs. Their paper concluded that TEMS utilization could: (1) improve operational aircraft availability, maintenance practices, and flight safety; (2) reduce logistic support costs; and (3) provide the catalyst for implementation of On Condition Maintenance (16:1,69). Degrande and Eickmann recommended a single Air Force manager for TEMS be appointed in order to increase standardization of TEMS (16:74,75).

STATEMENT OF THE PROBLEM

Presently, there is no single agency responsible for coordinated guidance, planning, development, and implementation of TEMS for use by the U.S. Air Force engine management system. Instead, various Air Force agencies are pursuing relatively independent courses of action with respect to TEMS. This proliferation of approaches is resulting in the progressive lack of commonality and standardization of TEMS hardware and software for a number of Air Force aircraft. Additional short term problem areas include duplication of effort concerning manpower and funds allocations for research, development, testing and acquisition.

Although these problems are significant, they have not seriously affected the present situation because most of these TEMS have not been deployed to operational units. However, if this trend of separate TEMS efforts continues, future major problems could likely result in overall increases in inventory levels for TEMS components, increased TEMS auxiliary/support equipment costs, increased TEMS related maintenance costs, increased TEMS acquisition costs, increased personnel training costs, and increased complexity of the interfaces with the engine information management system. These potential problem areas may decrease the responsiveness and increase the cost of the Air Force engine management system.

OBJECTIVE

The objective of this thesis is to develop a practicable management concept capable of effectively dealing with present and future problems associated with U.S. Air Force Turbine Engine Monitoring Systems (TEMS).

RESEARCH HYPOTHESES

1. The present management structure for TEMS development and implementation is inadequate to meet the needs of the Air Force.

2. A single manager concept for TEMS would be the most beneficial approach to the overall management of Air Force engine monitoring systems.

RESEARCH QUESTIONS

1. Which Air Force agencies are directly involved in the planning, development, or implementation of TEMS?

2. What is the extent and relationship of each agency's involvement in the engine monitoring systems?

3. What are the advantages and disadvantages of the present TEMS management structure?

4. What would be the advantages and disadvantages of a TEMS single-manager structure?

RESEARCH DESIGN

This research effort was exploratory and descriptive in nature, and was looking for useful insights and ideas rather than statistically oriented information. The primary means of obtaining information were the review of pertinent literature and personal interviews with people who had practical experience with TEMS. An attempt was made to gather and synthesize information and experience by gaining insight into relevant interfaces and relationships between various agencies involved with TEMS.

Sources of Information

1. Literature Review. A thorough search for literature relevant to TEMS provided numerous articles, studies, reports, and theses from which to draw information. In addition, briefing guides, technical reports, plans, films, policy letters, and other written documentation were provided by Air Force Logistics Command (AFLC) and Aeronautical Systems Division (ASD). Although a large amount of written information concerning TEMS was available, very little information about the management structure of the TEMS program was found.

2. Personal Interviews. Due to the limited amount of literature concerning the TEMS management structure, heavy reliance was placed on information obtained from personal interviews. Members of several Air Force agencies involved in engine management and TEMS were contacted. These people held positions from which various aspects of the TEMS program could be observed, and they had acquired a pool of experience and information from which to draw. Many of these personnel were located at Wright-Patterson AFB, Ohio, assigned to HQ

AFLC and Aeronautical Systems Division (ASD). Subordinate organizations of concern include AFLC Directorate of Propulsion Systems (LOP), AFLC Logistics Operations Comprehensive Engine Management System (LO CEMS), ASD Directorate of Engineering and Test (YZE), ASD New Engine Program Office (YZN), the Aero Propulsion Laboratory (APL), and Air Force Acquisition Logistics Division (AFALD) Directorate of Propulsion Logistics (YZL).

Respondents were chosen from these particular organizations because each organization has a role in planning, development, or implementation of TEMS programs. Organizations which were not intimately affiliated with some aspect of TEMS were not included as sources for this research effort.

During all personal interviews, variations in points of view were highly encouraged and sought after. Due to the heterogeneous nature of the organizations considered and different types of experiences of individual respondents within these organizations, it was expected that different points of view and insights would be gained.

Scope

The research was divided into four parts. The first part included a thorough literature review and unstructured interviews with individuals who by reason of their previous experience and present positions had become specialists in various areas related to TEMS. This information was collected, consolidated, and used to gain a general understanding of Air Force engine management and maintenance procedures, capabilities of various past and present TEMS equipment, and past and present uses of TEMS equipment. The initial interviews were not intended to be highly systematic, but rather were designed to be a flexible first step to form a basis for parts two, three, and four.

Part two involved a clarification of the issues concerning TEMS which had become apparent after analyzing the information gained during part one. From this analysis a structured interview guide (Appendix) was designed to ensure that all persons interviewed responded to the same set of specific questions. This systematic interview guide was also designed to remain somewhat flexible to allow respondents the freedom to raise issues and questions not previously considered. All previous respondents were interviewed a second time using the structured interview guide.

Part three included an analysis of information gathered in part two. This led to the development of a conceptual representation of the TEMS organizational interrelationships perceived by the respondents. Also, several alternative concepts were formulated to attempt to overcome the management problems identified by the respondents.

In part four, the alternative organizational concepts were presented to the personnel previously interviewed. The interviewees were questioned as to the advantages and disadvantages of each alternative. Advantages and disadvantages of each concept were identified and analyzed. From this analysis, a modified organizational concept was developed to provide a recommended structure for effectively utilizing TEMS for Air Force engine management.

Chapter 2

LITERATURE REVIEW

AIR FORCE ENGINE MANAGEMENT SYSTEM

The Air Force engine management system consists of three management levels (command level, depot level, and base level) (12:11). The command management level includes HQ USAF and HQ AFLC. HQ USAF is ultimately responsible for the overall performance of the engine management system for the entire USAF engine inventory (8:12-13). The primary functions include engine management policy and guidance, determination of future management requirements, and surveillance of the engine reporting system. In general, these responsibilities have been directly delegated to HQ AFLC. In this capacity HQ AFLC attempts to integrate engine logistics support for all Air Force organizations involved in engine management. This is accomplished over the entire life cycle of all engines. In order to facilitate integration of engine logistic support Air Force wide, AFLC has established policies for inventory control and maintenance procedures, and has also developed the software to perform logistical analysis and support (12:14).

The second engine management level, depot level, consists of two Air Logistics Centers (ALCs): Oklahoma City ALC and San Antonio ALC. At each of these ALCs there are Engine Item Managers (EIMs) who are assigned overall responsibility for managing particular engine types.

> EIMs process and use historical data to forecast failures and scheduled removals over a two year period, to predict workloads, spare parts procurement, and to calculate stockage objectives for both depot and base levels [12:13-14].

The third management level, base level, is the lowest management level within the system. Management is performed by the Base Engine Manager (EM) who monitors the inventory and movement of all the engines which are assigned to the base. One of the EM's primary tasks is to ensure that engine status change reports are submitted in an accurate and timely manner.

In addition to the engine management levels, the operational commands provide a parallel management function. The Major Command Engine Managers (MAJCOM EMs) are concerned with monitoring fleet performance. They require a high degree of visibility into engine health for determination of the mission performance capability and readiness posture of each base and the overall command fleet.

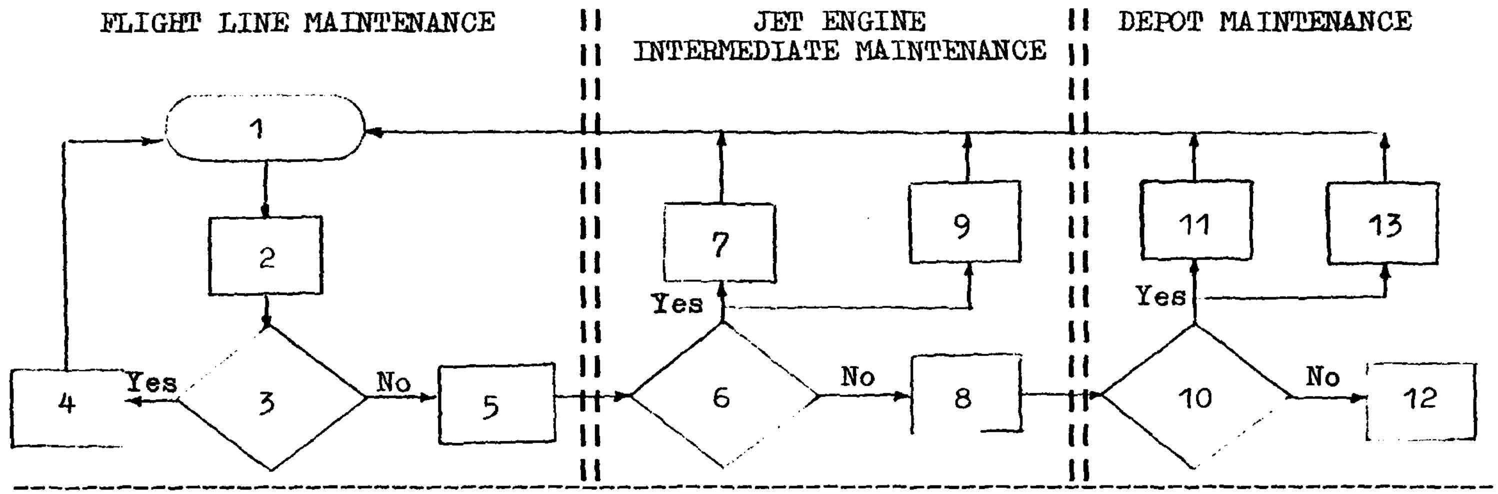
> Like their counterparts at the ALC's, MAJCOM EMs also predict workloads, determine spare engine requirements, and calculate stockage objectives [8:14-15].

AIR FORCE ENGINE MAINTENANCE SYSTEM

The engine maintenance system also consists of three levels: flight line level, Jet Engine Intermediate Maintenance (JEIM), and depot level.

Figure 1 illustrates the various interrelationships between these levels by depicting the engine maintenance flow cycle. The lowest engine maintenance level is flight line maintenance which is designed to troubleshoot engine problems on the flight line while the engine is still installed on the aircraft. Flight line maintenance has limited repair capability but can repair many minor engine discrepancies. If a repair capability exists at this level, the engine is repaired (subject to monetary and manhour constraints) while still installed on the aircraft and is returned to operation. Problems which are not repairable at the flight line level are assigned to JEIM.

> The transition from flight line maintenance to JEIM is predicated upon the identification of scheduled or unscheduled tasks which require engine removal. Factors which indicate removal of the engine have included estimated repair time, capability to repair the failure while the engine is installed and ability to accurately identify the failure [12:11].



1. Engine installed on aircraft, normal operation
2. Maintenance, overhaul, or repair required
3. Flight line repair capability
4. Repair engine while installed and return to operation
5. Assign task to JEIM
6. JEIM repair capability
7. Repair and return to operation
8. Send to depot
9. Base engine spare inventory
10. Depot repair capability
11. Repair and return to operation
12. Salvage/disposal
13. Depot spare

Figure 1

Engine Maintenance Levels and Engine Flow Cycle

Jet Engine Intermediate Maintenance may be conducted at the base or at a centralized engine repair facility. JEIM troubleshoots the engine to assess the problem and evaluates whether the capability is available to repair or modify the engine. If JEIM possesses repair capability, the work is accomplished (subject to monetary and manhour constraints), and the engine is returned to the flight line for reinstallation on an aircraft or for placement in the base spare engine inventory. If repair is beyond the capability of JEIM, the engine is sent to the depot level. A spare engine may be made available to the flight line from the base spare inventory, if needed.

> The transition from JEIM to depot level maintenance has been determined by several factors including criticality of the base engine stock level, cost of repair versus hours remaining before maximum operating time, possibility of discrepancies undetectable at base level, and failure of base level maintenance to correct discrepancies [12:13].

After receiving an engine needing repair, modification or overhaul, the depot will determine whether or not it is practical to repair. If not, engine components are either salvaged or disposed of.

Engines which are repaired are then shipped back to the base level to be installed on an aircraft or to be placed in the base engine spare inventory. The depot also has an engine spare inventory which can be used to provide spare engines to the base level when needed.

D024, PROPULSION UNIT LOGISTICS SYSTEM

The management information system used by the Air Force to manage its entire engine inventory is known as the D024, Propulsion Unit Logistics System. This system uses a base line file which facilitates selective management through serialized control of the Air Force engine inventory (8:15). Oklahoma City ALC serves as the central point of contact for information relating to all reportable aspects of an Air Force engine (primarily because Oklahoma City is the location of the system's central computer).

The primary objectives of the D024 System include specifying how to manage engines and monitoring how well engines are being managed.

> Data collected are intended to provide management with the information needed to determine allocation of funds, procurement, computation of overhaul requirements, engine inventory and distribution, spare engine requirements and disposal, and to provide the budget estimate. The intermediate objectives are to maintain an accurate and timely engine inventory, to reduce pipeline times, to speed transportation, to reduce overhaul time, to extend field maintenance capabilities and, in general, to streamline engine management techniques [8:12].
>
> The source document for the D024, Propulsion Unit Logistics System, is the AF Form 1534, Engine Status Report. This is a comprehensive form designed to follow a particular engine by serial number, from procurement through salvage [8:28].

This form is submitted by Base Engine Managers in order to update the central engine master file (12:17). The AF Form 1534 includes such data as engine serial number, engine location, engine condition, engine operating time, engine removals, engine installations, engine shipped to or from any location, and type of engine transaction (8:18; 12:20). These data are input to the system central computer via Automatic Digital Network (AUTODIN) for editing and storage (8:18). The master data file is, therefore, able to provide

> . . . a historical record of all transactions that have taken place on the engine, by serial number, from the time it was brought into the Air Force inventory until its subsequent removal (salvage through reclamation, transfer to another service, or loss by crash) [8:14].

In order to provide specialized data system support to the various engine management functions, the master file data is analyzed and processed in several different formats including D024B Item Inventory Control, D024C Allocation Distribution, D024D Pipeline Analysis, D024F Actuarial Analysis, D024I Configuration Control, D024J Financial Inventory Accounting, and D024K Actuarial Computation Forecasts (8:28).

> The MAJCOM EMs and ALC EIMs accomplish engine status monitoring through the use of D024 system output products. Among these were daily status, condition and location information, weekly not-mission-capable (NMC) status for each serial

numbered engine on a worldwide and command basis, monthly failure and inventory data, and quarterly averages of pipeline time. An update of operating hours and inventory reconciliation was received quarterly from each AF engine reporting activity [12:21].

Users of D024 output data include HQ USAF, Major Air Commands, Engine Item Managers, the National Guard Bureau, the Air University, and HQ AFLC (8:17).

RELIABILITY CENTERED MAINTENANCE (RCM)

The Federal Aviation Administration (FAA) recognizes three primary maintenance processes (25:1). These processes are included in the Air Force Reliability Centered Maintenance Program (RCMP), which is defined as:

> . . . a failure modes and effects analysis technique (FMEA) for significant aircraft and engine structures, assemblies and items. It uses a decision logic procedure based on the Airlines/Manufacturers' Maintenance Planning Document, MSG-2. This structured approach to maintenance requirements analysis, identifies minimum essential requirements consistent with safety and readiness [12:32].

The objective of the RCMP is to provide a maintenance plan that ". . . prevents deterioration of the inherent design levels of reliability and operating safety at the minimum practical cost [12:32]." To meet this objective, aircraft components are analyzed and placed into one of three maintenance categories. These categories or processes are Hard Time Limit, On Condition, and Condition Monitored (28:19).

Hard Time Limit

The Hard Time Limit category emphasizes the prevention of failures. Maximum intervals are set for performing maintenance based on the Maximum Operating Time (MOT) of a component or end item. The MOT is established from tests, operating experience, and safety factors and is based on Mean Time Between Failures (MTBF). The MTBF is measured in terms of flying hours which represent usage. The varying usage associated with flying at different altitudes, speeds, and other flight conditions is not directly considered. Because engine usage is dependent on variables other than flying hours, using flight times on which to base the Hard Time Limit does not accurately represent engine life remaining (25:2).

Chapman and Page developed the conceptualization shown in Figure 2, which represents a hypothetical graph of the effects of the MOT method on engine replacement. Although this method usually results in repair before failure, the efficiency of this method is suspect. In Figure 2, Part A, the depiction of a theoretical normal distribution of the number of engine failures over time indicates that by establishing a MOT based on MTBF minus a safety factor, a majority of engines would require maintenance before the end of their useful life. Extending

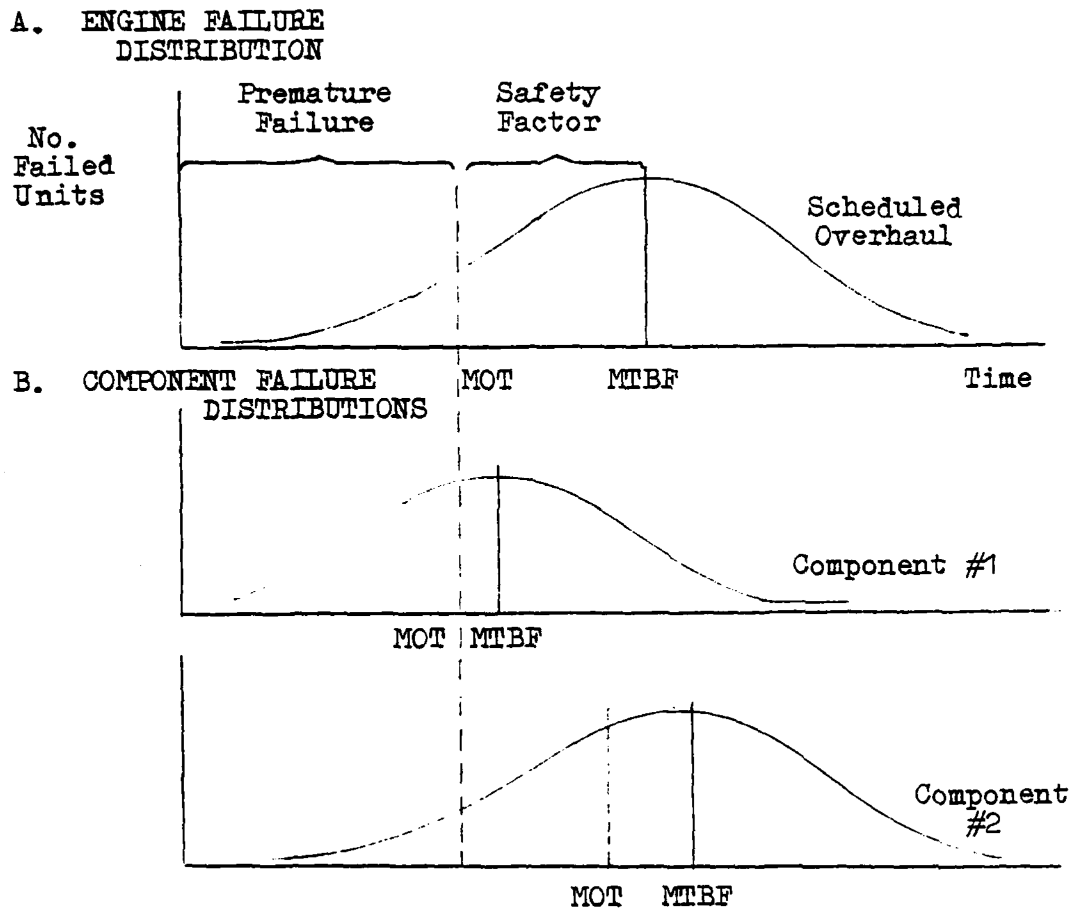


Figure 2

Effects of MOT Concept

Source:

Captain Jack W. Chapman, USAF and Captain Charles L. Page, USAF. "An Analysis and Synthesis of Engine Condition Monitoring Systems." Unpublished Master's thesis. LSSR 27-79B, AFIT/SL, Wright-Patterson AFB, OH, September 1979.

this conceptualization to engine components or modules, Figure 2, Part B, depicts the engine MOT as being equal to that of the engine component or module with the lowest MOT. Significant amounts of operational readiness time could be lost due to early scheduled maintenance for MOT components (12:29-30).

The information necessary for base level engine management of Hard Time Limit components is minimal. The requirement exists only to track the operating times of each of these components.

On Condition Maintenance (OCM)

On Condition Maintenance seeks to prevent failures by establishing periodic inspections or repetitive tests to check component parts or end items against an operational standard. OCM is defined by AFR 66-14, Equipment Maintenance Policies, Objectives, and Responsibilities, as:

> . . . The application of inspection and testing procedures and techniques without removal or disassembly that allows the condition of equipment to dictate the need for maintenance or the extent of repair required to restore serviceability [25:2].

The preceding definition identifies two key advantages of the OCM concept over the Hard Time Limit Maintenance concept. One advantage is that inspection and testing do not require removal or disassembly to determine the condition of equipment. Byrd and Tall state that:

> . . . For engines that are past their introductory problems and the effects of dilution caused by new engine introduction into the fleet, maintenance costs are directly related to engine removal rates [25:2].

The present overhaul concept of complete engine overhaul at specified time limits is a critical cost burden to the Air Force. OCM allows more maintenance tasks to be performed at base level and reduces engine removal rates (20; 33).

The second advantage of OCM is that the condition of equipment is established as the basis for maintenance and extent of repair rather than a Hard Time Limit. Under the overhaul concept for MOTs, parts which show any noticeable deterioration are replaced to ensure reliability for another time interval. Many manhours and resources are consumed repairing and replacing parts that are not broken or excessively worn (25:2). In contrast, under the OCM concept, these parts are repaired or replaced based on their condition with respect to the established standards for operational reliability. By repairing or replacing only when necessary, manhours and resources are conserved, and costs are reduced.

To effectively implement OCM, the requirement exists to track the condition of individual components. This factor requires additional information to be available for the engine manager. One of the objectives of TEMS development is to provide this information in a manageable form.

Condition Monitored (CM)

This maintenance category includes items that have neither Hard Time Limits nor any specific On Condition inspection or monitoring system.

> Condition monitoring is categorized as an unscheduled maintenance process [and] is primarily applicable to only those aircraft units the failure of which does not jeopardize crew safety [28:28-29].

These items are repaired after failure is noted by the crew or maintenance personnel.

Summary

The progression of Air Force engine maintenance from maintenance management based completely on the MOT concept to RCM is expected to cut costs of engine management. To more effectively implement RCM and increase the use of On Condition Maintenance, the CEMS and TEMS are being developed, tested, and implemented to provide better and more timely information to engine managers.

TURBINE ENGINE MONITORING SYSTEMS (TEMS)

The various TEMS programs have implemented "manual/automatic data acquisition, sorting and storage of data, and subsequent manual/computer processing and trending" to put data "into a format which permits timely and pertinent decisions to be made concerning maintenance, logistics, operations, etc. [14:3]." Most efforts have centered on developing and testing diagnostic techniques necessary to implement automatic engine monitoring. A brief review of past and present engine monitoring programs follows.

Early Systems

Engine Analyzer System (EASY) 1962-1967. This system was tested on 36 F-105 and F-4 aircraft to monitor performance degradation. The large volume of data provided untimely analysis and was difficult to interpret into maintenance actions. The need for more reliable sensors, better data correlation and sorting, and greater data compression was indicated (14:D1).

Time Temperature Recorder Integrator (TTRI). This system attempted to predict engine life based on engine temperatures recorded over a period of time and number of operating cycles. A statistical relationship between engine life and temperature measurements was not established in the service tests (14:D1-D2).

Turbine Engine Diagnostic System (TEDS) 1969-1971.

> This program demonstrated the feasibility of automatically determining the mechanical condition and functional status of turbine engines using data acquisition, interpretation, and processing hardware [14:D3].

Sensors correctly indicated problems in engines with bad parts installed.

Operational Systems

Malfunction Analysis Detection and Recorder System (MADARS). This system is installed on the C-5A and is the only operational Air Force automatic monitoring system. MADARS monitors over 800 parameters on the airframe and its subsystems including 28 engine-related parameters. In-flight monitoring is continuous, but data are recorded only when commanded by the crew or when preselected parameter limits are exceeded. Flags are displayed in the cockpit for out of limit conditions which allow the flight engineer to accomplish appropriate fault isolation procedures. The data are ground processed and analyzed upon mission completion at Oklahoma City ALC. In some instances feedback to maintenance personnel has been as low as 30 minutes. MADARS data and trend information have been used to increase time between overhaul (TBO) rates and to detect abnormal deterioration rates. However, According to AFLC, only a small portion of the available MADARS data is presently used for engine maintenance purposes. This situation exists due to volume of data produced and to the absence of engine maintenance concepts keyed to the use of the MADARS outputs [14:10].

In-flight Engine Condition Monitoring System (IECMS). This system has recently been put into operational use by the U.S. Navy on two squadrons of A-7E aircraft. The major objective of this program is to detect in-flight engine problems early enough to prevent aircraft loss. Forty-nine engine and aircraft parameters are monitored continuously and on-board analysis and recording takes place (1) when parameters are exceeded, (2) during certain flight operations, or (3) on pilot command. This system provides an on-board malfunction indication system which warns the crew of damage which may threaten mission completion. Flags are set in the maintenance avionics bay for less severe malfunctions, and basic maintenance requirements are identified to indicate turn-around readiness status. Ground analysis processes the data for fault isolation and trending and provides printouts for corrective actions to be performed by maintenance personnel (30:19).

Strategic Air Command (SAC) Reliability Improvement Program (RIP) (5; 6). SAC RIP is a program designed to improve engine reliability for all KC and EC-135s and B-52 aircraft within SAC. The specific objectives of SAC RIP are: (1) To predict engine failures before they occur. (This is predicated on early detection of engine problems); (2) To reduce air aborts and in-flight shutdowns; and (3) To improve engine management in order to reduce maintenance costs. The means used to accomplish these objectives include: (1) Partial power takeoffs which lower the severity of engine use; (2) Normal engine care; and (3) Engine condition monitoring. Concerning engine condition monitoring, SAC has implemented the Engine Condition Monitoring Program (ECMP) which is designed to identify and repair engines with internal damage or deterioration prior to engine or component failure. ECMP procedures use the following three-step iteration: observe, interpret, and correct.

Once during the cruise portion of each flight, flight crews observe and record the following data for each engine:

1. Exhaust Gas Temperature (EGT),
2. Engine Revolutions Per Minute (RPM),
3. Fuel flow,
4. Vibration of each throttle (pilot's subjective evaluation), and
5. Throttle position for RPM (2 above).

A sixth observation, engine oil consumption, is obtained by maintenance personnel after the aircraft has landed.

SAC is using this manual engine monitoring technique because they considered automatic monitoring systems cost prohibitive for KC-135 and B-52 aircraft.

The observed flight data are converted to a standard trend base and plotted on charts by an engine monitoring team. These trend plot values are equivalent cockpit readings for engines being flown at Flight Level (FL) 300 with an outside air temperature (OAT) of -20°C and a true airspeed of 450 knots. Data corrections are needed when actual flight conditions (altitude, OAT, and true airspeed) are different from FL300, -20°C, and 450K, respectively.

Each engine creates its own unique trend plot, or signature, over a period of time. Any significant deviation from this established signature indicates potential engine problems. Maintenance technicians attempt to determine specific engine problems by interpreting deviations in engine signatures.

When possible engine problems are identified, maintenance personnel inspect and/or perform corrective maintenance. If visual inspection confirms a problem, then appropriate maintenance is accomplished. After corrective maintenance is performed, the engine is checked for signature improvement. If the signature reveals a change back to the original characteristics, then it indicates that the problem was corrected. If, however, the signature remains abnormal, the source of this deviation has not been determined. Continued observation and interpretation is necessary.

The key to the ECMP is accurate and timely recording of in-flight observations by flight crews.

Developmental/Test Systems

F-100 Engine Diagnostic System (EDS). EDS is designed for use with the F-100 engine, the propulsion system for the F-15 and F-16 aircraft. The F-100 EDS program is currently in engineering development with a ten month demonstration program to follow (7:5). EDS is configured to fault isolate various Line Replacement Units (LRUs) on the flight line, and major gas path components at the intermediate level (23:4-12).

EDS consists of approximately 40 engine mounted sensors for measuring 44 engine performance parameters. EDS hardware includes an engine mounted multiplex unit (EMUX) for signal conditioning and analog to digital conversion, an airframe mounted Data Processing Unit (DPU) to monitor and record selected signals, and a ground suitcase type Diagnostic Display Unit (DDU) for data transfer fault isolation, and to aid in performing ground engine trim (23:3-1). The system continuously monitors engine operating conditions and records data when: (1) normal operating limits are exceeded, (2) the aircraft flies through trend and performance check "windows", and (3) on pilot command (23:4-1). Any detected event which is out of limits initiates data recording for the five seconds afterward (7:5). If an operational limit is exceeded, a "NO GO" indicator will appear on a status panel which can be checked by maintenance personnel on the ground to ascertain engine post flight status (23:4-1). The EDS cumulatively counts and records major engine cycles and total time above critical temperatures (7:5). The system also has the capability to perform engine trim (23:4-1).

T-38 Engine Health Monitoring System (EHMS). EHMS was developed by Northrop for operation on the T-38 aircraft. EHMS hardware includes two basic items of equipment: (1) an Electronics Processor Unit (EPU), and (2) a Data Display Unit (DDU). An additional item not mandatory for EHMS operation is a hard copy printer (24:A-1). The EPU is aircraft mounted and weighs nine pounds. It receives parameter signals from 21 engine and airframe mounted sensors. These signals are converted to digital format, processed by the EPU microcomputer, and compared to normative values.

> When one or more compared values exceeds programmed limits, the microcomputer performs diagnostic analysis using internally stored logic trees and transmits the maintenance information to the on-board storage module [24:A-1].
>
> The DDU is a rugged, portable unit weighing less than 25 pounds. When the aircraft lands, the ground crew can meet it and couple the retractable umbilical cord to the DDU to the aircraft by a quick-disconnect connector. Pressing the data transfer switch of the DDU transfers all stored data from the flight or multiple flights in approximately two seconds . . . . All data is [sic] related to time of occurrence in the flight and duration of exceedance of limit. The portable DDU has its own battery and uses the same low power microcomputer used in the airborne EPU . . . . Since the DDU is teletype compatible, the information could be transmitted over a telephone line to other teletypes or computer centers, if desired [24:A-1,A-3].
>
> Engine health data are stored only under the following three conditions: (1) when engine parameters exceed normal limits, (2) on pilot command, and (3) under preprogrammed flight conditions. When any of the three conditions occur, all parameter data as of that moment are recorded (snapshot recording) [7:7].

<u>A-10/TF34 Turbine Engine Monitoring System (TEMS)</u>. Modifications were made to the already existing T-38 Engine Health Monitoring System (EHMS) for adaptation to the A-10/TF34 engine. No changes were made to the EHMS ground support equipment or data processing unit. This modified system was called the A-10/TF34 TEMS. A service evaluation (flight test) was initiated in November 1979

at Myrtle Beach AFB, SC, using five TEMS equipped A-10 aircraft; a sixth aircraft was equipped with TEMS in April 1979. Two-thousand (2000) program flying hours were completed in October 1979 with additional service evaluation extending to March 1980. The service evaluation was intended to be an evolutionary transition to production design with no radical changes in system hardware. A production decision will be made based upon completion of the service evaluation (19).

Generic TEMS. In January 1979 the commander of HQ AFSC directed ASD to develop a "Generic TEMS". The Generic TEMS is to be general in nature and applicable to any type of turbine engine. The objectives of Generic TEMS are to obtain maximum standardization among various TEMS, eliminate TEMS proliferation, and support OCM. Generic TEMS is primarily conceptual in nature and emphasizes the development of standardized information and hardware interfaces rather than "black boxes". Additionally, validated technology base programs are being applied to define and develop TEMS support equipment, avionics, and diagnostic techniques which will be responsive to the engine maintenance/management system and management information system requirements (10).

Summary

Early TEMS efforts concentrated on developing measures of engine reliability and performance. Operational and developing TEMS have demonstrated the feasibility of engine monitoring techniques, but the cost effectiveness of an automated TEMS has not been conclusively determined. Birkler and Nelson summed up the importance of TEMS in the following statement:

> . . . whether EDS passes or fails in the narrow sense of cost savings over the short term should not be the sole criterion on which it is judged. The potential benefits of anticipating needed maintenance, helping maintenance crews and engineering support personnel better understand engine failure cause and effect, and verifying that maintenance has been properly performed have substantial value. These benefits are especially significant now that the Air Force is moving toward an on-condition maintenance posture . . . [7:vi].

Chapter 3

EVALUATION OF PRESENT AND PROPOSED MANAGEMENT STRUCTURES FOR TEMS

PRESENT MANAGEMENT STRUCTURE

The present management structure for TEMS development, acquisition, and support is depicted in Figure 3. This depiction was formulated from the answers given by the interviewees to questions 4, 5, 9, 10, and 11 of the Structured Interview Guide (Appendix). A very general description of the roles and responsibilities of each agency as perceived by the respondents follows (9; 11; 17; 18; 21; 22; 26; 27; 29; 34; 35).

HQ USAF

Matters relating to TEMS are addressed by the Scientific Advisory Board; Directorate of Research, Development, and Production; and Directorate of Maintenance and Supply.

Scientific Advisory Board (SAB), Ad hoc Committee for TEMS. This committee is charged by HQ USAF to investigate the A-10 TEMS, F-100 EDS, and Generic TEMS programs to identify problem areas and to make suggestions/recommendations for program improvement. Final reports

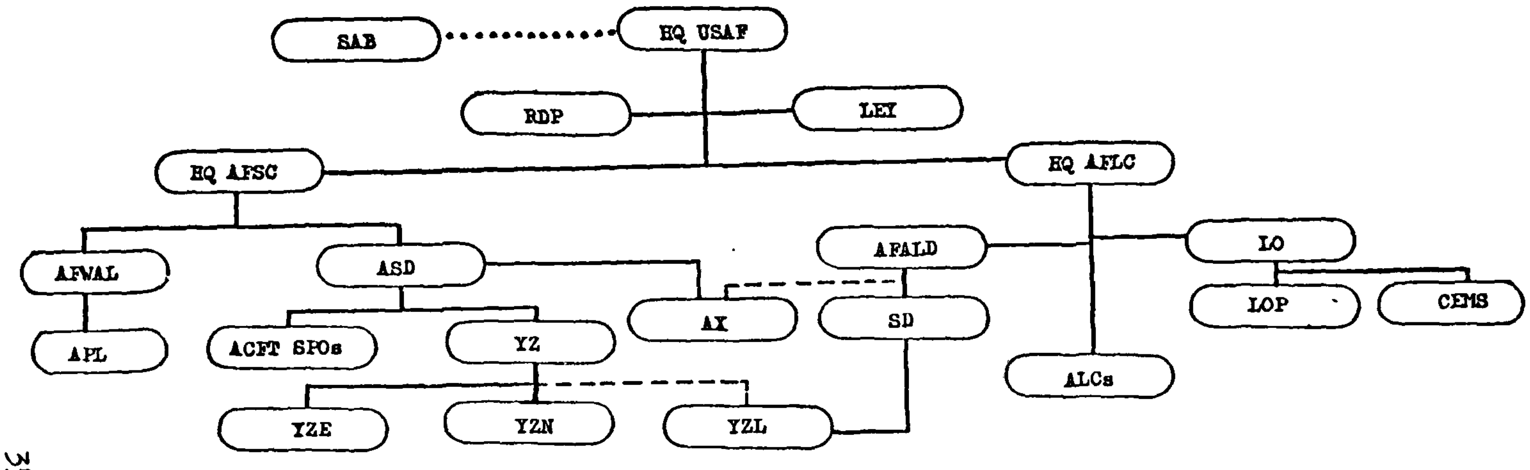


Figure 3

Present Management Structure for TEMS

Organizational Relationships

- ——— Formal, Hierarchical
- - - - - Matrix
- . . . . Advisory

from SAB meetings are given to HQ USAF, HQ AFSC, HQ AFLC, MAJCOMs, and others for information and appropriate action.

Directorate of Research, Development, and Production (RDP). RDP is responsible for formulating policy on the research, development, modification, support, and usage of gas turbine engines for aeronautical systems. RDP also coordinates this policy with related contracting, fiscal, engineering logistics support, and user functions within the Air Staff. Currently, this office is monitoring all TEMS related activities.

Directorate of Maintenance and Supply (LEY). LEY ensures that user commands' requirements for TEMS are articulated to Congress in order for funds to be appropriated. This office also coordinates Program Management Directives (PMDs) which provide program authorization and funds for implementation. Currently, LEY is monitoring all TEMS programs (A-10 TEMS, F-100 EDS, Generic TEMS) for logistics aspects of engine maintenance.

HQ Air Force Logistics Command (HQ AFLC)

HQ AFLC is responsible for supporting aircraft and aircraft weapons systems which are currently in operational use. Primary support responsibility occurs following Program Management Review Transfer (PMRT) from AFSC to AFLC.

San Antonio and Oklahoma City Air Logistics Centers (ALCs). These ALCs are responsible for determination and implementation of inventory and pipeline requirements for all engines/engine components Air Force-wide. They are also responsible for engine depot maintenance and modification programs for engines which have completed PMRT. San Antonio ALC was the location of key personnel involved in the A-10 TEMS test project. Key personnel included the test director, contracting officer, and engineering technicians.

Logistics Operations (LO). This office is responsible for all logistical operations for AFLC. Their primary responsibility is to ensure support of operational aeronautical systems following PMRT.

Logistics Operations Propulsion (LOP). LOP's responsibilities are to define and convey AFLC's supportability goals and objectives to all agencies involved in engine development and acquisition; to prescribe, monitor, review, and provide guidance on the logistics support management of engines in all phases of development; and to determine user and AFLC engine management information requirements. LOP is also responsible for the articulation and implementation of the OCM concept. As such, LOP is attempting to develop diagnostic tools to support the OCM concept. LOP is managing the A-10 TEMS program and using this program to demonstrate and test the TEMS concept in an operational environment. The A-10 TEMS test program was conducted at Myrtle Beach AFB, SC, with San Antonio ALC providing the contracting officer, engineering support, and program test director.

Logistics Operations CEMS (LO CEMS). LO CEMS' responsibility is to build a management information system which will integrate engine data acquisition and processing. This is intended to provide more meaningful information to engine managers which will allow them to make proper logistics decisions concerning engine management and maintenance. LO CEMS is using information requirements generated by LOP to develop CEMS Increment IV. The A-10 TEMS Program is serving as the prototype for Increment IV.

HQ Air Force Systems Command (HQ AFSC)

AFSC is responsible for the development and acquisition of aircraft and aircraft weapons systems.

Aero Propulsion Lab (APL). The APL is responsible for developing a technology base for TEMS in that they are developing TEMS hardware and software capability. They are attempting to develop analytical tools for engine diagnostics. They have contracted for a study to develop turbine engine fault detection and isolation algorithms and for determination of engine management information requirements at all levels of engine management and maintenance. Another contracted study involves an analysis of management information system data flows and interfaces for TEMS. The APL also provides technical support to the A-10 TEMS program.

Aeronautical Systems Division (ASD). ASD is responsible for the development and acquisition of all aircraft and aircraft weapon systems for use by the U.S. Air Force.

Aircraft System Program Offices (SPOs). The aircraft SPOs are responsible for development, acquisition and initial support of specific aircraft and aircraft weapon systems. The primary responsibilities for SPO directors are to ensure system performance specifications are met, costs are kept to a minimum, and the system is provided to the user on schedule. The SPO Director should also be concerned with system supportability after delivery is made to the user.

Engine System Program Office (YZ). YZ is responsible for development, acquisition, and initial support of all engines used by the U.S. Air Force.

New Engines (YZN). YZN is responsible for the development, acquisition, and initial support of all new engines except for the F-107 and F-100 which have separate program offices. YZN is also the ASD focal point for all matters relating to TEMS. YZN is currently managing the F-100 EDS and Generic TEMS programs.

Directorate of Engineering and Test (YZE). YZE is responsible for the engineering requirements of the F-100 EDS and Generic TEMS. YZE also provides engineering support to the A-10 TEMS program.

Deputy for Avionics Control (AX). AX is a joint AFALD/ASD program office responsible to develop an Air Force avionics master plan and to provide the Air Force a focal point for the coordination and approval of the development, acquisition, maintenance and modification of all Air Force avionics and related support equipment. They are also tasked to control the proliferation of avionics control systems as much as possible (2:5).

Air Force Acquisition Logistics Division (AFALD)

AFALD is responsible for improving force readiness and reducing life cycle costs of Air Force weapon systems by challenging weapon systems requirements and assuring consideration of supportability, reliability, and maintainability during the design, development, and production phases of acquisition; and to direct acquisition programs which use already developed systems to meet operational needs (2:1).

Deputy for Aeronautical and Armament Programs (SD). AFALD/SD is responsible for providing the U.S. Air Force with planning and management needed for effective logistics support of new and major modified aircraft armament systems.

Directorate of Propulsion Logistics (YZL). AFALD/YZL is responsible for ensuring that maintainability and reliability considerations are included in development and acquisition phases prior to production of aircraft propulsion systems or subsystems. Consideration of logistical elements prior to production is intended to enhance the system's design for supportability, thereby lowering life cycle costs. YZL is currently providing logistical support inputs to the F-100 EDS and Generic TEMS programs and is also monitoring the A-10 TEMS program.

Major Commands (MAJCOMs)

MAJCOMs include SAC, TAC, MAC, and ATC. MAJCOMs are responsible for developing and reviewing TEMS requirements from a functional, rather than equipment, point of view. They also identify and develop command positions concerning operational needs and applications for TEMS.

Interrelationships and Lines of Communication

There are two major focal points for TEMS management within the Air Force: ASD/YZN and AFLC/LOP. Although several other agencies have a direct relationship with TEMS, only these two are focal points. Figure 4 depicts the various lines of communication to and from LOP and other related agencies. Similarly, Figure 5 depicts lines of communication to and from ASD/YZN and other related agencies. Lines of communication are lettered and explained in the accompanying legends.

MANAGEMENT PROBLEMS IDENTIFIED

The initial interviews conducted using the guide in the Appendix revealed numerous management problems as perceived by the respondents (9; 11; 17; 18; 21; 22; 26; 27; 29; 34; 35). To aid in analyzing these problems, they were compiled and divided into three major problem areas: (1) structure and role problems, (2) integration and information flow problems, and (3) leadership and command problems. These problems are listed in Tables 1 through 3, respectively. The problems that did not fit into one of these major areas were not classified and were analyzed separately as they related to the major problem areas.

Structure and Role Problems

Interview respondents identified structure and role problems which were classified into two major areas: (1) the fragmentation of TEMS management throughout the

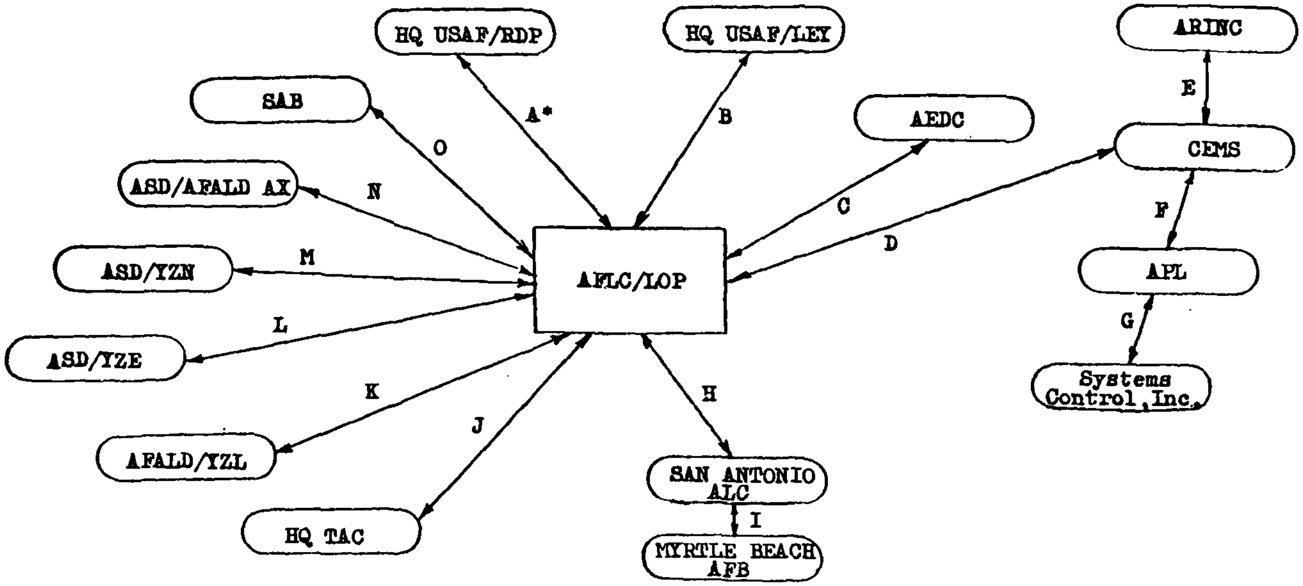


Figure 4

Lines of Communication To and From AFLC/LOP

*See Legend for Figure 4.

LEGEND FOR FIGURE 4

A RDP monitors A-10 TEMS program development but has no direct involvement.

B LEY coordinates with Congress for the A-10 TEMS program authorization and funds appropriation (PMD). LEY also monitors the A-10 TEMS program for logistics aspects of engine maintenance.

C AEDC developed the A-10/TF34 TEMS maintenance handbook. They also did gas path analysis studies.

D AFLC/LOP determines engine management information requirements and furnishes this to CEMS. CEMS is using information requirements generated by LOP to assist in the development of CEMS Increment IV. CEMS is using A-10 TEMS as a prototype for Increment IV.

E LO CEMS has a contract with ARINC concerning the requirements for CEMS Increment IV.

F Aero Propulsion Lab has furnished information concerning Maintenance Information Management System (MIMS) interface and data flows. Also, developed software algorithms.

G Systems Control, Inc. (SCI) was under contract for turbine engine fault detection and isolation algorithms. Also, SCI analyzed the engine information requirements for the various engine management and maintenance levels.

H San Antonio ALC was supporting the A-10 TEMS program test. The program test director, contracting officer, and engineering support were located there.

I Myrtle Beach AFB was the field location for the A-10 TEMS program test. A-10 aircraft and personnel assigned to Myrtle Beach AFB participated in the program test.

J HQ TAC provides inputs to LOP as to TEMS requirements and applications for the A-10 aircraft.

K YZL monitors the A-10 TEMS program for logistical considerations. YZL currently has no other direct relationship with LOP.

L ASD/YZE has provided engineering software support, and data reduction for the A-10 TEMS program.

M LOP inputs AFLC requirements for F-100 EDS and Generic TEMS programs. YZN and LOP share lessons learned and program developments on an informal basis.

N AX monitors A-10 TEMS program to ensure avionics standardization.

O The SAB periodically reviews the A-10 TEMS program. They make suggestions and recommendations for program improvement.

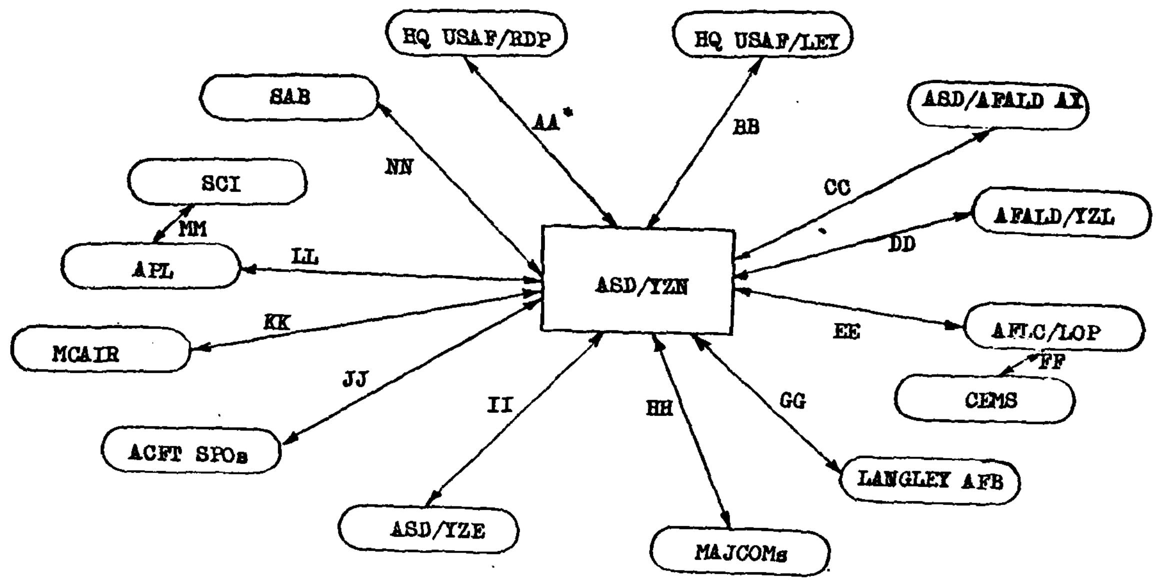


Figure 5

Lines of Communication To and From ASD/YZN

*See Legend for Figure 5.

LEGEND FOR FIGURE 5

AA HQ USAF/RDP monitors all TEMS programs including F-100 EDS and Generic TEMS.

BB HQ USAF/LEY monitors F-100 EDS and Generic TEMS programs for logistical aspects of engine maintenance. LEY also coordinates TEMS user requirements with Congress to receive PMDs.

CC AX monitors the F-100 EDS and Generic TEMS programs to ensure standardization of avionics.

DD YZL ensures that logistics elements are considered for F-100 EDS and Generic TEMS programs.

EE LOP provides inputs to YZN concerning TEMS requirements for new engines. LOP and YZN also have an informal sharing of lessons learned and program development.

FF AFLC/LOP determines engine management information requirements and provides this to CEMS. CEMS uses these requirements to assist in developing CEMS Increment IV. CEMS is using the A-10 TEMS program as a prototype for CEMS Increment IV.

GG Langley AFB, VA is the location of the F-100 EDS operational test program using F-15 aircraft and TAC maintenance personnel.

HH HQ TAC provides inputs to YZN concerning requirements and application of the F-100 EDS. All MAJCOMs provide inputs to YZN concerning requirements and applications for the Generic TEMS.

II YZE provides engineering support to YZN for F-100 EDS and Generic TEMS programs.

JJ All aircraft SPOs direct engine health monitoring/diagnostic matters to YZN.

KK MCAIR is the primary contractor for the F-100 EDS program.

LL The Aero Propulsion Lab is providing research and development efforts to develop fault detection and isolation algorithms for turbine engines. They are also engaged in diagnostic research and development for the F-101 engine which may have an application for the Generic TEMS program.

MM SCI was contracted to develop fault detection and isolation algorithms for turbine engines. SCI also analyzed engine information requirements for the various management and maintenance levels.

NN The SAB periodically reviews the F-100 EDS and Generic TEMS programs. They make suggestions and recommendations for program improvements.

Table 1

STRUCTURE AND ROLE PROBLEMS

Fragmentation

1. No management structure for TEMS development.

2. TEMS management structure fragmented throughout the Air Force.

3. TEMS has no development home.

4. Lack of focal point for TEMS at each level of command.

5. Management too decentralized.

6. Management too diversified.

7. Duplication of effort.

Reversal of Roles

1. AFLC is in development business.

2. AFLC not geared for basic development.

3. AFLC management of A-10 program is a quirk in the system.

4. AFLC does not have adequate engineering support and must rely on contractor integrity.

5. AFLC/LOP is physically separated from most of its support levels.

6. Need more involvement from ALC engine management personnel.

7. A-10 program being managed from HQs level.

8. AFLC must get development funds through AFSC.

Table 2

INTEGRATION AND INFORMATION FLOW PROBLEMS

Competition

1. Organizations looking and fighting for money to finance their own TEMS programs.

2. Competing for recognition and dollars.

3. Unhealthy competition between AFLC and ASD.

4. Competition and politics involved.

Crossfeed

1. No feedback for lessons learned. No crossfeed.

2. Agencies involved are not aware of what is going on in other agencies.

3. ALD representatives in YZN are not being adequately informed about the A-10 program.

4. CEMS relates to ASD through LOP. No direct coordination.

5. Need better coordination between LOP and YZN.

Interface

1. Failure to look at overall system. Every organization working on its own problems and looking at own piece of the pie.

2. No integration/standardization between TEMS programs.

3. Need better organizational interface.

4. ALD still learning interface job, and needs to do a better job of coordination and integration.

5. ALD needs to be more involved at all management levels.

6. Good cooperation, but clumsy and hard to manage.

7. AFLC, ASD, and users need to work together better.

Table 3

LEADERSHIP AND COMMAND PROBLEMS

Direction and Guidance

1. No central guidance for the various agencies involved in TEMS development.

2. Lack of directives to force integration and coordination between agencies involved in TEMS.

3. Lack of direction for TEMS development authority (focal point).

4. Lack of timely and adequate guidance from Air Staff.

5. Lack of master development process.

6. Lack of clarity in management and maintenance concept proposed or purported by AFLC for TEMS use.

Support

1. Lack of upper management support at AFSC, ASD, and YZ to extent necessary to provide worthwhile program and funds necessary.

2. Lack of immediate support of development programs at Air Staff level.

3. Lack of support at AFLC except for A-10 program.

4. Low priority for funding and manpower for TEMS development.

Air Force, and (2) the reversal of normal, assigned roles by those involved in TEMS development. (See Table 1 on page 47).

The problem of fragmentation was viewed and expressed in several different ways. The respondents indicated that the management structure for TEMS development was somewhere between non-existent and too diversified or decentralized. As was shown in the basic structure, numerous agencies are involved with TEMS development. Although ASD/YZN and AFLC/LOP were identified as the two central agencies in TEMS development, TEMS management was seen as fragmented or spread between many other Air Force organizations.

Closely related to the fragmentation problem was the problem of reversed and unclear roles. Much of the fragmentation appeared to be caused by the lack of clarity for authority and specific roles for TEMS development. Each organization was autonomous to some extent and to some degree determined its own role in TEMS development. As brought out in the interviews, the most obvious example of the role change is AFLC's involvement in TEMS development. With AFLC assuming a development role which is normally assigned to AFSC, several other problems were encountered. The interviews indicated that AFLC is not suited or tasked for basic development and lacks adequate engineering support. Therefore, AFLC has had to depend on contractors and ASD for A-10 TEMS engineering support. However, for ASD to provide support, funds must be budgeted for use in this capacity. Also, funds for any development undertaken by AFLC must be provided by AFSC since no development funds can be legally budgeted for AFLC. In addition to these problems, AFLC/LOP is an headquarters level organization managing the A-10 program and is physically separated from most of the support levels within AFLC such as the ALCs. Normally, headquarters set policies, and the divisions such as ALC run the programs.

This fragmentation of the management structure and reversal of roles among organizations has led to duplication of effort and no central agency to coordinate TEMS development and monitor all the various TEMS efforts and related activities. Therefore, good communication, cooperation, coordination, and integration between these agencies are required.

Integration and Information Flow Problems

Integration and information flow among the various parts of a decentralized organization is critical to effective and efficient operations. TEMS development for the Air Force is faced with a number of problems in this critical area. The problems revealed in the interviews were grouped into three sets: (1) competition between agencies, (2) lack of information crossfeed between agencies, and (3) lack of integration and interface between agencies involved in TEMS development. (See Table 2 on page 48).

The competition problem was viewed as being very subtle and below the surface. This problem was not readily apparent to the interviewers but was apparent to those involved with TEMS. The underlying cause went back to the fragmentation and role conflicts of the agencies involved. TEMS development requires manpower and money, both of which are limited resources. The competition between AFLC and ASD was also influenced by AFLC's immediate need for a tool to provide better support for OCM whereas ASD is more concerned with performance and cost. This immediate need led AFLC to undertake the A-10 program. The underlying competition between AFLC and AFSC for money, manpower, and recognition for their programs has contributed to a lack of information flow and integration between agencies involved in TEMS development.

The limited information flow between agencies was reflected by the set of problems listed under crossfeed. The most prevalent area of concern voiced was the lack of crossfeed and information flow between CEMS and YZN. In general, most of the information flow between any of the agencies was very informal, and many of the agencies felt they lacked adequate knowledge about the activities, progress, successes, and failures of other agencies involved in TEMS development.

The final set of integration problems was classified under Interface. There were several aspects to these interface problems. One was a failure of the agencies working on TEMS development to look at the overall system. Each agency had a tendency to concentrate on its own problems and not worry about integrating with the other agencies and their problems. The result has been no integration and standardization among TEMS programs due to this lack of organizational interfacing. Although most of the respondents felt that genuine efforts for cooperation were put forth, this cooperation was clumsy and hard to manage.

The other aspect of the interface problem concerned the role of AFALD. Some respondents indicated that as ALD representatives in ASD become more experienced in their interface role, coordination, communication, and integration between AFLC and ASD would improve. These respondents also felt that ALD needed to be more involved in TEMS integration at higher management levels.

Leadership and Command Problems

The leadership and command problems identified were divided into two areas: (1) lack of adequate direction or guidance, and (2) lack of adequate support for TEMS development. (See Table 3 on page 50).

The interviewees perceived a lack of direction and guidance in several areas of TEMS development. First, the various agencies involved were not provided central guidance as to the goal of TEMS development as it relates to each of the agencies. The second area lacking was directives for integration, coordination, and a focal point or authority for TEMS development. Guidance in this area was seen as needed in order to provide clear definitions of roles to reduce role conflict and ambiguity. Although Air Staff monitored the TEMS programs, it had very little direct involvement and provided very little written direction. Another problem was the lack of a master development process for TEMS. In addition, before direction for TEMS development could be given, the problem of each agency not clearly understanding the management and maintenance concepts for which TEMS is a tool should be resolved.

The lack of support problem seemed to be pointed mostly at upper level managers at AFSC, ASD, and YZ, who were not convinced that TEMS is a necessary tool for OCM or that it will reduce the high cost of engine support. Although interest in TEMS was apparent at Air Staff, interviewees felt that no immediate support for development programs was available in order to ensure necessary funding. Some respondents also perceived a lack of support in AFLC except for the A-10 program. However, to the interviewers, AFLC seemed to be the biggest advocate of TEMS development for all new aircraft engines. As a result of this lack of support, TEMS suffers from a low priority for funding and manpower.

Other Problems

The remaining problems that appeared significant were grouped into three areas: (1) Personnel, (2) Continuity, and (3) Incentives. These problems are listed in Table 4.

PROPOSED STRUCTURES

The structured interview guide (Appendix) elicited suggestions for overcoming the TEMS management problems perceived by each respondent. Several ideas for improvement of the organizational structure and roles for Air Force management of TEMS were recommended. Based on the problem analysis and the suggested structure and role

Table 4

OTHER PROBLEMS

Personnel

1. Lack of experienced personnel in diagnostics.

2. Lack of nucleus of personnel from systems development standpoint.

3. Lack of overall expertise in diagnostics.

4. Lack of electronics engineers in YZ.

5. Organizations involved have limited manpower, time, and money to learn or teach technology.

Continuity

1. Lack of continuity and stability in personnel expertise and assignments.

2. Lack of consistency in support for TEMS.

3. Lack of focal point for TEMS across each level of management in each organization.

4. Degree, dedication, and stability for TEMS development in each organization is different.

5. More than one "pusher" and expert needed in each organization.

Incentives

1. Incentive low for SPO Director to consider TEMS for new aircraft.

2. Lack of emphasis from command levels to push SPOs to use proven parts of TEMS technology.

3. SPOs are evaluated on cost, schedule, and performance for which TEMS could be a liability.

changes, four proposals were formulated with each proposal including three key elements: (1) an organizational structure, (2) an assignment of roles for key agencies, and (3) lines of interorganizational communication.

Another set of interviews were conducted to solicit comments concerning the advantages and disadvantages of each proposal. A brief description of each proposal and the advantages and disadvantages identified by the respondents follows (10; 13; 17; 18; 19; 22; 25; 27; 29; 35).

Proposal 1

Proposal 1 essentially left the existing management structure unchanged while allowing AFLC/LOP to continue with the A-10 TEMS Program to completion. This proposal would also designate YZN as the single Air Force focal point for all TEMS development and acquisition programs except the A-10/TF34 TEMS. This proposal is depicted in Figures 6A and 6B.

The major advantage identified in this proposal was that a single focal point for all TEMS development would be established after the A-10 program is completed. Another advantage recognized was the possible benefits that could be derived from the testing and proliferation of two different approaches to TEMS development. In some cases competition could lead to greater efficiency and a

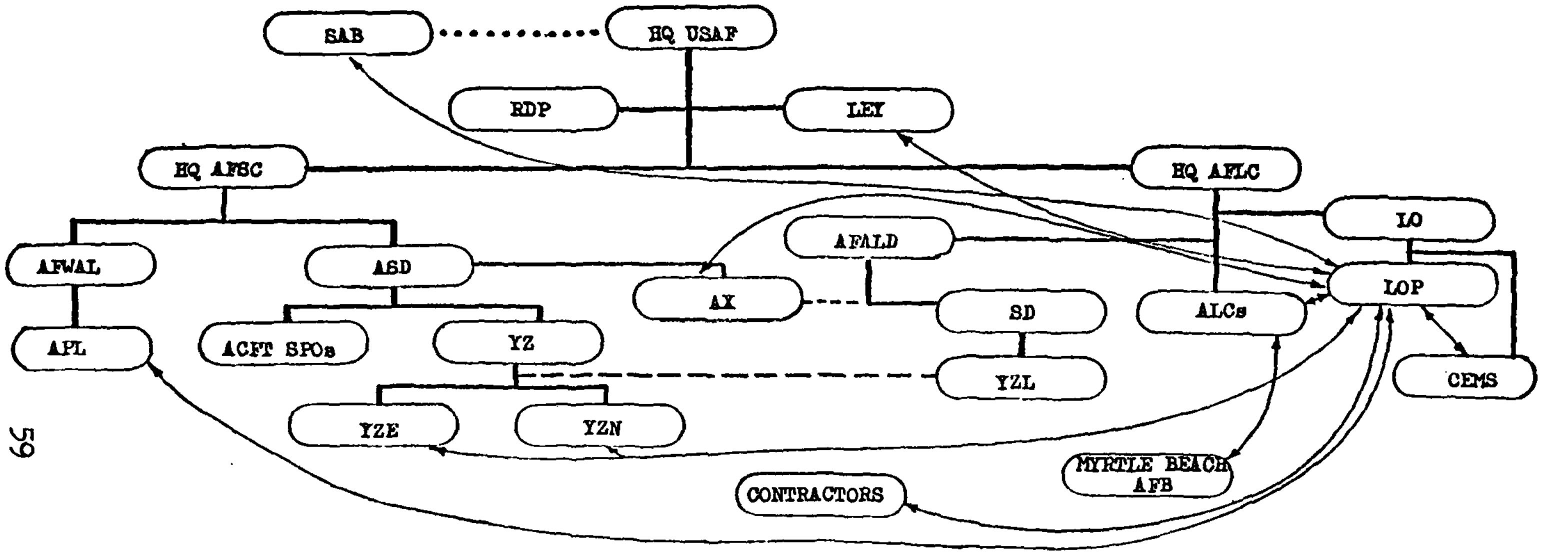


Figure 6A

Proposal 1, Part A--A-10/TF34 TEMS

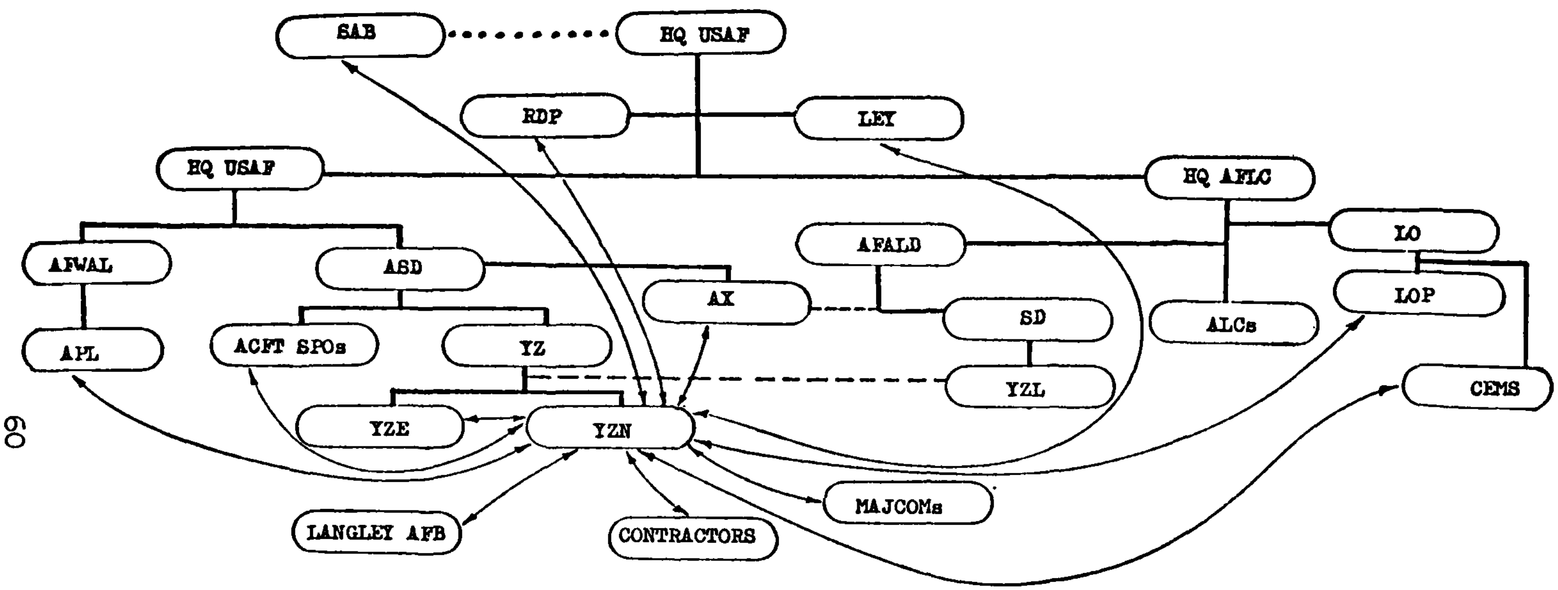


Figure 6B

Proposal 1, Part B--All TEMS Except A-10/TF34 TEMS

Organizational Relationships

—— Formal, Hierarchical
----- Matrix
..... Advisory
↔ Lines of Communication

better system if information concerning successes, failures, and lessons learned is shared. Stagnation of ideas may be avoided and new ideas encouraged.

Several disadvantages for this proposal were pointed out by the interview respondents. Prior to completion of the A-10 program, the organizational structure, role, and interface problems identified in the present management structure would not be resolved. AFLC would remain in development for the A-10 TEMS and would still be competing with ASD for recognition and limited funds. Several other problems relating to AFLC acting in a development role would likely continue. Fragmentation and duplication of effort would be encouraged. The feedback and crossfeed problems for information and lessons learned would not be solved. In addition, the perceived lack of support at upper management levels of AFSC, ASD, and YZ could hamper the TEMS effort within YZN. Manpower was already critical and any further reductions could have a devastating effect on TEMS development and application.

Proposal 2

The existing management structure remained unchanged for Proposal 2, and LOP was allowed to continue to manage A-10 TEMS development. Proposal 2 differed from Proposal 1 in that YZN was designated as the focal point for TEMS development for all new engines that had not completed PMRT. LOP was designated as the focal point for development of TEMS after the engine had been transferred to AFLC. This proposal is depicted in Figures 7A and 7B.

Some respondents indicated that a possible advantage of Proposal 2 would be more priority, support, and responsiveness to the TEMS needs for older engines. This opinion was based on the perception that, for older engines, ASD/YZN would have lower priority and support of TEMS than would AFLC/LOP.

In addition to the competition and integration problems discussed earlier, several disadvantages were identified. The most significant problem in the eyes of the respondents was that AFLC would remain in the development arena. Also, if this proposal was implemented, the ALCs, rather than LOP, were recognized as being more capable of acting as a development focal point for old engines. However, ASD was seen as the agency with the expertise and assigned role to develop new systems. The shortage of engineers Air Force-wide was identified as another disadvantage which further endorsed the case for ASD with its locus of engineers to remain as the single focal point. The concept of two developers also defeats the concept of generic TEMS.

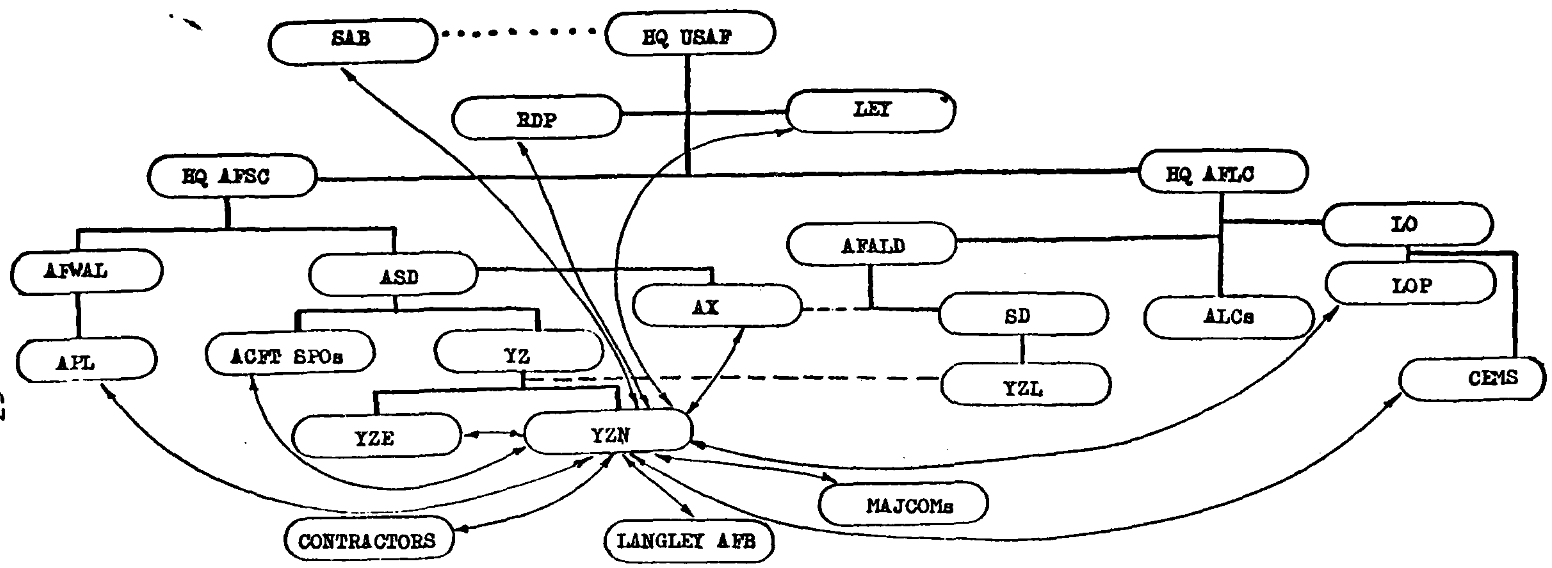


Figure 7A

Proposal 2, Part A—TEMS Development for Engines Prior to PMRT

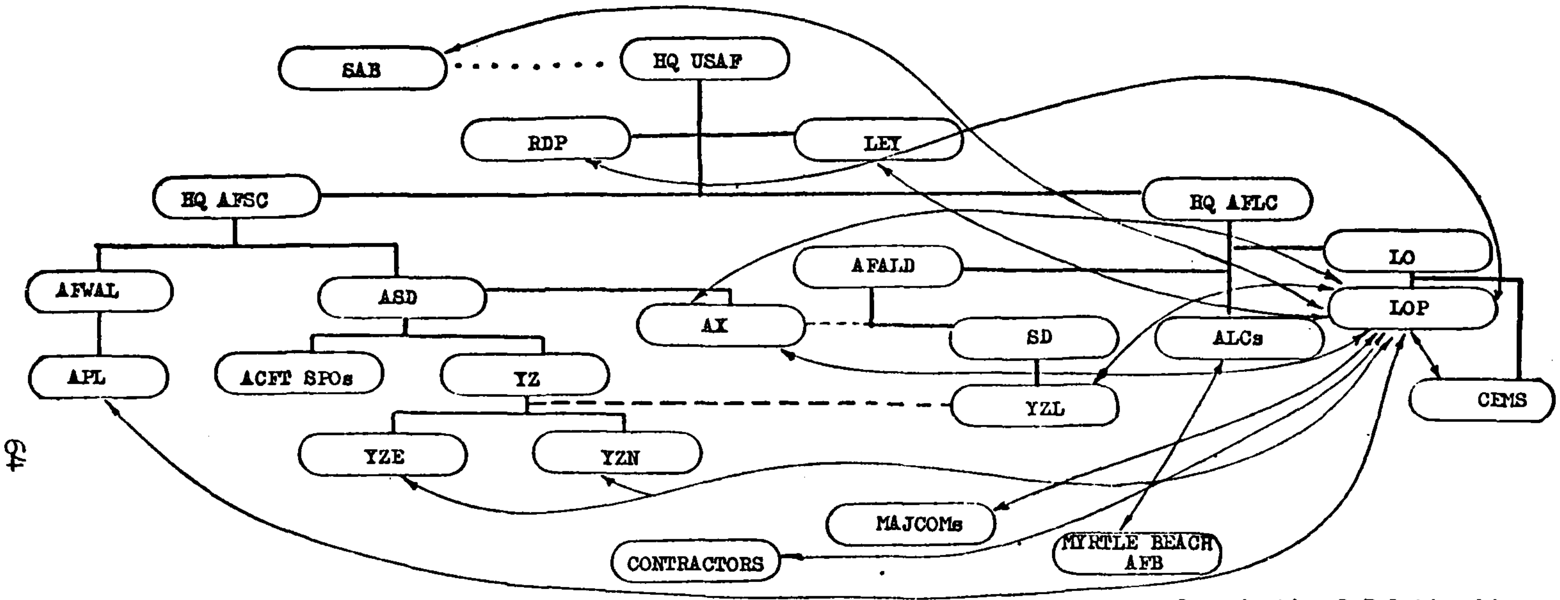


Figure 7B

Proposal 2, Part B—TEMS Development for Engines After PMRT

Organizational Relationships

——— Formal, Hierarchical
- - - - - Matrix
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⟷ Lines of Communication

Proposal 3

This proposal would establish a new office under ASD/YZ which would be responsible for all TEMS development and acquisition matters Air Force-wide including the A-10 TEMS program. This office would not be a subunit of YZN but would report directly to YZ. The remainder of the management structure would be the same as that for Proposals 1 and 2. Lines of communication would be as indicated in Figure 8. It is recognized that a great deal of interorganizational communication would go through formal, hierarchical channels. For purposes of simplicity, lines of communication have been purposely drawn between ultimate sender and receiver agencies.

Respondents identified several probable advantages and disadvantages associated with management of TEMS under Proposal 3. Advantages cited were that this proposal would:

1. Facilitate definition and clarification of Air Force requirements and goals for TEMS.

2. Provide centralized planning, programming, budgeting, coordination, control, and policy making for all TEMS development and acquisition.

3. Provide better interorganizational communication.

4. Establish TEMS priorities to resolve conflicts created by differing suborganizational goals.

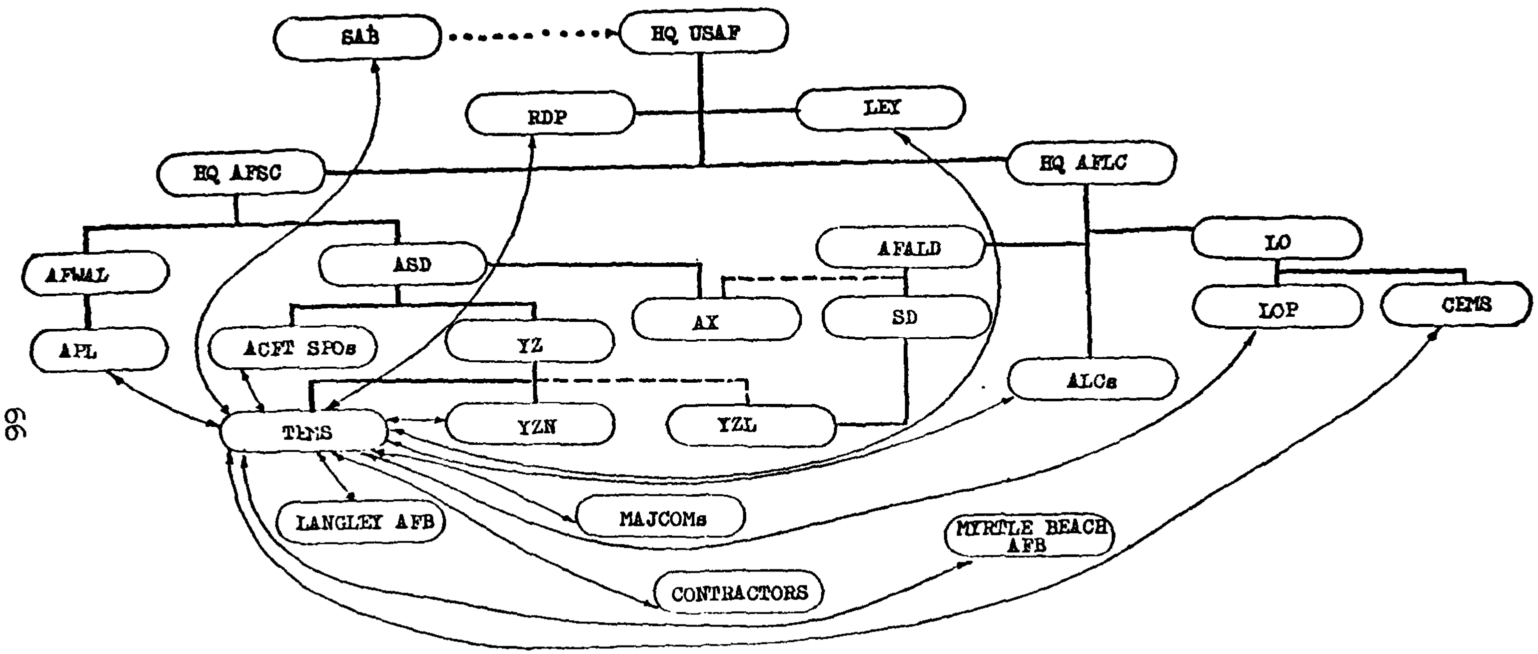


Figure 8

Proposal 3--YZ/TEMS

Organizational Relationships

——— Formal, Hierarchical
- - - - Matrix
. . . . Advisory
↝ Lines of Communication

5. Provide a systematic approach to TEMS management problems rather than allowing a piecemeal approach. This could enhance system interfaces.

6. Control TEMS hardware and software proliferation by ensuring standardization where practical.

7. Provide a single point of contact for MAJCOMs, sister services, allies, contractors, etc. This would enhance the application of lessons learned.

8. Provide added emphasis and concentration of effort (specialization) on TEMS by separating YZ/TEMS from YZN.

9. Permit greater TEMS program visibility at the Air Staff and Congressional levels to facilitate funds appropriation.

10. Probably result in lower total dollar costs than otherwise.

Respondents suggested that management of TEMS under Proposal 3 would have the following disadvantages:

1. The YZ/TEMS organizational concept may be too narrow to warrant a separate office dedicated only to TEMS.

2. The present priority placed on TEMS by ASD may not be high enough to justify a separate office.

3. Resources used for TEMS will decrease resources available for other programs.

4. Since ASD's primary concern is not supportability, YZ/TEMS may lack an appreciation as to AFLC and user needs and requirements for TEMS. This may be particularly true for older engines (engines after PMRT).

5. Absorption of the A-10 TEMS program by YZ/TEMS may cause behavioral problems for AFLC personnel involved with the A-10 TEMS program.

6. Benefits gained by competition between the A-10 TEMS and F-100 EDS programs would be lost.

7. Centralization of TEMS efforts may repress fresh ideas concerning TEMS. Good ideas may be rejected or changed to conform to YZ/TEMS thinking.

8. No well-defined relationship exists to clarify responsibilities, authority, and procedures to interface TEMS and CEMS.

Proposal 4

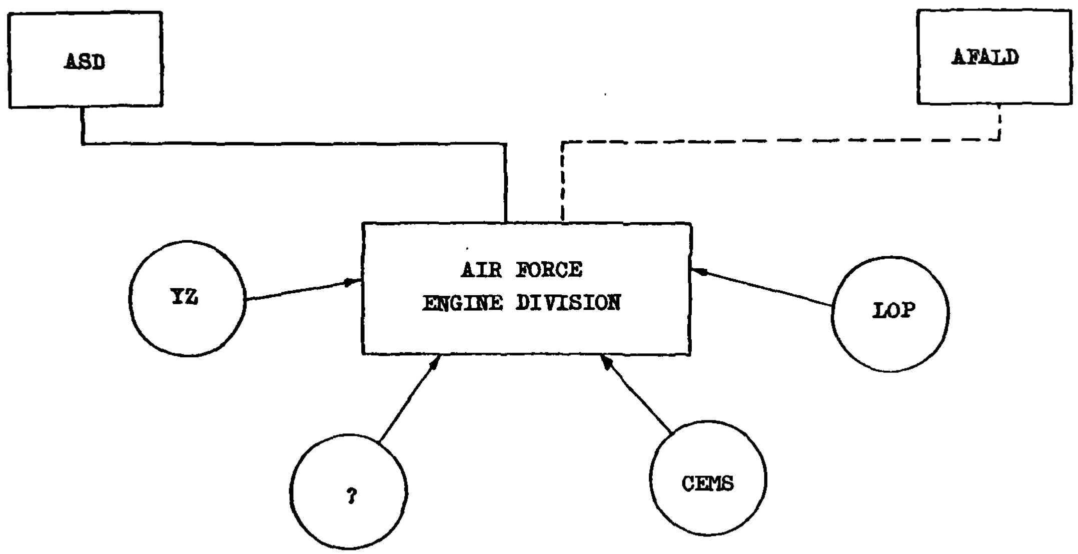
This proposal would establish a joint AFALD/ASD Engine Division which would handle all matters relating to engines (including TEMS). This new organization would be composed of all the YZ offices, CEMS, LOP, and ALC representation, as well as other pertinent agencies. This proposal is depicted in Figure 9. The formal organizational relationship would be to ASD with matrix relationship to AFALD. Lines of communication are not depicted since all necessary agencies would be consolidated into one organization.

Respondents suggested that management of TEMS under Proposal 4 would have the following advantages:

1. This concept would consolidate all engine related activities within one organization. This would permit cradle-to-grave management for all engines and probably reduce engine life cycle costs.

2. This concept would facilitate a more effective integration of engine supportability considerations into engine system development and acquisition. Long range engine supportability would receive a comparable status with performance, schedule, and cost criteria since the same organization would develop, acquire, and support engines. Therefore, built-in supportability features would be enhanced.

3. This may be an effective way to integrate OCM, TEMS, and CEMS.



Organizational Relationships

—— Formal
---- Matrix

Figure 9

Proposal 4—Air Force Engine Division

Respondents also suggested that Proposal 4 would have the following disadvantages:

1. This concept would view the engine subsystem as a system in itself. The engine subsystem may then exert an excessive influence on the total aircraft system design, thereby decreasing total system effectiveness.

2. ASD/EN is not considered in this proposal.

3. The entire propulsion system needs to be included rather than only the engine and its components.

4. Cost and behavioral problems would result from extensive reorganization.

SUMMARY OF ANALYSIS

This thesis had two hypotheses: (1) the present management structure for TEMS development and implementation is inadequate to meet the needs of the Air Force, and (2) a single manager concept for TEMS would be the most beneficial approach to the overall management of Air Force engine monitoring systems. Each hypothesis will be addressed separately.

Hypothesis 1

Analysis of respondents' comments from the Structured Interview Guide revealed that a highly developed organizational management structure already exists. This structure, however, was not designed specifically for the purpose of managing TEMS because TEMS is a relatively small part of a much larger system. Respondents pointed out that, although a management structure is present, many problems exist for the development of TEMS. These problems were listed in Table 1, 2, 3, and 4. A closer examination of respondent comments led to the identification of the most important problems.

1. Key organizations (AFLC and ASD) have different perceived needs. AFLC needs to find a solution to the ever increasing cost of supporting operational systems. While engines are becoming more and more complex and expensive to support, personnel experience and ability to support these systems are decreasing. AFLC views TEMS as a possible solution to these problems because advocates claim that TEMS can increase operational capability using less experienced maintenance personnel with lower total support cost. ASD, on the other hand, needs to produce systems which meet performance specifications, at a minimum cost, and on schedule. TEMS does not improve performance because it adds weight, takes up space, and adds more complexity to the system. TEMS is expensive to develop and acquire which adds to the total cost of the system. Inclusion of TEMS also decreases the probability that the system will be developed and acquired on schedule. Although System Program Directors are required to consider system logistical support, it is not apparent that supportability is given equal priority with performance, cost, and schedule

criteria. TEMS, therefore, is not perceived as a critical need by ASD.

2. AFLC is trying to develop diagnostic tools to more effectively deal with engine supportability needs. In an attempt to satisfy these needs, AFLC has become the chief Air Force advocate for the development and acquisition of TEMS even though their assigned mission does not include systems development and acquisition. Respondents from AFLC, ASD, and elsewhere indicated that AFLC has this role because ASD has not given TEMS the support and priority that AFLC desires. Neither HQ USAF nor HQ AFSC has given strong support for TEMS. Due to a lack of support from HQ USAF, HQ AFSC, and ASD, Air Force priority is relatively low for development and acquisition of TEMS.

3. HQ USAF has failed to provide formal (written) policy or guidance which establishes clear lines of authority, responsibility, and accountability for TEMS management. Therefore, suborganizational role ambiguity and role conflict has evolved, particularly between AFLC and ASD. This lack of leadership from HQ USAF has encouraged TEMS management to be operated on a fragmented basis rather than being treated as an integrated whole. As such, there is no comprehensive Air Force strategy for TEMS management. Additionally, there is a general

inability to effectively communicate among suborganizations with different roles.

4. The relationships and interfaces between various suborganizations are complex, particularly concerning OCM, TEMS, and CEMS. Although this complexity is a major problem, there appears to be no structural design or policy guidance which will force the integration of these interfaces.

Although there are major problems associated with the present management of TEMS, as indicated above, significant improvements could be made through the existing organizational structure if HQ USAF would take a more active leadership role in defining policy, providing guidance, and clarifying roles for AFSC, ASD, and AFLC in the development and acquisition of TEMS. Weaknesses in the management of TEMS was primarily due to lack of support and priority. The organizational structure appears to be flexible enough to accommodate TEMS development if adequate support and priority is given by HQ USAF, HQ AFSC, ASD, and AFALD. The organizational structure can be improved upon if TEMS receives appropriate support and priority. Without it, however, there is little to be gained by changing the organizational structure. Although the present management structure could be improved, the analysis shows that the structure is adequate to meet Air Force needs for TEMS development and acquisition. Therefore, Hypothesis 1 is rejected.

Hypothesis 2

Respondents commenting in the Structured Interview were nearly unanimous in the opinion that a single organization should be tasked for the overall management of TEMS development and acquisition. Some respondents pointed out that single management of TEMS would risk sacrificing different approaches which may have yielded fresh ideas. They also pointed out that competition between the A-10 TEMS and F-100 EDS programs was having some positive influence on both programs in terms of efficiency and sharing of lessons learned in two separate programs.

The advantages of a single organization to manage TEMS which were mentioned most often included: (1) designation of a single focal point for all organizations to coordinate with, get directions from, or address questions to; (2) goal clarification from a single source; and (3) centralized management for integrated planning, programming, budgeting, and control of TEMS. These improvements were perceived to effect the following changes: more effective and efficient utilization of resources; better coordination of effort by reducing role ambiguity and duplication; improved interorganizational communication; improved interface effectiveness due to leadership, guidance and communication; elimination of A-10 TEMS/F-100 EDS program conflicts; and increased assurance of TEMS hardware/software standardization. For these reasons Hypothesis 2 was accepted.

Chapter 4

CONCLUSIONS AND RECOMMENDATIONS

KEY ISSUES AND CONSIDERATIONS

During the course of the interviews three recurring issues appeared to have a significant bearing on respondents' concepts of an appropriate management structure for TEMS. These issues were: (1) respondents' perception of OCM; (2) cost effectiveness of TEMS; and (3) proper relationships between OCM, TEMS, and CEMS. Conflicting views on these issues may be the crux of the TEMS management problem. An additional consideration for standardization is TEMS avionics classification.

Perceptions of OCM

AFR 66-14 defines OCM as:

> . . . the application of inspection and testing procedures and techniques without removal or disassembly that allows the condition of equipment to dictate the need for maintenance or the extent of repair required to restore serviceability [14:2].

This definition is rather broad and is subject to widely differing interpretations. For instance, most respondents said that it is extremely difficult to practice OCM without some kind of TEMS. Other respondents indicated that the Air Force has been practicing OCM for years in the form of the Oil Analysis Program (OAP), Non-Destructive Inspection (NDI), and borescope. It appears that both viewpoints have valid arguments depending upon the interpretation of OCM.

Most respondents agreed that the OCM concept is not an either/or proposition but rather a continuum of various degrees of OCM implementation ranging from low to high. Figure 10 depicts this description. According to the definition in AFR 66-14, techniques such as OAP, NDI, and borescope qualify as OCM tools. This position was not questioned by any respondent. However, the consensus of opinion suggested that the techniques were only a first step in OCM implementation and that a more extensive application of OCM would require the utilization of a more sophisticated technique, such as TEMS.

Extent of OCM

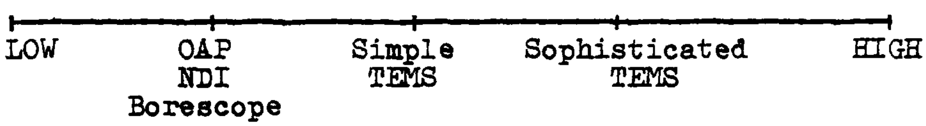


Figure 10

OCM Continuum

OAP, NDI, and borescope are shown to lie on the lower end of the OCM Continuum while a simple, relatively unsophisticated TEMS would lie somewhat further to the right. A more sophisticated TEMS would lie still further toward the "HIGH" end of the continuum.

The primary issue is, to what extent does the Air Force intend to implement OCM? Without this clarification, suborganizations involved with OCM will determine the extent of OCM which best fits their own needs and desires without adequate consideration of other suborganizations' views. This will necessarily result in a lack of goal congruence and breakdown in effective communication concerning the nature and requirements of OCM.

If OCM concept implementation is to expand, it is apparent that more advanced techniques, such as TEMS, must be applied. However, HQ USAF has not clearly communicated the Air Force's position on this issue.

Cost Effectiveness of TEMS

Past TEMS programs such as the T-38 EHMS and C-5 MADARS, failed to demonstrate the cost effectiveness of the TEMS concept. Although current TEMS programs, such as A-10 TEMS and F-100 EDS, have not been fully analyzed, they also have not clearly demonstrated TEMS cost effectiveness. As the current programs continue to supply operational test experience, a cost effectiveness determination should be forthcoming.

Four variables should be considered in the development, testing and evaluation of TEMS. These variables are: (11; 17; 20; 26; 33)

1. TEMS hardware/software complexity,
2. engine sophistication,
3. engine maturity, and
4. the mission environment.

As TEMS increases in sophistication and complexity, it becomes more costly to develop, acquire, and maintain related hardware and software. However, an increase in TEMS sophistication creates a greater capability to provide needed engine health information (see Figure 11). A tradeoff exists between the cost of TEMS and the value of the information it provides. How much TEMS sophistication is enough? The answer to the question is not readily apparent because there is a great degree of uncertainty as to the actual value of information provided by TEMS. Figure 12 illustrates a conceptual relationship between TEMS sophistication and the value of TEMS-generated information. As TEMS sophistication increases, the value of TEMS information increases up to point B. After B, the value of information decreases due to information overload. Russell L. Ackoff gave the following description of information overload:

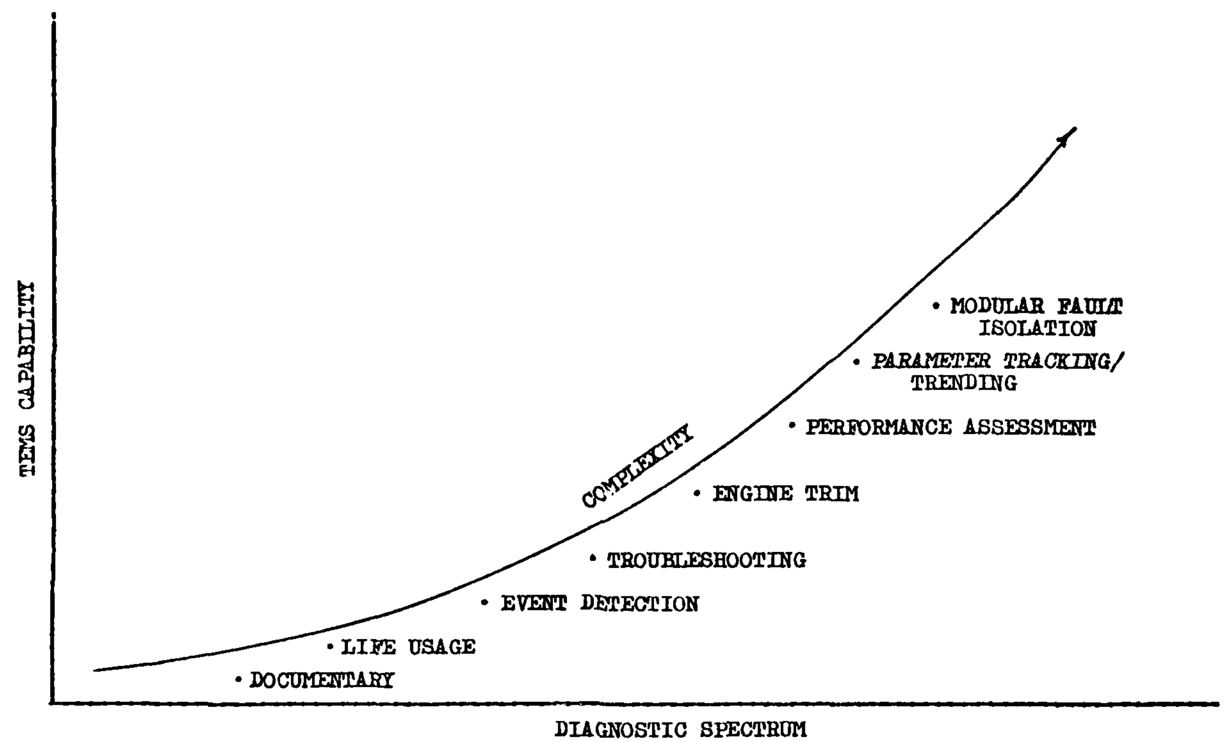


Figure 11

TEMS Sophistication Perspective

SOURCE: Major Robert J. Carlson, USAF. F-100 EDS and Generic TEMS Program Director, ASD/YZN. "Generic TEMS." Briefing to the USAF Scientific Advisory Board, Ad Hoc Committee on TEMS, Wright-Patterson AFB, OH, 16 April 1980.

Most managers receive much more data (if not information) than they can possibly absorb even if they spend all of their time trying to do so. Hence they already suffer from information overload. They must spend a great deal of time separating the relevant from the irrelevant and searching for the kernels in relevant documents . . . . Unless information overload to which managers are subjected is reduced, any additional information made available by an MIS [management information system] cannot be expected to be used effectively [1:B147].

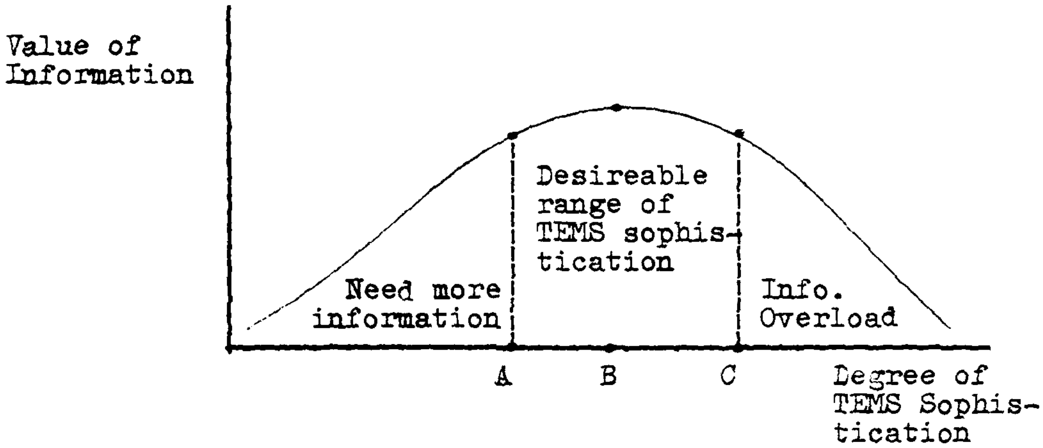


Figure 12

TEMS Sophistication Vs. Value of Information

An ideal relationship would match the degree of TEMS sophistication with the highest value of TEMS-generated information. This ideal match would tailor TEMS sophistication in the range of point A to point C. TEMS sophistication outside of this range (A to C) would be undesireable. A very simple TEMS technique may provide some

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useful information but may not be able to provide all that is needed. Borescope, NDI, and OAP are possible examples of this situation. A very complex TEMS may provide too much information so that needed information is lost or obscured; the C-5 MADARS is a possible example.

The degree of engine sophistication has an impact on the requirements and nature of a TEMS. In general, the greater the degree of engine sophistication, the greater the need for TEMS sophistication. Since highly sophisticated engines are generally more complex than less sophisticated engines, the probability for engine malfunctions for a sophisticated engine is higher than that of a simpler engine. One of the primary purposes for TEMS is to identify engine component conditions which will lead to engine malfunction or failure. Once these problems are identified they can be corrected prior to actual malfunction/failure. Additionally, if a malfunction/failure has already taken place, TEMS can be used to minimize maintenance troubleshooting efforts by isolating the location and nature of the problem. These functions become more difficult as engine complexity increases. Therefore, the benefit potential for TEMS increases as engine sophistication increases.

The maturity of an engine also has an impact on the nature and requirements of a TEMS. Engine maturity should not be confused with the chronological age of a specific engine. Maturity refers to the degree of operational experience for a particular type engine without regard to the chronological age of a specific engine.

For newly developed engines, acquired knowledge concerning potential engine problem areas is small. The phenomenon of infant mortality creates a need to gather large amounts of information due to the uncertainty of future engine problems. Some of this information may become quite useful while some may be relatively useless. However, knowledge gained through operational experience with an engine type allows the identification and correction of built-in defects or weaknesses. This leads to greater engine reliability and lessens the need for TEMS. Therefore, a newly developed engine probably has a greater need for TEMS than does a mature engine.

The fourth TEMS consideration is the degree of stress imposed upon the engine due to its operational environment. Greater environmental stresses will tend to create or accelerate the occurrence of engine malfunctions and failures. For example, an engine on a fighter aircraft is likely to experience more Gs (one G is equal to the force exerted by gravity on a body at rest and used to indicate the force to which a body is subjected when accelerated), higher exhaust gas temperatures, higher sustained revolutions per minute, more throttle bursts, and higher angles of attack than would a similar engine on a cargo aircraft. Due to the greater environmental stresses imposed on the fighter aircraft, it can be expected that this engine will experience more severe and frequent malfunctions than would the cargo engine. For this reason, TEMS would have relatively more application for the fighter engine than for the cargo engine. Consequently, the operational environment will directly affect the degree of sophistication and type of TEMS needed for a particular engine/aircraft combination.

It is generally agreed that TEMS sophistication should be specifically tailored to fit the engine sophistication/complexity, engine maturity, and mission environment combination. Under or overemphasis on any of these variables will have a detrimental effect on the effectiveness of TEMS. If the T-38 EHMS, C-5 MADARS, A-10 TEMS, F-100 EDS, or other TEMS programs fail to achieve a proper mix of the four variables, it would be difficult to draw meaningful conclusions as to the effectiveness of TEMS. Program results should be tempered with an understanding of the relationships of these four variables. Of all the Air Force engine health monitoring programs and tests to date, only one has had unchallenged success-the SAC Engine Condition Monitoring Program (ECMP). In this program, the four TEMS variables were effectively interrelated to achieve an estimated cost savings of 20 million dollars per year (26). Although no TEMS "black boxes" were used, the TEMS concept was nevertheless applied. The SAC ECMP stands as an example of how the TEMS concept can be cost effective.

Additionally, the Scientific Advisory Board (SAB) cautioned that any cost benefit analysis for TEMS would be misleading if several intrinsic benefits were not considered.

> TEMS promises to provide the Air Force with intrinsic benefits that cannot be readily quantified. Some of these intrinsic benefits include accurate recording of data and its automatic insertion into the Management Information System. This kind of operation avoids transcription errors. A second intrinsic benefit is the increased confidence in the ability of the wings to generate sorties when a surge is needed. A third benefit of this kind is that TEMS provides the line maintenance staff with a better understanding of the engine; hence, in the long term, more efficient troubleshooting processes will result. A fourth benefit could be the use of TEMS data for referee purposes if the Air Force should go to warranty-type procurement. Nevertheless, the cost benefit analysis will be of little value if the overall system issues have not been clarified previously and intrinsic benefits taken into account [15:1-2, 1-3].

The Air Force position concerning the cost effectiveness of TEMS should consider the appropriateness of the four previous mentioned variables as well as the intrinsic benefits of TEMS. Failure to do so may effectively delay or destroy a potentially powerful management tool.

The Interrelationships of OCM, TEMS, and CEMS

If OCM is viewed as a continuum (see Figure 10), and the goal is to move outward on this continuum to a more extensive level of OCM, the use of TEMS appears to be a necessity. To respond to OCM requirements, the degree of TEMS sophistication should be determined by engine sophistication, engine maturity, and the mission environment. Regardless of sophistication, however, overall TEMS effectiveness will largely be determined by the ability of CEMS Increment IV to integrate TEMS-generated information into the management information system.

For example, consider a situation were TEMS is effective in collecting relevant information in the appropriate quantity, quality, format, and time frame, and CEMS is unable to integrate this data into the engine management information system. In this case, engine managers above the flight line and intermediate maintenance levels will have little use for TEMS and the potential benefits of TEMS-generated information will be substantially diminished. Figure 13 depicts four potential situations resulting from TEMS/CEMS interrelationships. Obviously, the ideal situation would be an effective TEMS and an effective CEMS. Outcomes in all other quadrants are undesireable especially when both TEMS and CEMS are ineffective.

	EFFECTIVE TEMS	INEFFECTIVE TEMS
EFFECTIVE CEMS	Effective Application of OCM concept.	Relatively ineffective application of OCM concept.
INEFFECTIVE CEMS	Relatively ineffective application of OCM concept.	Extremely ineffective application of OCM concept.

Figure 13

OCM, TEMS, CEMS Effectiveness Grid

OCM, TEMS, and CEMS appear to be highly interdependent, and a change in any one will necessarily influence the other two. Also, the interface between TEMS and CEMS appears to be especially critical to the success of On Condition Maintenance application. Due to the nature of these interdependencies, OCM, TEMS, and CEMS should be viewed and managed as an integrated system rather than as separate entities. Currently, the management structure has not been modified to deal with this problem in an integrated fashion, and HQ USAF has failed to state a position on this issue.

TEMS Avionics Consideration

A TEMS consists of four basic parts: (20)

1. sensors and wire bundles,
2. hardware (electronics),
3. software, and
4. ground support equipment.

AFR 800-28, Air Force Policy on Avionics Acquisition and Support, defines avionics as:

> All the electronic and electromechanical systems and subsystems (hardware and software) installed in an aircraft or attached to it. Avionics systems interact with the crew or other aircraft systems in these functional areas: communications, navigation, weapons delivery, identification, instrumentation, electronic warfare, reconnaissance, flight controls, engine controls, power distribution, and support equipment [32:para 1-1].

If TEMS is identified as avionics, ASD/AFALD AX should have a direct relationship in developing an Air Force master plan for TEMS acquisition, modification, support and standardization (32:para 1-5). If TEMS is not totally avionics, at least some portions of it should be classified as avionics. In any event, the TEMS role of AX needs to be clarified.

TEMS TASK FORCE (TTF)

Regardless of the eventual management structure for TEMS, there is a need for an organizational vehicle to:

1. define the overall purpose and goals of TEMS;

2. clarify responsibilities and authority of each suborganization involved with TEMS;

3. establish clear lines of interorganizational communication on matters relating to TEMS;

4. ensure integrated short and long term planning to achieve the overall goal of TEMS;

5. establish a more specific definition of OCM which means the same thing to all organizations;

6. address the cost effectiveness issue of TEMS;

7. define proper relationships among OCM, TEMS, and CEMS concepts; and

8. define the TEMS role for ASD/AFALD AX concerning avionics standardization.

No individual or suborganization is likely to have the knowledge, understanding or skill necessary to effectively deal with all of these issues. A collection of representatives from each of the TEMS-related suborganizations is necessary. Suggested representation for this group (to be called the TEMS Task Force (TTF)) should include the following:

1. YZ Engine Supportability (explained on page 91),

2. YZL,

3. YZE,

4. LOP,

5. CEMS,

6. MAJCOMs,

7. Aero Propulsion Lab,
8. AFALD, and
9. ALCs.

This task force should be chaired and directed by one of the following: Director for Engine Supportability, HQ USAF/RDP, HQ USAF/LEY, or AFALD. HQ USAF should charter one of the aforementioned agencies to establish a task force by providing adequate funds, personnel, and authority to ensure task completion. Initially the TTF should be given a specified period of time to accomplish its assigned purpose. A final report should be prepared by the TTF Director and coordinated to appropriate organizations for information and/or action.

MODIFIED PROPOSAL

Each of the four proposed structures was considered as an alternative solution to the TEMS management problem. Respondents evaluated all four proposals and provided comments on the acceptability of each. All but one of the respondents was of the opinion that Proposals 1 and 2 were inadequate management structures. The primary reason for this position was the general objection to an AFLC role in development, test, and acquisition because this role is assigned to and best performed by AFSC.

All respondents acknowledged that there were potential advantages to Proposal 4; however, all but one indicated that the disadvantages far outweighed the advantages. The primary objection was the possibility that the engine subsystem would exert an excessive influence on the total aircraft system which could cause a reduction in the mission effectiveness of the overall aircraft system; not unlike the "tail wagging the dog" syndrome. For this reason Proposal 4 was also rejected.

Proposal 3 was preferred over all other proposals. However, nearly all respondents felt that TEMS was too narrow in scope to warrant a separate office on the same level as YZN. Most respondents also felt that this structure was doomed to failure due to the present lack of priority and support given to TEMS by HQ AFSC and ASD. For these reasons Proposal 3 was also rejected.

Although each of the proposals was rejected, Proposal 3 appeared to offer a partial solution to the TEMS management problem. For this reason Proposal 3 was modified in an attempt to retain its advantages and reduce its disadvantages. The modified Proposal 3, entitled Modified Proposal, is depicted in Figure 14. This proposal leaves the structure of Proposal 3 basically unchanged except for ASD/YZ. Under the Modified Proposal, a new office of Engine Supportability would be created

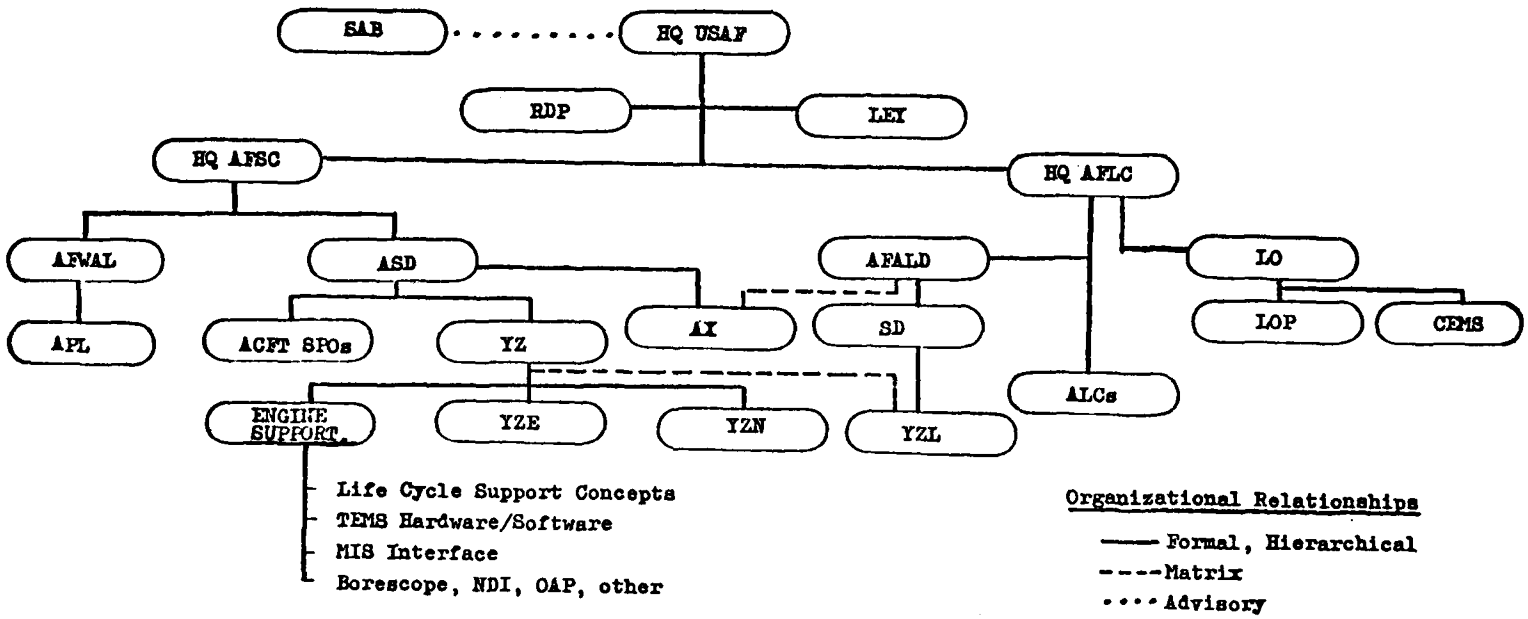

Figure 14

Modified Proposal

on an equal level with YZN. This office would be responsible for:

1. Ensuring that engine life cycle support concepts are developed and considered for integration in new engine development and application for old engines with particular attention given to the requirements and nature of reliability centered maintenance.

2. Providing program management for all TEMS hardware and software development and acquisition. This would include the A-10 TEMS, F-100 EDS, Generic TEMS, and future TEMS programs.

3. Ensuring that TEMS effectively interfaces with the engine management information system. Particular attention should be given to the TEMS/CEMS interface.

4. Developing and improving other techniques of engine health monitoring such as borescope, NDI, OAP, or manual trending.

This proposal has attempted to broaden the scope of TEMS to include engine supportability in general. This approach is intended to give greater visibility to engine logistical considerations in the ASD/YZ community as well as to create an improved atmosphere for an effective TEMS/CEMS interface. Some disadvantages associated with Proposal 3 would still persist. These include ASD priority and support for TEMS, behavioral problems due to AFLC losing A-10 TEMS management, loss of A-10 TEMS/F-100 EDS competition, and possible stagnation of ideas. The Modified Proposal was made using the following assumption: HQ AFSC and ASD will provide adequate priority and support for engine supportability. Without this priority and support the proposal is meaningless and all identified disadvantages would likely continue. Therefore, it is incumbent upon HQ USAF to provide the priority and guidance necessary to ensure AFSC/ASD support if engine supportability (including TEMS) is to improve.

RECOMMENDATION

Based on the findings of this research effort, the Modified Proposal is recommended as the most practicable management concept for effectively utilizing TEMS for Air Force engine management. The establishment of a TEMS Task Force is recommended to enhance the effectiveness of dealing with present and future problems associated with the development of Air Force Turbine Engine Monitoring Systems.

APPENDIX

STRUCTURED INTERVIEW GUIDE

APPENDIX

1. What is your job title?

2. How long have you been in this position?

3. How many years experience have you had in engine-related fields?

4. What is your role/involvement with the TEMS program?

5. What additional involvement does your organization have with TEMS?

6. How long have you been involved in this program?

7. In your opinion, what is the present and future importance of TEMS?

8. In your opinion, what are the major problems to be overcome in the TEMS program?

9. From your perspective, what is the present management structure for TEMS development and implementation?

10. From your perspective, what other organizations are involved with TEMS, and how do you perceive their role?

11. How does your role in TEMS relate to/integrate with other organizations' roles?

12. In your opinion, what problems, if any, exist due to the present TEMS management structure?

13. What suggestions do you have for overcoming these problems?

14. In your opinion, should a single organization be tasked with the overall responsibility for TEMS? Why or why not?

15. If yes, which organization do you feel would provide the best management for TEMS or should a new organization be created? Why?

16. What problems do you foresee with a single manager for TEMS?

17. In your opinion, what changes, if any, should be made in the TEMS management structure in your organization and in the manner your organization relates to other organizations involved with TEMS?

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Ackoff, Russel L. "Management Misinformation Systems," Management Science, Vol. 14 (December 1967), p. B147.

2. Air Force Acquisition Logistics Division, Office of Information. "Air Force Acquisition Logistics Division." Fact sheet. Wright-Patterson AFB OH, May 1979.

3. Air Force Logistics Command, DCS/Logistics Operations. "Comprehensive Engine Management System (CEMS) Executive Summary Data Project Plan (DPP-HAF-D-76-001." Wright-Patterson AFB OH, December 1978.

4. ________. "Comprehensive Engine Management System (CEMS) Economic Analysis: Executive Summary." Staff Study, AFLC/LOP, Wright-Patterson AFB OH, 1979.

5. Air Force Systems Command, Aeronautical Systems Division. "Engine Condition Monitoring." Videotape. February 1977.

6. ________. "Engine Condition Monitoring for Maintenance." Videotape. September 1977.

7. Birkler, J. L. and J. R. Nelson. "Aircraft Turbine Engine Monitoring Experience: Implications for the F100 Engine Diagnostic System Program." Unpublished research report No. R-2391-AF, The Rand Corporation, Santa Monica CA, April 1979.

8. Brady, Captain James F., USAF and Captain Michael J. Scritchfield, USAF. "An Examination of the Current United States Air Force Engine Reporting System." Unpublished Master's thesis. SLSR 9-72B, AFIT/SL, Wright-Patterson AFB OH, September 1976. AD 750910.

9. Capps, Major Ted, USAF. Aircraft Maintenance Staff Officer, Directorate of Maintenance and Supply, HQ USAF, Washington, DC. Telephone interview. 11 April 1980.

10. Carlson, Major Robert J., USAF. F-100 EDS and Generic TEMS Program Director, ASD/YZN. "Generic TEMS." Briefing to the USAF Scientific Advisory Board, Ad hoc Committee on TEMS, Wright-Patterson AFB OH, 16 April 1980.

11. ________. F-100 EDS and Generic TEMS Program Director, ASD/YZN, Wright-Patterson AFB OH. Personal interviews conducted on 16 April and 25 April 1980.

12. Chapman, Captain Jack W., USAF and Captain Charles L. Page, USAF. "An Analysis and Synthesis of Engine Condition Monitoring Systems." Unpublished Master's thesis. LSSR 27-79B, AFIT/SL, Wright-Patterson AFB OH, September 1979.

13. Chopin, M. H. Chief, TEMS Engineering Branch, ASD/YZE, Wright-Patterson AFB OH. Personal interview. 29 April 1980.

14. ________ and Mark S. Ewing. "Turbine Engine Diagnostic Monitoring Systems: A State-of-the-Art Assessment." Unpublished technical memorandum ENJE-TM-74-10, ASD/ENJ, Wright-Patterson AFB OH, July 1974.

15. Covert, Eugene E. Chairman, Ad hoc Committee on TEMS, USAF Scientific Advisory Board. Letter, subj: Detailed Remarks from TEMS Meeting of September 7 to September 9, 1979 to HQ AFLC. undated.

16. Degrande, Major Joe, Jr., USAF and Major Kenneth E. Eickmann, USAF. "A Study of Turbine Engine Monitoring Systems." Unpublished research report 0510-78, Air Command and Staff College, ACSC/EDCC, Maxwell AFB AL, April 1978.

17. Delong, George A. Logistics Management Specialist, Engine Diagnostic Branch, AFALD/YZL, Wright-Patterson AFB OH. Personal interviews conducted on 8 April and 25 April 1980.

18. Hamilton, Keith. Diagnostics and Instrumentation Task Manager, Aero Propulsion Laboratory, Wright-Patterson AFB OH. Personal interviews conducted on 11 April and 2 May 1980.

19. Kohlberg, Major Bernard J., Jr., USAF. Director, On Condition Maintenance, Directorate of Propulsion Systems, HQ AFLC. "A-10/TF34 TEMS Review." Briefing to USAF Scientific Advisory Board, Ad hoc Committee on TEMS, General Electric Aircraft Group Facility, Lynn MA, 6 September 1979.

20. ________. Director, On Condition Maintenance, Directorate of Propulsion Systems, HQ AFLC, Wright-Patterson AFB OH. Personal interviews conducted intermittently 1 October through 19 October 1979.

21. ________. Director, On Condition Maintenance, Directorate of Propulsion Systems, HQ AFLC, Wright-Patterson AFB OH. Personal interviews conducted on 10 April and 28 April 1980.

22. Maley, Lieutenant Colonel James L., USAF. Deputy Project Manager, Comprehensive Engine Management System (CEMS), DCS/Logistics Operations, HQ AFLC, Wright-Patterson AFB OH. Personal interviews conducted on 3 April and 1 May 1980.

23. McDonnell Aircraft Company. F100 Engine Diagnostic System Hardware and Software Definition Phase. MDC A4270, St. Louis MO, 15 July 1976.

24. Northrop Corporation Electronic Division. T-38 Engine Health Monitoring System (EHMS): Hardware Demonstration Program Final Report. NORT 76-206, Palos Verdes Peninsula CA, February 1976.

25. Pettigrew, Lieutenant Colonel James L., USAF. "Is EMS the Key to Operational Readiness for Less Money With On-Condition Maintenance?", Presentation to Fourteenth Annual International Logistics Symposium, 1979.

26. ________. Deputy Director Engineering and Test Deputy for Propulsion, ASD/YZE, Wright-Patterson AFB OH. Personal interviews conducted on 10 April and 29 April 1980.

27. Roadruck, Major Max, USAF. Chief, Integrated Logistics Support, ASD/YZN, Wright-Patterson AFB OH. Personal interviews conducted 22 April and 29 April 1980.

28. San Antonio Air Logistics Center. "Program Orientation: Reliability Centered Maintenance." Unpublished training guide, Information Spectrum, Inc. Undated.

29. Small, Les. Acting Technical Area Manager for Controls and Diagnostics, Components Branch, Aero Propulsion Laboratory, Wright-Patterson AFB OH. Personal interviews conducted on 11 April and 2 May 1980.

30. Technical Cooperation Program. Aeronautics Subgroup. Outlines of Current Military Gas Turbine Engine Health Monitoring Programs. TTCP technical report HAG-2-77, August 1977.

31. U.S. Air Force. Office of the Inspector General. Report On Inspection of Propulsion Unit Management (PN 74-506), Norton AFB CA, 19 December 1973.

32. U.S. Department of the Air Force. Air Force Policy on Avionics Acquisition and Support. AFR 800-28. Washington: Government Printing Office, September 1978.

33. Williams, Dr. Benjamin R. Program Director, Comprehensive Engine Management System (CEMS), DCS/Logistics Operations, HQ AFLC, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 1 October 1979 to 19 October 1979.

34. ________. Deputy Director, Directorate of Propulsion Systems, DCS/Logistics Operations, HQ AFLC, Wright-Patterson AFB OH. Personal interview. 12 April 1980.

35. Yanker, Jerry. Chief, Logistics Engineering Division, Directorate of Propulsion Logistics, AFALD, Wright-Patterson AFB OH. Personal interviews conducted on 22 April and 29 April 1980.

B. RELATED SOURCES

Air Force Logistics Command, DCS/Logistics Operations. "Comprehensive Engine Management System (CEMS)." Briefing to the Assistant Secretary of the Air Force/Financial Management, Wright-Patterson AFB OH, 22 May 1979.

________. "Comprehensive Engine Management System (CEMS)." Briefing to USAF/CC, Pentagon, Washington, DC, 14 October 1978.

________. Concept Certification Documentation for the Comprehensive Engine Management System (CEMS). Wright-Patterson AFB OH, 1 January 1979.

Pettigrew, Lieutenant Colonel James L., USAF. Deputy Director Engineering and Test Deputy for Propulsion, ASD/YZE, Wright-Patterson AFB OH. Personal interviews conducted intermittently from 1 October 1979 to 19 October 1979.

________ and Keith Hamilton. Proceedings Seventh Annual Tri-Service Meetings for Aircraft Engine Monitoring and Diagnostics (ASD-TR-79-5040). Arnold Engineering Development Center, Arnold AFS TN, 19 July 1979.

Society of Automotive Engineers Committee E-32. Aerospace Recommended Practice: Gas Turbine Engine Monitoring System for Aircraft. Technical report ARP 1587, Warrendale PA, 1979.

Technical Cooperation Program, Aeronautics Subgroup. Outlines of Current Military Gas Turbine Engine Health Monitoring Programs. TTCP technical report HAG-2-76, September 1976.

TEMS Review Group. "Turbine Engine Monitoring System (TEMS) Review Group Report." Briefing presented to AFLC/LO, Wright-Patterson AFB OH, 25 May 1977.