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AIRCRAFT GAS TURBINE ENGINE MONITORING SYSTEM GUIDE

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) is a system guide for Engine Monitoring System (EMS) definition and implementation. This keystone document addresses EMS benefits, capabilities, and requirements. It includes EMS in-flight and ground applications consisting of people, equipment, and software. It recommends EMS requirements that are a balance of selected benefits and available capabilities. This ARP purposely addresses a wide range of EMS architecture. The intent is to provide an extensive list of possible EMS design options.

NOTE:

a. Section 3 describes an EMS.
b. Sections 4 and 5 outline benefits and capabilities that should be considered for study purposes to define EMS baselines for how much engine monitoring is required.
c. Section 6 provides implementation requirements that should be considered for an EMS after study baseline levels of EMS complexity are selected.

1.1 Purpose:

The purpose of this ARP is to provide an Aircraft Gas Turbine Engine Monitoring System Guide for commercial and government users, aircraft manufacturers, engine producers and equipment suppliers. This ARP is not intended for use as a legal document but only as a system guide. Other SAE documents (Aerospace Standards, Aerospace Recommended Practices, and Aerospace Information Reports) address specific component specifications, procedures and "lessons learned". A list of the most relevant is shown in Section 2 and a summary of SAE Engine Monitoring activity can be found in SP728.

2. REFERENCES:

The following publications form a part of this document to the extent specified herein. The latest issue of all SAE Technical Reports shall apply.

2.1 SAE Publications:

The following documents have been developed by the SAE E-32 Committee and are available from the SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AIR1828 Guide to Oil System Monitoring in Aircraft Gas Turbines
AIR1839 Guide to Vibration Monitoring for Aircraft Gas Turbine Engines
AIR1871 Lessons Learned from Developmental and Operational Turbine Engine Monitoring Systems
AIR1872 Guide to Life Usage Monitoring and Parts Management for Aircraft Gas Turbine Engines
AIR1873 Guide to Limited Engine Monitoring Systems for Aircraft Gas Turbine Engines
AIR1900 Guide to Temperature Monitoring in Aircraft Gas Turbine Engines

2.1 (Continued):

AIR4061 Guidelines for Integration of Engine Monitoring Functions with On-Board Systems
ARD50002 A Discussion of Standardized Concepts for Condition Monitoring and Performance Analysis Software

SP 728 Aircraft Gas Turbine Engine Monitoring Systems

2.2 Related Publications:

Other documents and standards, which are of general interest or importance to engine monitoring, are listed below:

2.2.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP755 Gas Turbine Engine Performance Station Identification & Nomenclature
ARP1217 Instrumentation Requirements for Turboshaft Engine Performance Measuremts

2.2.2 Military Publications: Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-STD-1553B Aircraft Internal Time Division Command/Response Multiplex Data Bus
MIL-STD-1777 Internet Protocol
MIL-S-52779(A) Software Quality Assurance Program Requirements
MIL-E-5007 General Specification for Turbojet and Turbofan Aircraft Engines (Ref. Para 3.7.6)

DOD-Std-2167(A) Defense System Software Development
DOD-Std-2168 Defense System Software Quality Program

2.2.3 Other Publications:

AGARD-CP-448 Engine Condition Monitoring - Technology and Experience AGARD Conference Proceedings No. 448 June '88 Quebec

ARINC 429 Mark 33 Digital Information Transfer

ARINC 629 Multi-Transmitter Data Bus Part 1 Technical Description

DLR (Institute for Flight Guidance, Braunschweig, Germany) Symposiums (1987, 1989, 1991) on Aircraft Integrated Monitoring Systems

RTCA DO-178 Software Considerations in Airborne Systems and Equipment Certification

2.3 Terminology and Definitions:

The following list defines terms commonly used in EMS disciplines. The list is typical and is not necessarily complete or universally used.

ACTUARIAL DATA: Refers to the type of information used to define the engine, installation, subassemblies and components (e.g., serial numbers) and often includes the bookkeeping of data that indicate the life usage on these components (e.g., operating hours, LCF counts, hot section usage).

AIRCRAFT INTEGRATED MAINTENANCE SYSTEMS (AIMS): The broad term to identify a family of systems that acquires, processes, and records data that are used to determine the functional status and condition of various commercial aircraft systems, including engine and engine components.

ALGORITHM: A step-by-step procedure for solving a problem or accomplishing some end.

BASELINE: A quantifiable physical condition or level of performance from which changes are measured.

BITE: Equipment built into a unit to provide a self-test capability for the unit.

CLASSIFICATION: Implies a decision rule where data or information may be identified and grouped (e.g., waveforms or signatures) to be an indication of a particular status, discrepancy, or failure mode.

DAMAGE FACTOR: A relative number assigned to indicate a defined amount or unit of engine component or piece part life usage, e.g., LCF counts, hot section factors.

DEGRADATION: The condition or status indicating impaired or deteriorating condition, function or physical state.

DIAGNOSTIC: An analysis result pertaining to the detection and isolation of a malfunction or discrepancy.

DIAGNOSTIC ROUTINE: A sequence of tests or fault tree logic designed to use data inputs and predetermined standards or operational limits to establish condition status and locate a malfunction or discrepancy.

DIAGNOSTIC SENSITIVITY: A measure of the threshold level at which a change of condition or functional status yields symptomatic indications with a given diagnostic routine or technique. The threshold level is an accumulation of all error contributions which input into the diagnostic routine or technique.

DISCREPANCY: Deviation from an expected condition.

ENGINE ACCESSORY: A part or assembly usually driven by the engine associated with a subsystem (e.g., lube, fuel).

2.3 (Continued):

ENGINE COMPONENT: A part or assembly of the basic engine.

ENGINE HEALTH MONITORING: The general discipline or technique for indication of status of the mechanical or functional condition of an engine or engine components; sometimes referred to as Engine Condition Monitoring.

ENGINE MONITORING SYSTEM (EMS): An EMS is a complete system approach to define engine, engine component, and subsystem health status through the use of sensor inputs, data collection, data processing, data analysis, and the human decision process. This system approach can consist of an integrated set of hardware and software and several separate engine monitoring system elements and can be manual, computer aided, or automated.

FAILURE: A functional status or physical condition characterized by the inability of an engine, engine component, or subassembly to fulfill its design purpose; the most severe degree of malfunction.

FAILURE DETECTION: The process or technique of identification of engine, engine component or subsystem failure.

FAILURE MODE AND EVENT CRITICALITY ANALYSIS: An analysis of the particular manner or sequence of events that is indicative of a specific engine, engine component, or subsystem failure and the severity of the result of that failure.

FAILURE PATH: The chain of events or set of circumstances that result in an engine, engine component, or subsystem failure because of interrelationships between components and subsystems.

FAULT DETECTION: The process, technique or capability of identification of a discrepancy.

FAULT ISOLATION: The process, technique, or capability of the specific identification of engine component, subsystem or piece part causing a discrepancy.

FAULT ISOLATION MANUAL (FIM): A document or software package which assists in the interpretation of EMS data to assist troubleshooting.

FAULT TREE: An expression for a logic path used to establish engine, engine component or subsystem functional status and condition.

INCIPIENT FAILURE: A functional status or condition which is existing at the beginning of a failure of engine, engine component or subsystem.

IN-FLIGHT ENGINE STATUS: In-flight indications (real time or near real time) of potential failures and warnings of a cautionary or advisory nature, e.g., high vibration.

LIFE USAGE INDICES: Measured or calculated indicators of engine life used.

2.3 (Continued):

LIMIT EXCEEDANCES: Parameter excursions beyond preestablished values.

LONG-TERM TRENDING: Tracking of engine, engine components or subsystem degradation on a periodic basis, often by flight. This type of tracking indicates a deviation of monitoring data from an established trend (see Trend Analysis).

LOW CYCLE FATIGUE (LCF): Component material life usage incurred by cyclic stress excursions.

LINE REPLACEABLE UNIT (LRU): Propulsion component or assembly that may be replaced at the first (flight line) level of maintenance, sometimes called a Weapon Replacement Assembly (WRA).

MALFUNCTION: Abnormal condition or status of an engine, component, or subsystem.

MEASURAND: A physical quantity, force, property, or condition which is to be measured.

MONITORING: The act or technique of establishing functional status or condition.

a. In-Flight Monitoring: Monitoring by on-board equipment during the period from engine start to engine shutdown.

b. On-Site Monitoring: Utilization of data on site. Ground test of engines using on-board or portable ground test equipment.

c. Remote Monitoring: Utilization of data at a remote (off site) location.

MAINTENANCE STEERING GROUP (MSG): An ATA (Air Transportation Association) sponsored study group which publishes recommended methodologies and analytical procedures for developing a maintenance plan for aircraft, engines and systems.

OFF-LINE MAINTENANCE INFORMATION: Data to indicate long-term engine degradation through trend monitoring of performance data and tracking of engine usage history.

ON CONDITION: A term used to indicate maintenance based upon the functional, structural, or other condition of the unit or part, as differentiated from time schedule maintenance (see Primary Maintenance Processes).

OPERATIONAL LIMIT: A preestablished reference for engine, engine component or subsystem operation.

PARAMETER: A measurable or calculated quantity which varies over a set of values.

2.3 (Continued):

PERFORMANCE DEGRADATION: The condition or status indicating impaired or deteriorated engine gas path performance as referenced to some established or predetermined condition.

POSTFLIGHT ENGINE STATUS: An immediate GO/NO GO indication of engine availability for next flight and if in a NO GO status situation, indication of required maintenance action as appropriate.

POWER INTERRUPT: A loss of power to the engine monitoring equipment which could result in possible loss of data.

PREFLIGHT ENGINE STATUS: Cockpit indications to aid in pretakeoff checks, e.g., thrust check.

PRIMARY FAILURE: A failure which is not a result of another failure.

PRIMARY MAINTENANCE PROCESSES: Three primary maintenance processes are recognized and defined by MSG-2 for classifying the way in which a particular aircraft element is maintained. These primary maintenance processes are:

a. Overhaul Time Limit or Part Life Limit (Hard Time): This is a preventive primary maintenance process. It requires that an engine or part be periodically overhauled in accordance with the operator's maintenance manual or that it be removed from service. These time limitations may be adjusted based on operating experience or tests as appropriate.

b. On Condition Maintenance (OCM): This is a preventive primary maintenance process. It requires that an engine or part be periodically inspected or checked against some appropriate physical limit to determine whether it can continue in service. The purpose of the limit is to remove the unit from service before failure occurs. These limits can be adjusted based on operating experience or tests as appropriate.

c. Condition Monitoring (CM): This is a maintenance process for items that have neither "Hard Time" nor "On Condition" maintenance as their primary maintenance process. CM is accomplished by having appropriate means of data collection and analysis by which an operator obtains information from the whole population of a system or item in service and uses this information to allocate resources.

PROGNOSIS: The forecast of future functional status and condition based on current and accumulated inputs.

QUICK ENGINE CHANGE (QEC): A package or kit of hardware items not included on the engine as delivered by the engine producer but required in the buildup of the engine prior to installation in an aircraft.

SAFETY OF FLIGHT EVENT: An engine, engine component, or subsystem functional status or condition that could seriously jeopardize flight integrity.

2.3 (Continued):

SAFETY OF FLIGHT WARNING: Timely crew warning to permit in-flight correction of problems seriously affecting flight integrity or leading to catastrophic engine failure. (The intent is to provide either real time crew warning or postflight maintenance indication for all engine discrepancies that could cause an unsafe flight situation).

SECONDARY DAMAGE: Damage resulting from a primary failure.

SENSOR: A mechanical, electrical, optical, or fluidic device that provides data inputs, e.g., transducers, position indicators, discretes.

SENSOR OUTPUT FORMAT: The form of the signal or waveform supplied by the sensor, e.g., analog, pulse frequency, digital.

SHORT-TERM TRENDING: Tracking of engine, engine component, or subsystem operational degradation by noting data on a particular flight or ground check and comparing with a preestablished trend (see Trend Analysis).

SIGNATURE: A signal or combination of data inputs that are characteristic of an individual engine, engine component, or subsystem that can be used to indicate functional status and condition.

SONIC VIBRATION: Refers to the dynamics of mechanical vibration waveforms in the frequency range up to 20KHz.

TRANSDUCER: A hardware sensing device which measures a physical phenomenon (e.g., pressure, temperature, position) and outputs a calibrated signal.

TREND ANALYSIS: A technique to utilize deviation of recorded data and signature characteristics with respect to time to assist in the diagnosis or prognosis of a malfunction or failure.

TRIM CONDITION DATA: Data to indicate an out of trim engine condition and to implement a corrective action to return to scheduled trim.

ULTRA SONIC VIBRATION: Refers to the dynamics of mechanical vibration waveforms in the frequency ranges of more than 20KHz.

3. DESCRIPTION:

An EMS includes the people, equipment, software and procedures used to provide engine monitoring data (Figure 1). An EMS collects, processes, and displays data to assist engine maintenance, logistics, safety, operation, management, and design. EMS data are acquired, recorded and processed in-flight and on the ground. EMS data are available for timely use by flight crew and ground support personnel. EMS data lead to actions taken on the basis of judgments made from directly measured or inferentially determined information. An EMS can be manual, computer aided or automated (see AIR1873). A manual data acquisition system is utilized in many operational aircraft as part of the

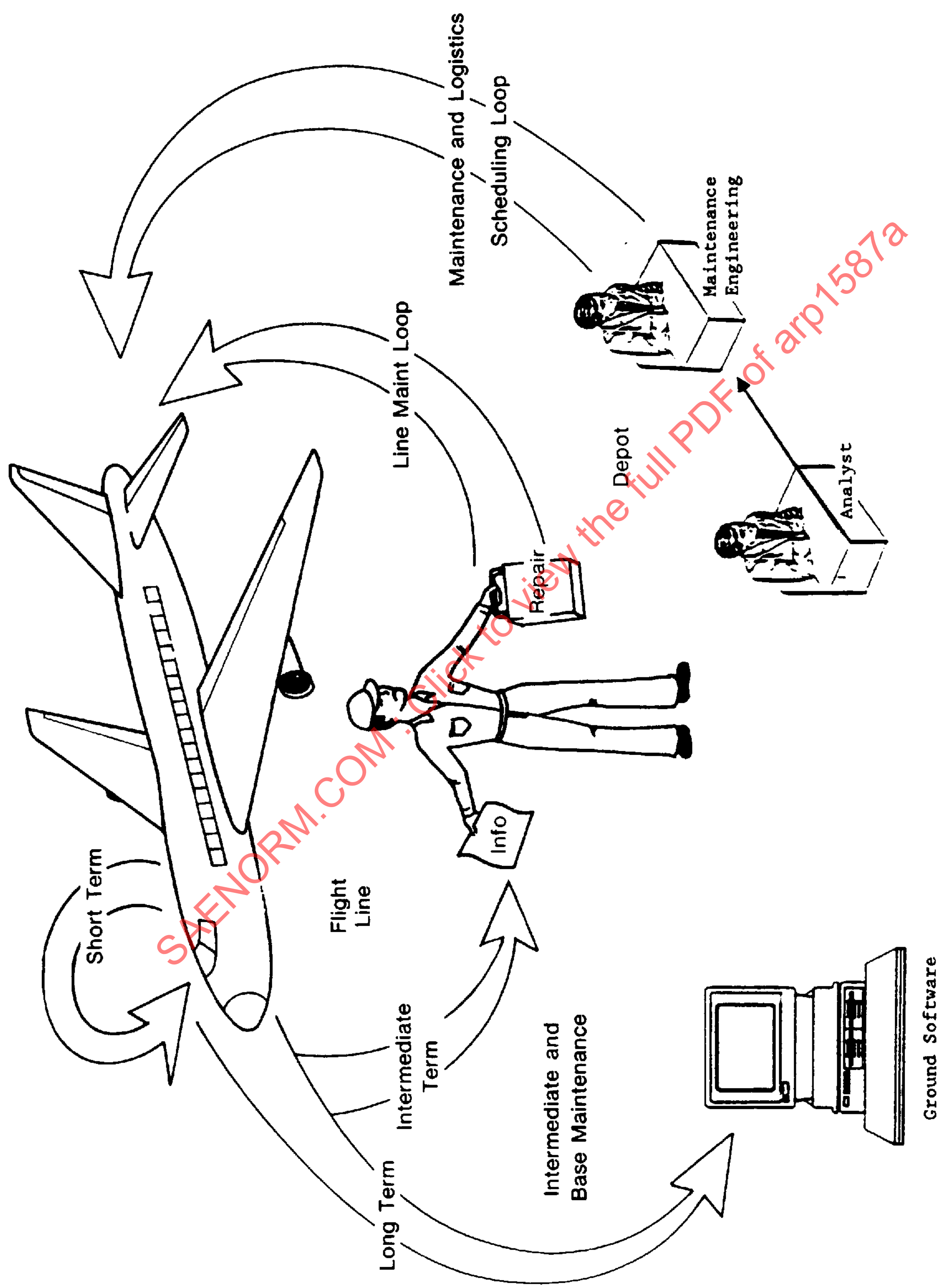


FIGURE 1 - Engine Monitoring System (EMS)

3. (Continued):

engine maintenance plan. An EMS can enhance the engine maintenance plan and also can complement aircraft and engine operations. An EMS may be part of an overall Aircraft Monitoring System.

EMS functions can be performed by dedicated people and equipment, or can be integrated and shared with the functions of other systems (see AIR4061). An EMS should be versatile and continuously evolving. An EMS configuration can allocate different hardware and software distributions among installed engine and aircraft elements, as well as among ground based, on-site and remote EMS elements. An effectiveness evaluation is required to determine partitioning of EMS hardware and software and airborne and ground functions. While each EMS can be unique, EMS design, development, and implementation methodology should be consistent and commensurate with engine monitoring needs.

An EMS is part of the engine management system. As a source of information, an EMS is at the center of the communication network required to implement an effective engine maintenance and support program. EMS data handling information requirements merit particular attention and should address the following:

a. What information is generated.
b. Why and when is information utilized.
c. How and by whom is information communicated and used.
d. Where is information recorded, displayed, stored, and retrieved.
e. What equipment routines and personnel procedures are applied.

EMS equipment should not be addressed exclusive of human factors. A cooperative effort involving all EMS participants and addressing human resources available is essential. How EMS information is formatted and presented to different user groups has a direct bearing on the value and use of the information that has been collected.

4. BENEFITS:

Benefits of an EMS include reduced cost of engine and aircraft ownership, increased availability, improved mission effectiveness, and improved safety.

Requirements for an EMS cost benefit analysis are presented in 6.4. EMS effectiveness evaluation requirements are presented in 6.5.1.

EMS benefits can accrue in different ways as described in 4.1 through 4.8.

4.1 Safety:

An EMS is primarily a maintenance tool. Related safety requirements and benefits of an EMS will vary between military and commercial applications. For military applications, especially for single engine aircraft, an EMS may be an operational requirement. For commercial applications, engine instrumentation and systems fault data to meet minimum safety requirements is

4.1 (Continued):

approved by governing regulatory bodies. Extended twin engine operation (ETOPS) drives some level of maximum continuous margin trending. The absence of EMS may drive some level of sample disassembly and inspection to support an "on condition" program.

4.2 Cost Savings:

Applying EMS data to better determine and manage engine operation, condition, life usage, and life remaining can provide cost savings in the areas of hardware, labor, fuel, operations, and logistics.

a. Hardware cost savings can result from more accurate assessment of remaining life in life limited components (Figure 2) and also from early failure detection resulting in the elimination or reduction of secondary damage.

b. Labor cost savings at different maintenance levels can result from reductions in hardware repair, time for fault isolation, and time for fault correction and repair.

c. Early detection and correction of performance deficient engine modules can save fuel costs and reduce additional engine runs for trim and troubleshooting.

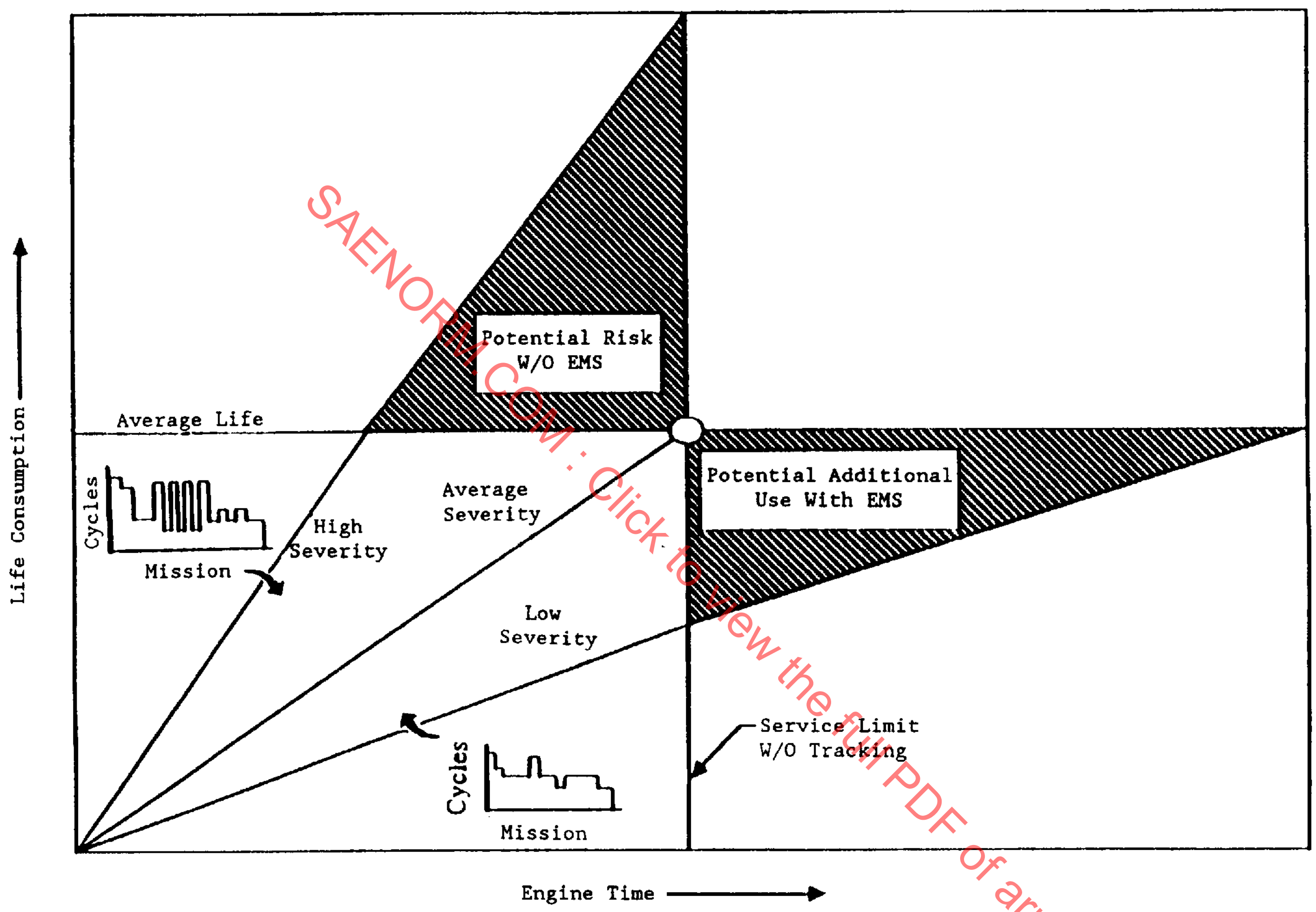
d. Operations and logistics cost savings can include a reduction in flight delays, bookkeeping of engine records, spare parts provisions and storage, and shipping costs for spare engines and modules. The increased troubleshooting effectiveness afforded by EMS data can favorably impact aircraft turnaround time and availability and can reduce logistics costs associated with engine and component removals for unconfirmed causes. Enhanced maintenance planning can reduce the overall cost by reducing the number of spare parts and locations.

4.3 Operational:

An EMS can improve engine and aircraft availability and mission completion rates. Accurate engine operational usage monitoring (see AIR1872), long-term correlation of parts consumption and maintenance manhours can provide a basis for a reassessment of component life limits or an updating of the criteria used to maintain parts, e.g., removal based upon "hard time", "on-condition" maintenance or "condition monitoring" maintenance.

4.4 Flight Deck:

EMS flight crew support can be manual, computer aided, or fully automated. EMS benefits to the crew can include a determination of abnormal engine conditions with increased warning time and more information than normally obtained from cockpit indicators.



*An EMS provides a convenient and enhanced means of tracking engine life usage and component life consumption.

FIGURE 2 - Engine Life Tracking With an EMS

4.5 Line and Station Maintenance:

Engine condition and component life usage EMS data can assist scheduled and unscheduled maintenance. Rapid acquisition and presentation of EMS data can reduce the time required for fault isolation, assist in defining required maintenance and assess the availability of an engine for aircraft use. EMS data also can verify the correctness of maintenance actions.

4.6 Depot and Main Base Maintenance:

An EMS can enhance the effectiveness of maintenance personnel by improving:

a. Maintenance forecasting and scheduling
b. Turnaround time
c. Fault isolation and identification of repair requirements
d. Productivity through availability of more and better correlated information

4.7 Logistics:

An EMS can improve:

a. Inventory management of spare engines and parts
b. Scheduling and utilization of people and equipment
c. Opportunistic and convenience engine removals, repairs, and overhauls

4.8 Engine Management:

Better engine management decisions can be achieved by analysis, correlation and feedback of EMS detected engine problems, parts consumption and usage data. With the increased use of warranties and incentives for both commercial and military engines, an EMS can be used to quantify user and supplier liabilities.

An EMS can improve:

a. Prioritization of engine product improvement programs
b. Task emphasis and funding allocation
c. Understanding of engine operation by users and manufacturers
d. Future engine requirements and designs

5. CAPABILITIES:

An EMS is an information system that can be used to perform the following tasks:

a. Assessing engine usage
b. Determining remaining life and engine operational readiness
c. Detecting incidents and magnitude of limit exceedances
d. Detecting and isolating engine problems and verifying correction

5. (Continued):

e. Trending engine condition and tracking life limited hardware
f. Maintaining engine history
g. Supporting engine management and logistics decisions

For convenience, EMS capabilities are classified into three categories as shown in Figure 1.

a. Short-term
b. Intermediate
c. Long-term engine monitoring

Some of these engine monitoring capabilities can apply to more than one category.

5.1 Short-Term:

Short-term EMS capabilities can include:

5.1.1 Safety: If an EMS is installed to provide safety benefits (see 4.1), timely warnings can direct flight and ground crew attention to problems either affecting mission integrity or leading to engine failure.

5.1.2 Preflight: EMS indications of a precautionary or advisory nature can aid preflight checks.

5.1.3 In-Flight: An EMS can provide real time monitoring of engine condition and generate appropriate "warnings and cautions" to the flight crew. Provision for data recording of critical events, either automatically or on pilot command, also can be included.

5.1.4 Postflight: An EMS can provide a GO/NO GO indication of engine availability for the next flight. NO GO causes can be isolated to the major engine module level, line replacement unit (LRU) or more detailed level. EMS data can assist in troubleshooting and clearing pilot reports.

5.1.5 Included in the above can be the following:

a. Engine Limit Exceedances: An EMS can indicate and record the magnitude and duration of engine limit exceedances, e.g., overtemperature and overspeed.

b. Lubrication System: EMS data can indicate a lubrication system problem (Ref. AIR1828), e.g., oil debris indication, low oil quantity, excessive oil consumption, overtemperature, low or high oil pressure.

c. Vibration Data: An EMS can collect and process vibration data to indicate an engine problem (see AIR1839). Vibration analysis techniques can fault isolate to the engine module level. Vibration analysis techniques can range from total level trending and signature tracking to more detailed frequency and amplitude analysis. EMS vibration data can support on-the-wing engine rotor trim balance.

5.1.5 (Continued):

d. Engine control fault data that affects the dispatch capability of the airplane.

5.2 Intermediate Term:

Intermediate term EMS capabilities can include:

5.2.1 Event Analysis: An EMS can provide data to analyze an event caused by a limit exceedance detected in flight or on the ground. Storage of steady state and transient aircraft and engine data prior to and subsequent to an event can be provided. The causes and factors leading to an event and the extent of possible resultant problems can be analyzed.

5.2.2 Trim Condition: Engine out-of-trim indication and data for corrective trim action can be provided by an EMS for pre-FADEC/electronically controlled engines.

5.2.3 Gas Path Performance Analysis: An EMS can provide data to indicate and project engine and module performance level and extent of degradation. Engine, as well as nonengine accessories that affect performance, can be monitored to better isolate gas path performance degradation from changes due to other than engine causes, e.g., bleed airflow and power extraction.

5.2.4 Trending: An EMS can provide data to support engine trending to indicate and project overall engine and module condition. EMS trending capability can include engine performance, vibration and lube system condition.

5.2.5 Accessory Components: An EMS can provide event detection and isolation to the accessory component level. Engine, as well as nonengine accessories and components can be monitored, e.g., bleed airflow and power extraction.

5.2.6 Nondestructive Inspection and Testing: Nondestructive inspection and testing (NDI and NDT) techniques available to complement EMS capabilities include: borescoping, radiography, eddy current, ultrasonic inspection, liquid penetrants, thermal paints, and acoustics.

5.2.7 Additional: Additional EMS capability can be provided, e.g., monitoring of gearboxes, powertrains, fuel, and thrust management.

5.3 Long-Term:

Long-term EMS capabilities can include the following.

5.3.1 Data Validity, Self-Calibration, Check and Correction: An EMS should provide a continuous self-calibration and self-check of its hardware and software, e.g., sensor signal validity, computation and calibration checks and built-in-test equipment (BITE). (If an EMS provides cockpit indication, the EMS should indicate to the flight crew when it has malfunctioned). Techniques include rate and range checks, spike detection and rejection through median determination, comparison of dual sensors and verification with model values.

5.3.2 Off-Line Maintenance Information: EMS capability can include indication of engine degradation, e.g., long-term performance and vibration trends and engine usage life history, e.g., engine hours, starts, low cycle fatigue (LCF) and hot section usage.

5.3.3 Flexibility and Growth: A modular EMS hardware and software design can meet anticipated and unanticipated total system needs and can better integrate additional existing or advanced EMS technology.

5.3.4 Data Feedback: The capability can be provided for transmitting and confirming EMS data to commercial and governmental users, aircraft manufacturers, engine producers and equipment suppliers.

5.3.5 Life Usage Tracking: An EMS can provide accrued usage data for life limited engine modules, components, and parts. Cold and hot section engine life usage data can be provided, e.g., low cycle fatigue (LCF), creep and wear. Life remaining projections can be made.

5.3.6 Mission Profile and Engine Usage: EMS can be designed to include increased data acquisition capability in support of engine and aircraft usage severity determination, e.g., engine throttle excursions and aircraft mission profiles definition.

5.3.7 Record Keeping: EMS data can be collected for configuration status of engines, engine modules and components. Actuarial data can be recorded and maintained to support a fleetwide engine management system.

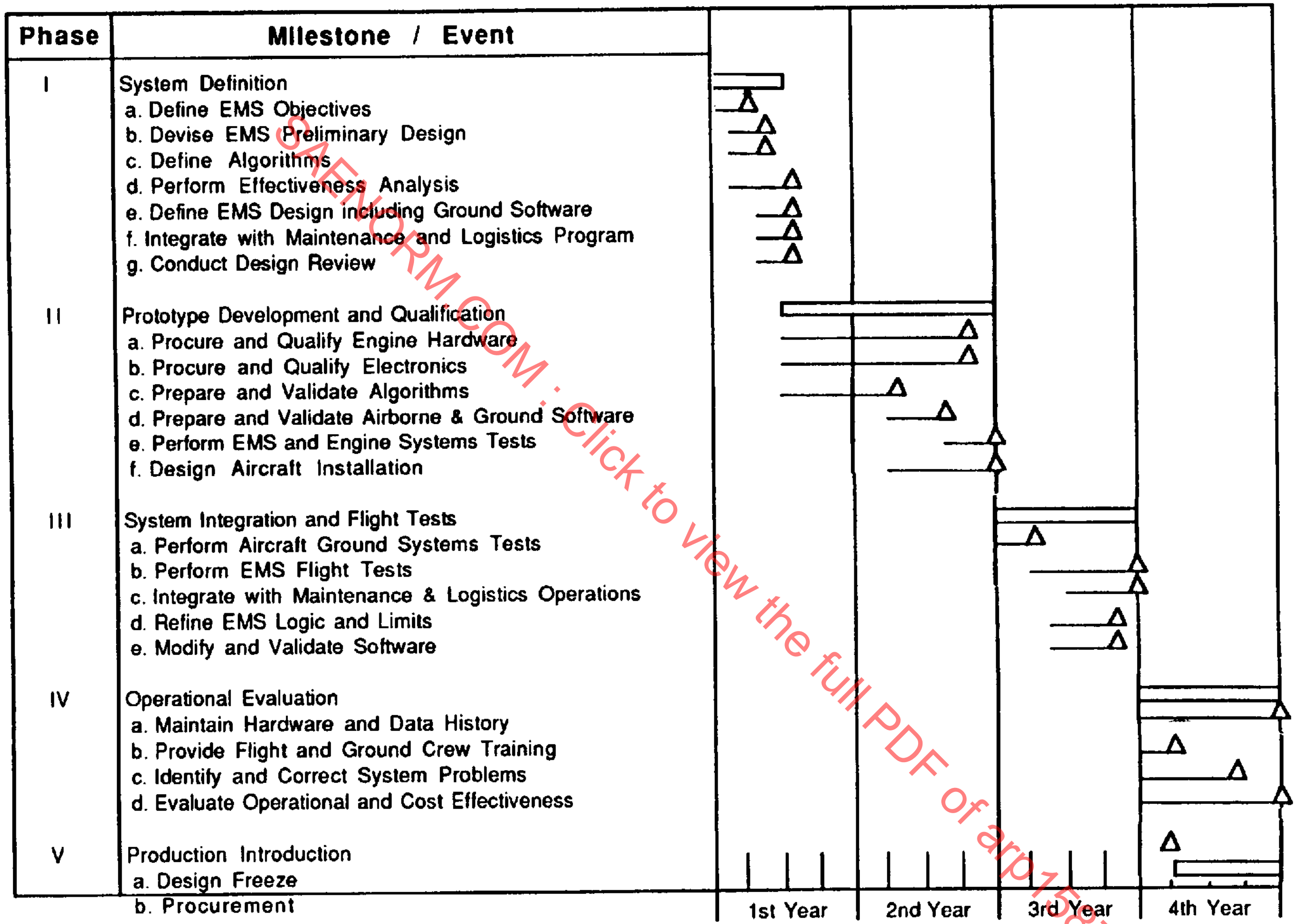
6. IMPLEMENTATION REQUIREMENTS:

EMS requirements are a result of a balance of selected benefits, available capabilities, and analytical tools (FMECAs and other methods of safety/hazard analysis). EMS requirements are determined by an analysis of aircraft and engine operational environment, maintenance concept and user organization. The requirements are influenced by the degree of integration with engine controls (FADEC) and/or avionic systems. Lessons learned (see AIR1871) must always be taken into consideration.

An EMS should be an integral part of any new engine and aircraft development program. Delayed introduction of an EMS to in-service engines will be more costly and may result in a less than desirable EMS capability but still yield a substantial return on investment and positively impact maintenance, logistics, safety and operations. An engine retrofit program may require different mixtures of EMS responsibilities, interfaces and program milestones.

6.1 Program Management:

The phased program milestones as shown in Figure 3 is an example of the design, development and qualification of an EMS through production introduction.



NOTES:
- It is recognized that four years may be too long for many programs.
- The above plan assumes starting with a blank page - most systems are derivative.

FIGURE 3 - Typical EMS Program Plan

6.1 (Continued):

Retrofit and accelerated EMS development can require a compressed program schedule as shown below, e.g., adaptation of an EMS to engines in current production to take advantage of in-service experience will require different phasing and scheduling.

The software development task, including ground software, must be carried out concurrently with the outlined program phases.

The EMS program schedule of 18 to 48 months (see Table 1) can vary considerably, depending on the degree of system complexity, engine development schedule, availability of off-the-shelf hardware and the number of monitoring functions. Considerable emphasis, particularly commercial, is being placed on reducing cycle times.

TABLE 1

		New	Retrofit
Phase I	System Definition	6 months	2 months
Phase II	Prototype Development and Qualification	18 months	8 months
Phase III	Flight Test and System Integration	12 months	2 months
Phase IV	Service Evaluation	12 months	6 months
Phase V	Production Introduction/1/	--	--
		48 months	18 months

/1/ Phase V starts during Phases III or IV and continues after completion of Phase IV.

An EMS is assumed to include aircraft and engine data recording and also is assumed to include ground data processing, print-out and analysis.

Resulting EMS characteristics are most influenced by Phases I and IV. Phase I establishes the system requirements to support user operational needs. Phase IV is a field service evaluation which allows for software refinement and demonstrates system effectiveness.

6.1.1 System Definition (Phase I): The definition of an EMS for a particular application should be a balance between user needs, system complexity, available technology, projected benefits, and favorable return on investment (ROI). Figure 4 illustrates a relationship between EMS complexity and ROI. A recommended methodology to be followed to achieve a cost effective EMS is presented in Figure 5. EMS definition methodology should include:

a. Defining user engine monitoring requirements
b. Performing trade studies on several alternative EMS configurations
c. Selecting a preferred EMS for development
d. Determining compatibility with other interfacing aircraft systems
e. Incorporating lessons learned (see AIR1871)

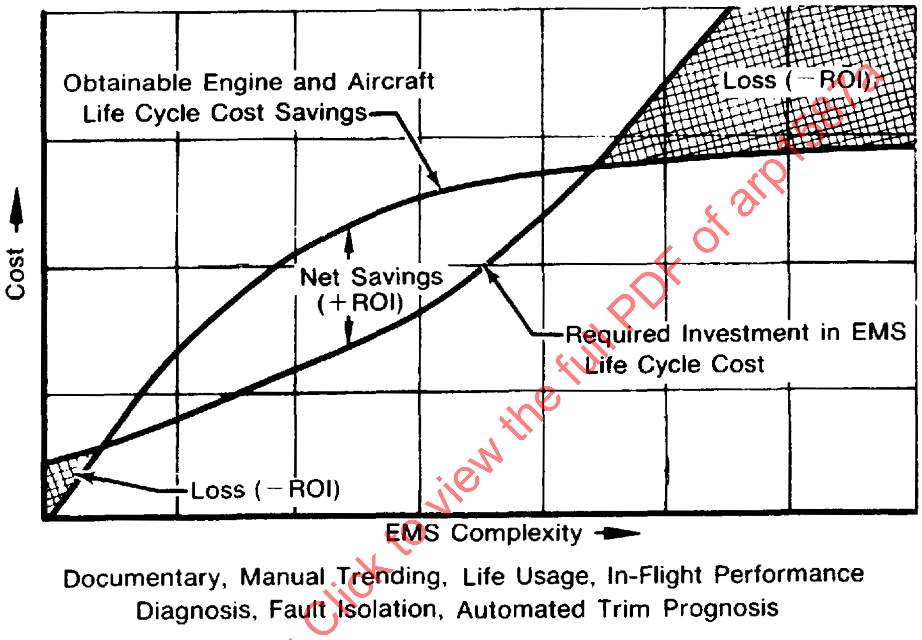


FIGURE 4 - EMS Complexity Impacts Return on Investment (ROI)

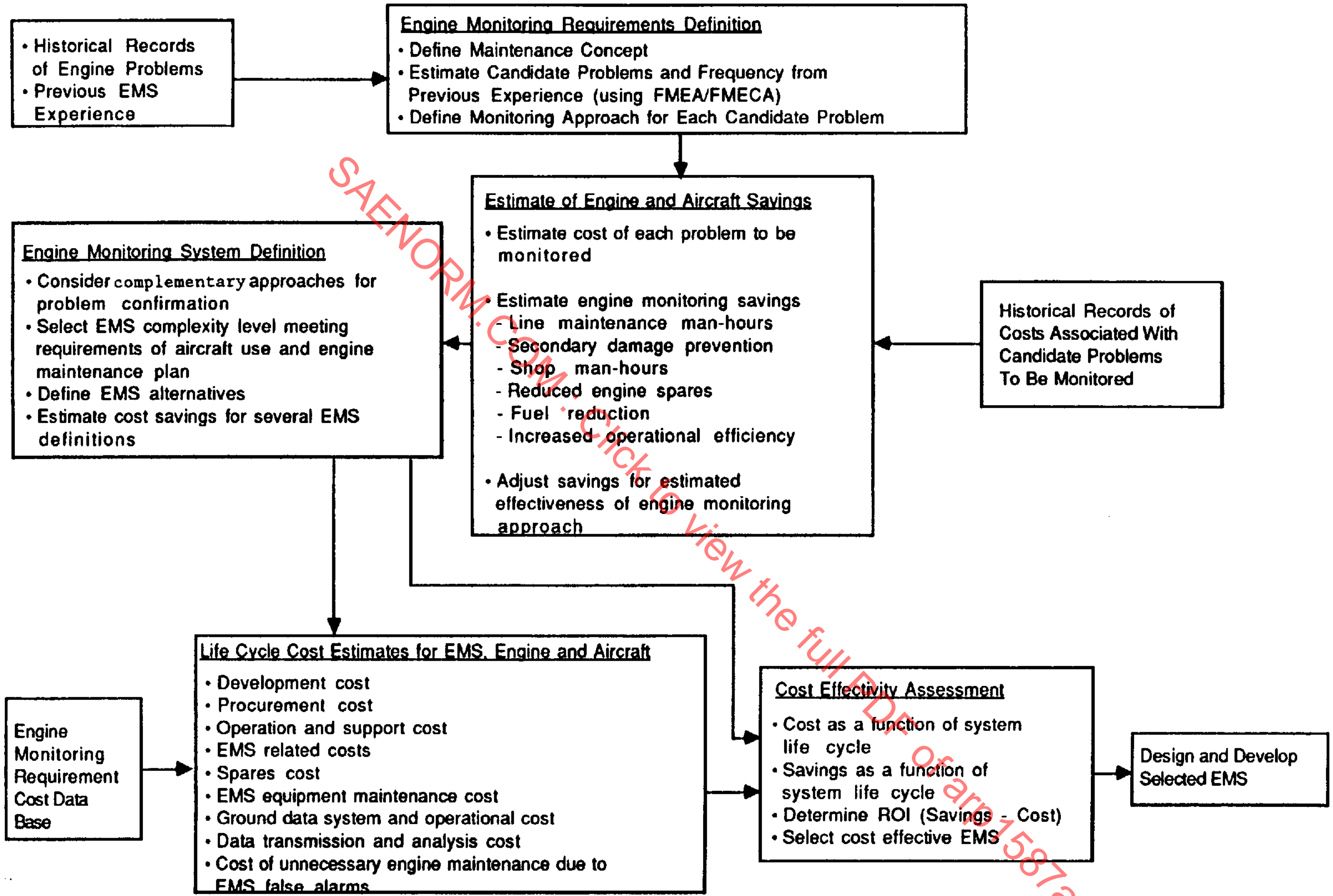


FIGURE 5 - Methodology for Defining an EMS

6.1.1 (Continued):

EMS definition requirements include:

a. Determining maintenance concepts for the engine

b. Identifying engine problems from historical and predicted data (FMECA)

c. Selecting projected benefits (Section 4) and desired capabilities (Section 5) to define an EMS

d. Analyzing how an EMS will benefit the engine maintenance concept

e. Establishing desired level of engine monitoring to meet user needs

f. Assuring personnel and material resources are available to support the selected EMS

g. Establishing ground processing capability to support an EMS in a timely manner

h. Studying the availability of air-to-ground data link

i. Defining complex support equipment for EMS maintenance

j. Establishing software requirements (see 6.6.2) needed for both on-board and ground-based equipment

EMS equipment selection should follow cost benefit analyses guidelines of 6.4. These analyses should include costs of program Phases I through V.

System definition of EMS equipment should consider:

a. Alternative configurations that meet engine monitoring requirements

   (1) On-board equipment (see 6.6.1.1)
   (2) Data transfer equipment
   (3) Ground equipment (see 6.6.1.2)

b. Growth capabilities to support enhanced algorithm and advanced technologies (e.g., neural networks) integration

c. Ground support equipment needed for maintaining on-board and ground-based equipment

d. Fault tolerance of system components

e. Manpower requirements to operate and maintain equipment including data retrieval, processing, analysis and distribution

6.1.2 Prototype Development and Qualification (Phase II): Hardware/software is designed and developed during Phase II. Completion of Phase II requires that:

a. The EMS has been successfully assembled and tested. Individual hardware components,software modules and system testing will be accomplished both off and on an engine. For new applications, hardware/software development should be accomplished along with engine development testing. For retrofit of in-service aircraft, similar design and development activities must be performed usually without the benefit of significant factory tests.

b. The EMS design must demonstrate established performance criteria before it is considered ready for transition to Phase III, System Integration and Flight Test.

EMS design and development should include, as a minimum:

a. Algorithm development and validation through system modelling or sensitivity analysis
b. Engine mounted hardware
c. Airframe mounted hardware
d. Ground system and download/data link
e. All system software including integration, documentation and validation
f. Fault isolation manual (FIM) leading to T.O.'s/Repair Manuals
g. All interface/data bus definition and demonstration
h. User manuals (airborne and ground system)
i. Qualification tests
j. Supportability documentation

6.1.3 System Integration and Flight Test (Phase III): The System integration and flight test phase provides for the installation and initial field design evaluation of the EMS which is required to verify that the EMS is ready to proceed to Phase IV, Operational Evaluation. Once again as complete an EMS as possible should be run as a part of all flight tests and should include validation of ground software and fault isolation manuals.

Recognizing that the EMS is an integral part of the aircraft system, it must be up and running to detect events at all times during the flight test phase. Flight test data should be evaluated to determine effect of sensor repeatability and drift. Diagnostic threshholds and sensitivity to spurious electronic noise and transient inputs should be established.

EMS software "fine tuning" should be accomplished by continuing assessment of engine monitoring logic and limits during Phase III.

System integration and flight test requirements include:

a. Avionics system integration tests
b. Installed ground tests
c. Software effectiveness validation and modification
d. Integration with engine maintenance and logistics programs

6.1.3 (Continued):

e. Establishment of personnel skills required to operate system
f. Initial evaluation of FIM and troubleshooting procedures

6.1.4 Operational Evaluation (Phase IV): The operational evaluation program phase demonstrates EMS performance in the user environment. It is a functional test and operational evaluation of EMS capabilities and benefits. Operational evaluation data require detailed analyses, with criteria for measuring EMS effectiveness to assure user confidence in Phase IV results.

Tasks required to perform an Operational Evaluation include:

a. Evaluation group assignment
b. Required personnel skills validation
c. Software enhancement and configuration management
d. Maintenance benefits assessment
e. Mission and operational effectiveness
f. Engine condition and EMS output correlation
g. EMS hardware reliability assessment and improvement
h. Maintenance and logistic support documents evaluation
i. Baseline production configuration and integrated maintenance concept recommendation

6.1.5 Production Introduction (Phase V): A detailed plan should be developed for incorporating the baseline configuration into production.

Considerations for hardware and software prior to production introduction include:

a. System documentation
b. Configuration control
c. Quality assurance procedures
d. Long lead time procurement
e. Product support programs
f. Training

6.2 Responsibility Requirements:

An overall program manager should be identified to establish the requirements of an EMS program to meet user needs. A coordinated approach is required between EMS participants to develop an effective system which is affordable and supports the users maintenance concept. Total quality management and/or continuous improvement philosophies can be used to great advantage in the design and development of such a system.

The program manager has prime responsibility for defining the design options and performance tradeoffs so that the user can participate in selecting the EMS which meets their need.

6.2 (Continued):

EMS requirements should be specified by a team composed of the program manager, airframe manufacturer, engine producer, equipment supplier, and the user. The user will define top level system requirements, e.g., availability, fault isolation, etc., and the other team members are responsible for defining system interfaces and component level capabilities required to achieve this goal. The value of an EMS rests in how effectively it collects and processes data, draws conclusions, and presents information for use by decision makers. The user's support is, therefore, required to define the desired format and output from an EMS. The user will often have requirements from a number of different departments - all of which must be addressed by the team members.

6.2.1 System Integration:

6.2.1.1 Coordination: Coordination is required among all EMS participants: equipment suppliers (often more than one), engine producers, aircraft manufacturers, and commercial and government users. Since many EMS coordination requirements can be performed by more than one EMS participant, it is essential that each EMS participant establish and concur with coordination arrangements.

6.2.1.2 Human Factors: The success of an EMS is dependent upon its acceptance by user personnel. The EMS user should be involved in definition of EMS data presentation formats. Ground-based systems should provide the capability for more detailed displays and more thorough analyses depending on the skill level and needs of the user.

The use of EMS data for personnel monitoring should be limited to significant and constructive criticism, e.g., safety, training.

6.2.1.3 Interfaces: EMS interfaces can include engine/aircraft, aircraft/ground and ground base/central processing station. An EMS should interface with existing maintenance programs including:

a. Engine maintenance data collection system, e.g., scheduled and unscheduled removals, shop findings, bench checks and reliability reports

b. Performance tracking of in-service propulsion systems

c. Configuration management programs for changing aircraft and engine due to design and maintenance procedures

As part of the engine management program, an EMS should interface with each level of engine maintenance. Typical examples include:

a. Level 1: Line, field or organizational maintenance performs turn-around checks and servicing, identifies potential problems, provides minor repairs, LRU removal and replacement and engine change

6.2.1.3 (Continued):

b. Level 2: Intermediate or support maintenance changes engine modules and incorporates minor changes and modifications

c. Level 3: Depot, repair facility or overhaul maintenance tears down, overhauls and rebuilds engines, engine modules and components, and incorporates major changes and modifications

6.2.2 User and Supplier Responsibility: The following identifies general areas of responsibilities among the participants who develop, supply, and use an EMS. It is essential that responsibilities are clearly defined since omissions can cause serious problems and delays.

6.2.2.1 System Requirements: The EMS user has the responsibility for defining top level system requirements. The aircraft manufacturers, the engine producer and the equipment suppliers have the responsibility for defining the impact of these requirements. For general aviation and small operators, the aircraft manufacturer may assume the responsibilities of the user.

6.2.2.2 Parameter Selection: The engine producer has prime responsibility for selecting the parameters to meet the desired functional requirements established by the EMS user.

6.2.2.3 Engine Sensors: The engine producer has prime responsibility for selecting and qualifying engine supplied sensors to meet EMS functional requirements (Ref AIR 1900). The aircraft manufacturer is responsible for the QEC (Quick Engine Change) package. Equipment supplier(s) responsibilities can include engine sensor signal conditioning. The engine producer and aircraft manufacturer have responsibility for the accessibility of engine installed EMS components.

6.2.2.4 Aircraft Sensors: The aircraft manufacturer has prime responsibility for providing aircraft signals required by an EMS. The engine producer provides requirements to support this activity. The equipment supplier(s) must be informed and can be responsible for special signal conditioning requirements.

6.2.2.5 Manual Inputs Provisions: Manual inputs should be coordinated between EMS participants. The user should define manual input requirements. The engine producer should provide manual input requirements in support of their algorithms.

6.2.2.6 Logic and Software: Engine monitoring logic and software has and continues to be implemented in a variety of ways depending on user needs and what is delivered with the engine. The engine producer should have prime responsibility for identifying, developing, and supplying diagnostic and fault detection logic necessary to meet user EMS requirements. As an additional service, the engine producer may provide software services to implement this logic.

6.2.2.6 (Continued):

EMS logic and software can be supplied by equipment suppliers. Aircraft manufacturers and users also can develop and supply additional software and algorithms for specific EMS data handling tasks. The following further delineates responsibilities for EMS software programs and algorithms:

a. Operating Executive Program

(1) Executive software is normally provided by the equipment supplier and can be within the engine control, on the engine, on the aircraft or on the ground

b. Application Programs

(1) Engine algorithms and data analysis programs should be developed, supported, and maintained by the engine producer. Standard interfaces should be defined between the applications and the executive software to facilitate the integration of these applications. In some cases, the equipment supplier can use information from the engine producer to generate algorithms and develop a data analysis program.

(2) New installations and changes to engine monitoring application programs should be reviewed and developed by the engine producer and EMS user. EMS program revisions by the user without the written consent of the aircraft manufacturer, engine producer and equipment supplier should be discouraged.

c. Output Format Program

(1) On-board: The user should define requirements and the equipment supplier should develop the program.

(2) Ground Station: The user should define requirements and either the user or equipment supplier should develop the program. It is most desirable that the ground software provide the user with a flexible output system that allows user modification to meet specific needs.

6.2.2.7 Aircraft Avionics: Requirements for aircraft avionics which influence EMS interfaces should be coordinated between user, aircraft manufacturers, engine producer, and equipment supplier(s).

The equipment supplier should be responsible for developing and supplying hardware. For new aircraft and engines the aircraft manufacturer should provide installation requirements, contracting specifications, and test demonstrations. For retrofit aircraft and engines, the EMS user should provide installation requirements, contracting specifications, and test demonstrations.

6.3 Design Considerations:

An EMS design requires consideration of the following:

a. User objectives
b. Parameter selection and accuracy measurement
c. EMS capabilities and benefits
d. Engine reliability and maintainability analyses including failure mode, effects and criticality analysis
e. Payback due to enhanced engine maintenance practices
f. Algorithm sensitivity analysis through the use of models
g. Manual and computer aided provisions
h. Weights and envelope
i. Engine/EMS safety and hazard analyses
j. Installation compatibility
k. Power requirements and sensitivity to power spikes and interruptions
l. Engine historical data
m. EMS life cycle cost analyses
n. Human factors
o. Engine maintenance and logistics
p. System growth capacity
q. Available resources
r. Data bus interfaces
s. EMS support requirements

6.3.1 Engine Maintenance Management Plan: The engine maintenance management concept affects EMS requirements. A plan should be established covering the maintenance management information required to support the engine during its operational life. Categories of engine monitoring and related parameters include:

a. Mission Usage: Parameters required to provide a mission profile for computation of engine component lives may be specified. This requirement may only be needed for a statistically significant number of engines in the fleet. Provisions for acquiring and processing this information must be addressed.

b. Parts Tracking: Parameters should be specified (e.g., engine speeds, temperatures, pressures, time) for counting life usage indices on all engines. These life usage indices are then used for life limited parts life tracking on the ground. Maintaining an accurate engine/parts configuration is also essential to the success of a Parts Life Tracking System.

c. Operational Maintenance: Parameters to provide fault detection, diagnosis and isolation of engine modules and components to desired maintenance levels based on wearout or failure should be specified. Fault isolation to the engine LRU, module or lower (more detailed) level might be required as indicated by failure modes and effects criticality analysis.

6.3.1 (Continued):

d. Performance: Parameters (primarily gas path related) should be specified to be acquired manually or automatically for ground analysis to provide overall engine performance and deterioration trends. First level performance parameters should indicate overall engine health and may include a recommendation for engine removal. Second level performance parameters are used to isolate deterioration to engine modules and require an expanded sensor complement. Second level performance parameters might be obtained in a test cell with ground test instrumentation or in flight with a more sophisticated on-board acquisition system and additional sensors.

6.3.2 EMS Analyses and Constraints: An existing or projected aircraft and engine maintenance concept definition is required for EMS design purposes. After an EMS design is formulated, it requires a conceptual integration into the existing or projected aircraft and engine maintenance concept such that methodologies can be applied to determine EMS cost and benefit trades.

Analyses are required to define engine subsystems and components to be monitored. This effort should start with historical records of problems previously experienced on similar engines used for the application under consideration. Failure modes and criticality analyses, test equipment analyses and maintainability type analyses are important to EMS design considerations.

Constraints should be considered with EMS trades. Constraints frequently determine boundary conditions that limit the use of an EMS and should limit its design, e.g., existing or projected organizational constraints can limit available skill levels at different levels of engine maintenance while finite resources (people, equipment, funds) can limit a timely application of EMS.

6.4 Cost Benefit Analysis:

Aircraft and engine life cycle costs (LCC) for various EMS configurations, with different benefit savings for a specific engine application, allow iterative cost benefit trade-offs analyses to be performed. Too much or too little EMS complexity can prevent achievement of LCC savings, Figure 4. An analysis criterion is to maximize ROI by matching an appropriate EMS to a particular set of projected cost savings. There should be a convergence through the cost benefit trade-off analyses toward a preferred EMS that meets user requirements.

The objective of the cost benefit trade-off analyses is to determine levels and methods of implementation of engine monitoring that are cost effective, Figure 5. Typically, EMS savings are not realized until after the engine is operational and its design and development are completed, Figure 6. Cost benefit trade-off analyses require a comparison between two major cost elements:

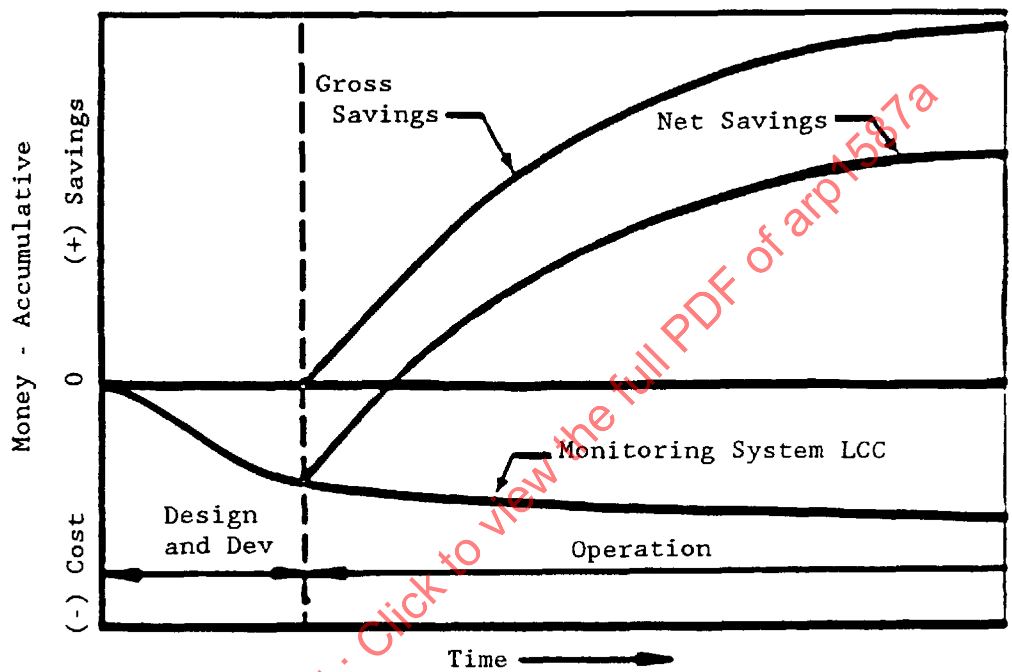


FIGURE 6 - Typical EMS Cost Benefit Analysis Results

6.4 (Continued):

a. Life cycle cost (LCC) of the aircraft and engine
b. LCC and savings attributable to the implementation of an EMS

Return on investment (ROI) is an underlying justification for an EMS. Labor and material EMS cost should be identified, projected, and tracked to assess ROI benefits. Benefits, such as improved aircraft safety, availability and engine part scheduling, should be included and can be weighted for emphasis.

The main elements of a cost benefit analysis will be the beneficial impact of the EMS on engine maintenance (manhours, aircraft availability, etc.) and parts consumption due to variations in the life usage of life limited components. For an established engine, it should be possible to derive the maintenance benefits from historical data and, therefore, the savings can be calculated with reasonable confidence by the LCC model. However, life usage distributions can vary significantly, particularly among a fleet of military fighter aircraft, and, therefore, without an existing EMS life usage database the assumptions used in the LCC model are unlikely to produce accurate predictions of parts consumption. This situation also applies to new engines where there is no historical data at all, in which case the LCC model must be entirely based on theoretical assumptions.

6.4.1 Costs: Life cycle cost elements of an EMS are similar to those of other aircraft or engine systems, and include:

a. Development costs
b. Production costs
c. Operational and support (O&S) costs

Development EMS costs include:

a. Requirements definition
b. Design
c. Development
d. Qualification

Production EMS costs include:

a. Aircraft and engine EMS hardware, including spares
b. EMS ground support and data processing equipment

Operational and support EMS costs include:

a. Maintenance labor and material including component replacement or repair
b. Fuel consumed due to the weight of engine monitoring hardware
c. Labor and material for transmission, processing and analysis of EMS data
d. Cost of unnecessary engine maintenance due to EMS false alarms
e. Software maintenance and enhancements

6.4.2 Benefits: Knowledge of system benefits is required for EMS cost benefit analyses. Section 4 presents projected EMS benefits. These benefits should be quantified to estimate and determine EMS savings. Analyses of EMS benefits should consider:

a. Projected reduction in maintenance manhours per flight hour
b. Fuel savings through reduction of ground test runs
c. Fuel savings through recognition of inefficient degraded engines
d. Time savings through confirming pilot reports and maintenance repair actions
e. Time saving by fault isolation to specified malfunction
f. Reduction in required spare parts through elimination of unnecessary repairs
g. Reduction in unnecessary engine and component removals
h. Engine hardware savings by increased engine and module availability
i. Reduction in down time
j. Early identification of unexpected fleet deterioration
k. Reduction in secondary engine damage through removal and replacement of defective parts prior to catastrophic failure
l. Fewer mission aborts
m. Ability to predict and schedule future maintenance
n. Clearer identification of fault and corrective action

6.5 General Requirements:

The following EMS general requirements apply to most aircraft gas turbine engine applications:

6.5.1 Effectiveness Evaluation: An evaluation to assess the effectiveness of the development, production, and operation of an EMS is desirable but difficult. Overall system effectiveness can be measured by observing and projecting the impact of an EMS upon user established parameters. Hand calculations, computer simulations, ground and flight tests, and operational records are sources of estimates and data for EMS effectiveness evaluations. Examples of effectiveness indices include:

a. Maintenance manhours per flight hour
b. Aircraft and engine readiness
c. Number of departure delays
d. Engine removal rate
e. Turnaround time
f. Repair actions at each maintenance level
g. Material cost per repair action
h. Time between removals
i. Engine mean time between failures
j. EMS mean time between failures
k. EMS maintenance manhours per flight hour
l. False fault rate
m. Engine parts inventory volume

6.5.1 (Continued):

Effectiveness indices frequently are normalized and can provide additional EMS effectiveness assessments, e.g., percent mission completion, percent aircraft availability.

An example of evaluation factors for on-board EMS equipment is shown in Figure 7. This example applies to on-board equipment that provide a GO/NO GO engine status indication at the end of each flight for items specifically monitored. Similar factors can be developed for other EMS equipment and procedures. Since the EMS incorporates BITE, then the EMS itself becomes one of the monitored systems, i.e., success or failure in detecting engine faults. Typical evaluation factors for on-board EMS equipment can be defined as follows:

1. GOOD (correct assessment): The on-board EMS equipment indicates a correct assessment of no engine discrepancy and the engine is operational and capable of making a subsequent flight without maintenance (on-board EMS engine status indicator GO).

   (a) The crew or support personnel along with the EMS did not note any discrepancies that would prohibit a subsequent flight.

   (b) The crew or support personnel report a discrepancy that on-board EMS equipment is programmed to detect; however, no problem is indicated. The engine discrepancy reported by the crew or support personnel is found to be not engine related and is unconfirmed by subsequent troubleshooting.

2. HIT (correct assessment): An engine discrepancy has occurred and is correctly identified by on-board EMS equipment (on-board EMS engine status indicator NO GO).

   (a) On-board EMS equipment alone correctly detects an engine discrepancy which requires immediate corrective maintenance action.

   (b) On-board EMS equipment along with the crew or support personnel detects an engine discrepancy which requires corrective maintenance action.

   (c) On-board EMS equipment correctly identifies an engine discrepancy (usually a limit exceedance), but severity and duration of the problem does not warrant immediate maintenance action based upon a judgment decision by authorized personnel. Such discrepancies can be designated "precautionary" or "watch" items.

3. MISS (incorrect assessment): On-board EMS equipment indicates no engine discrepancy even though a discrepancy which should be recognized did occur. The engine discrepancy is reported by other means. Verification of the discrepancy is a prerequisite to confirm a MISS and in some cases requires suspect component inspection and teardown (on-board EMS engine status indicator GO).

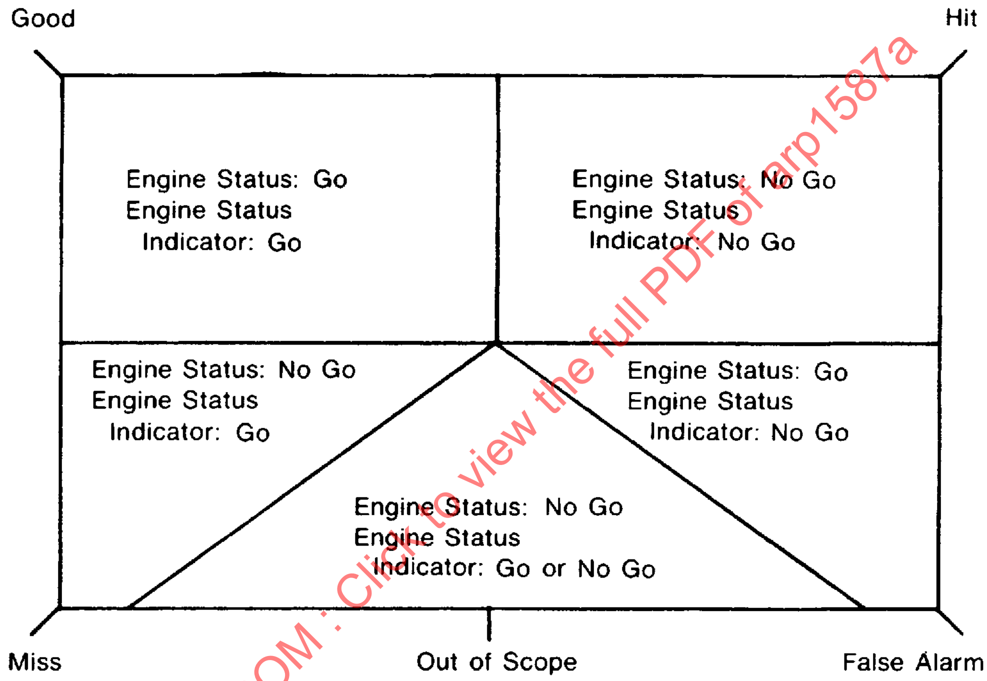


FIGURE 7 - Evaluation Categories
(Example for On-Board EMS Equipment

6.5.1 (Continued):

4. FALSE ALARM (incorrect assessment): On-board EMS equipment incorrectly indicates an engine discrepancy when none has occurred. Verification of engine GO status is made by other than EMS means and in some cases requires suspect component inspection and teardown (on-board EMS engine status indicator NO GO).

5. OUT OF SCOPE: An engine discrepancy has occurred, but is not being monitored by on-board EMS equipment (on-board EMS engine status indicator GO or NO GO).

All engine discrepancies fall into categories 2, 3, or 5. The ratio of each category to the total number of flights provides a measure of on-board EMS equipment effectiveness. The number of out of scope incidents should be considered by the evaluation so that design limitations do not unduly bias an assessment of on-board EMS equipment and future design scopes can be influenced.

Fault detection success ratios include the following shown in Table 2:

TABLE 2

Success Ratios	Ideal Goals
$\frac{\text{Good + Hits}}{\text{Total Flights}}$	Approaching 100%
$\frac{\text{Misses}}{\text{Total Flights}}$	Approaching 0%
$\frac{\text{False Alarms}}{\text{Total Flights}}$	Approaching 0%
$\frac{\text{Out of Scopes}}{\text{Total Flights}}$	Approaching 0%

EMS fault detection ratios are cumulative values for the time interval of the effectiveness evaluation. Results of an EMS fault detection effectiveness evaluation should be compared to previous calculated estimates and test data. Consideration should be given to relating the contribution of EMS fault detection effectiveness to other aircraft and engine effectiveness parameters. These results can be used to quantify an EMS's contribution to safety and increased engine and aircraft availability and reliability with reduced cost of ownership (see 6.4).

6.5.2 Configuration Identification: Labeling of EMS hardware and software, data, instructions and procedures is required.

6.5.3 Engine Stations and Symbols: SAE ARP755 is recommended for consistent engine station identification and related symbol usage (see 2.2.1).

6.5.4 Power Protection Provisions: Power interrupt, power down and power polarity EMS protection is required. Occurrence of power interrupts should be flagged.

6.5.5 Self-Check: An EMS, in addition to monitoring the engine should also monitor itself through built in test. Manual, computer aided and automated EMS checkout and substantiation requirements are necessary. A backup plan for EMS failures is recommended (see 6.5.8).

6.5.6 Configuration Control: Effective hardware and software configuration control is essential for a successful EMS. EMS configuration management procedures for on-board and ground hardware and software updates are required. Revision instruction procedures for EMS personnel also are required.

EMS revisions by the user without written consent of the aircraft manufacturer, engine producer and equipment supplier are strongly discouraged and will be the responsibility of the user. Revision procedures should be consistent with EMS identification and configuration control provisions (see 6.5.2).

6.5.7 Options and Customized Provisions: Requirements for EMS options should be considered. Customized EMS provisions require additional consideration and coordination with EMS participants.

6.5.8 Backup Plan for EMS Failures: A backup plan should be developed to account for EMS failures. Development of the back-up plan is essential if engine monitoring integrity and engine usage history are to be maintained. Fall back provisions can include a cycle count based on engine hours, data from another engine or manual input based on crew records or operational experience.

6.5.9 Documentation: Documentation of manual, computer aided and automated EMS hardware and software is required with associated EMS personnel instructions, procedures and user manuals. Electronic EMS user manuals for laptop or other computers should be considered if desired by the customer. Menu driven user aids for software installation, interpretation and other functions should also be considered.

User Manuals should be prepared and delivered to the EMS user. The User Manuals should include a description of on-board, on-site and remote (off-site) interactions between EMS personnel and equipment and computer programs.

User Manual content is normally defined by contract, but a suggested format follows:

1. Introduction

2. Table of Contents

6.5.9 (Continued):

3. Engine Description: A general description of the engine(s) being monitored by the EMS should be provided. This description should include the type of engine(s) and engine configuration(s) with performance and operational characteristics. The engine description should be sufficient for user understanding required to achieve EMS objectives.

4. Hardware Description: A general description of EMS hardware and its interfaces should be provided.

5. Software Description: A general description of EMS software and its interfaces should be provided.

6. System Description: A general system description of EMS personnel instructions should be provided. The system description should include a flow chart definition of organizational relationships of personnel and equipment required for EMS operation. This section also should describe provisions for engine management, maintenance and monitoring and should delineate EMS functional support of these engine provisions.

7. Hardware Installation and Operation: User personnel instructions and information needed to operate EMS hardware should be provided. This section also should describe tests that the supplier provides for hardware checkout by the user.

8. Software Installation and Operation: User personnel instructions and information needed to operate EMS software should be provided. Sufficient information to install the computer program(s) should be provided with instructions for modification of software limits and coefficients if user modifiable.

9. Inputs/Outputs and Messages: This section should describe each EMS input and output in sufficient detail to avoid ambiguity and should list the units of all input and output parameters. This section also should list and explain each EMS fault message.

10. Options: This section should enable the user to better understand the full capabilities of the EMS and should describe specific EMS options, limitations and other features.

11. Interpretation of Data: This section should provide guidance to the user on how to interpret data gathered by an EMS and, in particular, the interpretation of trends. This is the most difficult and usually requires fine tuning as experience is accrued.

6.5.9 (Continued):

12. Identification, Configuration Control and Revision Provisions: An EMS hardware parts list (if not included in the engine parts list) and an EMS software programs list (Version Description Document) should be provided. EMS identification, configuration control and revision provisions should be delineated. User Manual update provisions also should be included in this section.

13. Nomenclature: This section should include terminology, definitions and other information required to understand the EMS and its User Manual.

14. References: This section should include a listing of background documents used in the preparation of the EMS User Manual.

6.6 Hardware and Software Requirements:

An EMS can be configured with various degrees of manual, computer aided or automated hardware and software capabilities to meet different user requirements. Allocation of hardware and software requirements can vary with respect to installed aircraft systems and ground based, on-site and remote operating system elements (Figures 8 and 9). Equipment should be designed to meet applicable on-board and ground base environmental and functional requirements. The ruggedness of the equipment should reflect the selected installation environment, e.g., engine, nacelle, pylon or avionics bay.

Trade studies must be performed for each application to determine the optimum partitioning of hardware and software not only within the on-board system, but also between airborne and ground functions. The presence or absence of engine digital electronic controls and/or other avionic systems together with aircraft data bus interface requirements will strongly influence these decisions. Early on-board monitoring systems obtained input from cockpit signals and were stand-alone, often add-on devices. The demand for more, usually performance, information required sensors and equipment being added solely for monitoring purposes. The advent of electrical and/or digital control systems results in much more information being available in digital form at the airframe interface with fewer unique monitoring sensors being added. Data acquisition, event recognition, and fault diagnosis are performed either in unique monitoring equipment, or within an airframe maintenance computer system, or within the engine control itself, or in a combination of the above. Lessons learned from previous programs should be factored into new systems (see AIR1871).

Required EMS parameters are a function of engine complexity, the level of monitoring required and the engine maintenance plan. Figure 10 presents a typical minimum EMS parameter list. The EMS parameter list can be more or less extensive, e.g., multiengine and single engine aircraft. The parameter list can be different for different applications, e.g., helicopter engine parameters such as torque and power turbine speed (see ARP1217).

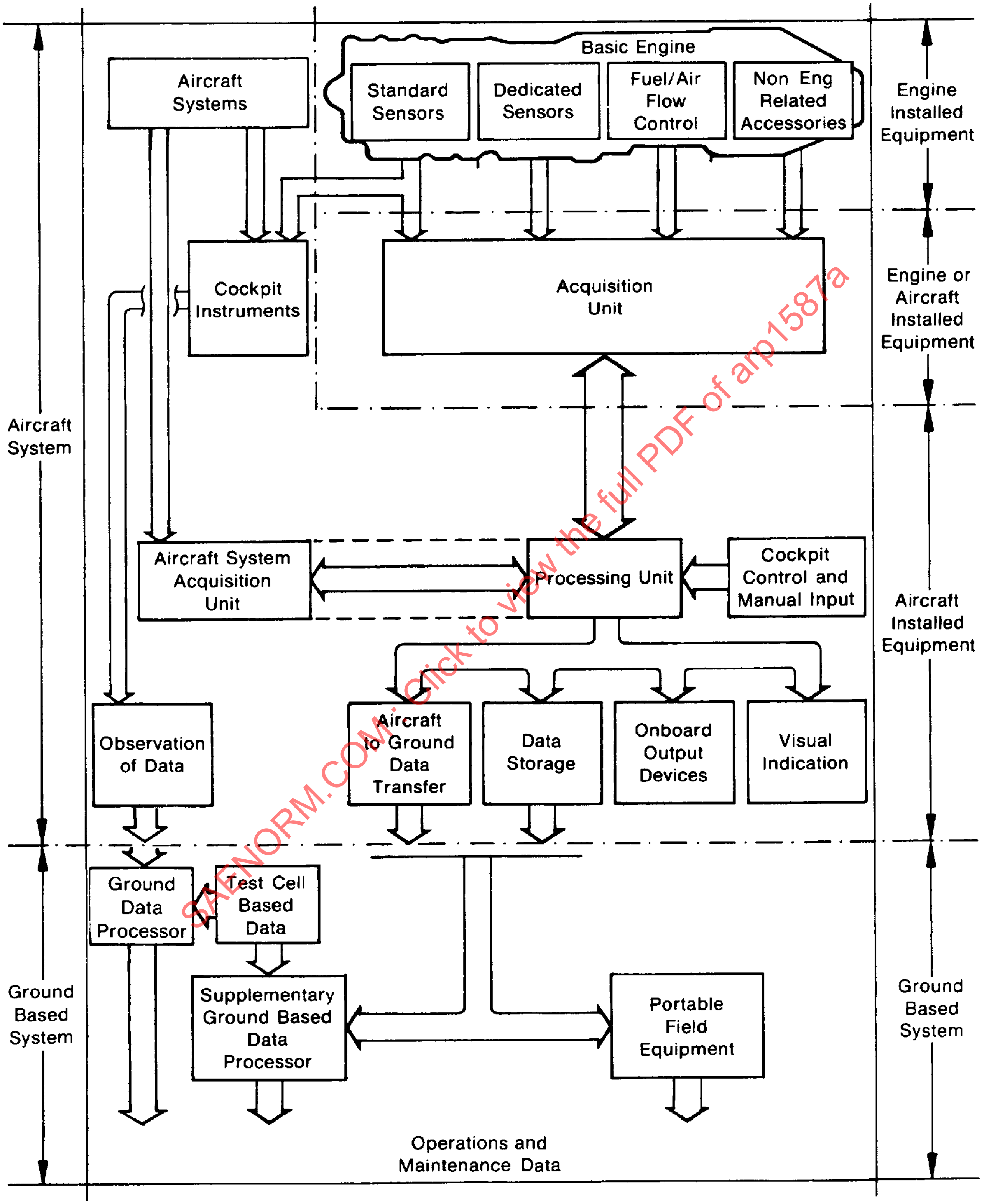


FIGURE 8 - Typical EMS Architecture