WHO NEEDS ENGINE MONITORING?

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ABSTRACT

The requirement for Engine Monitoring Systems (EMS) is elusive even for its advocates. Decisions not to invest large sums of up front money in equipment which will be of uncertain value are easily made by conscientious program managers. Even as on-condition maintenance (OCM) is being established as the desired approach in the Air Force, many people in the decision chain doubt the potential value of on-board engine monitoring equipment.

EMS advocates have not provided convincing answers to many hard questions, some of which are: "Should the EMS capability provide on-board GO-NO-GO information? How much engine monitoring is enough? What parameters are required? How will the EMS capability be used to direct maintenance actions? Does the environment require only engine parts tracking, engine usage, or performance trending data?" Answers may not have uncontested technical support but may require judgement based on something like Pareto's 80-20 law applied to operational data.

The true EMS values are certain only in the future operational environments. The EMS advocates' problems are to find for the system managers acceptable up front rationalization for the added EMS cost. Past operational evaluations of a few EMS units for short periods have not all produced convincing results. This presentation will discuss these evaluations and their lessons learned, then review the options for each required EMS phase, and close with a review of the guidance being provided for EMS on new systems.

COST TRENDS

Table I shows the maintenance cost of flying various Air Force engines for thousand engine flight hours. The maintenance cost are in 1980 dollars. In most cases, these costs equal or exceed the acquisition cost for that engine. The acquisition costs shown are first production contract costs in then year dollars. For a true comparison, the earlier engine cost would be corrected for inflation. From these numbers, the throwaway engine might not be such a bad concept, especially when you remember that with increasing engine age performance deteriorates and engine service life between repair shortens. Maintenance manhour per flight hour on the newer engines is also increasing to some very high numbers.

FAILURES

Failures result from wear, leaks, structural damage and human error. There are many things which influence operating time before engine failure. An Engine Monitoring System (EMS) provides a data base from which failures can be predicted, detected, and diagnosed early, before there is a loss in mission capability.

IMPORTANCE OF VIEWPOINT

The viewpoint from which an individual looks on things has a large influence on what he is able to see. This is illustrated by the old saying that "A jackass on a hill can see more than a genius in a valley."

An EMS is more than black boxes full of electronic circuits. The people who look at an engine monitoring system as the black boxes might be considered the genius in the valley. In the total system view, EMS is the executive control system which tells the maintenance supervisor that an individual engine requires diagnostic work to find out why it is abnormal. The EMS data function is similar to the blood pressure check performed by the doctor. If he finds any abnormalities in blood pressure he runs other diagnostic tests to determine what is causing you to be abnormal.

REQUIRED TASKS

Figure 1 illustrates the data flow in an EMS. Data can be obtained in ways ranging from a manual recording of cockpit instrument readings to sophisticated complete electronic systems which automatically records, stores, and transfers the data to ground computers. Airborn engine monitoring system electronics often have decision logic to determine engine status as soon as the aircraft lands. Airplanes with two pilots and mission requirements for a cruise leg are generally able to use manual recording. On single pilot aircraft work load generally prevents the use of manual recording. The ability to get in-flight engine performance is the missing piece for single pilot fighter aircraft. Therefore, current thrust in developing EMS capability is improvement of in-flight data acquisition ability.

Before the in-flight data can be used to predict, detect and diagnose failures, it must be validated, corrected, compressed, displayed, and then interpreted. There are a number of ways of interpreting. The status of engines can be obtained from the data by limit exceedence or by observing trends. The important results from an EMS is the effect of the information on the maintenance system. If we only gather the data, and look at the data, and do not use it to direct maintenance, EMS is of little value to the total system.

WHY OCM

In February 1974, the Department of Defense gave the following logistics and material support guidance:

1. Establish engine maintenance policies to eliminate maximum operating time.

2. Exploit modular designs in new engines.

3. Use on-condition maintenance techniques.

4. Apply to existing engine types wherever practicable.

With the on-condition maintenance you need a methodology to tell you what the existing condition is within the engine so you can schedule it for maintenance. Figure 2 illustrates why on-condition maintenance has an advantage. It can reduce risk and save dollars.

Engine usage varies by the mission being flown. For example, a fighter aircraft on a low-level mission flying at 600 knots, Mach .95, would have its inlet pressure increased by a factor of 1.8. On the low-level mission, the engine with a 20 to 1 compression ratio would have a combustor case pressure of 36 atmospheres. On the other hand, an intercept mission which cruises out at 30,000 feet MSL would only see 12 atmospheres combustor case pressure. The cruise engine obviously is capable of operating more hours before failure because of the less stressful usage. If maintenance is driven by maximum operating time, the additional operating capability of an engine used at the lower rate will not be utilized. If the condition of each engine determines when it must be repaired, then the full engine capability can safely be used.

AIR FORCE EMS PROGRAMS

Air Force EMS programs are divided into three categories: (1) developed with aircraft, (2) contract maintenance, and (3) add-ons to operational aircraft. See Table II for a listing of EMS developed with aircraft.

MRS is a Maintenance Recording System that is applied on the SR71 with a J58 engine. It is an analog recorder that gives a continuous trace of the engine operating parameters throughout that mission. It has an approximately 1100 hours meantime between failure (MTBF), and is considered a successful EMS system. Its data is automatically acquired and formatted with manual interpretation by a technician rolling the strip chart and looking at total trace for each sortie. That strip chart may be 8 to 10 feet long for a sortie. The interpretation of the analog traces is a disadvantage on this system.

The Malfunction Detection Analysis and Recording System (MADARS) was built and developed with the C-5 aircraft. It automatically acquires and formats the data. Interpretation is both manual and automatic. Logis is proved to print out the maintenance action required in many cases. A shortcoming of MADARS is an overall system MTBF. MADARS monitors all aircraft systems. The MTBF for the engine portion of the MADARS which provides engine data is approximately 100 hours.

The Central Integrated Test System (CITS) is another system designed to monitor the total airplane as well as the engine; it has been tested on the four B-1's during their Category I & II flight tests. It is rather complex and there are some differences of opinion on its real potential benefit to the operational weapons system.

The two systems at the bottom of the figure, Events History Recorder (EHR) and Engine Time Temperature Record (ETTR), are different in that they record usage more than they record the traditional performance monitoring parameters. The ETTR infers engine health from counters that pick up the amount of time above a certain temperature and the speed cycles on the engine in terms of core engine speed. This information allows low cycle fatigue tracking. The operational units have some problem of short meantimes between failure. The EHR runs about 600 hours and the ETTR runs about 2500 hours.

Contract maintenance is used on systems with only a few aircraft. Under this approach, the Air Force uses the aircraft and asks the aircraft company to provide all of the support away from the flight line. The maintenance approach used by the Air Force is a threefold approach: flight line, intermediate, and depot maintenance.

Flight line maintenance does remove and replace activities, as well as servicing. The intermediate maintenance shop located at the base does minor overhaul work. The major overhaul facilities does the complete overhaul. In the contracted approach, the contractor provides the intermediate and the depot maintenance.

Contract maintenance systems have a Contractor Operated and Managed Based Supply system (COMBS) at each base operating the type aircraft. Blue suit, flight line maintenance personnel go to the COMBS facility which provides a replacement part over-the-counter. See Table III for a summary of USAF contract maintenance programs.

The T-43 aircraft uses a flight log engine monitoring program with manual data acquisition, automatic computer formatting and both automatic and manual interpretation. The C-9 uses ground trim data from routine ground runs as a basis for determining engine conditions. From the Air Force standpoint, both of these programs are still fairly new. The T-43 is just now reaching the first overhaul on the engines. The KC-10, also contract maintenance, will use flight deck monitoring with manual acquisition, automatic formatting and manual interpreting of the data. The E-4, which is the SAC Command and Control airplane, also uses flight deck monitoring, with manual recording, automatic formatting and manual interpretation.

EMS EXPERIENCE

These applications show the wide range of choices available to accomplish each of the required EMS tasks. Each of the systems discussed currently fulfills the engine monitoring requirements for its weapon system. However, cost benefits from the EMS application are difficult to accurately quantify. The benefits are real, but normal system data has not been defined to break out the results. These systems give insight into how the next monitoring system should be designed and built. A selling point often used to justify an EMS is elimination of all ground support equipment. These programs generally show that ground equipment may even see additional use. Monitoring EMS data does give us additional insight into engine health, and is capable of controlling on-condition maintenance.

ADD ON EMS

Several operational aircraft have added EMS for service test in an attempt to demonstrate the value of the engine monitoring. See Table IV for a summary of EMS add-ons to operating aircraft. The Engine Health Monitoring System (EHMS) was tested on the T-38. It automatically acquired and formatted the data for semiautomatic and manual interpretation. The results of the T-38 test indicates that EMS probably would not be cost effective. The operational use for the airplane is important. The Air Training Command wants to assure highly reliable engines. Therefore, its overhaul interval is shorter. The test was run within the ATC standard operational framework; therefore, there were few failures. If the engines do not fail, the monitoring system cannot prove its capability and benefits.

Engine Condition Monitoring Program (ECMP) employed in SAC is flight deck monitoring. ECMP is being credited with secondary damage savings of $2 million dollars a month and reducing the in-flight shutdown rate on the SAC fleet by better than 50%. The 50% is based on the three year, in-flight shutdown rate average prior to implementation of the program, compared against the three years since the program has been in use.

Again, look at the concept of operation. ECMP is used on a multi-engine aircraft. With multi-engine aircraft, in-flight shutdowns do not have a strong safety indication. Therefore, the overhaul interval is much longer than on a single engine aircraft. Failures do, therefore, occur within the maximum operating time. The ECMP was able to detect these failures before occurrence, allowing repair when the deterioration was in the earlier stages. More than 2000 engines have been repaired solely because of ECMP indications. Only six have been disassembled during this period where no problem could be identified.

The A-10 Turbine Engine Monitoring System (TEMS) has been service evaluated with positive results, and is following on with a squadron level evaluation planned to determine how well that system functions to drive maintenance in the operation scenario.

The electrostatic probe is new technology that came out of the Air Force Institute of Technology (AFIT) about ten years ago. The theory is that rub or errosion in the engine gas path produces an electrostatic charge in the exhaust stream. The quantity measure of electrostatic charge per unit time infers the rate of deterioration within the gas path. The phenomena has been verified but it has not been operationally employed as a monitoring system.

The engine diagnostic system EMS is a monitoring system for the F100 engine in the F-15 aircraft. It is a service test to validate state of the art EMS capability against thirty-two goals. The results proved the system would get the data with accuracy equal to the test stand.

GENERAL RESULTS FROM ADD-ON TESTS

Experience does not show optimistic near term expectations for add-on monitoring systems. EMS generally drives the maintenance cost higher. Start-up problems show that a successful new system takes time to mature. Software problem solutions have taken longer than expected before the EMS successfully records in-flight data. Test plans often are written to conduct the evaluation within normal operating scenario which prevents the test yielding conclusive evidence on EMS value. The test aircraft are used to meet mission requirements in the normal manner. Maintenance is done by the TOs with little flexibility allowed to meet test objectives. Therefore, the test articles may not obtain sufficient flight hours or get appropriate focus.

Many valuable benefits come from a monitoring system. You get design feedback, correlation between the testing and operation usage, and verification of repair effectiveness. Verification of repair is often overlooked in the benefits analysis of the program. Maintenance replaces the wrong part, puts the aircraft back in service and it flies without a squawk, so it is concluded that the repair fixed the original squawk. Data from the monitoring system allows one actually to see the performance trace change providing a powerful quality control capability on maintenance and repair. EMS certainly provides improved knowledge of failure modes.

Technical orders are based on a number of A PRIORI assumptions. These assumptions are presupposed by experience, and are not subject to further examination or analysis. Based on A PRIORI assumptions, technical orders are written as if the A PRIORI knowledge illustrates the true behavior of an engine.

A monitoring system may provide data which causes one to question A PRIORI assumptions. EGT margin is believed to have full capability to effectively identify an engine as good or bad. EMS data shows that the EGT does go through the red line just before the engine is torn asunder. However, experience with a SAC monitoring program showed that severely deteriorated engines with basket case turbines often run cooler with a greater EGT margin. The cooler operating engine can be explained by the facts that the EGT probes are not covering the total exhaust stream and that the turbine nozzle areas change with deterioration. Engines were found by the SAC program with missing first stage nozzle and burner center cones broken off and laying back against the first stage nozzle. These engines passed EGT tests. In fact, two-thirds of them passed complete test runs and were certified for flight. Teardowns later found the bent and broken hardware within the engine. See reference 1 for an example from the SAC ECMP.

The ECMP showed that the beginning failure in the majority of the J57/TF33 engines started with fuel nozzles. Some fuel nozzles in a couple of burner cans would plug with the engine continuing to meet performance specs. The good burner cans got more fuel causing hot spots which resulted in burning and bowing of the vanes. Hours later, a vane would eventually burn through. The piece of broken vane would have about an 80% probability of making it through the turbine without engaging in the stationary and rotating vane rows. That is hard to believe, but under the monitoring system, many engines were missing a half first stage turbine nozzle vane on tear down. The missing piece had marked the turbine stages as it passed through. In other cases, the piece would engage between the rotating turbine wheel and stationary nozzle with sufficient force to break a blade. The engines are amazingly tough.

The SAC ECMP uncovered a change in depot maintenance procedures. Fuel nozzles were designed to be repaired in matched sets. It was decided that overhaul of the fuel nozzles in matched sets was too costly. So, like parts were worked in batches. Nozzles were assembled randomly from the batches. Tolerance control was gone from the batch repaired fuel nozzles. The result was a very short service life on badly mismatched sets.

Within six months after depot changed overhaul procedure, fleetwide ECMP monitoring on SAC engines identified the problem. The fuel nozzle overhaul problem potential will never be known because it was not allowed to exist long enough to have its full impact on the fleet. ECMP identified engines with bad nozzles for repair before other parts were damaged. How do you value something that is responsible for turning a problem around before its impact is documented?

MANAGEMENT LESSONS LEARNED

Responsibilities should be defined at the outset of an EMS program. Keep on board equipment simple which may be aided by limiting the in-flight task to data acquisition. Do the formating and interpretation of the data in the ground system. Remember that every pound of weight on a fighting aircraft costs performance. The mission of the Air Force is to fly and fight. Man should be in the loop so he is able to understand what the output from the monitoring system means. Provide realistic time and training, support equipment, and EMS spares. Organize a realistic, timely base monitoring team to use the in-flight data to drive maintenance actions. Effectiveness is improved if the EMS system is built-in versus retrofit. One should not wish to monitor everything.

TECHNICAL LESSONS LEARNED

If the necessary parameters can be defined, it is possible to minimize sensor requirements. Insure that the output of the in-flight equipment is compatible with the existing test equipment. Provide flexibility so the necessary data can be obtained to track a new failure mode. Provide self-check to isolate the bad data. Trending does allow you to determine deterioration within the engine. Increasing fuel prices are emphasizing the need to obtain the engine data while the engine is in the revenue service, to use the airline term, rather than do a ground run. If the engines don't have problems, you don't need monitoring. Good engines receive no benefit from being monitored. If you know what the engine's performance parameters are doing, you can determine its reliability potential and therefore enhance flight safety.

THE ADVOCATES PROBLEM

Why is it such a problem to get EMS on AF equipment? (See Figure 3)

The figure shows the time line for a weapons system versus accumulative or life cycle costs. Air Force System Command (AFSC) is responsible for the acquisition process until Program Management Responsibility Transfer (PMRT). then, Air Force Logistics Command (AFLC) takes over for logistic support. The process begins with an approved operational requirement for a specific weapons system to do a job. The System Project Office (SPO) director is assigned the responsibility for the acquisition. He is given a certain budget and has to acquire the required capability within that budget. An engine monitoring system adds an immediate cost increase to the system which is apparent. EMS benefits accrue in system operation after PMRT. Several years of operation may pass before the meantime between failure for the major items of the system is reached. During the acquisition phase there is no way of knowing the correct slope on the operations cost curve. Therefore, the SPO director on his watch sees only the impact of EMS cost on his system. EMS potentially available benefits accrue in service after PMRT when AFLC has the watch.

ELEMENTS OF SYSTEMS EFFECTIVENESS

Earlier the importance of viewpoint was discussed with the idea that the "jackass on the hill could see further than the genius in the valley." Analyze that idea from a standpoint of system effectiveness. (See Figure 4) Three people are involved in the Weapon System Effectiveness Problem: The overall field commander decides what weapon will be employed on what target at what time, and the branch on the right of figure 4 represents his interest; The wing commander has to implement the field commander's orders as the center branch represents his interest. He wants X equipment on the line and ready to meet the mission requirement. The Deputy Commander

Maintenance (DCM) is charged with the responsibility of making that equipment available. His interest is in the branch on the left. The EMS system in order to be judged cost effective and worthy of purchase by the SPO director must clearly improve each of these elements for total system effectiveness. That is the heart of current EMS development guidance that is being given to industry for the new weapon system starts.

EMS DEVELOPMENT GUIDANCE

The following general guidance for the development of an Engine Monitoring System (EMS) was provided by the Propulsion Director of Engineering, 30 January 1981, to maximize system effectiveness of our new weapon systems.

The EMS will be dedicated primarily to the performance of "Engine Monitoring," i.e., capture of in-flight engine operating data. The EMS function operating within the planned logistics/maintenance concept will not be compromised by over sophistication of tasks and multiple roles for the EMS hardware. Where airframe monitoring systems are to be used, the EMS must be compatible and compliment that system. However, an option for independent operation of the EMS should be planned in the event that an integrated airframe/engine monitoring system is not included. The current development guidelines for on-board EMS capability are:

1. Simplify on-board equipment by limiting in-flight requirements to data capture with data interpretation on the ground.

2. Limit EMS design goals to evaluation of engine suitability for continued service rather than fault isolation to an individual module/component.

3. Plan use of ground test equipment, e.g., borescope, chip detector, to confirm EMS indications and enhance diagnostics prior to engine removal.

4. Integrate the EMS output from an operational weapons system viewpoint by use of ground station data processing with the man in the loop for interpretation and direction of maintenance.

PLANNED APPROACH

During the early phases of each EMS program the engine contractor will be tasked by the Air Force to prepare a detailed feasibility analyses covering the following areas:

1. A list of aircraft/engine parameters to be monitored/recorded in-flight by the EMS.

2. Feasibility of performing the following engine monitoring/diagnostic functions using the parameters recorded in-flight:

- Engine Documentary Data
- Parts Life Tracking
- Parameter Tracking/Trending
- Engine Suitability for Flight
- Warranty Validation (if required)
- Suitability for Flight

In addressing the feasibility of performing each of the above functions with the EMS, the contractor must direct his analysis to answering the following questions:

a. Does the technical expertise exist currently to adequately perform each function without causing a negative impact on the planned maintenance/logistics concept for the application?

b. How would each function's data product interface with the planned maintenance/logistics concept?

c. Where and by what means would the EMS data product be converted into useful information?

d. Who would eventually use the information?

e. What will an EMS do for system effectiveness?

Once this feasibility analysis is provided, a complete review will be conducted by the Air Force. The direction for the development of the EMS for the engine will then be established.

TOTAL SYSTEM VIEWPOINT

The engine contractor should be tasked with the responsibility for developing all aspects of the EMS system with Air Force assistance. This includes all hardware required on-board, on the flight line and in the ground station, plus all software required for the EMS to function satisfactorily. The EMS must work hand in hand with the planned engine logistics/maintenance concept. As such, both systems or programs must be developed concurrently to insure optimum utility of the EMS. It is essential that a total system perspective (airframe, maintenance, logistics) be the overriding consideration in the development process and that the EMS and the maintenance concept be concurrently developed. The overriding question is: "How much EMS is enough for system effectiveness optimization while remaining affordable?" Pareto's criteria can help zero in on the answers during the acquisition phase.

Using the weapon system approach as an evaluation criteria early in the acquisition phase will hopefully help get the genius out of the valley onto the back of the jackass on the hill so that they can together gallop toward realization of potential EMS capabilities.

REFERENCE

1. McCord, Robert M.; Engine In-Flight Monitoring (Part II). Maintenance Magazine, Air Force Inspection and Safety Center, Norton AFB, California, 1977, pp. 31-38.

USAF TURBINE ENGINES

MAINTENANCE VS ACQUISITION COST TRENDS

INITIAL OPERATING CAPABILITY	ENGINE NOT MISSION CAPABLE %	MMH/1000EFH	REMOVALS 1000EFH	1980 MAINT COST $ DOLLARS/1000EFH	ACQUISITION COST-THEN $
NON AB					
1966 (TJ)	8	650	1.26	$181K	$175K
1960 (TF)	2	700	0.65	$88K	$210K
1969 (TF)	13	1060	0.36	$728K	$888K
1975 (TF)	26	620	1.2	$681K	$570K
AB					
1959 (TJ)	14	144	3.1	$320K	$160K
1962 (TJ)	22	87	4.2	$53K	$ 85K
1967 (TF)	18	269	7.4	$878K	$730K
1970 (TF)	17	323	8.2	$2,000K	$1,960K

TABLE I - MAINTENANCE COST TRENDS FOR USAF TURBINE ENGINES. AS A BASIS FOR COMPARING ACQUISITION COST, THE COST FROM THE INITIAL ACQUISITION CONTRACT IS PROVIDED IN THEN YEAR DOLLARS. THE COST DATA IS EXTRACTED FROM THE 1980 ASD ENGINE ADVISORY GROUP (EAG) MINUTES DATED 23-24 SEPTEMBER 1980.

ENGINE MONITORING SYSTEMS

DEVELOPED WITH AIRCRAFT

SYSTEM	DATA ACQUIRE	DATA FORMAT	DATA INTERPRET	AIRCRAFT/ENGINE	STATUS
MRS	A	A	M	SR71/J58	OPERATIONAL MTBF 1100 HOURS
MADARS	A	A	M/A	C5A/TF39	OPERATIONAL MTBF 100 HOURS TOTAL MADAR SYSTEM 8 HOURS
CITS	A	A	M/A	B1/F101	OPERATIONAL IN CAT I&II TESTS COMPLEX NOT READY FOR OPERATIONAL DEPLOYMENT
EHR	M	M	A	F15/F 16/F100	OPERATIONAL MTBR 600 HOURS
ETTR	M	M	A	A10/TF34	OPERATIONAL MTBR 2500 HOURS

TABLE II - SUMMARY OF ENGINE MONITORING SYSTEMS DEVELOPED WITH AN AIRCRAFT.

ENGINE MONITORING SYSTEMS
ADD-ONS TO OPERATIONAL AIRCRAFT

SYSTEM	DATA ACQUIRE	FORMAT	INTERPRET	AIRCRAFT/ENGINE	STATUS
EHMS	A	A	M/A	T38/J85	JUDGED NOT COST EFFECTIVE
ECMP	M	M	M	KC135/TF33 B52D,G/57 B52/H/TF33 C 141	OPERATIONAL SAVES $2 MILLION IN SECONDARY DAMAGE EACH MONTH REDUCED IFSD RATE BY NEAR 50%
TEMS	A	A	M/A	A10/TF34	SERVICE EVALUATION ON 5 AIRCRAFT WARRANTS FOLLOW ON SQUADRON EVALUATION
ELECTROSTATIC PROBES	A	A	M	NUMEROUS ENGINES	PHENOMENA VERIFIED
EDS	A	A	M/A	F15/F100	SERVICE TEST ON 5 AIRCRAFT MEETS MANY OF THE 32 DESIGN GOALS ACCURACY EQUALS TEST STANDS

TABLE III - SUMMARY OF ENGINE MONITORING SYSTEMS TESTED AS ADD-ONS TO OPERATIONAL AIRCRAFT.

ENGINE MONITORING SYSTEMS
CONTRACT MAINTENANCE

SYSTEM NAME	DATA ACQUIRE	FORMAT	INTERPRET	AIRCRAFT/ENGINE	STATUS
FLIGHT LOG CIEMAS*	M	A	A/M	T43/JT8D 9	FLT LINE BLUE SUIT COMBS***UNITED/SFO OCM CYCLE LIMITS
GROUND TRIM DATA TRENDED	M	M	M	C-9/JT8D 9	FLT LINE BLUE SUIT COMBS HARD TIME CYCLE LIMITS
EPM**	M	A	M	KC-10/CF 6-50CZ	FLT LINE-BLUE SUIT COMBS OCM-CYCLE LIMITS
EPM	M	A	M	E4A/CF6 50	FLT LINE-BLUE SUIT COMBS OCM-CYCLE LIMITS

* CENTRAL INFORMATION ENGINE MONITORING AND AIRCRAFT SYSTEMS
** ENGINE PEFORMANCE MONITORING - GE
*** CONTRACTOR OPERATED AND MANAGED BASE SUPPLY - INCLUDES INTERMEDIATE AND DEPOT ACTIVITIES

TABLE IV - SUMMARY OF ENGINE MONITORING SYSTEMS USED WITH USAF AIRCRAFT OPERATED THE CONTRACT MAINTENANCE CONCEPT.

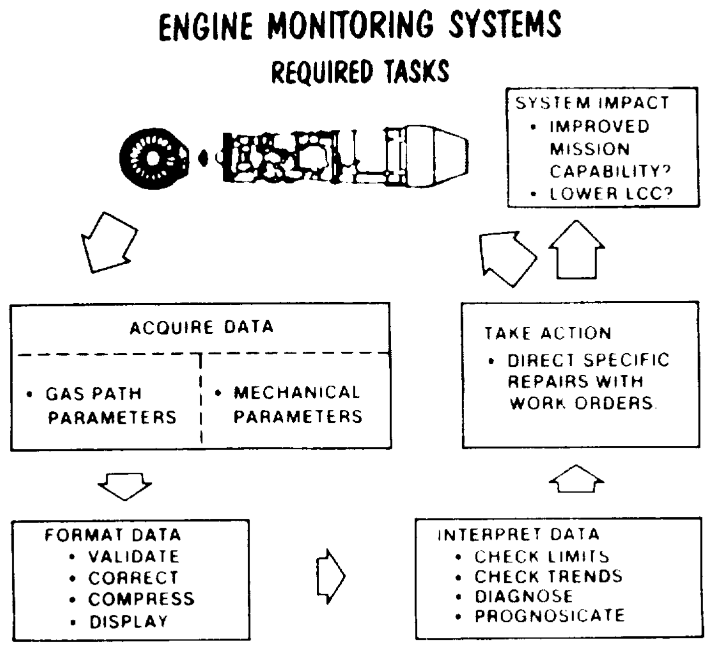


FIGURE 1. THE TASKS WHICH MUST BE ACCOMPLISHED FOR DURING THE OPERATION OF AN ENGINE MONITORING SYSTEM. THERE ARE OPTIONS AT EACH LEVEL WHICH RANGE FROM PENCIL AND PAPER TO CAPABLE ELECTRONICS. THE MOST IMPORTANT LINK IS INTERACTION WITH THE OPERATIONAL SYSTEM.

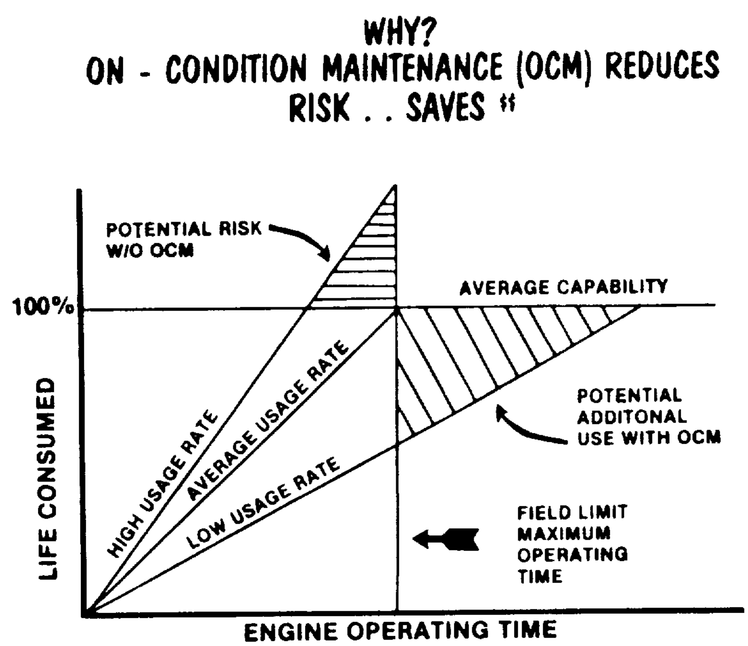


FIGURE 2 - WHY USAF WANTS ON-CONDITION MAINTENANCE (OCM). IF IT IS NOT BROKEN, WHY FIX IT? MAXIMUM OPERATING TIME MAY FIX ONE GOOD ONE WHILE ANOTHER FLIES TO FAILURE. OCM IDENTIFIES THE EXTREMES AND MAKES THE REQUIRED REPAIRS AT THE APPROPRIATE TIME.

ELEMENTS OF SYSTEM EFFECTIVENESS

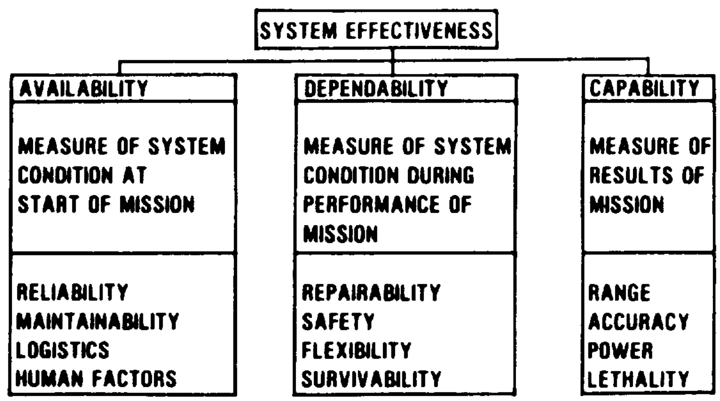
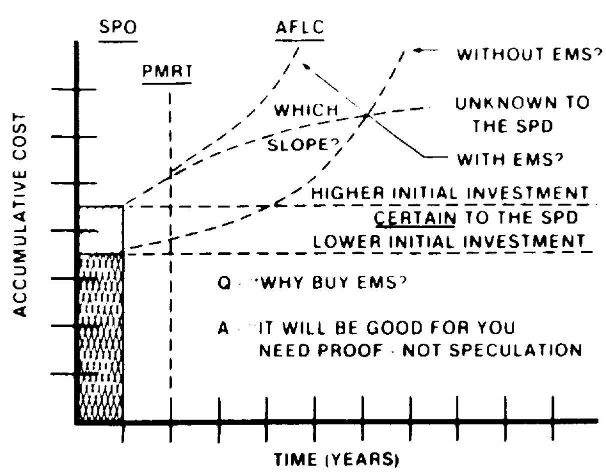


FIGURE 3 - THE ELEMENTS OF SYSTEM EFFECTIVENESS. POSITION IN STACK EXERTS GREAT INFLUENCE ON INDIVIDUAL VALUE PLACED ON EACH ELEMENT OF SYSTEM EFFECTIVENESS. THE ULTIMATE VIEWPOINT IS SYSTEM EFFECTIVENESS.

THE ADVOCATE'S PROBLEM

PROVE EMS VALUE FROM SYSTEM VIEWPOINT



MTBFs - GENERALLY GREATER THAN EXPERIENCE AT PMRT

FIGURE 4 - THE ADVOCATE'S PROBLEM. CONVINCE THE SPO DIRECTOR TO SPEND THE UP-FRONT MONEY REQUIRED TO BUY AN ENGINE MONITORING SYSTEM.

TOTAL SYSTEM VIEWPOINT

WHO DOES WHAT?

HOW MUCH IS ENOUGH?

GOAL

MAXIMUM SYSTEM EFFECTIVENESS

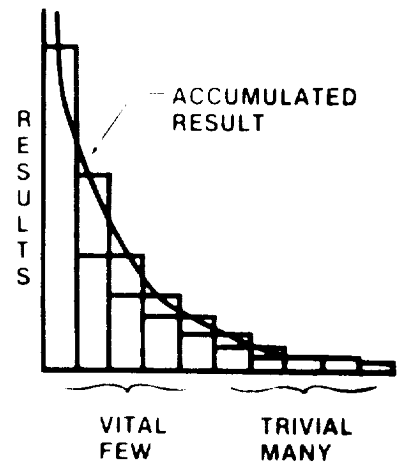


FIGURE 5 - THE TOTAL SYSTEMS VIEWPOINT AND PARETO'S LAW MAY IN COMBINATION BE THE KEY TO ANSWERING CRITICAL QUESTIONS NEEDED TO DEFINE THE REQUIRED ENGINE MONITORING SYSTEM.