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Superseded by ARP4176

Cost Versus Benefits of Engine Monitoring Systems

RATIONALE

The AIR has been superseded by a completely new document, ARP4176, which not only takes a different approach to cost and benefits of Engine Health Management, but also provides much more up-to-date information. The original AIR is, thus, out of date and of no value to readers. So, the document should be cancelled and not stabilized.

CANCELLATION NOTICE

This document has been declared "CANCELLED" as of March 2015 and has been superseded by ARP4176. By this action, this document will remain listed in the Numerical Section of the Aerospace Standards Index noting that it is superseded by ARP4176. Cancelled specifications are available from SAE.

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1. SCOPE:

The purpose of this SAE Aerospace Information Report (AIR) is to provide information that would be useful to potential users/operators and decision makers for evaluating and quantifying the benefits of an Engine Monitoring Systems (EMS) versus its cost of implementation.

This document presents excerpts from reports developed to analyze “actual aircraft cost/benefits results”. These are presented as follows:

- a. First, to outline the benefits and cost elements pertaining to EMS that may be used in performing a cost versus benefits analysis.
- b. Second, to present considerations for use in conducting the analysis.
- c. Third, to provide examples of analyses and results as they relate to the user/operator and decision-maker community.

The document encompasses helicopters and fixed wing aircraft and distinguishes between civilian and military considerations.

This document is not intended to be used as a technical guide, nor is it intended to provide methodologies, be a legal document, or be a standard. The findings are informational and are presented in the words of the report authors.

2. REFERENCES:

There are no referenced publications specified herein.

3. COST/BENEFIT ANALYSIS - THE CONCEPT AS APPLIED TO EMS:

Iterative cost benefit trade-off analysis can be performed for aircraft and engine life cycle costs (LCC) for various EMS configurations, with different benefit savings for specific engine applications. Too much or too little EMS complexity can prevent achievement of LCC savings (see Figure 1). An analysis criterion is to maximize return on investment (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 (see Figure 2). Typically, EMS savings are not realized until after the engine is operational and the design and development are completed (see Figure 3). Cost benefit trade-off analyses require a comparison between two major cost elements:

- a. LCC of the aircraft and engine
- b. LCC and savings attributable to the implementation of an EMS

3. (Continued):

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 impact of the EMS on engine maintenance (man-hours, aircraft unavailability, 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.

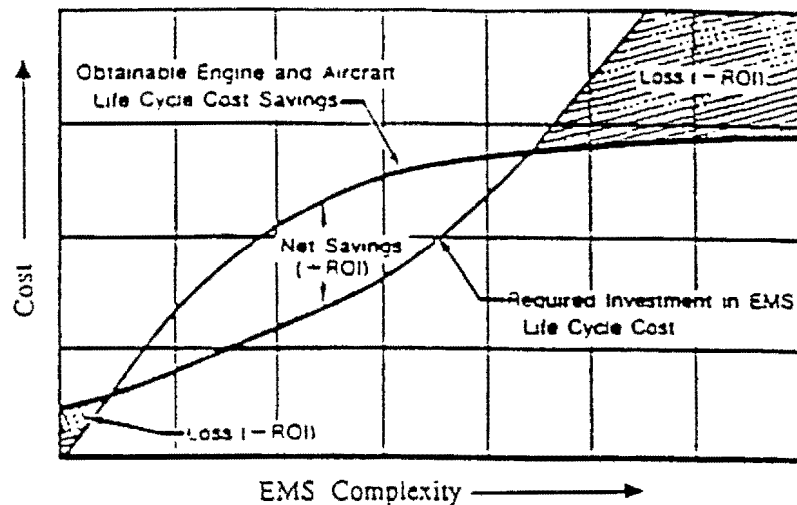


FIGURE 1 - EMS Complexity Impacts Return on Investment (ROI)

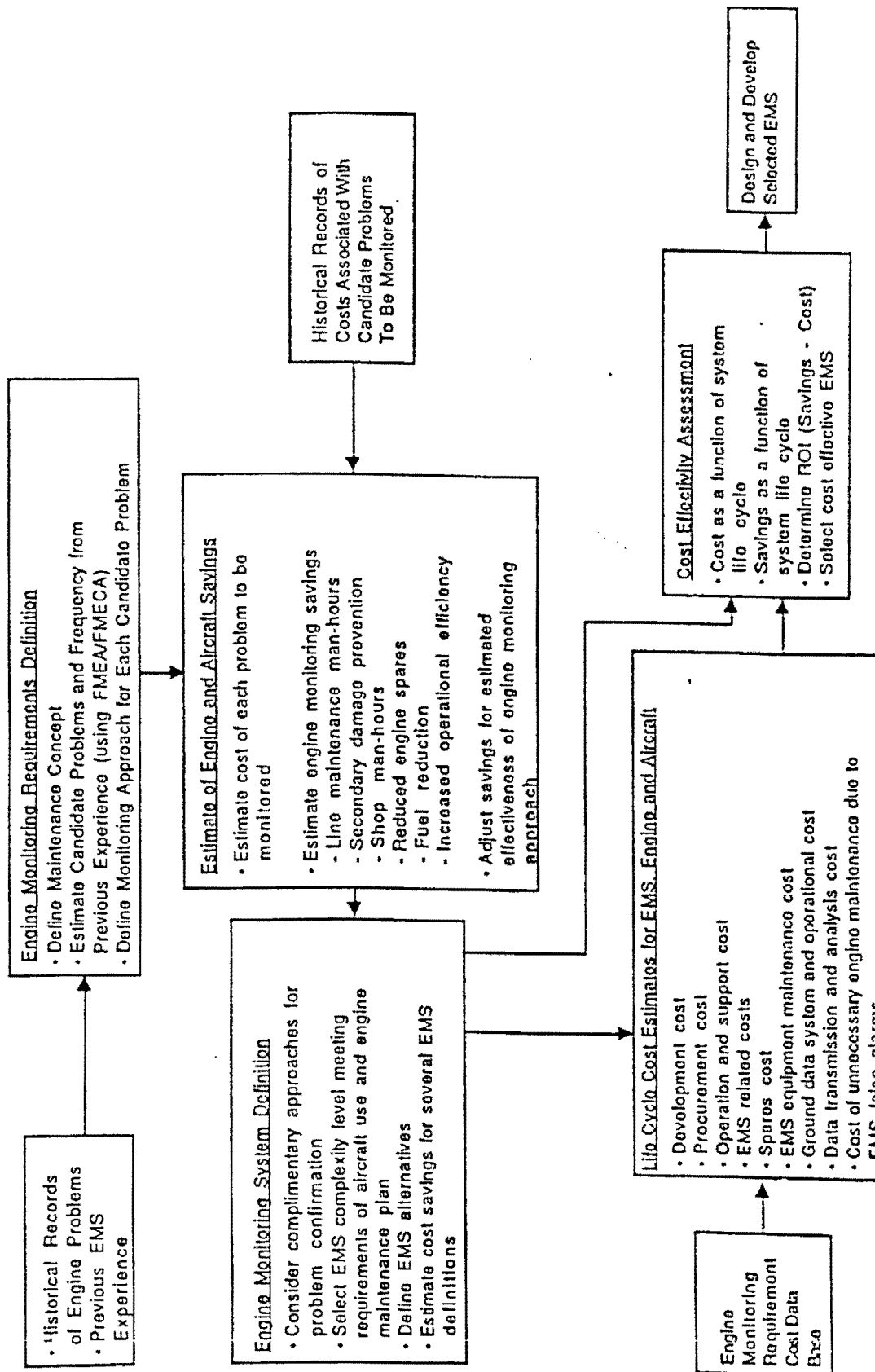


FIGURE 2 - Methodology for Defining an EMS

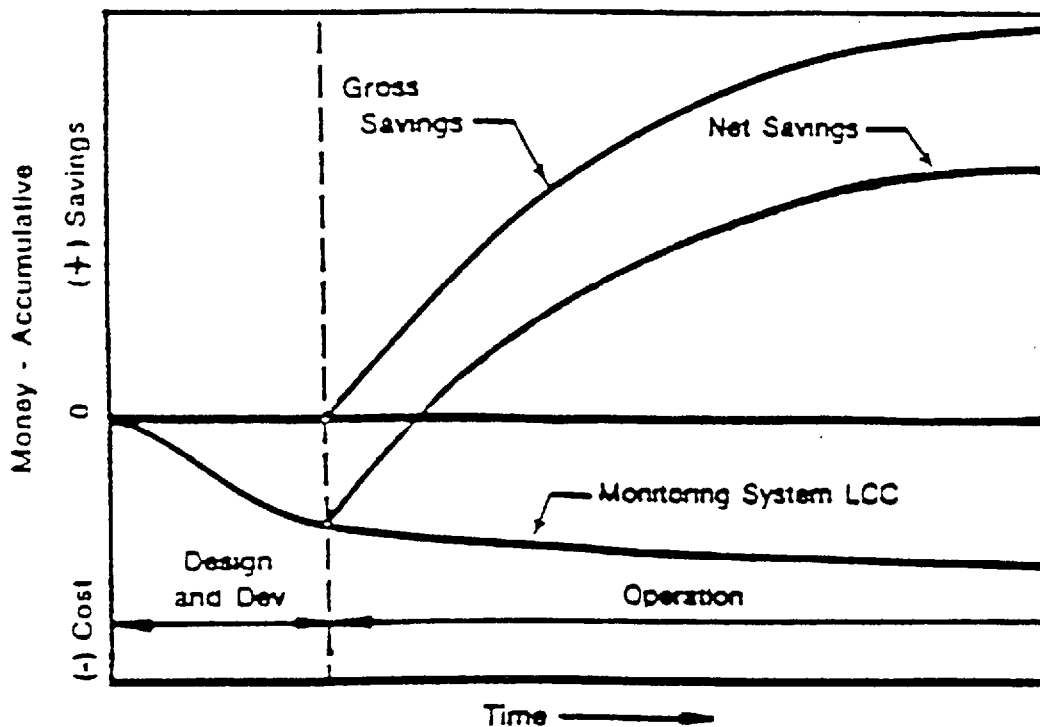


FIGURE 3 - Typical EMS Cost Benefit Analysis Results

3.1 Costs:

Life cycle 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

(1) Development EMS costs include:

- (a) Requirements definition
- (b) Design
- (c) Development
- (d) Qualification

(2) Production EMS costs include:

- (a) Aircraft and engine EMS hardware, including spares
- (b) EMS ground support and data processing equipment

3.1 (Continued):

(3) Operational and support EMS costs include:

- (a) Maintenance labor and material including component replacement or repair
- (b) Fuel consumed and lost revenue due to weight of engine monitoring hardware and added fuel
- (c) Labor and material for transmission, processing and analysis of EMS data
- (d) Projected cost of unnecessary engine maintenance due to EMS false alarms
- (e) Software maintenance and enhancements
- (f) Training costs

3.2 Benefits:

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

- a. Maintenance cost savings
- b. Fuel cost savings
- c. Operations and revenue benefits
- d. Parts and engine savings

(1) Maintenance Cost Savings

- (a) Projected reduction in maintenance labor hours per flight hour
- (b) Time saving by fault isolation to specified malfunction
- (c) Early identification of unexpected fleet deterioration
- (d) Avoidance of engine changes away from a major maintenance base
- (e) Ability to predict and schedule future maintenance

(2) Fuel Cost Savings

- (a) Fuel savings through reduction of ground test runs
- (b) Fuel savings through recognition of inefficient, degraded engines
- (c) Fuel savings through identification of malfunctioning components such as bleed systems and control sensors.

(3) Operations and Revenue Benefits

- (a) Time savings through confirming pilot reports and maintenance repair actions
- (b) Reduction in down time
- (c) Reduced maintenance man-hours per flight hour
- (d) Fewer canceled and/or delayed flights

3.2 (Continued):

(4) Parts and Engine Savings

- (a) Reduction in required spare parts through elimination of unnecessary repairs
- (b) Certification of flight profile assumptions during design and establishment of rotating life-limited parts limits.
- (c) Reduction in unnecessary engine and component removals
- (d) Engine hardware savings by increased engine and module availability
- (e) Reduction in secondary engine damage through removal and replacement of defective parts prior to failure
- (f) Life usage monitoring for life critical parts
- (g) Reduction in life cycle usage due to reduced operational cycles
- (h) Reduction in life cycle damage from operating at high turbine temperatures

4. CASE STUDIES - OVERVIEW (see Figure 4):

What follows are excerpts from actual studies conducted by and for customers who have made the decision to install (EMS). The studies provide real examples of the varied approaches taken to understand the cost and benefit of EMS systems.

4.1 SAS Case Study (Section 5):

This analysis covers the use of the Aircraft Condition Monitoring System (ACMS) on the SAS MD-80 fleet of 40 aircraft. The engine concerned is the JT8D-200. Cost benefits accrue from the verified avoidance of engine changes and Fuel Control Unit (FCU) replacements, plus associated costs, as a result of parameter confirmation using ACMS. Total savings identified were \$1357K during 1990. Running costs for ACMS during the same period amount to \$625K producing a net savings of \$750K US. The annual savings per aircraft was \$18 274.

4.2 Lufthansa A-310 Case Study (Section 6):

This paper reviews the application of an expanded aircraft integrated data system (AIDS) on A310 and A300-600 aircraft. The system collects data for subsequent ground analysis and storage to allow diagnosis and trending. Savings accrue from:-

- (a) Fuel savings derived from optimal adjustment of variable stator vanes (VSV) and bleed valves
- (b) Avoidance of dedicated engine runs for MEC optimization and fan trim balancing
- (c) Reduction in maintenance costs due to the identification of performance shortfall to module level allowing the recovery of severely deteriorated modules and the return to service of those only slightly deteriorated.

The paper also identifies potential further cost benefits areas not currently capable of quantification. Total savings during the test period (5 years) are projected for the 10 year project life and amount to some \$7.9 million. Running and acquisition costs amounted to \$4.0 million producing a net saving of \$3.7 million US. The annual savings per aircraft was \$23 000.

		COSTS			BENEFITS			
		DEVELOPMENT	PRODUCTION	OPERATIONAL	MAINTENANCE	FUEL COST	OPERATIONS	PARTS/ENGINES
SECT.	STUDY							
4.0	SAS (ACMS)		■	■	■	■	■	■
5.0	Lufthansa A-310 (ECM)			■	■	■	■	
6.0	US Air (FPM)	■						■
7.0	USAF F-100/PW220 (EMS)				■		■	
8.0	Tri Star (AIDS)				■	■		■
9.0	UH-1 (ODDS)		■	■	■		■	■
10.0	USAF A-10 (TEMS)		■	■	■	■	■	■

FIGURE 4 - Summary Comparison of Actual Studies Versus Cost/Benefit Factors

4.3 US Air Flight Profile Monitoring (FPM) Study (Section 7):

This study reports on the savings benefit of utilizing an automated FPM to be able to utilize Published Safe Cyclic Life for limited life rotating parts. The system operates with the Rolls Royce Tay engine powering FOKKER 100 aircraft. Total savings for a fleet of 80 aircraft is \$3 745 760 of usable disk life, with an annual savings per aircraft of \$11 706.

4.4 USAF F100-PW-220 EMS Case Study (Section 8):

This report documents experience gained on the use of a comprehensive Engine Management System (EMS) utilizing high speed data bus communications with aircraft systems and the Digital Engine Electronic Control (DEEC). The system as operated on the F-16 USAF aircraft assisted in the reduction of maintenance man-hours per flying hour by 33% and the improvement of flight ready status by a factor of 5. The DEEC/EMS combination is expected to reduce maintenance manpower requirements to less than 30% of non-EMS engines at maturity. Further benefits from Logistic Support performance and Engineering Data Acquisition for trouble shooting have been identified but not quantified.

4.5 RAF Tristar Case Study (Section 9):

This report outlines the benefits accrued from use of the AIDS and GRAF9 ground station used on the RAF Tristar fleet of aircraft. Benefits occur due to the avoidance of removals and repairs, the avoidance of ground running for the adjustment of VIGV controllers, the avoidance of secondary damage and the avoidance of engine changes away from the main operating base. Other less quantifiable benefits are detailed but not costed. Quantified benefits are assessed very conservatively and do not include manpower savings. Never-the-less savings of £1.43m can be positively identified during the 5 year period of the study. These savings represent two to three times the cost of acquisition and running of the system during the period. Based upon current flying rates expected future savings are assessed at £400K to £500K per annum, which is equivalent to £23.59 per engine operating hour.

4.6 UH1 Helicopter Oil Debris Detection System(ODDS) Case Study (Section 10):

This study concerns the flight test evaluation of the ODDS on a fleet of 50 UH-1 helicopters owned by the US Army. Thirty-eight aircraft were fitted with ODDS systems and the remainder were used as a control group. Benefits accrued from the ability of ODDS to distinguish between benign and abnormal debris thus allowing only equipment with incipient failures to be removed. The system reduced the cockpit chip light alerts by 48% thus avoiding unnecessary precautionary landings. The projected cost savings for the retrofit use of the system on the 400 aircraft fleet have been conservatively estimated at \$7.83m per year and potential savings of 65 556 aircraft flight hours were also identified. Payback on the \$12m retrofit cost would therefore be less than 2 years.

4.7 USAF A-10 TEMS Case Study (Section 11):

This paper assesses the benefit accrued from the use of the Turbine Engine Monitoring System (TEMS) on the USAF A10 aircraft. The study is based upon a six month trial period during 1989 but uses operational statistics over longer periods to assess cost benefits. The paper outlines the additional costs of operating the system and conservatively estimates a net savings from reduced maintenance amounting to \$5.4m per year for the total A10 fleet of 410 aircraft, or \$11 020 per aircraft per year.

4.8 Summary:

Different approaches were taken by the organization performing the actual studies. Very likely each had different requirements that had been established at the outset of the program.

Each study has been compared against the major cost and benefit categories described in 3.1 and 3.2. As can be seen not all the factors were considered in actual studies performed for or by the aircraft operators.

The reader should keep in mind in reading each study that the results vary with the approach taken by the originator of the study. Other studies could produce different results.

5. SCANDINAVIAN AIRLINES - COST BENEFIT ANALYSIS¹

This analysis covers the use of ACMS on the SAS MD-80 fleet consisted of:

Year: 1990

Fleet Size:	BOEING 767:	8
	DC-10-30:	6
	MD-80:	40
	DC-9:	57

This Cost Benefit Analysis covers the MD-80-fleet with P&W JT8D-200-series engines.

5.1 Current Use of Engine Data for Technical Purposes:

- a. Readouts from Quick Access Recorder Tapes for troubleshooting, confirm/deny aircraft log remarks and description of certain events
- b. Engine Condition Monitoring program (ECMII) for engine trending

¹ Author Staffan Elmen, SAS, September 9, 1992

5.2 Verified Cost Reductions:

Fifteen events of engine hot-starts and one event of EPR Overboost happened in 1990. In ten of these cases "engine change was avoided" due to readout of tapes which confirmed that temperatures and/or time over limit were within acceptable limits.

These events avoided the following costs:

a. 10 engine changes:	\$ 60 000 USD
b. 10 engine transportation:	\$ 35 000 USD
c. 10 shop visits:	\$1 000 000 USD
d. Fuel:	\$ 3 000 USD
e. 10 lost revenue flights:	\$ 165 000 USD
f. Total:	\$1 263 000 USD

Flashing Fuel Flow and EGT-indications have been a problem that have caused many delays. Due to tape readouts, it has been possible to verify the values and seven replacements of the FCU were avoided.

a. 7 FCU replacements:	\$ 7 850 USD
b. 7 FCU shop visits:	\$17 500 USD
c. Fuel:	\$68 400 USD
d. Total:	\$93 750 USD

ACMS Cost for the same period: \$625 800 USD

Cost Benefit: $\$1\,356\,750 - 625\,800 = \$730\,950$ USD

6. LUFTHANSA AIRBUS A310 - ENGINE MONITORING SYSTEM²:

As an early failure detection tool Engine Condition Monitoring (ECM) has been an integral part of Lufthansa's "On Condition" maintenance concept since the early 1970s and has been paying an essential contribution towards enhancing dispatch reliability and safety.

At the beginning of the 1980s, the development of improved engine diagnosis procedures and the increasing availability of digital electronics in the aircraft led to Lufthansa's decision to introduce a new and more comprehensive engine condition monitoring concept along with the advent of the AIRBUS A310.

² Authors: Heinrich Schlueter, Lufthansa Maintenance Systems & Reliability
Rolf Schoedert, Lufthansa Engineering Department Propulsion Systems, AGARD
Conference Proceeding No. 448

6. (Continued):

The advanced system is aimed at achieving, in addition to the reduction of operational irregularities, a minimization of the engine's total operating cost (fuel, material, maintenance). Also, reduction of ground operation for lower emission has ever increasingly gained in significance in the past years.

This paper reviews the application and economical aspects of this concept based on 5 years of operational experience with the combined A310/A300-600 fleet.

6.1 Conceptual Background:

A modern ECM system is intended to allow comprehensive assessment of each aircraft engine's condition through:

- a. Diagnosis of its gas path performance down to the level of each individual module
- b. Diagnosis of its mechanical condition in regard to vibration and lubrication system parameters

The objectives in detail are:

- a. Verification of engine health
- b. Detection of incipient engine problems
- c. Optimum adjustment of engine controls (fuel, speed margin, stability);
- d. Avoidance of engine run-ups
- e. Assistance in engine removal planning
- f. Optimization of the engine's overhaul workscope

Aimed at efficient and cost effective application of ECM, major emphasis was put on the establishment of an information system, which is characterized by the following conceptual highlights:

- a. Expanded engine instrumentation and propulsion
- b. Data multiplexer (PMUX)
- c. Automatic on-board data acquisition system
- d. Integration of all engine condition relevant information from operations, maintenance, work shop, and test cell
- e. Central organization/analysis;
- f. High degree of actuality;
- g. High degree of user friendliness, versatility and expandability

6.2 System Description (Figure 5):

The Lufthansa A310s and A300-600s are equipped with an expanded AIDS which generates reports for later on ground analysis. Included in this system is an airborne printer which serves as the prime data output device. The layout of the printed reports meets Optical Character Recognition (OCR) Standards which by this permits automated reading.

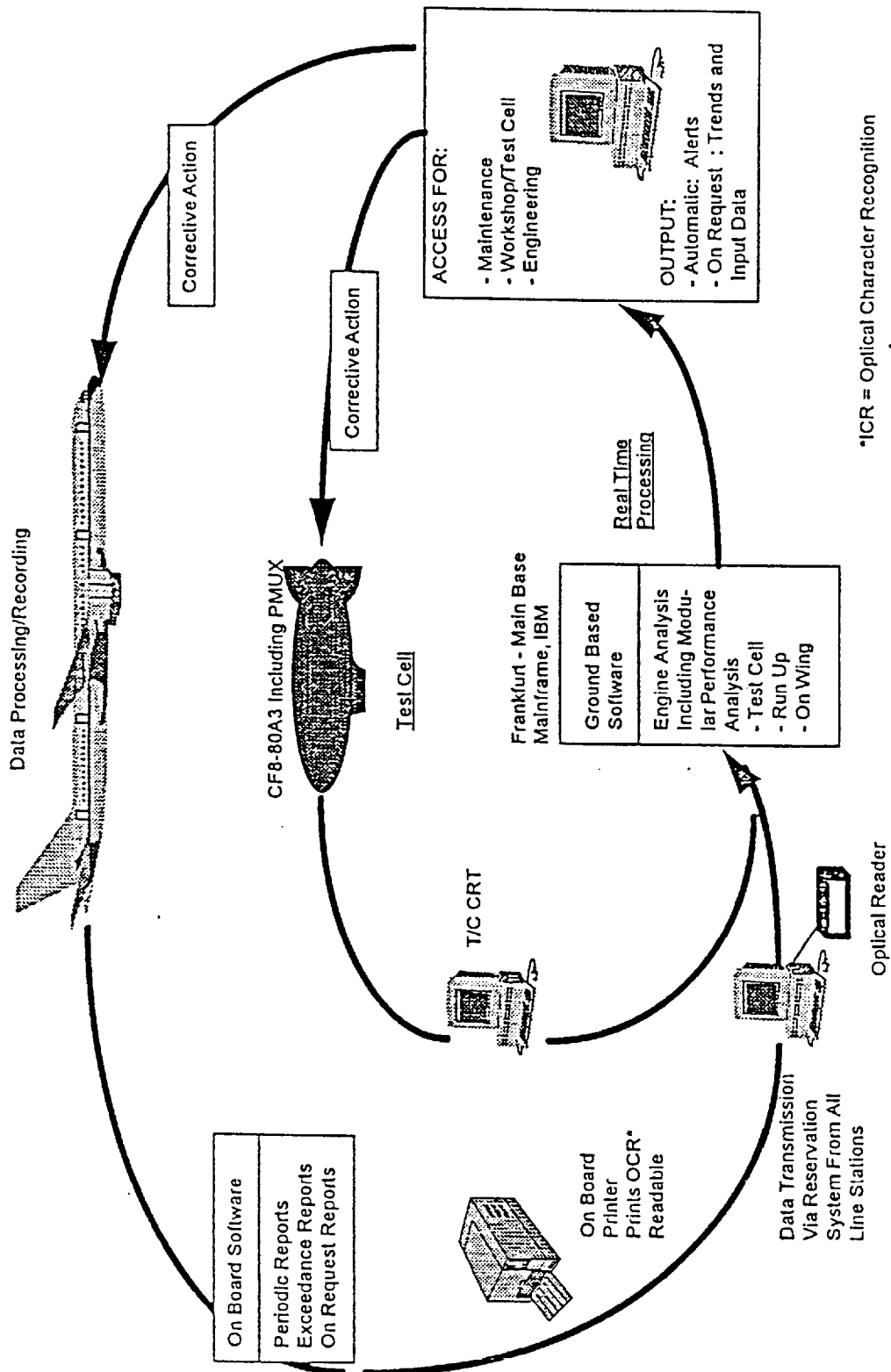


FIGURE 5 - LH 310/A300-600 Engine Condition Monitoring System

6.2 (Continued):

Since a data link is currently not available at Lufthansa, this inevitably leads to a time lag between data recording and central analysis. For a high degree of actuality, however, a fast data transmittal medium is required. An extended on-board diagnosis capability is not considered a rewarding goal.

The contents of the reports generated during flight are entered into Lufthansa's ground-based computer network from all flight destination stations. After line station personnel have submitted the data by means of hand held video scanners those are transmitted to the central computer at the Frankfurt maintenance base where extended analysis was specified in a combined GE/airlines effort.

All input data and results are stored in a data base for trending purposes thus making complete ECM histories available. Upon analysis all results are automatically checked for findings and, if significant, are output to the maintenance engineers in the form of an alert message. This concept releases the maintenance personnel from the previous need to inspect all engine data and thus assists in concentrating on problem cases. For in-depth data analysis engine history output is provided on request via computer terminals.

In case an engine removal is due the overhaul engineers make use of engine history information for definition of the optimum shop work scope.

Upon test cell acceptance which the engine has to pass after overhaul PMUX as well as test cell instrumentation data are transmitted to the central computer for modular performance analysis. While the engine is still running the analysis results are made available automatically by return to the test cell personnel indicating the quality of measurement and performance of the engine and its individual modules.

The ECM user family connected to the ground based information system is depicted by Figure 6. Maintenance engineering in charge of the daily monitoring and troubleshooting work is located at the maintenance base in Frankfurt. Engine overhaul, production planning and control, engine test cell, as well as central engineering are located in Hamburg. The engine manufacturer, i.e. General Electric in Cincinnati, is also connected to the ECM system.

6.3 Review of Application:

In the following the main application areas are discussed focusing on cost and savings.

The financial balance as depicted in Figure 7 is based on the experience gained between 1983 and 1987 and is projected until 1992 to cover the planned aircraft operating time of 10 years.

For the given long haul (LH) A310/A300-600 fleet and the considered time period the resulting net savings through ECM amount to 3.9 m US\$.

This is 23 000 US\$ per aircraft and year.

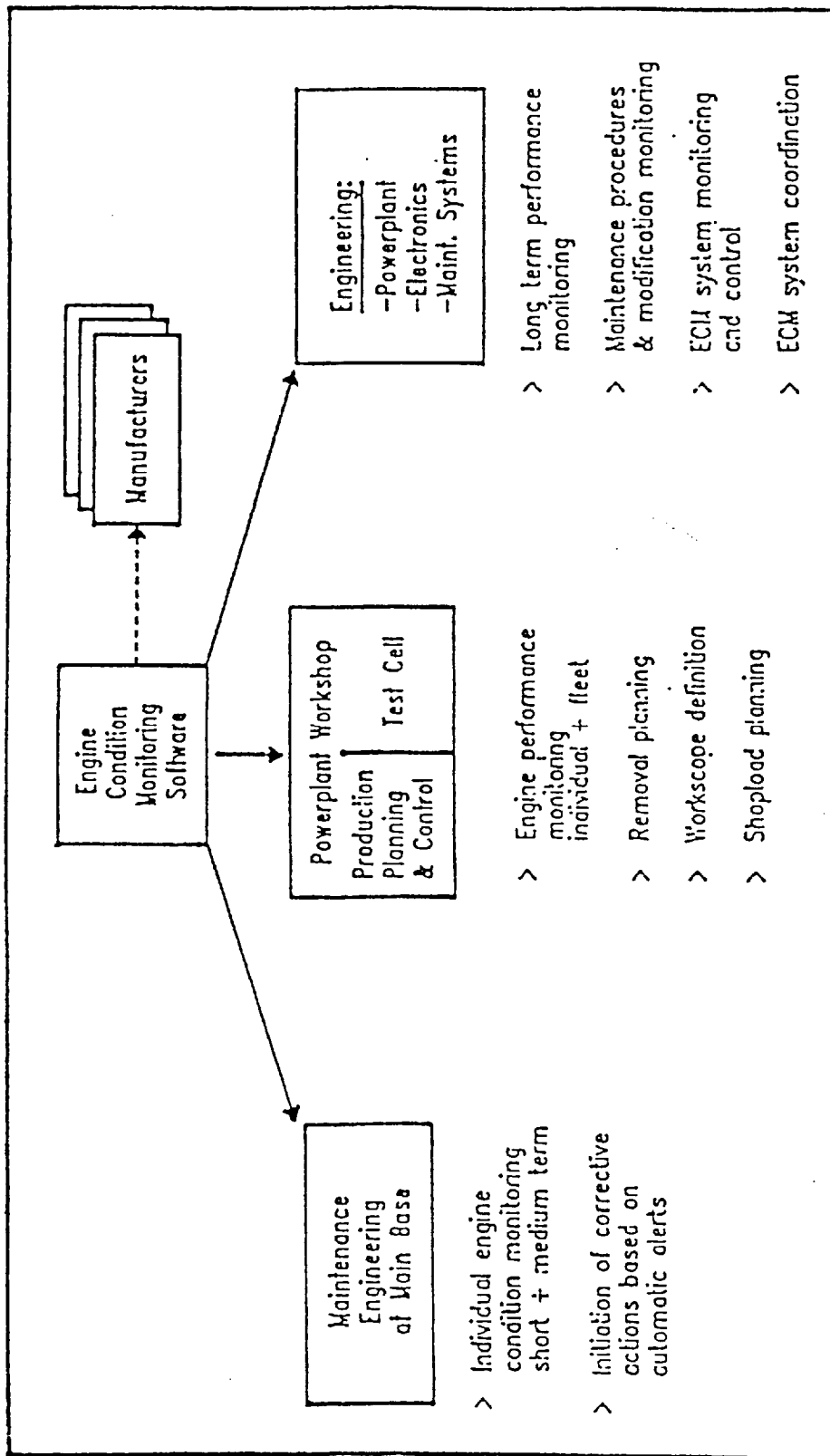


FIGURE 6 - ECM Users Community

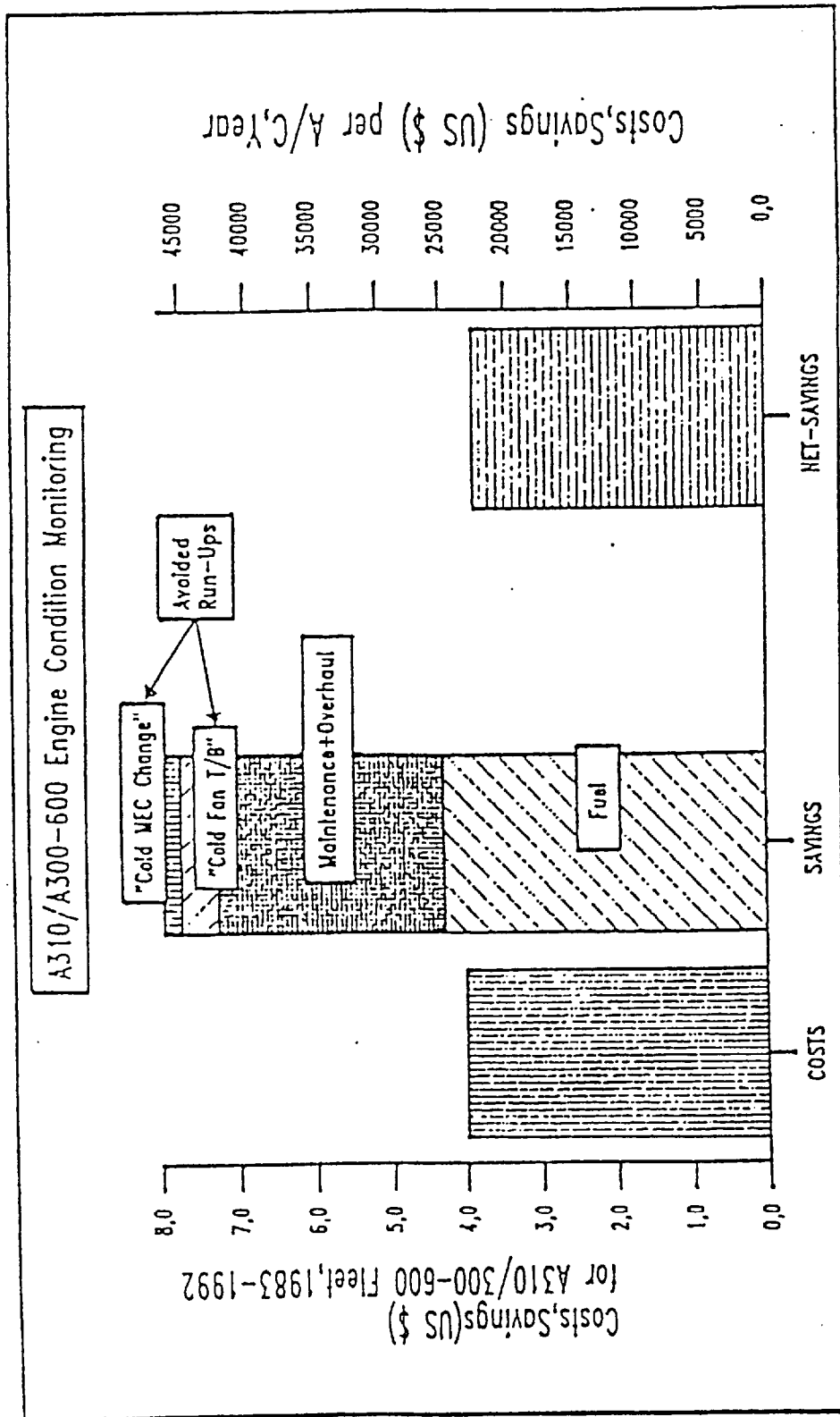


FIGURE 7 - Costs/Savings

6.3 (Continued):

a. Cost: There are four main factors:

(1) "On-Board Hardware": This factor includes the cost for expanded instrumentation and PMUX as well as a 50% share for the Airplane Integrated Data System attributed to ECM.

(2) "Project Cost": Establishing the basic computer structure required expenditures for:

- (a) Creation of the software for data input at line stations
- (b) Peripheral hardware investment
- (c) Creation of a new real time/on-line data/software structure
- (d) Incorporation of manufacturers' programs into LH's computer environment

It has to be emphasized that most of the project costs are one time-investments charging the A310 fleet for the pioneering effort without recurring for the further fleets to come.

(3) "Computer Processing Cost": Currently this amounts to approximately \$1000 (US\$) per engine a year which is 0.3% of the engine maintenance cost. This is deemed to be favorable. Intended program optimization will further reduce this figure.

(4) "Software Maintenance": To a certain extent, the ECM software is subjected to continual modification for its analytical functionality. This also extends beyond the project period and requires some manpower on a permanent basis.

6.4 Savings:

a. "Fuel" (Optimum Control Adjustment): Currently the largest portion of the savings is achieved by ensuring optimum adjustment of the VSV and variable bleed valves (VBV).

Since the hydromechanical Main Engine Control (MEC) is per design not able to compensate internal deterioration this task has been integrated into ECM:

Maintenance engineering is automatically informed about off-optimum-schedule shifts derived from inflight VSV/VBV data. The corrective action, so triggered, is reduced to a verification of the transducer calibration and the adjustment itself by turning the MEC adjustment screw a defined number of turns.

No ground run is required!

The consequent application of this feature does reduce the fleet fuel consumption by 0.5%!

The associated savings depend on the actual price of fuel. For the time beyond 1987 the price has been assumed to keep the '87 level - for the cost/benefit balance a conservative approach.

6.4 (Continued):

- b. "Avoidance of Engine Run-Ups": Acquisition of operational data by ground runs is no longer required in particular for troubleshooting and verification of maintenance actions due to expanded instrumentation and availability of appropriate inflight data.

Two features are reducing especially the number of high power runs:

After replacing the MEC an optimum rig run/tracking check is normally required. Through ECM, pre-adjusted MECs get this optimum adjustment using inflight data. Only an engine leak check is performed.

For fan trim balancing the specific engine characteristic is derived from inflight data subsequent to installing a 'trial' balance weight. From this the optimum balance bolt configuration in the fan spinner is determined. The convenience of this method allows a frequent application to keep fan vibration to a minimum for the entire fleet.

The savings are based on the experience that for both adjustment procedures 2 run-ups per engine a year are avoided with total cost of \$1000 (US\$) per run-up.

- c. "Maintenance Cost": For engine overhaul it is of essential importance to optimize the workscope with respect to both performance recovery and cost. By the availability of performance data down to the individual engine module, this task can be performed.

The information provided includes the modular performance parameter deltas (efficiencies, flow capacities) relative nominal and apparent measurement errors. The contribution of each individual module to the engine's exhaust gas temperature as the most indicative performance quality parameter is derived from this.

The overview of the actual engine health status is completed by:

- (1) Initial modular performance information
- (2) Overall performance status (T/O EGT margin)
- (3) Nongas path related information (Oil Consumption SOAP, Vibration)

The above mentioned information derived prior to engine disassembly provides assistance in defining the workscope. Modules requiring performance recovery in any case are indicated as well as modules with slight degradation to be returned to the engine assembly line without overhaul.

The reduction of maintenance cost currently amounts to 5%.

The realization of these savings is highly dependent on experience, which was gained on deteriorated engines since 2 years. For the financial balance this figure is kept constant beyond 1988 although higher savings can be expected with further practice.