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Superseded by ARP5120

A Guide to the Development of a Ground
Station for Engine Condition Monitoring

RATIONALE

The SAE Aerospace Information Report (AIR) has been superseded by a completely new document, ARP5120, which provides guidance on how to develop and implement an integrated end-to-end health management system for gas turbine engine applications. The original AIR4175A information was updated and transformed into ARP5120. ARP5120 consolidates AIR1873, AIR4061B, AIR4175A, and AIR5120 into one document per the direction of the SAE E-32 committee.

CANCELLATION NOTICE

This Technical Report has been declared "CANCELLED" as of November 2016 and has been superseded by ARP5120. By this action, this document will remain listed in the respective index, if applicable. Cancelled Technical Reports are available from SAE.

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FOREWORD

Today, most gas turbine propulsion systems enter service with some form of Engine Monitoring System (EMS) capability. The drive behind these systems is increased availability, reduced delays, cancellations, mission aborts and cost of ownership. Implementation varies across operators where EMS can be integrated into the aircraft or be dedicated to the propulsion system itself. The capabilities and technologies required to support the EMS continue to be developed, becoming progressively more sophisticated to meet the increasing requirements for data processing both on and off-board. There are also numerous EMS interfaces with various Customer/Operator and Original Equipment Manufacturer (OEM) logistic systems to be considered.

Normally, the EMS functionality is split between an on-board Engine Monitoring Unit (EMU), which is either platform or engine mounted, and a Ground Support Station (GSS). The GSS is a critical part of the EMS and it is essential that sufficient funds be in place to complete its development. This split is largely determined by Customer requirements and aircraft operating environment. In the commercial world, the on-board system tends to be integrated at the platform level and is not engine specific. The platform system is referred to as the Airborne Condition Monitoring System (ACMS). Therefore, for commercial operators, the EMU and GSS terminology does not necessarily apply. Where applicable, the EMU is more usually referred to as the Data Management Unit or Data Acquisition Unit.

The functionality of the GSS and its associated complexity must match the defined use and requirements of the system. Ideally, it should be scaleable to meet the various needs of different users. The GSS components of the EMS exist entirely off-board the aircraft and include:

- (1) Data transfer to/from the aircraft (telemetry, physical media transfer, personal maintenance aids (PMA))
- (2) Data Processing elements
- (3) Data Storage elements
- (4) User Interface elements

This may be a single PMA that plugs directly into the engine Full Authority Digital Engine Control (FADEC) or aircraft, all the way up to a wide-ranging network involving satellite data transfer, distributed mainframe processing, on-line manuals, and directed troubleshooting under wing via wireless PMA, and Internet access by various user groups.

As a rule of thumb, data relating to an engine incident or exceedance should be available after every flight or during the current engine run, as corrective maintenance is normally required. Therefore, algorithms to detect or trigger a snapshot recording of these events must be included in the EMU software. Ideally, this event data needs to be transmitted during the flight to enable ground personnel to be ready with any replacement parts required for a repair. This reduces troubleshooting and hence aircraft turn around times. In reality, technology on the majority of platforms cannot support this and data can only be interrogated after the aircraft has returned. Other data, especially that used for long term trending or life calculations, is not so urgently required and can be recorded in the EMU to be downloaded for subsequent analysis in the GSS. With data storage capability increasing all the time, this method of recording the data for analysis in the GSS is now preferred by many OEMs and Customers, mainly because of the reduced cost and increased flexibility off-board processing offers compared to on-board implementation in the EMU.

There may, however, be specific operational scenarios where this rule of thumb does not apply and off-board analysis remains inappropriate. Military operational requirements for example, may dictate that all maintenance and trend data is available at the aircraft in order to meet either turn around times or a requirement to have no dedicated Ground Support Equipment (GSE). This drives all the EMS functionality into the EMU. This will only change when data can be rapidly and reliably transmitted remotely from the EMU to the GSS, preferably in seconds, and any subsequent analysis can be performed in a matter of minutes. For commercial aircraft operations, which have tended to place more emphasis on the long-term trending of engine parameters, there is a greater reliance on total flight data recording and ground based data analysis. Therefore an integration of the EMU and GSS functions, either into the engine control system or using a separate computer is possible. In cases where complex analysis of data is required, or very high sample rates are involved precluding continuous flight recording, data compression techniques can be used to enable all the information to be stored in the EMU.

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1. SCOPE:

An effective GSS is vital to the successful implementation of an EMS and is a fundamental part of the total monitoring system design, including asset management. Unlike the on-board part of the EMS which principally uses real time data to indicate when engine maintenance is required, a GSS can offer much greater processing power to comprehensively analyze and manipulate EMS data for both maintenance and logistics purposes.

This document reviews the main EMS functions and discusses the operating requirements used to determine the basis design of a GSS, including the interfaces with other maintenance or logistic systems. A brief discussion is also included on some of the more recent advances in GSS technology that have been specifically developed to provide more effective diagnostic capabilities for gas turbine engines.

1.1 Purpose:

The purpose of this AIR is to firstly examine the role of a GSS for processing data as part of the overall EMS functionality. Secondly, it considers the role of a GSS in supporting both Customer and OEM total logistics management systems. Thirdly, this AIR will provide guidelines for the development and use of a GSS in an aircraft operational environment. Finally, this document addresses the program management requirements associated with the initial development and on-going support of a GSS.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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

ARP1587	Aircraft Gas Turbine Engine Monitoring System Guide
AIR1828	Guide to Engine Oil System Monitoring
AIR1839	A Guide to Aircraft Turbine Engine Vibration Monitoring Systems
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
AIR4061	Guidelines for Integration of Engine Monitoring Functions with On-Board Aircraft Systems
AIR4174	Guide to Power Train Monitoring Techniques (Draft)
AS4831	Standard Software Interfaces for Ground Based Monitoring Systems
AIR5120	Engine Monitoring System Reliability and Validity (Draft)
AS8054	FAA TSO (Draft)

2.2 Glossary of Terms:

ACARS	Aircraft Communication Addressing and Reporting System
ADR	Accident Data Recorder
BIT	Built-In-Test
CRC	Cyclic Redundant Code
DBMS	Database Management System
DRU	Data Retrieval Unit
DTD	Data Transfer Device
DVD	Digital Versatile Disc
EEC	Electronic Engine Controller
EMC	Electro-magnetic compatibility
EMI	Electro-magnetic interference
EMS	Engine Monitoring System
EMU	Engine Monitoring Unit
FADEC	Full Authority Digital Engine Control
FDR	Flight Data Recorder
GSE	Ground Support Equipment
GSS	Ground Support Station
LSAR	Logistic Support Analysis Record
OEM	Original Equipment Manufacturer
PPI	Power Performance Index
QAR	Quick Access Recorder

3. OPERATIONAL CONSIDERATIONS:

The number of GSS units needed to support a particular operation is determined by the number of aircraft or maintenance sites and operator requirements for system performance, portability, networking and user access. Military aircraft for example, especially those operating in diverse locations, will require a number of GSS units per squadron. This could enable military aircraft within the same squadron to perform not only home base operations, but also carrier detachments and out of theatre operations to all be covered. Military operational requirements are also likely to drive the GSS design because interference with other systems is of paramount importance. It will be necessary in this case to consider electro-magnetic interference and compatibility (EMI/EMC) in the GSS development. The requirements for commercial aircraft are likely to be less numerous with aircraft flying between airports, though there may also be different requirements for each maintenance level. Certain data processing or primary tasks need to be performed more quickly than secondary tasks. The latter can be carried out when the GSS is less busy. The type of information fitting into these primary and secondary data categories is listed below:

a. Primary tasks

1. Exceedance advisories
2. Event diagnosis
3. Engine life status

b. Secondary tasks

1. Parameter trending/projection
2. Trend analysis
3. Parts life tracking/management
4. Database updating
5. System hardware integrity checks

The data collected by a GSS may fall into several categories and come from more than one source. Keyboard entry data, special collection devices, memory cartridges, floppy disks, custom tape units, secure wireless communication and data transfer from other computers systems are all potential requirements for consideration. The GSS must be able to output information to the user at various levels such as engine, aircraft, squadron, fleet, etc. Formatted reports, data tabulations and various plots are all typical output requirements. These outputs may be printed or displayed on screen, and in some cases may extend to communication with another computer.

3. (Continued):

Provision must, therefore, be made in both hardware and software to implement these capabilities. Special attention should also be given to human factor considerations when designing the composition and format of output products. Where possible, manual data input should be reduced to a minimum, as this always becomes the weak link in the chain. Economizing on the number of pages to be printed, or the number of screens to display data, must be balanced with the readability and ease of understanding.

4. SYSTEM FUNCTIONAL REQUIREMENTS:

Most military monitoring systems calculate life usage on critical rotating parts, failure of which may result in an uncontained engine failure, an event that can result in catastrophic aircraft loss and even aircrew fatality. It is common to also calculate thermal fatigue and creep usage of hot section components such as turbine blades or nozzle guide vanes. The drive behind calculating life usage, either on a sample of engines or every engine, results from the wide ranging military aircraft mission variability. The reverse is true of commercial aircraft operations, which are typically repetitive with only engine rating varying from flight to flight; therefore, it is usual to log flying hours or flight cycles as a means of recording life usage.

Commercial operators traditionally have given greater attention to parameter trending. OEMs and Operators, sometimes working in conjunction, have developed software packages to trend engine performance and diagnose the cause of parameter shifts that could result in the loss of engine availability. This capability has prompted a greater level of interest among military operators where consideration is being given to the development of similar trending capabilities for fighter aircraft.

Recently, military and commercial aircraft EMS are adopting much more sophisticated algorithms and technologies to diagnose engine problems. Examples of this are more sophisticated vibration monitoring techniques, real time performance analysis, novel fault prediction, detection and isolation algorithms and the application of new technologies to monitor gas path health, ingestion events, oil debris and condition and rotor blade health.

4.1 Exceedance/Event Diagnosis:

Many monitoring systems are equipped to identify and record event data, giving the maintainer access to all the data from the subject engine run. In this instance, the GSS will interrogate the data and identify the cause of the incident or exceedance. Others record all of the flight data continuously, although the software will ensure flight crew or plant maintenance indications are provided where necessary. Continuous data allows the maintenance engineer to review all the data to identify the cause, often aided by similar algorithms used in the on-board EMU. This will enable more efficient troubleshooting which might otherwise involve the expense and delay associated with carrying out expensive engine testing.

The application of automatic troubleshooting procedures or expert system diagnostics in the GSS offers distinct benefits in this respect if the rules can be adequately defined. Automatic diagnostic methods endeavor to identify the most probable cause, or causes, of an event and estimate the extent of any damage sustained by the engine. Some GSS equipment can already operate to this level of diagnostic capability. In addition, these systems also list the appropriate maintenance actions to be taken and call out the maintenance publication references where the detailed maintenance instructions can be found.

4.2 Parameter Trending and Trend Analysis:

Parameter trending is generally regarded as a GSS function because of the amount of storage capability required to accumulate sufficient data for meaningful results. One method involves the EMU selecting either a single or multiple records of data for trending purposes at one or a number of repeatable conditions. Alternatively, the complete flight profile can be recorded and the GSS will extract the snapshot(s) and perform the same level of trending to that performed by the on-board system. The benefit of this approach is the ease with which the snapshot algorithm can be changed if required. This will of course be subject to GSS software certification issues although these are likely to be less stringent than for the EMU where a similar change requires a formal modification to the software, probably to a higher software certification level and this takes time and is expensive.

Historically, other types of non-electronic data not generally available from an EMU were also trended by the GSS. Examples of this additional information included oil consumption and magnetic chip detector debris rates. These parameters offer a useful means of monitoring the general condition of the oil washed parts of an engine. More recent EMS developments have considered automatic oil debris monitoring sensors and even an oil condition monitor is being considered. These provide information continuously to the EMU to indicate a sudden rise in debris accumulation or oil degradation.

4.2 (Continued):

All trend data, from whatever source, is normally displayed to the user in graphical format as trend plots. These plots provide a visual indication of how parameters are changing in relation to each other and over the lifetime of the installed engine. Graphical formats also provide the user with a good indication of the general quality of trend data and whether the selected record is providing sufficient data to produce contiguous trend points. In normal operation, and provided there has been no damage to any part of the turbo machinery, the trend plots should develop in a predictable manner, indicating natural performance deterioration. This would appear as a gradual, long-term, movement on the trend plots. A sudden, short-term change in the trend line for any of the parameters, either singularly or in combination, may include a change to the engine's performance characteristic, or possibly a sensor fault. If after data validation, the possibility of a sensor fault can be eliminated, the parameter trends are then analyzed to determine what is wrong with the engine.

Shifts in engine trends may be detected visually or by automated detection logic. For an operator with a sizeable fleet, the provision of an automatic alerting function to signal the occurrence of a significant performance trend shift is a valuable enhancement to the GSS. Trending is not only concerned with keeping track of historical data. It is mostly used to anticipate the need for engine maintenance by projecting the trend lines forward to estimate when a performance limit will be reached. This will, of course, impact engine safety, economics and availability.

4.3 Engine Parts Life Management:

Engine speed, temperature and pressure changes will all cause low cycle/thermal fatigue or creep to be incurred by certain parts of an engine. The algorithms required to calculate life usage on these components can be coded in the EMU software. Alternatively, the EMU can record the parameters required by the algorithm with the computation performed on the GSS. As with performance monitoring, this is the most flexible approach as it also provides unprocessed data for analysis if algorithms change or become more complex in the future. The latter is the biggest danger to an EMU because it means that the correct life can no longer be calculated, as there is no historical data to compute the life used to date.

Historically, it was not always possible, or necessary, for an EMU to calculate the life usage for all components. If the number of monitored components was less than those that were life limited, it was usual to employ factoring algorithms to translate the life usage count from the monitored components to the unmonitored ones. As an example, monitoring one stage of the compressor, i.e. stage 1, would enable the life of the other stages, i.e. stage 2, to be calculated through the application of a defined factor, e.g. 1.5 times. These factoring algorithms were often incorporated in the GSS and applied whenever the life usage database was updated. Today, on-board processing is much more capable, whilst on-board storage capability continues to increase in volume with no increase in cost. All this means that there is now the capability to compute cyclic life for more components than ever before on-board using a consistent algorithm approach.