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

RATIONALE

AIR4175A has been reaffirmed to comply with the SAE five-year review policy.

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:

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(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.

4.3 (Continued):

Alternatively, all the data can be recorded for analysis by the GSS in the usual way. The latter approach remains the most flexible way to perform life usage monitoring but puts extra burden on the air to ground data throughput and storage requirements.

4.4 Flight Profile Monitoring:

Where complete flight recordings are available from the EMU, these can be used to validate engine design assumptions and monitor changes using the GSS. By looking specifically at the flight profile of the aircraft with regard to any contracted operational envelope, this information can be used to determine the flight hour/cycle life rate or the charge levied by the OEM to the operator. The statistical analysis of this data is usually performed on user request and does not therefore have a significant impact on processing resources.

Certain commercial aircraft regulating authorities such as the Civil Aviation Authority in Europe and the National Transportation Safety Board in the United States would like to make flight profile monitoring a mandatory requirement for operational safety. If these requirements do indeed become mandatory, the EMU functionality will need to be able to accommodate the appropriate data storage capabilities.

4.5 Data Storage:

Many of the functions performed by a GSS depend upon the information stored or accessed by the system. The GSS will normally make use of a database for this purpose, although older systems may rely on stored data files. This database may be custom developed for sophisticated GSS applications, although this is extremely expensive. Therefore, use of one of the commercially available relational database software products such as Oracle or Access may provide the optimum solution.

Another option is to look at where the GSS fits into the overall EMS architecture. This could enable some of the GSS functions to be reduced by benefiting from capabilities in other systems. In this case, the GSS may look after the short term management of installed engines, passing relevant data such as hardware and software configurations, life usage information, installed performance and vibration information to the EMU. In return, the GSS will receive either processed or raw flight data from the EMU for analysis and/or incorporation into the database. The GSS may also interface with Customer and OEM logistic systems passing and receiving part configurations, life usage information and baseline engine information. There is always the option of using the GSS as an electronic logbook for the installed engines it is managing.

4.6 Initialization of On-Board Systems and Interface Devices:

Many modern systems utilize a non-volatile Quick Access Recorder (QAR) or Data Transfer Device (DTD), such as a PCMCIA card, as the primary mode of data transfer from the on-board to off-board system. The solid state PCMCIA card is a small, stable device that can hold a substantial amount of data. These are preferential to PCMCIA cards that are not solid state, which should be avoided due to data corruption problems. Solid state PCMCIA cards are expensive however and can be used in most computers, so as a result, can be attractive to light fingered personnel. If PCMCIA cards are used, they should be formatted to a Windows FAT32 format to ensure the widest use. Optical discs are also a popular medium for data transfer. Although they do not hold as much data as a PCMCIA card, they are equally stable and inexpensive. There are still a few systems around that utilize a tape recording device for this function but these are gradually being upgraded to solid state. Unfortunately, all portable storage media can get mislaid or lost. Many airlines are using the Very High Frequency Aircraft Communication Addressing and Reporting System (ACARS) transmission for near real-time data download to the ground based system. Where possible, systems should be compatible with the various upcoming wireless technologies for data transfer. Wireless methods provide transmission reliability, unlike methods that require human intervention that have much higher failure rates than non-contact methods. These methods are also getting cheaper and systems using wireless mobile phone technology that can operate at the gate are being considered in preference to ACARS.

It will be necessary for the GSS to clean and reinitialize this memory device before reusing. This is performed via an interface with the hardware DTD that reads the data storage media and is likely to include the information listed below. Other systems are downloaded using a data retrieval unit (DRU). Some EMS designs may require the GSS to upload data/information as defined by the EMU supplier or OEM. This will be achieved using the appropriate device or by wireless communication.

On-board media such as PCMCIA cards or optical discs will be considered as either an aircraft or engine repairable part, depending on where the system is located and will therefore be subject to the appropriate regulatory requirements. The DTD or DRU will be considered as GSE tools and therefore subject to those regulatory requirements.

4.6 (Continued):

The following is a list of functions that require the GSS to prepare a file to be uploaded into the EMU.

a. Life usage values for a newly installed engine, module or component for use in on-board EMU algorithms (but only where total life used is stored)

b. New material coefficients or enhanced algorithms to be used in the EMU life usage calculations

c. If a high level of component configuration checking is performed by the EMU, the ability to add configuration information must be available as new engine models or components enter service

d. Updates to engine exceedance limits

e. Updated engine models or performance decks to support on-board EMU parameter trending e.g. Power Performance Index (PPI)

f. Baseline engine vibration build information used for EMU anomaly detection

g. Data acquisition criteria and filters e.g. parameters, frequency, capture conditions, etc

h. Engine accessory and EMU configuration information

When data is downloaded from the EMU, it will be necessary to establish that the data has not been corrupted. A checksum routine is a simple method of ensuring that the transferred information is not corrupted by checking elements such as header information for the correct data, thus ensuring that problems such as data skew, missing data blocks and pages are identified. A more complex method, Cyclic Redundant Code (CRC), looks for changes to file structure that may be indicative of an error before and after copying. The CRC method provides around 98% effectiveness, slightly higher than for checksums. The EMU will create the checksum or CRC routine and this will then be checked at each data exchange, i.e. between the EMU and the DTD/DRU, between the DTD/DRU and GSS and between the GSS and Customer/OEM logistic systems. This process will also need to be used when there is a wireless data transfer between the various elements of the system.

5. INPUT DATA:

In order to satisfy the various EMS functional requirements described in section 3, a GSS must receive certain input data. The operator of the system is responsible for ensuring that this data is provided. The GSS will be required to process and store several types of data as defined by the system functional requirements. In general, the system inputs will comprise any of the following data types:

a. Continuous recorded flight data

b. Processed flight data e.g. life counts, PPI, vibration, etc

c. Logistics data, e.g. engine configuration, location, etc

d. Maintenance data, e.g. event data, incident snapshots or exceedances, etc

e. Data transfer validity data (checksum)

All engine data would be downloaded using the tools detailed in the previous section of this document. In addition to these hardware devices, it is also possible to use telemetry or satellite communication to transfer data to the GSS. The advantage of this is the reduction in troubleshooting time gained by being able to analyze data before the aircraft has landed and the recording media has been retrieved. Currently this capability is expensive and constrained by transmission packet size and bandwidth. Logistics and maintenance data would historically have been entered manually from hard-copy records, but this has been improved by the use of Customer/OEM electronic logistic data systems. Not surprisingly, continuous data demands the most storage capacity because it contains both steady state and transient data for an entire operation. This is likely to include multiple engines, and where appropriate, installation parameters, e.g. aircraft, position, etc. The advantages of having all the flight data and what that brings in terms of flexibility compensates for these demands. Data storage is also cheaper than on-board EMU implementation when software development, qualification, validation and verification are considered.

The GSS needs to be suitably equipped to replay any data and to convert it into a form required for detailed computer based analysis. This conversion process requires a function to interpret the position of the bits and words in the data frame, relevant to each parameter, and then apply the correct equation to convert these into engineering units. Where this data has been recorded from a digital source such as the engine control system or aircraft, it may already be in engineering units.

5.1 Continuous Recorded Flight Data:

This technique is an offshoot from the development of the crash-protected Accident or Flight Data Recorder (ADR or FDR). In the commercial aircraft community, this is currently governed by ARINC characteristics 573 and 717. Commercial aircraft have used ADR/FDRs to record flight data since the mid-sixties. This technique is also now also becoming common in military monitoring systems too, for reasons previously explained.

5.2 Processed Flight Data:

Processed data is generated by the EMU and includes; life usage data, event data, trend data, and built-in-test (BIT) data. Where time-history records are included as part of the processed data, it is normal for these to already be converted to the appropriate engineering values. Processed flight data falls into the following categories:

a. Event (snapshot) data
b. Trend data
c. Life usage data
d. BIT data

a. Event (Snapshot) Data

Event or snapshot data is produced by a detected symptom or failure, such as exceedances, off-schedule operation or a pilot initiated event the EMS may not be able to detect. A typical EMS will store a record of data whenever an engine operational limit, such as speed or temperature, is exceeded or another detectable event such as surge, flameout or digital control channel switchover occurs. The amount of data in each record is not necessarily of fixed size; some systems record a snapshot for a set duration, usually around 20 or 30 seconds, while others record for as long as the exceedance event persists. It is normal for a few seconds of pre-event data to be included in the record. Some post-event data may also be included. A potential disadvantage of this approach is that the primary event may not have actually been recorded in the snapshot due to an insufficient amount of data. An example of this may be an incorrectly scheduled variable inlet guide vane causing a high pressure compressor overspeed. In this case the EMS, using simple exceedance monitoring, would detect the effect but not the cause.

5.2 (Continued):

b. Trend Data

Trend data is regularly scheduled and generally consists of engine and flight data records in the same form as event data, triggered when trend conditions are met. Examples would be take-off, climb, cruise, and thrust reverse reports. This data is critical for use by off-board systems for performance trending, which drives engine removals, maintenance and troubleshooting. A special trend record may also be defined, consisting of only those parameters needed for trending that particular event. For all types of performance trending, engine parameters must first be converted to international standard atmosphere (ISA) conditions in order to correct the effects of different ambient pressures and temperatures. A record should be sufficient to produce a statistically valid input to the performance trend algorithms. In most applications the job of correcting data and calculating trends is a GSS function. When a very large number of trend records are involved, a requirement to compress trend data on the GSS database may exist. To assist in this process, it may be advantageous to group together and average older sections of the trend history to produce a clearer view of the overall trend movement.

c. Life Usage Data

The life usage database is updated using the information provided to the GSS by the EMU. For example, some systems that perform on-board life consumption store cumulative totals for each component. In this case, the GSS should compare the latest on-board totals with the last previous reported totals and check that the rate of usage is within acceptable bounds. Another approach is to calculate the life used on a particular flight. In this case the GSS will need to reduce its record of life used by that amount for each component. Other on-board systems record all the flight data for download to the GSS where individual flight counts are calculated and stored for a large number of flights. This data can also be used for re-lifing components in circumstances where algorithms have changed or been updated. In situations where the EMS data has been corrupted or lost, the GSS should incorporate facilities to update the database from alternative data sources, e.g. aircraft operating records. For this purpose, the affected data would be replaced with substitute values based on a flight hour to cycles conversion factor derived from fleet or individual engine data.

5.2 (Continued):

d. Bit Data

One of the key EMS interfaces is between the EMU and Electronic Engine Controller(s) (EECs) or FADEC. The latter incorporates extensive BIT capabilities to detect and isolate faults within the device, circuits and equipment that interface with it. While a BIT fault could produce an event record, it will generally produce only a single data word. When interpreted this provides an indication of the failure of a component within the device or an item connected to it. Some basic data may also be included, depending on the level of data transfer from the EEC/FADEC. BIT data is normally interpreted immediately although it may be necessary to download the data to the GSS to perform fault isolation from the identified component ambiguity group. The GSS also has the advantage of including electronic technical publications or have such links in place to minimize troubleshooting times and increase engine availability.

5.3 Logistics Data:

Access to logistics data is essential to the GSS in order to maintain a configuration database. This may be as simple as keeping track of an engines location but should include the EMU configuration, since various software versions could exist. The GSS should incorporate, or have access to a database containing details of each engine, including the part number configuration, serial numbers and life data for all the life limited parts. When a new engine is received, its configuration must be added to the database, normally using the interface to Customer or OEM systems to ascertain the information. This is especially important for the operational management of the engine in cases where an aircraft is undertaking deployed operations. Increasingly, the long-term management of the engine is being transferred to the OEM under commercial arrangements such as total care and fleet hour agreements.

Engine configuration data must be updated each time an engine or accessory is either transferred to a new location by the operator or removed and replaced. Special consideration may be required for a depot facility, which needs the capability to configure individual modules in addition to complete engines. A common output either from, or based on calculations performed by the GSS, is a list in ascending order of life remaining of all the life managed serialized parts. For this purpose, it is usual for the life remaining to be converted from cycles or counts into hours, the preferred operator measure for maintenance and logistic purposes, using appropriate conversion factors for each part.

5.4 Maintenance Data:

Maintenance data may be required in the GSS for several purposes. Engine and module performance analysis and trending functions will require maintenance data to identify whether any equipment changes may be responsible for any apparent change in engine performance. A recorded change of balance weights leading to changes in vibration trend history is another example. As previously mentioned, the removal and installation of engines or accessories must be logged in order to assure the validity of the configuration database. Similarly, all maintenance actions to remove and replace tracked parts must be logged. In some cases, tracking the status of maintenance actions until they are closed out may also be a GSS requirement.

If the user has a separate system for logging engine maintenance, the GSS should not require duplicate entry of that information. The GSS should be integrated or networked with any Customer/OEM automated maintenance data system if one already exists. In this case the GSS will either serve as the prime entry point for maintenance data, or receive its required information directly from the maintenance data system. In many cases, supplementary information from the aircraft maintenance or flight log can assist the interpretation of EMS data. This is particularly useful when analyzing data from incident or failure events. It is also important that maintenance and flight crew reports are recorded in sufficient detail to allow meaningful interpretation at a later date.

5.5 Data Validation:

Although the level of EMU sophistication is continually increasing, there are practical limitations to the amount of data validation that can be performed on-board. Therefore, it cannot be assumed that all data downloaded to the GSS is free from error. Data errors can occur at any point in the data path from the sensor to the GSS. An error originating at the beginning of the data path, e.g. a pressure transducer will almost certainly affect the result of any subsequent processing which utilizes the data. This could be addressed by error detection and correction techniques incorporated to isolate and remove the data errors as close as possible to the point of origin. Errors may well vary in magnitude and character, causing a variety of effects in the final output, therefore a detection process, such as spike, datum, scatter, etc, is essential. All detected errors should be reported to the user and appropriate warning messages included in the final output. Human error is another common cause of error introduced during manual input processes. Suitable error trapping techniques can be incorporated in the input software routines in order to check the conformance of this data against the expected requirements. Data validation in usually carried out on the following:

a. Time history data
b. Life usage data
c. Engine build configuration data

5.5 (Continued):

a. Time History Data

When acquiring time history or continuous data, it is normal practice to construct some basic data validity checks using known signal characteristics relevant to each parameter. The simplest and most basic of these is to ensure that any parameter data is within an acceptable range. If a parameter can only be positive or not greater than a certain limit, the data need only to be checked to ensure it does not fall outside these two points. This is very crude however, providing only limited information on the overall quality of the data. Another fairly simple check is to compare the calculated rate of change between consecutive data points against the maximum possible rate defined for each parameter. A rate of change exceeding this limit, be it positive or negative, may indicate either electrical interference or possibly data flow interruption. Another common check is to look at the relationships between particular parameters. This could include comparing the engine shaft speeds, engine inlet and aircraft temperatures and engine bay pressure and aircraft altitude. There are arguments for and against the principle of reproducing these checks in the GSS to provide an independent secondary validation of the EMU.

b. Life Usage Data

Where an EMU calculates life usage totals, it is reasonable to expect the latest cumulative life counts to be greater than those previously stored in the GSS, but not so large as to be unrealistic. Likewise, it is reasonable to expect the difference between the two values, latest minus previous, to lie somewhere within a defined range. A negative difference between the latest and previous count totals would not be reasonable. This could be attributable to a number of possible causes; EMS malfunction, corrupt data, out of sequence data transfer, unreported engine change, or change of EMU. For this purpose, the GSS should incorporate cycle count limits per engine flying hour, through which the last reported usage must pass. In all cases, manual intervention would be required to take appropriate action.

c. Engine Build Configuration Data

If the GSS retains data on the engine build configuration, it is essential that this data is always valid. This is particularly important for the management of critical life-limited components that carry a unique serial number to enable traceability in the event of a component failure or material/batch problems. The most obvious validation check ensures that no duplicate part or serial number combinations exist in the database holding the current engine configuration data. It is important that this check be carried out at the time of entering new data in the GSS to stop any further manifestation of the error. Validation can be helped by introducing filters that allow only those serial numbers of a fixed length or character structure to be input to the GSS, thereby preventing the entry of component serial numbers that fall outside that range. There is a disadvantage however to imposing tight controls on field length and structure when, or if, a genuine new serial number falls

5.5 (Continued):

outside the specified field dimensions. The extent of this problem will depend largely on the level of system privileges that exist at local system level. If the end user can amend the character structure, the solution is simple, but less controllable than an arrangement that requires the system to be updated by a central organization with responsibility for the system or network. The system designer should carefully consider these issues with the operator before deciding what is best for the particular operation.

6. DATABASE MANAGEMENT SYSTEM:

The Database Management System (DBMS) for a GSS must satisfy the requirements of the particular monitoring system. This section discusses the scope and use of a DBMS, including the merits of a distributed versus centralized database, overall data integrity and the process of data archiving and retrieval.

In most cases, a GSS will require the ability to store, manipulate, and selectively report on large amounts of data. The types of data to be managed will include, but not be limited to: time-history data from sensor readings, test results, manual records, and calculated values. This data will quite often have a high degree of interdependence. Although most of the data processing, reporting, and management of the data is predefined or fixed, the ability to retrieve EMS data on an ad hoc basis is a common requirement.

6.1 Database Structure:

Depending on the configuration of the monitoring system, either a distributed or centralized system structure should be considered for the GSS DBMS. Distributed systems are preferable for operations involving several sites where local autonomy is a requirement. The main advantage of this being reduced risk associated with any single point of failure. This would be useful for the military operators with elements of a squadron based at a number of locations at any one time. If however, it is a requirement to ensure consistency of data in all databases, problems may arise when copying data from one GSS to another.

In a distributed data environment, records such as those required for fleet trending will invariably be copied and distributed to different sites, leading to possible replication between systems. In this case, controls such as advanced protocols for maintaining concurrency and integrity within the DBMS structure are vital to ensure proper data synchronization and effective operation. A two-phase commit protocol is a common mechanism used for ensuring concurrency when updating GSS data residing at two or more sites. The first phase prepares all the servers for the update, while the second phase co-ordinates the commit process. If any site should fail the update, the transaction is rolled back at all sites.

6.2 Size of Active Database:

Every EMS designer must decide how much to keep in the active database. This question is essentially answered by the requirements of the system as a whole. A trade-off between the amount of useful data available for the user and the speed of the system often needs to be made. As the amount of data increases, the speed of the system (access time, etc.) will decrease. In addition, the larger the amount of data in the database, the longer the backup procedure will take. Recent rapid increases in computing power and the relative low cost of these systems has helped to mitigate this problem. An important consideration when determining how much to keep in the DBMS is the density of the different types of data and its ultimate use. For example, trend data files are relatively small whereas event data files might be very large.

6.3 Data Archiving, Backup and Retrieval:

The ability to archive old data periodically and back-up current DBMS information to safeguard the database is a common GSS function. Several issues require consideration when designing these functions and the procedures for using them, including the need to later retrieve that data. The frequency and amount of time required to perform archive or back-up procedures will be a major concern of the GSS manager. The size of the active database will greatly influence the back-up time and as this increases, the user will become less willing to maintain it. The rate of data accumulation in the GSS should be considered because daily back up is more easily justified where vast amounts of data are entered every day than where a relatively sparse amount is entered. Automatic methods to prevent the database from growing indefinitely offer the most effective solution with old data archived as new information is entered, ensuring a fixed window is always available to the user.

The main types of storage media used for data archive and back-up are CD-ROM or optical disks, although magnetic tape may still be used for older systems. Re-writable optical disks provide the system designer with a robust form of storage medium with a very large capacity, supporting fast transfer times permitting larger amounts of data to be easily archived and backed up. Although CD-ROMs are popular, cheap and offer similar storage and transfer rates, they are not recognized as a permanent storage medium in the same way as optical disks. The Digital Versatile Disc (DVD) has just started to be used in preference to CDs because of the much increased data storage capability.

Consideration must also be given to the method of retrieving archived or deleted information from the primary database. Archive data retrieval is only required in exceptional circumstances and therefore will not occur frequently. A good retrieval system should include the capability for the user to select data, whereby only a subset of the database need be retrieved. The user might want to retrieve data for a particular aircraft or engine for a specified time period for example. Without the capability of data selection, the retrieval system can be cumbersome and become virtually useless, especially when the amount of archived data increases to exceed the memory capacity of the GSS.

6.4 Security and Storage:

It is likely that both military and commercial operators of either aircraft will expect the GSS to offer various levels of security for database access, maintenance and protection. Access and maintenance are covered elsewhere in this paper but protection of information is a key issue. In certain cases, the GSS database may contain information relating to the location of assets and this will need to be protected. The addition of read-access protocols such as passwords and firewalls to prevent external interference or access should address this issue. To prevent certain information within the database being accessed for restricted operations, the GSS may operate stand-alone and only perform synchronization with the other distributed systems when the platforms return to unrestricted operations.

The storage of information archived or backed up from the GSS DBMS needs to be maintained to enable it to be accessed following system failure or accidental data loss. One possible solution to this problem is keeping master copies of archive or back-up disks in a different location. This should preferably be off-site to ensure that data can be recovered even if the GSS location is destroyed. In circumstances where this may not be possible such as a ship, the data should be held in a special location such as a fire store.

7. OUTPUT DATA REQUIREMENTS:

The main use of the GSS is to provide outputs to support maintenance and logistics organizations. This may include individual and fleet-wide performance assessments as well as the administration of performance guarantees. The output from the GSS should be provided in a compatible format, such as American Standard Codes for Information Interchange (ASCII), to ensure it can interface with existing off-the-shelf database and spreadsheet software products.

7.1 Maintenance Data:

The most useful GSS outputs for maintenance purposes are:

a. Time history plots/listings
b. Maintenance action advisories
c. Condition status reports

7.1 (Continued):

a. Time History Plots/Listings

It is common for the EMU to record some form of time history data, either for incidents or continuously. Performance related indices and trends can be derived from this data and identified through graphical display by the GSS. In the case of multi-engined applications, the deterioration of an engine can be detected through comparisons with sister engines. This information is essential in the administration of performance guarantees.

b. Maintenance Action Advisories

The GSS should alert maintenance personnel to any pre-defined incident or exceedance recorded and downloaded from the EMU. An event record will also be produced whenever the pilot senses that something is wrong which the EMU may not normally detect. This capability is dependent on whether an aircraft is equipped to allow the pilot to initiate an event record. Generally, this data will include all the available parameters for the duration of the event, possibly including a few seconds before and afterwards. The GSS must therefore be able to produce a standard range of graphical and tabular outputs related to each type of incident or exceedance. This should include individual and fleet-wide assessments of such event.

c. Condition Status Reports

Another GSS function is to produce information on the current condition of an engine. This information is varied, covering: life usage, performance, vibration, and exceedance/ event data for example. From a routine maintenance viewpoint, there is little incentive to examine GSS data if there are no engine problems, particularly when so many different groups of data have to be accessed individually. However, if the salient data from each of the main outputs are concentrated into a single GSS report, requiring only a single computer transaction, it can be used as a quick-look summary of either an engine, or fleet condition.

7.2 Logistics Data:

GSS data has a significant role in medium to long-term planning of maintenance and logistics activities if managed correctly. Many old systems have been developed to help with the management of engines, modules, and parts using a manual data input. In order to realize the benefits from any automated EMS capability, these must either be augmented or replaced with more capable systems to utilize the vast amount of extra data produced by an EMS and make use of essential information held electronically in other systems. There are two types of information considered as key logistics data:

a. Forecasting of engine part removals
b. Upward interfaces

7.2 (Continued):

a. Forecasting Of Engine Part Removals

The life consumption by a particular engine will be directly proportional to its usage. With accurate life usage data held in the GSS database, the potential exists to develop simple extrapolation algorithms to plan engine removals. This can be performed on various components, using current life usage rates to forecast the optimum time to the next scheduled engine removal and which components will be in need of replacement at that time to meet the required engine release life. It should be noted that cyclic life usage monitoring does not replace the requirement to record engine operating time or engine flying hours, since many non critical parts will continue to require periodic servicing which may necessitate prior removal of the engine.

b. Upward Interfaces

Engine life usage data is invariably required by logistic systems to allow forward scheduling of engine shop visits and inventory planning. The GSS, therefore, needs to be capable of exchanging data routinely with these logistic systems without interfering with routine processing.

8. ADVANCED CAPABILITIES:

This section introduces advanced GSS functions that utilize the specialist knowledge of the OEM and/or operator. Other systems utilize historical knowledge from experienced users of the systems and equipment in an empirical manner to relate diagnostic information and results on a GSS. Some of the capabilities developed by the OEMs are marketed as proprietary products.

8.1 Expert Troubleshooting Systems:

It is possible to provide the GSS with some form of intelligence or interpretative capability to evaluate the data. Recent developments have led to the incorporation of expert systems for event data analysis and maintenance diagnostics into GSS. The objective of this analysis is to isolate the probable cause of the incident and suggest the appropriate maintenance actions to be performed.

Expert systems are software programs that attempt to "capture" the knowledge of experienced experts and make it available to the less skilled. While it is possible to develop an expert system for a particular application, it is more common to use a commercial product or "shell" into which the knowledge for a particular application is incorporated. Commercially available expert system packages cover a wide spectrum of capabilities and it is essential to select one that will provide the level of sophistication required, as well as being compatible with the target hardware environment. The decision to utilize this technology, as part of the overall EMS architecture should be made bearing in mind the following considerations:

8.1 (Continued):

a. Ease of learning to use the system

b. Ability to interface with other software

c. Ease of maintaining the knowledge based system

d. Facility for documenting the knowledge base

Expert systems typically process the EMU recorded data automatically using the same logical steps as an experienced maintenance operative. They can work with any amount of data although they offer the most benefit when large amounts of information are available for diagnostic analysis. This level of data volume will produce complex symptom relationships that could not reasonably be included in a maintenance manual. The use of a suitable, ruggedized laptop computer has enabled this process to be performed by connecting directly to the engine.

Data analysis can be performed interactively, with the user examining data and responding to questions from the system. Alternatively the system can perform the search for key symptoms itself. This type of system requires a knowledge base to be developed using the knowledge and experience of experts, neither of which may exist for a new engine. In this case it may be necessary to develop the initial knowledge base using experience from other engines and/or from engineering analyses.

8.2 Module Performance Analysis:

Performance algorithms estimate both the component efficiency and flow capacity deviations from the observed measurement deviations whilst simultaneously estimating the measurement error in the gas path data. The analysis of performance trends to module level can involve complex computational processes that make use of the thermodynamic design data for the particular engine type under investigation. The objective of module performance analysis is to determine which components are responsible for an observed engine performance deficit and to help the user decide an appropriate work scope to restore performance. Performance analysis software is usually implemented in the GSS because this location simplifies access to data from earlier flights and to the maintenance history of the engine.

The EMU records module performance data, normally during cruise in order to limit the impact of modeling errors. This is important because engine transients change component efficiencies and add to the uncertainty of the analysis. It is also important to account for variable geometry, active clearance control, and other control elements. Measurement error is a major problem that must also be considered if useful results are to be produced from the analysis. The first step of the analysis is to determine the offset of the gas path measurements from a predicted level. This level may be generated using

8.2 (Continued):

the OEMs cycle model (performance deck), or it may be derived from a representative fit of flight (or test cell) data. If a cycle model is used, it is adjusted to better predict the gas path measurements via the use of representative service data.

Module performance analysis is now a reasonably established technique but should be viewed as only one source of information for making engine removal and work scope decisions. Inspection results, pilot reports, maintenance records, and other input should all be considered in addition to module performance analysis results in making these decisions.

8.3 Integrated Logistic Support Disciplines:

Most aircraft systems, especially military ones, are developed under Integrated Logistic Support (ILS) principles. In particular, the extensive Testability Analysis and Logistic Support Analysis Record (LSAR) work can now be incorporated in the GSS. The Testability Analysis is a probabilistic approach to fault detection and isolation, normally developed for line replaceable components such as engine accessories. These normally include items such as the engine control unit, fuel and/or afterburner control units, engine sensors, igniter plugs, etc. This analysis can provide a probabilistic hit list for maintainers to address against each fault mode. The hit list can be linked through the LSAR to Technical Publications, especially if they have been developed to the AECMA 2000D Standard. Moreover, the GSS can facilitate a closed loop system in this area where maintainer feedback can be entered into the system such that hit list can be improved. This feedback, will also underpin the LSAR and Testability Analysis, increasing its accuracy resulting in a potential of continuous improvements in engine maintainability.

8.4 On-Line Maintenance Manuals:

Recent developments in mass data storage technology have made it possible to incorporate electronic manuals into the GSS. These manuals can complement more traditional GSS functions, providing displays for identifying components and procedures for removal and replacement. On-engine test procedures for fault isolation are also appropriate material for incorporation in an electronic manual. Whether this type of technology should actually be applied in a GSS will depend on how and where it will be used and whether the hardware requirements for both activities are compatible. For example, the viewing and printing resolutions required for detailed technical illustrations are much greater than for GSS data. These special hardware requirements may not be justifiable or practical for some applications.

9. USER CONSIDERATIONS:

The human operator is often regarded as a mere user of the EMS, though in reality they are probably the most important part of the sys tem. If the user cannot operate, or has no confidence in the system and what it does, it may very quickly lose credibility and become useless. It is, therefore, of paramount importance to consider human factors when designing not just the operational, but the functional aspects of a GSS, too. After all, the purpose of an EMS is to help engine maintenance personnel do their job more efficiently. The opinions and requirements of the user should be solicited throughout the system design and development phase and implemented as far as possible when the system is eventually fielded. Thorough and detailed training is therefore essential to the successful implementation of a GSS.

9.1 User Requirements Analysis:

At the project initiation stage, there should be a system requirements document defining the functional algorithms, hardware platform, interfaces, operating environment, etc. A complete detailed system requirements document should not be finalized without undertaking a full user requirements analysis involving the personnel who will actually use the system when it begins operation. This could benefit from existing ‘use case’ analysis processes and should ideally examine every aspect of the GSS in order to encourage full user participation at the initial design stage and to develop a sense of ownership for the eventual system. The main focus of this analysis should be the user interfaces, since these are the interactive parts of the system. These aspects generally concern basic features such as operating protocol, screen formats, menu options, hard copy requirements, etc.

Naturally, this is more easily accomplished if the GSS is being developed for an existing engine. For applications where the engine is not yet itself in operational service, there will be no experienced user with whom to consult. However, every effort should be made to gain access to suitably experienced personnel within the operator's organization who can provide a qualified comment on the system design proposals and offer lessons learnt from other similar systems.

9.2 Human Factors:

It is important that the intended users can operate the GSS with ease, without unnecessary complication or the need for frequent reference to technical documentation. Most users will have a reasonable knowledge of computer systems and should have no need to use their complex functions at regular intervals. Wherever possible, the GSS should enable the user to perform easy and understandable straightforward transactions. Ideally, the user should not be required to enter more than one or two key presses to execute a particular function. Screen format, menu structure and the use of color all contribute to producing a user-friendly environment. Moreover, a well designed on-line help facility can serve as an excellent training aid for new personnel who have limited experience of using a GSS for engine maintenance. In addition, the user should have easy access to system support such as a point of contact via a telephone number or email address. This could be based on existing successful commercial off-the-shelf models provided by numerous information technology suppliers today.

9.3 User Access Control Considerations:

The cost-effectiveness of the GSS and thus its fiscal health may be dependent on its ability to satisfy a number of different requirements. A GSS may therefore have other functions such as operational quality assurance data analysis, auto flight systems performance, extended range operations effectiveness, airframe structural fatigue monitoring, and perhaps even meteorological data gathering resident on the same computer system. For a system to support a wide range of users, there is an increased need for clear and well-defined access management, concentrating on free access, but only to the appropriate data, by each user. The system designer must be aware of these requirements to enable end user access to the data and results which they "own", and the need to prevent unauthorized users from changing data in the database.

The following issues need to be considered:

a. General facilities
b. Privilege functions

9.3 (Continued):

a. General Facilities

The method of controlling access to GSS data will vary, depending upon the facilities available in the environmental software. Some operating systems, for instance, will have privilege setting arrangements already available, others will require the system manager to procure them. In any case, it will be the system manager's job to set them up. The method by which the users are to gain access to "their" data must be taken into account. In a centralized system, where all the output peripherals are in one room, access can be arranged locally, with password control of the relevant print functions, for example. For distributed systems with remote terminals, the geography of the site must also be part of the access control arrangement. Access control may alternatively be vested in authorized personnel; indeed, many will argue that this is the most effective. For example, if the operator doubles as the system manager, they are the only person authorized to handle the output, ensuring that this is passed directly to the authorized end users. However, this arrangement is heavily reliant on individuals and is not generally seen as a dependable solution.

b. Privilege Functions

Privilege levels are usually arranged with the system manager since they will have the highest privilege level with access to all system functions. Each end user must have their own privilege arrangement, giving access to specific data or output routines while preventing access to certain other data. This is best arranged on the operating system using password, user-name or account-name control. For distributed systems, particularly where a network uses modem or other non-specific lines or post-boxes, rigorous arrangements are necessary to ensure protection against “hackers" or accidental unauthorized agents. Consideration should also be given to provisioning these functions, where necessary, to maintain export control restrictions.

9.4 User Instruction:

This section discusses the importance of the following as part of the overall user instruction requirements:

a. Operating manuals
b. System operator training
c. System manager training

9.4 (Continued):

No matter how well designed a GSS may be, the ability to use it will depend on the know ledge vested in the user. Although it is possible to assign a new user in order for them to operate the system, this is likely to cause frustration and lead to errors if they have had no organized training. For this reason, it is imperative that adequate operating instructions are available, preferably supported by an appropriate training program.

a. Operating Manuals

Operating manuals should provide the user with all the information necessary to enable the installation, set up, and operation of the GSS hardware and software. A "Getting Started" section, including simplified instructions for familiarizing an unacquainted or inexperienced user with software operating procedures, should be ideal for providing a good understanding in the shortest possible time. Additionally, the manual should include a 'Quick Start' section for simple tasks. This builds user confidence and encourages the user to use the system. Detailed instructions should be provided for the experienced user with sections containing shortcuts being considered. Examples of screen displays, menu options, plots, and other outputs should also be included. It is very important to provide a list of all error messages with details of the possible causes and remedial actions to be taken.

b. System Operator Training

A complete training program reduces the incidence of operator errors due to unfamiliarity with the system and the need for outside assistance in the operation of the GSS, once the system is in place. Once properly trained, support staff will be able to use the GSS more efficiently and with greater confidence. The amount and type of training will depend on the application, budget restrictions, availability of users, and the Customer's requirements/constraints. In general, the users need only be trained on the operation of the GSS in order to perform data processing tasks, since for most operations; there will be a system manager. If the maintenance site is very small, it is possible there might not be a specific system manager and that all users need to be trained in system administration. Whatever the course focus, a combination of classroom and over-the-shoulder training is ideal. For a moderately sized GSS operation, both methods should be employed.